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on Electronics, Communications  
and Computing  
CHISINAU, MOLDOVA, October 21-22



# Technical University of Moldova

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***and Computing (IC|ECCO-2021)”***

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**October 21-22, 2021**

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***Computer, Informatics and Microelectronics Faculty***

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### **A. Computer Science:**

- Mathematical Modelling and Applications;
- Algorithms and Computing Theory;
- Data Science/Data Engineering;
- Artificial Intelligence;
- Bioinformatics.

### **B. Computer Engineering:**

- Automatic Control;
- Robotics;
- Computer Design.

### **C. Software Engineering and Cybersecurity:**

- Methods and Tools of Software Engineering;
- Information Systems and Applications;
- Computer Security and Cryptography;
- Security and Privacy in Computing.

### **D. Electronics:**

- Applied Electronics and Embedded Systems;
- Micro & Nano-electronics.

### **E. Networks and Communications:**

- Telecommunications: Technology, Networks and Software;
- Electronics and Telecommunications: Operations, Administration and Maintenance;
- IoT Technologies: Software, Hardware and Connectivity;
- IT infrastructure and Cloud Computing;

### **F. Theoretical and Applied Physics:**

- Theoretical physics, General and cross-disciplinary physics;
- Statistical/mathematical and computational physics;
- Atomic, molecular and cluster physics, Condensed matter physics, Plasma and fluid physics;
- Optical physics, nanoscience, laser and photonics;
- Biological physics.

### **H. Knowledge-based society:**

- Research and Education for Knowledge-based Society;
- Education methods based on ICT;
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# New approaches for engineering superhydrophobic-superhydrophilic surfaces

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## **ABSTRACT**

Over the last decades, it has been demonstrated that micro-nanostructuring of the solid-state materials is a powerful tool for developing surfaces with controlled hydrophobicity/hydrophilicity. The research has been inspired by nature, in particular by the so-called “lotus effect” describing a superhydrophobic state with antiadhesive properties allowing water droplets to bounce on a lotus leaf. Development of superhydrophobic surfaces with designed adhesion prove to be important for various applications such as self-cleaning, deicing, vapor condensation / water collection, controlled droplet transportation etc. We used combined top-down and bottom-up technological approaches for engineering micro-nanostructured surfaces with controlled hydrophobic-hydrophilic characteristics. In this work, promising hybrid solid-state nanomaterials consisting of hydrophobic and hydrophilic components will be demonstrated. Besides, we will address the prospects for using the developed nanomaterials for the purpose of manufacturing mini-bioreactors to study living cells in specific confined conditions as well as artificial membranes resembling the membranes of living cells.



# Structure Evolution And Properties Of Multilayer Coatings Based On Refractory Metal Nitride Wn

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## ABSTRACT

Recently, the intensive development of modern technologies has been stimulating the need to improve the protective properties of materials and their durability. They must withstand extreme operating conditions, such as high temperatures, external stresses, and aggressive oxidizing environments, which can lead to their degradation and destruction. Therefore, protective coatings with high mechanical and tribological properties, resistance to heat and corrosion, and chemical inertness are successfully used in various industry branches. In particular, transition metal nitrides are very popular for different applications and are actively studied by materials science experts. For instance, in the form of thin coatings, they can be used for multilayer metallization of integrated circuits. Moreover, they can be excellent candidates for diffusion barriers, which are placed between metal and semiconductor/insulator to prevent any harmful interactions between two materials.

For many decades, single-layer nitrides have been widely used for tribological applications. However, numerous studies have shown that the multilayer architecture allows adapting the functional properties of the coating for technologically complex applications. Thus, this work reports on the deposition of WN-based multilayer coatings with different second layer MeN (Me = Zr, Cr, Mo, Nb, TiSi). The differences in microstructure, phase composition, surface roughness, mechanical properties, adhesion strength, friction performance, and wear behavior of the nanoscale WN/ZrN, WN/CrN, WN/MoN, WN/TiSiN, and WN/NbN coating systems deposited by the

cathodic-arc physical vapor deposition (CA-PVD) at the same parameters are comprehensively investigated. Polished stainless steel X6CrNiTi18-11 was used as substrates. The microstructure, chemical composition, mechanical and tribological properties of the samples were investigated using an X-ray diffractometer, a scratch tester with Rockwell-C indenter, a high-resolution scanning electron microscope, nanoindentation unit, and a device for tribological testing according to the "ball on disk" scheme. Coatings were roughly divided into two groups regarding microstructure: (i) all constituent layers had NaCl-type cubic structure (WN/Zr, WN/CrN, and WN/TiSiN) and (ii) WN layers had the face-centered cubic (fcc)  $W_2N$  phase, while other layers developed a combination of two hexagonal (WN/MoN) or hexagonal and fcc NaCl-type cubic phases (WN/NbN). The WN/ZrN, WN/CrN, WN/MoN, WN/TiSiN, and WN/NbN coatings exhibited a high hardness range from  $33.3 \pm 1.7$  GPa to  $37.3 \pm 2.4$  GPa. Since all multilayer systems exhibited hardness  $> 30$  GPa, they can be categorized as hard materials.

# Organic-based thermoelectrics: Where we are and what challenges we are facing

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## **ABSTRACT**

Thermoelectric materials based on organic semiconductor compounds are considered a highly promising approach towards sustainable, cost- and energy-efficient recuperation of waste heat at moderate temperatures. First proof-of-concept devices have impressively confirmed this appraisal for p-type conducting polymers, showing thermoelectric figures of merit of up to  $zT = 0.26$ . However, fundamental challenges remain and need to be addressed in forthcoming research on this subject. In particular, the general improvement of the electrical conductivity, the implementation of air-stable n-type organic semiconductors as well as the abrogation of the mutual interrelation between the primary thermoelectric parameters constitute major objectives that need to be achieved for a successful application of organic materials in thermoelectric devices. For the case of strong donor-acceptor materials, in particular, the class of low-dimensional organic metals, I will illustrate how these requirements can be fulfilled and transferred to new thermoelectric materials.

# From Organic electronics and Internet of Things to Neuromorphic Computing: What Nanotechnology Can Do

**Franz Faupe**

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## **ABSTRACT**

Electronics, communications and computing had a dramatic impact on the development of humankind during the last decades that now affects almost every aspect of our daily life. It can be foreseen that this influence will become even more important in the future resulting in new societal challenges including a strongly increasing energy consumption and environmental pollution. Here we illustrate that the huge progress in electronics, communications and computing was mainly driven by corresponding developments in nanotechnology and new materials, which proved to be a key enabling technology.



# IPv6-based 5G, IoT, Cloud & Blockchain

**Latif Ladid**

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## ABSTRACT

The IANA central IPv4 address space has been fully depleted back in February 2011 making the deploying of new large-scale networks especially 5G, IoT and Cloud networks not scalable and specifically not what IoT really stands for. Hence the new IP protocol IPv6 has been designed to cater for this already back in the 90s and waiting for its killer apps to take off. 4G was the first one to adopt IPv6 in larger scale.

The IPv6 Deployment worldwide is becoming a reality now with some countries achieving more than 50% user penetration with India, China and Belgium with over 60% at the top ranking (<http://labs.apnic.net/dists/v6dcc.html>) and reaching double digits v6 coverage on Google IPv6 stats. May Autonomous Networks (ASN) reach more than 50% with v6 preferred or v6 capable: (<http://labs.apnic.net/ipv6-measurement/Economies/US/>).

Over 1.9 Million users are accessing Internet over IPv6 and probably not even knowing it. If this trend continues, we should achieve 75% by 2025 which would be the inflection point when the full roll-out of IPv6-Only becomes a strategic plumbing decision of the networks, a topic that is avoided so far due to many strategic and resources issues (lack of top management decision-making, lack of v6 skilled engineers and v6 deployment best practices, very limited ISP v6 access deployment, ...).

The deployment of Carrier-grade NAT is in full swing making networking and user experience more brittle. The security and cybersecurity issues are like always brushed over at this

stage due mainly to lack of IPv6 security skills. However the US Government has announced last week June 16, 2021 that it will move to IPv6 Only by 2025. New topics are more on the lime light such as 5G and 6G, Cloud Computing, Internet of Things, SDN, NFV and Blockchain, ... However, these fields are taking IP networking for granted designing them on IPv4/NAT building non-scalable and non-end to end secure solutions. The IPv6 Forum is driving new initiatives to garner support and create awareness in these are with initiatives such as the IEEE Comsoc IoT, SDN-NFV and 5G: [www.ipv6forum.org](http://www.ipv6forum.org).

# Designing Interactive Experiences with Computer Systems that Understand Users' Body Movement and Gestures

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## **ABSTRACT**

A variety of computer systems and devices, from the prevalent smartphones and tablets to the newest smartwatches and smartglasses to large public interactive displays and surfaces, is available for users to access information and computing resources on the go, at any time, and from virtually any place. Despite the heterogeneity of these devices in terms of type, size, form factor, platform, operating system, etc., many afford natural interaction modalities, such as input based on body movement and gestures. In this talk, I will present results obtained in the Machine Intelligence and Information Visualization Research Laboratory (<http://www.eed.usv.ro/mintviz>) regarding designs of gesture-based interaction for wearable devices, large displays, touchscreens and interactive surfaces, augmented and mixed reality systems, smart television, and other application areas. Examples include gestures enabled by a wearable system designed for the finger and hand that makes users believe they are actually holding and manipulating digital content, gesture commands for controlling a smart TV that replace remote controls, and body-referenced gestures used to interact with digital content found in physical pockets on the user's clothes. I will also discuss the flexibility, versatility, expressivity, and other qualities of body movement and gestures as a natural input modality for interactive computer systems.

# Methodology for Performance Evaluation of Ethereum Blockchain Infrastructure

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## **ABSTRACT**

Blockchain is being recognized as a software infrastructure by its new feature of constructing blockchain using hash values. Two main features of blockchain are preserving the integrity of information and providing reward to the participants and those two features attract people to deploy the blockchain infrastructure for their newly launching services. However, the blockchain software infrastructure requires lots of computing resources to conduct all the required functionality. In addition, it is very hard to say that the blockchain infrastructure is adequate for performance sensitive software. In this presentation, we introduce our journey for evaluating the performance characteristics of blockchain particularly Ethereum. In our experiment, we devised new concepts for evaluation of performance of services such as time scaling (TS), experimental frame (EF) and system entity structure (SES). The time scale concept enables us to conduct the performance evaluation testing in a short period of time without the loss of context of the test. By introducing the experimental frame concept, we could separate the experiment scenarios from the testing target services. At last, the system entity structure helps us to test the diverse software composition for the same service. We developed test target services such as content delivery and auction service for the experiment. The main performance index of our experiment is turnaround time for the service request and we derived the index for each blockchain-based and database-based service to figure out the amount of performance degradation caused by the deployment of the services over the blockchain software infrastructure. Our experiment is not limited to the turnaround time. As a further study, we investigated every functionality of Ethereum blockchain such as mining, writing and verifying blocks and measured the time consumption of the procedures of Ethereum.

# Nanoparticles as Building Units for Bio-Inspired Electronics –Switching and Sensing

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## ABSTRACT

Owing to their high surface-to-volume ratio, their small size and the high number of intrinsic defects, nanoparticless (NPs) exhibit properties that go beyond typical bulk materials. Consequently, nanogranular systems, with NPs as their fundamental building units, differ in many aspects from their atom-assembled counterparts. In this work, gas phase synthesis of NPs is applied as it offers the benefit of a high purity, surfactant free deposition that is compatible with a broad range of substrates. At the example of three fundamentally different NP assemblies it is showcased, how the unique properties of NPs make them promising building units for electronic devices with neuron-inspired functionalities. First, metal-insulator-metal structures with sparse embedding of AgAu alloy NPs inside a dielectric matrix are investigated for their diffusive memristive switching with distinct, well-separable resistance states. Secondly, the dynamic transitions between multiple resistance states in highly interconnected multi-terminal Ag NP networks are described. Lastly, illumination-dependent resistance states are investigated in two-terminal TiO<sub>2</sub> NP sensor devices.

# New Vapor Deposited Dielectric Polymer Thin Films for Electronic Applications

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## ABSTRACT

Dielectric materials are of great interest in a vast amount of applications ranging from cable insulation to advanced electronic devices. The emerging trend of device miniaturization is creating an increased demand for dielectric thin films that can be produced precisely on the nanometer scale. In addition, special mechanical properties are often required, for example in the field of flexible organic electronics. Polymers are first-choice materials for this purpose. However, it is extremely difficult to produce precise nanoscale thin films, which have a low defect density and are free of e.g. residual solvent, by wet chemistry approaches. Initiated chemical vapor deposition (iCVD) is a solvent-free polymer thin film deposition process which can be used to produce high quality dielectric thin films with nanoscale control and circumvents thus these problems. This work demonstrates the versatility of the iCVD process in the field of electrical applications by some new application examples of iCVD coatings.

# TiO<sub>2</sub> nanotubes for chemical sensing

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## **ABSTRACT**

The importance of high performance gas sensing devices is rapidly increasing for a wide range of applications, including detection of toxic and explosive compounds in public spaces, military facilities, and chemical processing plants. Herein, we report the synthesis of highly ordered TiO<sub>2</sub> nanotubes and their gas sensing properties. The formation of pure and doped nanotube arrays considering the parameters of the electrochemical procedure is studied. The gas sensing properties of prepared materials towards different gaseous compounds are investigated. The morphology, structure and composition of nanotubes affect their sensing performance. The working mechanism of fabricated sensors is also proposed.

# $\text{Al}_2\text{O}_3/\text{CuO}$ non-planar heterostructures for VOCs vapors detection

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## ABSTRACT

In this work, the gas sensing properties of the non-planar heterostructures based on CuO thin films, grown by the direct ink writing and covered with an ultra-thin  $\text{Al}_2\text{O}_3$  layer, are presented as a function of the operating temperature. The obtained results demonstrates the excellent selectivity to volatile organic compounds (VOCs) vapors, namely n-butanol and 2-propanol in a operating temperature range of 200 – 350 °C. The relatively low gas response was observed at room temperature, which is very important for low-power operation. The dynamic gas response showed an ultra-fast response time of 2 – 3 s. The obtained results demonstrates the excellent potential of non-planar heterostructures based on metal oxides for use in high-performance environmental monitoring applications.



# Engineering of Semiconductor Compounds via Electrochemical Technologies for Nano-Microelectronic Applications

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## **ABSTRACT**

The paper is focused on electrochemical approaches for nanostructuring of semiconductor compounds with further applications in micro-nanoelectronic devices. A cost-effective technology for nanowires and nanotubes obtaining by pulsed electrochemical deposition is presented. Functionalization of elaborated nanostructures with gold or platinum via electroplating improve the properties of the nanostructures.

A varicap devise based on Pt/porous GaP with a capacitance density variation of about  $6 \times 10^{-3}$  pF/V for  $1 \mu\text{m}^2$  of surface is presented. An optimization of the varicap design to increase the capacitance is proposed and discussed.

In this work we report on the fabrication on GaAs nanowires and elaboration of the electrical contacts via different approaches for photoelectrical investigations. Accordingly, to the obtained results it was established that contacts manufacturing with Laser Beam Lithography is feasible for photodetector fabrication at characterization.

# Experince in Creating Nanosatellites of the "CUBESAT" "PolyITAN" Standard in Igor Sikorsky Kyiv Polytechnic Institute: Mission, Development and Exploitation Results

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## ABSTRACT

This article gives general information about the goals, requirements of missions and describe show these requirements are expressed in the development of nanosatellites (NS) of the PolyITAN series of CubeSat standard. The report also discusses the integration of electronics with the design and payload, provides information on the applied manufacturing methods and tests of NS of various modifications for performing tasks in orbit. The analysis of the results of flight tests of the NS (PolyITAN-1 and PolyITAN-2) and potential capabilities of the developed NS "PolyITAN-3" (assessment of the quality of shooting when sensing the Earth from an altitude of 400 ... 350 km) and "PolyITAN-4" (features of simulating the environment and plant growth under microgravity and cosmic radiation).

# The Experience of Preparing to Launch the TUMnanoSAT nanosatellite

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## ABSTRACT

In this paper, a brief overview of TUMnanoSAT's educational and scientific missions, the impact on system design and educational opportunities are presented. The main basic test procedures for the launch of this nanosatellite are described, including the structure, power supply and attitude control. The main mission of TUMnanoSAT is to provide practical experience to students not only in designing, building, but also testing the nanosatellite with various missions.

# Thin Films of Copper Oxide Nanostructured via Rapid Thermal Processing

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## ABSTRACT

The temperature dependent gas sensing properties of nanostructured copper oxide nanolayers obtained by the method of chemical synthesis from solutions (SCS) and exposed to post-growth rapid thermal processing (RTP) in air at different temperatures were investigated. Morphological properties of the layers were investigated using the scanning electron microscopy (SEM) technique. The fabricated sensor structures based on the metal oxide nanostructured films were tested to hydrogen gas with a low concentration of 100 ppm at an operating temperature range from 250 °C to 350 °C.

The change in the response of the thermally treated films in different regimes, i.e. at different temperatures, under exposure to the tested gas was observed, which was determined by the change in surface morphology. The hydrogen gas detection mechanism of prepared nanostructured layers has been proposed as well.

# Smart Device for Controlled Hypothermia

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## ABSTRACT

In this work we describe the construction of a non-invasive hypothermic system of descent a brain temperature used in the treatment of stroke. Thermoelectric effect is based on Peltier elements. The device is used for those who offer first medical aid. It usage helps with the stabilization of the patient's state and stops any aggravations. The helmet allows local or total cooling of the head, monitorization and displays body temperature on a graphical interface.

# Experimental and Computational Study of the Apparent Absorption Spectra of Nanostructured Manganese Tungstate Catalysts

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## ABSTRACT

The UV-Vis spectra of a series of MnWO<sub>4</sub> nanorods with different Mn/W ratio represent the subject of the present study. Since the surfaces of the obtained catalysts are damaged to understand the observed spectra transformations with the change of the Mn/W content homometallic binuclear, trinuclear and tetranuclear linear manganese clusters, binuclear tungsten clusters and mixed manganese-tungsten clusters of different nuclearity are examined. The choice of the linear manganese clusters of different nuclearity for examination is dictated by the revelation of MnO<sub>x</sub> units on the surface of the MnWO<sub>4</sub> nanorods. The structures of these different nuclearity species have been optimized, and their absorption have been calculated with the aid of density functional theory (DFT). It has been shown that homonuclear tungsten clusters demonstrate only ligand-metal charge transfer, while manganese clusters demonstrate both ligand-metal and metal-ligand charge transfer. At the same time ligand-metal and manganese-tungsten electron transfers are characteristic for mixed manganese-tungsten clusters. A comparison of the calculated absorption spectra of the modeled clusters with those observed for MnWO<sub>4</sub> nanorods showed, that chain-like manganese clusters mainly contribute to the high-energy part of the UV-Vis spectra, while the fall in the intensity of the observed spectra in the range of the longer wavelengths is connected not only with the decrease of the relative manganese content, but it also manifested due to decrease of the concentration of the mixed manganese-tungsten clusters, mainly contributing to this part of the spectra.

# Solution-Processed Bulk Heterojunction Solar Cells Based on a Zinc Phthalocyanine:Perylene Dimiide Derivative

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## ABSTRACT

A solution processed ZnPc:PTDCI bulk heterojunction solar cells doped with iodine were fabricated and characterized. Photovoltaic properties of the solar cells were investigated by optical absorption, current densityvoltage characteristic and external quantum efficiency. The absorption of ZnPc:I2:PTDCI was observed in the (300-800) nm region. Solar cells with a power conversion efficiency of about 2.4% has been obtained using simply drop casting and spin-coating methods without special treatment. The peak of the external quantum efficiency characteristics of the ITO/PEDOT:PSS/ZnPc:I2:PTCDI/Al solar cells is 10%.

# Formation and Decay of Excitons and Biexcitons Excited in CdSe/CdS/CdZnS Colloidal Quantum Dots

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## ABSTRACT

The kinetics of a strongly nonequilibrium state of electrons and holes excited in quantum dots by a long laser pulse in the p-states are studied using the time-resolved photoluminescence. Three bands of the transient photoluminescence spectra were identified, and the ignition and decay of each of them was investigated. The complex picture of the time evolution of the bands is explained by the fast processes of cascade intraband relaxation and the Pauli exclusion principle. The durations of formation and decay for each of the photoluminescence bands are determined.



# Superdense Coding of Information in Quantum Computer in the Paired Bosons Representation

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## ABSTRACT

An alternative approach to superdense coding of information in quantum computing is proposed on the basis of Schwinger's two-boson representation of angular momentum. Since the effective spin  $S = 2^{n-1} - 1/2$  corresponds to the  $n$ -qubit system, this representation can be used in the quantum computing. Operators of the logical elements of the quantum circuit were found, performing superdense coding of information in the paired bosons representation. It is shown that for superdense coding of information, the results obtained in the spinor representation and in the representation of paired bosons coincide. For one-qubit systems, one of the two representations cannot be favored. In the case of  $n$ -qubit systems for  $n \gg 1$ , the representation of paired bosons is probably more convenient for applications, since in this representation the explicit form of the Pauli operators  $X$ ,  $Y$ , and  $Z$  does not depend on  $n$ .

# Generation of Pulses with Excitable DFB Laser with Dispersive reflector

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## **ABSTRACT**

This paper is devoted to investigation of pulse generation by a DFB laser with an integrated passive dispersive reflector. This configuration is treated in the framework of the simple rate equation model. The theoretical results show that under certain condition the laser is operating in excitable regime suitable for pulse generation. We have identified the appropriate values of parameters for pulse generation. Finally, the influence of these parameters on shape of pulses is investigated.

# Thermoelectric Properties of a $p$ - $n$ Module Based on $\text{TTT}_2\text{I}_3$ and $\text{TTT}(\text{TCNQ})_2$ Organic Crystals

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## ABSTRACT

In this paper the thermoelectric properties of  $p - n$  thermoelectric module of organic nanostructured crystals is investigated. A thermoelectric module (TM) is a device designed for direct conversion of heat to electricity or for cooling effect by applying a small electrical current at the pairs legs. TMs are embedded in a various of devices: thermal generators for energy harvesting at industrial scale, personalized mini devices for power generation or local cooling effect for integrated circuits. In modern medical devices, TMs are used for accurate temperature control in PCR (polymerase chain reaction), biological samples and vaccines transportation, continuous temperature monitoring and others. However, most commercialized TMs nowadays are made of inorganic compounds with a low rate of energy conversion. By the other side, organic materials are more reliable, flexible with a higher efficiency at low temperature gradients. Earlier, it was established theoretically that organic crystals of  $\text{TTT}_2\text{I}_3$  of  $p$  – type and  $\text{TTT}(\text{TCNQ})_2$  of  $n$  – type are very prospective materials for thermoelectric applications at near-to-room temperature. For temperatures not exceeding  $\sim 400$  K, it is expected that crystals properties will not change significantly. The charge transport and thermoelectric properties are predicted to significantly enhance by some manipulations with carrier and impurity concentrations. In the following, the electrical conductivity, the output voltage, and the maximum power factor of a  $p$ - $n$  module made of these crystals is calculated numerically for different combinations of crystals parameters and temperature gradients.

# Localization of Objects in 3D Space by Using a Stereoscopic Video System

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## ABSTRACT

This article describes two implementation models of an artificial vision for specific tasks of localization of objects in three-dimensional space using a stereoscopic system of two cameras.

The periscopic model provides means for objects localization relative to the position of the stereoscopic system. This can be used for both detecting the position of bodies in space and for performing the technical system orientation with an artificial vision. The orthogonal model is capable of executing a high-precision dynamic localization of objects in space.

# The Tuning Method of the PID Controller to the Underdamped Systems

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## **ABSTRACT**

In this work, it is proposed the method for tuning the PID controller to the second order underdamped systems. The method was developed based on the maximum stability degree criterion and there are obtained the analytical expressions, that permits to calculate the tuning parameters according to the values of the damping ratio, natural frequency and transfer coefficient, that can be determinate from the experimental curve of the open loop system. To demonstrate the efficiency of proposed method the computer simulation was performed.

# Comparative Analysis of the PID Algorithm Synthesis at the Object Model with Astatism and Dead Time

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## ABSTRACT

The paper presents the comparative analysis of the synthesis methods of the PID tuning algorithm for the model of the object with first degree astatism and dead time. In the practice of industrial and technological process automation, mathematical models attached to processes are considered models with first degree astatism and dead time. It analyzes the methods that can be applied for tuning algorithms to these types of process models. Systems with dead time transfer elements do not have finite dimensional systemic achievements, but have an infinite number of poly-zeros. In practice, these models are approximated with rational forms known as Pade approximations with minimal and non-minimal phase. The method of tuning the PID controller shall be analyzed using analytical method of maximum degree of stability and method of maximum degree of stability with iterations. In the object model the dead time component is approximated with Pade approximations with minimal phase and for these models the PID algorithm is synthesized according to the method of the maximum degree with iterations. The PID algorithm is synthesized according to the proposed methods for two examples of values of the parameters of the model of the control object with astatism and dead time and the obtained results are analyzed. The advantages of the method of maximum stability with iterations are highlighted.

# Synthesis the PID Control Algorithm for Speed Control of the DC Motor based on the Genetic Algorithm

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## ABSTRACT

In this paper, it is proposed to use the genetic algorithm for synthesis the PI and PID control algorithms for speed control of the DC motor, according to the imposed performance, namely settling time. The obtained results were compared with maximum stability degree method with iterations and to demonstrate the efficiency of proposed algorithm the computer simulation was done. The designed algorithm searches for the controller tuning parameters:  $k_p$ ,  $k_i$ , and  $k_d$ , so that performance for the closed-loop step response to be satisfied.

# Design of Embedded Collective Computing System based on Membrane Computing Models

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## ABSTRACT

This paper addresses a method of applying Membrane Computing models in the design of embedded systems with Collective Intelligence properties. Embedded system topology is presented as a network of parallel and concurrent data processing devices that ensure communication between all its components. Definition model of the Collective Intelligence presents a set of rules based on the set of knowledge consisting of data and methods of processing them. There were elaborated: the cell structure, the interaction diagram of the cells and the way of forming the hierarchical structures and of Collective Intelligence. The formal and structural description language JSON was applied to automate the process of implementing Membrane Computing models in Hardware architectures. The result is presented in the form of JSON models of an elementary cell and the structure of the hierarchical embedded system with Collective Calculation.



# Multi-Agent System for Decision Making Based on Temporal Logic

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## ABSTRACT

The paper presents the results of the conceptual and structural design of a Multi-Agent system for decision making based on temporal logic. The decision making system has a Multi-Agent structure that forms a mesh network with broadcast communication, which ensures the organization of knowledge exchange between them. Functional elements and temporal logical operators are defined in the form of mathematical models, which allows their implementation based on hardware devices or software products. The functionality of the temporal logic is determined by the time function that calculates the credibility coefficient of the event and its influence on the decisions taken by the Agents.

# Synthesis of the PID Algorithm for Models of Objects with Double Astatism and Dead Time

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## ABSTRACT

The paper summarizes the tuning algorithm for models of objects with inertia and astatism of the second degree and dead time, which describe the dynamics of various technical objects and technological processes. These models of tuned objects have the original double pole and a negative pole and an infinity of poly-zeros due to the dead time component. In order to tune the PID controller algorithm to the model of the given object, the algorithm was elaborated based on the analytical method of the maximum degree of stability. The dead time component approximates by the Pade approximants with nonminimal phase. For the approximate object model, the PID algorithm is synthesized using the maximum degree method with iterations. In order to verify the results obtained at the synthesis of the PID algorithm by the analytical method and method with iterations of the maximum degree of stability, the synthesis of the tuned algorithm was performed using the method of polynomial equations. An example of a system with the control object model and the controller synthesized according to these methods with computer simulation in the MATLAB package was examined and the system performance was analyzed. The advantages of the method of the maximum degree of stability with iterations through reduced calculations and minimum time are highlighted, which lead to the simplification of the procedure for tuning the PID algorithm for these object models and higher system robustness.

# Multi-Criteria Distributed Decision-Making System Based on Genetic Algorithms

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## ABSTRACT

This thesis comprises the results of designing a distributed decision-making system in multi-criteria areas. The distributed decision-making system is the architecture of homogenous data-processing devices that form a Wireless network with Mesh topology. The decision-making process is based on finding an optimal solution that is implemented through the use of genetic algorithms. Aiming to identify the initial population of the genetic algorithm, there shall be calculated the partial derivative for each variable for the ordered process. The results of partial derivative serve as an identifier of values from the Chromosome structure.

There have been developed in this thesis: general algorithm of system functioning; population structure formed of Chromosomes and Genes; methodology of calculation of component values of the initial population; and an example of implementation of the distributed decision-making system based on Node MCU ESP32 devices.

# The Cauchy problem for quasilinear pseudodifferential equation with integral coefficients

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## **ABSTRACT**

We consider a quasilinear pseudodifferential evolution equation with the derivative of order one with respect to the time variable  $t$  and the pseudodifferential operator this symbol  $a_\gamma(\sigma)$ ,  $\sigma \in \mathbb{R}$ , homogeneous order  $0 < \gamma \leq 2$ , by space variable  $x$  with integral coefficients. Such equations describe diffusion on inhomogeneous fractals.

# Once again about the reliability of serial-parallel networks vs parallel-serial networks

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## ABSTRACT

The paper addresses the issue of comparing the reliability of two standard types of networks: serial-parallel and parallel-serial. Four variants of dynamic mathematical models are analyzed depending on the lifetime cumulative distribution function of each units of the network, the non-random / random character of the number of units in each subnet and of the number of subnets. Sufficient conditions have been determined for serial-parallel networks to be more reliable than parallel-serial networks. The main result is that these conditions do not imply the lifetime distribution of each unit but only the probabilistic distribution of the numbers of units and subsystems of the networks.

# The Analysis of Students Opinion About the Teachers Skills using Supervised Learning

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## ABSTRACT

The System for biannual teachers' evaluation made by students, acquires a large amount of information that becomes difficult to be analyzed by a manager. It is true that delivers a final score, but it is calculated based only on the answers to the questions with several pre-defined answer options. In their questionnaire, there are also open questions in which students can express themselves freely. These answers contain valuable information, but an educational manager needs a long time to read them all individually. In this paper is proposed an automatic module for interpreting the answers. The module will report to the educational manager only the answers that need to be analyzed. The module uses natural language processing techniques, and supervised machine learning for selecting the answers to be analyzed in a certain context.

# Cultural Heritage Digitisation Using Game with a Purpose

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## **ABSTRACT**

The digitisation of cultural heritage is a priority area in the European Union. This task require a close collaboration between researchers in humanities and computer scientists. The paper presents our effort to create a a training set of recognized handwritten text. To this mean we propose an online game with a purpose (GWAP). This is a human-based computing technique in which some stages of a computational process are transmitted to humans in a form of an online game. The input of the game is a line of handwritten text and the user have to type in its transcription. We investigated how to make this in an attractive and enthralling way in order to involve more users and obtain a large set of transcribed texts.

# Context Free Grammar Representation by the Colored Petri Net

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## **ABSTRACT**

Specification technique like Colored Petri Net (CPN) allows for the formal description and analysis of the discrete event systems. In this paper, it is presented the methodology for Context Free Grammar design, specification and analysis by the using Colored Petri Net technique. It is proposed the approach for representation of the Context Free Grammar by the Colored Petri Net language.



# A Second Order-Cone Programming Relaxation for Days-Off Scheduling Problem

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## ABSTRACT

This paper relates the numerical solution of one of the well-known problems related to production systems. Namely, it is about Days-Off Scheduling Problem, which is reformulated in terms of non-convex minimization problems with quadratic constraints. After relaxation of the above problem, a model based on second-order cone programming is obtained.

# The Case for Non-linguistic Approach to Teaching Engineering Thinking

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## **ABSTRACT**

Software engineering is a multifaceted discipline. Mastering it requires memorizing a lot of factual information as well as learning a particular set of skills that enable the learner to tackle complex engineering tasks in a more efficient manner. It also requires the knowledge of at least one programming language. This makes teaching software engineering efficiently difficult. The traditional way of teaching programming (and by extension - engineering) to students heavily relies on delivering information in the form of lectures and via textbooks. This paper argues that lectures are becoming less and less effective when it comes to teaching programming, and that there are methods of doing it using software solutions which take into account how the human brain processes code. This paper will provide several concrete examples of how software enables students to learn the “spirit of engineering and problem solving”. Lastly, it argues that teaching programming without using textual explanations can be more effective in some contexts, and identifies several key aspects of using software that allow teaching major programming concepts without using textual information in order to make the whole learning process more efficient.

# Using Luong's attention mechanism and simple classifiers to make people overcome psychological illnesses

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## ABSTRACT

Conversational AI is the set of technologies behind automated messaging and speech-enabled applications that offer human-like interactions between computers and humans. It can communicate like a human by recognizing speech and text, understanding intent, deciphering different languages, and responding in a way that mimics human conversation. The objectives of this research are to explore the applicability of conversational AI technology in creating a chatbot for assisting people struggling with psychological illnesses and mental dysfunctions.

The main hypothesis is that having an NLP system containing an NLG submodule (module for generation of the Natural text) and an NLU submodule (module for recognizing the emotional state of the person using this chatbot). We use an NLU submodule because we can't rely only on the artificially generated text as a response for a person in an awful emotional state. Even more, we can use the information from the NLU submodule for stronger strategies generation to ensure emotional support.

The system represents a chatbot with two NLP modules, Natural Language Generation, being represented by a Seq2Seq Neural Network with the Luong's attention mechanism, and a Natural Language Understanding module represented by a classical classification NLP Pipeline that classifies the text in multiple emotional state classes. To interact with the user it uses the Telegram API and is able to save the user messages and the chatbot answers into a simple SQLite Data Base.

Even if this implementation wouldn't replace the real psychologists, with accurate management and maybe with additional inputs for professionals in psychology it may become a tool for detecting people with possible psychological and mental illnesses which can become the first step in further therapy with a real psychologist.

# Proof-of-Stake Consensus Algorithms for the Software Components Blockchain

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## ABSTRACT

In the blockchain context, the information system is considered a part of its infrastructure. However, blockchain itself can be used for IS development using software components and services. As the trust for binary components or services is still an open question, we propose to use the blockchain of components to solve this problem. In this paper, the part of such solution, namely consensus algorithms, is discussed. We focus on Proof-of-Stake algorithms and present their feasibility to be used in the blockchain of software components.

# Prioritization of Cybersecurity Measures

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## **ABSTRACT**

The considerable losses caused by the low level of cyber security of companies, institutions and so on and the limited financial resources available imply the need to prioritize the implementation of measures to counter cyber attacks. For this purpose, the respective optimization problem is formulated as a Boolean mathematical programming one. At large dimensions, the use of known methods of solving the problem requires a large volume of calculations. That's why, a simple rule for approximately solving the problem is obtained. By computer simulation, it is shown that the error of the solution when using this rule decreases considerably with the increase of the number of cybersecurity measures, more accurate – the more detailed such measures are. In order to reduce the error of solutions, three other simple algorithms are also proposed. The latter of these algorithms is more detailed and allows to reduce to a greater extent the solutions' error.

# Task Completion Time Evaluation in Moving Target Defense Cloud Environment Based on Matrix SRN With Z-Fuzzy Parameters

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## ABSTRACT

Moving Target Defense (MTD) has recently emerged as a game-changing technique in confronting cyber attacks and defending cloud computing systems (CCS) and computer networks (CN). A MTD technique randomly modifies the configurations of the attacked CCS, thus creating great uncertainties of the attack surface against cyber-intruders. In this paper, is proposed an analytical modeling approach based on the Matrix Stochastic Reward Nets (MSRN) with fuzzy parameters, that allows attacker's behaviors compact modeling and analysis of the impact in which the use of a MTD technique influences the completion processing time of a running task by CCS. A numerical case study is presented to analyze the impact of different parameters on the expected task completion time and other evaluation metrics.

# Information Security in Microservices Architectures

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## ABSTRACT

In this paper we investigate how can be provided security of an information system, which uses a microservice architecture. So, using of microservice architecture means that information system can be easily developed, deployed, and tested, but, on the other hand it means that it should be protected differently than the information system using monolith architecture. Firstly, a software architect should decide if each service should be protected separately or should be better to protect the system on the whole. Choosing the right way of protecting is very important, because, in some cases, protection of each service separately is not the best idea, as this could lead to code duplication. This means that, in case of necessity of changes a piece of code or fixing a bug it should be done everywhere this code appears. To avoid this, there are developed some services - so called gateways, which, also, very often have implemented the function of user/client authentication and authorization using protocol OAuth 2.0. Anyway, at each stage of development and implementation of a software product, it is necessary to solve many security related problems, and if it will not be done properly, then the company may incur enormous material losses or even may be closed.

# A Service-Oriented Architecture for Multimedia Content Management

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## **ABSTRACT**

Creating and handling content is one of the most important aspects in today's web world. Most of it is represented by multimedia content and managing it in an optimal way has become a key factor for the success of many software products and services. This paper presents some specific requirements of the industry along with an architectural model that can help fulfilling them. The solution is aimed for many of the use cases that small and medium software businesses have to handle and takes also into consideration the cost impact for them. We compare it to other existing solutions and show the advantages of using it.



# Interest based adaptive billboard content management

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## ABSTRACT

The street advertising has undergone some significant changes last years: the traditional advertising billboards are progressively replaced by electronic display devices (LED screens) that are able to change the content in real-time and enable the dynamic content management. This paper aims to develop an adaptive advertising strategy based on the preference of the audience in front of the screen. Each person own on his smartphone special software in order to set up his interests in advertising broadcast. In this way the people define their profiles hat are collected by the billboard which selects the most appropriate type of advertising to be broadcasted at that time. The proposed method aims to transform a simple display equipment into intelligent one able to adapt the broadcasted content to the requirements of the nearness people. It aims to maximize the efficiency of billboard operation and, at the same time, to bring satisfaction to the audience.

# Benefits of Mobile Applications in the Healthcare Industry

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## **ABSTRACT**

The scope of this paper is to evaluate the benefits of applications designed for mobile devices in the healthcare industry. This study includes research on adoption of applications running on end users devices within the healthcare and investigates the benefits for the patients and medical organisations after initiating the process of implementation. Besides the mentioned, the article contains a overview regained most common use cases of mobile applications in healthcare, modern mobile frameworks used for development and a list of suggestions while developing such mobile application.

# Sustainable development of the Republic of Moldova on reducing water pollution through the prism of software tools

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## ABSTRACT

The paper addresses the issue of sustainable development in the field of water resources. A description of two Goals of the Moldova 2030 Strategy is provided: SDG6 and SDG14, both of which prioritize the reduction of water pollution. It shows how these goals complement one another. In order to successfully achieve these Goals, certain international practices for the elaboration and development of software tools must be implemented. The practices mentioned above allow the creation of models for predicting the water quality of aquatic ecosystems. The study of the most frequently used methods and software tools for controlling water pollution currently used is presented. Hence, it is proposed to use software tools to improve the situation of water pollution in the context of sustainable development.

# Research Opportunity To Estimate The Energy Gain Of The Received Signal Of The Cluster DVB-T2 SFN SISO

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## ABSTRACT

In this article, is explore the practical opportunity to estimate the energy gain of the signal, induced at the terminals of the receiving antenna, located in the service area of a cluster DVB-T2 SFN SISO. In order to achieve the research goal, it was assumed that two plane waves reach the input of the receiving antenna, but the reception of the signal is performed through the reference antennas with circular and directional diagrams.

# Using Design Science Research Method to Develop a Cyber Security Framework for HEIs in Moldova

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## **ABSTRACT**

This scientific paper presents how a problem in the field of cybersecurity can be solved by using the scientific method Design Science Research (DSR). The research problem is the lack of a comprehensive cyber security framework that meets international security standards for HEIs (Higher Education Institutions) in Moldova. Although the need for a centralized approach to cybersecurity in university networks, which are decentralized and open by design, is increasingly emerging with the digitalization of HEI. Thus, actions were identified for each stage of the DSR method, which as a result will produce a cyber security conceptual framework (CSCF) for increasing cyber security in HEIs.

# AAA protocol in IoT

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## ABSTRACT

This document is representing not only the description of AAA protocol. It is representing real production problems which I encountered in many years of work with it.

Each from this problem was taken separately. It was analyzed and the best solution was applied to it.

Article is containing not only analyzing of the problem. In this document the solution described was developed and tested in time on different networks starting with few hundred devices and finishing with tens of thousands of them. On production, solution applied worked for years. Based on this point, I can conclude that problems which were on the production, where solved by applying of those solutions.

In order to understand those problems, is needed to understand how this protocol is working and where are the bottleneck points of it.

# Reduction of Interference Level in CDMA Systems on the Basis of Analysis of Correlation Properties of Walsh Function Derivatives

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## **ABSTRACT**

The article discusses the correlation properties of pseudo-random sequences (PRS) used in the formation of noise-like signals in data transmission systems with code division multiple access (CDMA). The analysis, carried out in Matlab environment, showed that correlation properties of the Walsh functions derivatives, used for generating PRS, have much better correlation characteristics than the original Walsh functions. Besides, these properties depend on the type of generating function of Walsh functions derivatives. Correlation properties of various generating functions were investigated. It was justified the advantage of using these signals in the development of CDMA systems in order to reduce the interference level of multiple access.

# Mission Monitor and Control Platform for TUMnanoSAT Ground Segment

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## **ABSTRACT**

This document will cover the overview, development and implementation of mission control platform for TUMnanoSAT, a CubeSat developed at Technical University of Moldova. A mission control platform is essential for a space mission in order to command and control different subsystems, monitor their health, process telemetry and useful data, receive and control requests but also in presented scenario it should be strongly linked to radio software defined architecture from ground station.



# Empirical Study of Cyber Security Threats in Moldovan Higher Education Institutions

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## **ABSTRACT**

Higher Education Institutions (HEIs) have always been the target of cyber attacks due to the information assets they hold. The move to online study as a result of restrictions imposed in the spring of 2020 has led to increased cyber security threats to academia due to the vulnerabilities of online learning platforms and video conferencing applications. The hypothesis of this paper was that Moldovan Higher Education Institutions had to face cyber security challenges similar to international higher education institutions, through the empirical study, the use of the questionnaire-based survey to collect quantitative data from stakeholders of the institutions.

The results of the survey conducted between September and November 2020, showed that HEIs in Moldova are targeted by cyber attacks as well as international ones and the nature of threats is mostly the same, namely: malware, phishing and DoS attacks.

# From human knowledge to information technologies: some epistemological remarks

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## **ABSTRACT**

The knowledge based society developed the new technologies of information and communication in order to use better all the data at different levels and to manage them efficiently. Computers have the capacity to store information, to select it, or to provide it. Human mind, memory and other capacities, are replaced by the upgraded capacities of the computers. Computers are able to store just semantic information, but they do it better than any human epistemic subject. Computers incorporates tacit knowledge and use it also as information or rules to manage the data. Therefore, in KBS the human transition from information to knowledge is accompanied by a reverse computational transition from knowledge to information.

# The European Education Area and the Covid-19 Pandemic

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## ABSTRACT

Over the last decades, across the European Union (EU), the concern for improvement of vocational education and training within the member states grew in importance. The COVID-19 pandemic affected this area of a strategic importance. Therefore, the European Union is considering the adoption of the certain measures aimed at reforming it. According to the EU vision, vocational education and training are essential to the restoring of Europe after the COVID-19 pandemic. Each member state of the European Union manages its national education and training systems and establishes the content of the curricula. According to 165 of the Treaty on the Functioning of the European Union, (TFEU), the EU takes on the role of contributing to a quality education, encouraging the cooperation between member states. The fast outspread and the virulence of the COVID-19 pandemic led to the instauration of a panic feeling at global level. The global dynamics was turned upside down, causing survival, production and consume issues. Governments decided to introduce restricting measures across the economical and social plans. World economy was greatly affected: the markets collapsed, both in Europe and the United States, Latin America and Africa. The states adopted measures at national level, closing the borders and enforcing protectionist decisions. In their turn, citizens were ready to accept isolation measures in order to protect their health and lives. At the same time, free circulation and commerce, as well as the financial system, suffered as well. Therefore, autocratic and populist manifestations were greatly fuelled. Recession was in place and hundreds of millions of people became unemployed across the globe. State aids are the only financial resource for millions of people and numerous companies. A complex vicious circle came into being: the reduction of trust led to less crediting, unemployment and bankruptcy.

# Knowledge-based Society and the School

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## **ABSTRACT**

In a knowledge-based society, the school is the most important institution, being responsible for the society of the future. Dewey and Lipman showed that the traditional school failed, focusing on the transfer of knowledge from those who know to those who do not know, from teacher to student. Such a school is concerned with ensuring success, performance, but it offers answers to questions that students don't ask and ignores questions that they raise. On the whole, the school needs to adapt its practices so that students can learn how to ask questions and how to think for themselves.

# The Phenomenon of Consciousness From an Inter and Multidisciplinary Perspective

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## **ABSTRACT**

Contemporary science, in recent decades, reflects intensely on the phenomenon of consciousness. This fact is due to the accelerated development of cognitive sciences, biological and physical sciences, neuroscience, which have achieved certain successes in researching the problem of mind-body, consciousness. However, what is strictly required is the issue of the possibility of a scientific theory of consciousness, which would apply a new research methodology. The most recent approaches in this direction substantiate the need for research from a phenomenological structural perspective, which explains consciousness as a phenomenon determined by the subquantum level. Structural-phenomeno-logical theory holds that this level is a profound reality regulated by specific principles and laws that make consciousness possible.

# The Reason and Pragmatic Knowledge: Retrieving the Integrative Meaning

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## **ABSTRACT**

Knowledge has a major role, both in the development of a person, but also of the whole society. Today's society is a society of knowledge. Knowledge cannot evolve separately from information. The quantity and quality of information largely depends on its processing by artificial intelligence. The involvement of knowledge in the field of artificial intelligence is not possible without critical thinking. A knowledge society is not perceived without the involvement of researchers. They are those who promote and develop scientific knowledge. This type of knowledge is found in all areas of activity of the society. Hence the social responsibility of the scientists in the scientific context of direct activity. In order to diversify and differentiate the activities, it was identified the learning styles of the students according to the Honey and Mumford learning style questionnaire.

# Knowledge-based Civilizations: the Search of Development (Socio-Philisophical Trends)

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## **ABSTRACT**

Knowledge-based civilizations are considered as new socio-philosophical phenomena, the complexity of conceptualizing their initial attitudes is shown. The article substantiates the need to develop a theory of civilizational coding as a mechanism for the formation of new knowledge that affects the socio-economic and spiritual and moral development of civilizations, the acceleration of economic growth of states, the increase in the level of spirituality of a person and society in the conditions of challenges, risks and bifurcations. An attempt has been made to create a civilizational paradigm of concrete actions based on the acquisition and use of new knowledge, allowing to determine the meanings and guidelines for the development of various events, to identify the causes that determine certain negative phenomena.

# The Nonhuman Character Of Technology And Nature Revealed Through Photography

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## **ABSTRACT**

Tools, like photography, are helping the man fighting nature. However, inside the essential structures of photography there is no signification function. Therefore, the objects represented in the photograph appear as they are in nature, meaningless and without human presence. The photograph, like other technical devices, does not retain the meaning of things. And so, photography is equivalent to nature, which equivocally has nothing to do with human meanings and values.

Only in the field of subjectivity and human intersubjectivity the meanings given to world objects are able to survive. In addition, free of sense objects from photography or film, under the guidance of consciousness can combine in unexpected ways and, as a result, produce alternative meanings. Hereafter, the photograph circumscribes an element that corresponds to the basic function of art in general, namely the opportunity to readjust the daily life in which we live in by giving possible meanings and opening up alternative perspectives. In this context, the man is no longer formalized by abstract rationality, but returns to the rethinking of the living environment in which he cohabitates with others.



# Civilizational Code As A Definition, A New Scientific Discipline And An Innovative Paradigm (Socio-Political Trends)

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## **ABSTRACT**

The work explores the concept of a civilizational code, its features, structure, functions and analysis of the main subjects. The author's definition of the concepts of civilization code and code relations is proposed. The study of the civilizational code allows us to consider it not only as a scientific concept, but also as a teaching discipline and a scientific paradigm that would not only reveal the essence and content of the meanings and guidelines for the development of local societies, but also analyze the causes that determine the processes and phenomena taking place in society.

# Aspects of evaluation of students' activity in the seminar classes: problems and solutions

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## **ABSTRACT**

Given paper is presented as a theoretical-applied study that falls within the scientific dimensions of the theory and methodology of didactic evaluation.

The author uses descriptive and analytical research methods; comes with the literature review relevant to the stated topic; describes a formative assessment tool based on applying criteria and descriptors that could be implemented in the educational activities specific to the seminar classes within the university study programs with specializations in the field of Computer Science and ICT, but not only.

# Digital resources in financial education: premises for implementation in primary education

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## ABSTRACT

The digital resources available online provide quality teaching material so that students become familiar in a pleasant, simple, fun and playful way at the same time with elements of economic culture, so that they can easily enter the exciting world of money. From asking for money to making money is a distance that can be covered if certain basic, elementary information is acquired, which leads to certain financial skills that result in certain financial behaviors necessary in the attitude of tomorrow's adult - today's student. As the online environment is very accessible to most people, we consider that spending time in virtual learning new things, assimilating some notions in the financial field is a method available to anyone to inform themselves so as to avoid financially unpleasant situations in time, such as "loans", "card overdrafts", "mortgages", "guarantees", etc., especially when these are not necessarily necessary.

# Flipped Classroom: an Approach to Developing and Assessing Informatics Competencies

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## **ABSTRACT**

This paper describes the design and implementation of the flipped classroom approach, adapted to the education system in the Republic of Moldova, that was applied in “Spiru Haret” lyceum, Chisinau, the Republic of Moldova. The results of the experiment show the number of students who choose Informatics as a baccalaureate exam for the last six academic years, the Informatics exam is optional. Also, it is described four assessment methods appropriate to this approach.

In order to diversify and differentiate the activities, it was identified the learning styles of the students according to the Honey and Mumford learning style questionnaire.

# Hybrid lesson - a reality between two extremes

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## ABSTRACT

This article aims to analyse the essence, the specifics and the importance of the technical means that are used and applied in a hybrid lesson. Also, the arguments of the implementation of the hybrid model for full and part-time studies. In addition, the briefly analysis of the basic components of hybrid lesson such as, students, the teacher, teaching methods and technical means that are used for.

# Strategies for Professional Development of Staff in Economic Entities in the Field of ICT

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## **ABSTRACT**

Professional training is an important point of support in professional development and evolution, especially in the perspective of the last years of macroeconomic and social evolution. Increasingly frequent changes require a rapid adaptation to increasingly diverse and challenging professional situations. Thus, each professionally active person must specialize as much as possible and, where possible, in several areas of his field of activity.

In economic entities there are reluctances of both employees and organizations in which they operate in terms of time and financial availability, especially in times of economic crisis and the implications derived from it. Either of the two availabilities would be the first, it is desirable to look beyond these current impediments, namely to the benefits that long-term, and even short-term, training and professional development can bring in the next period of specialization or qualification in a field.

# The specific of IT Recruitment and what is the biggest challenge for an IT Recruiter

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## **ABSTRACT**

Recruitment includes the process of sourcing, attracting, interviewing, selecting, hiring and onboarding employees. In other words, it involves everything from the identification of a staffing need to filling it. Finding good, loyal employees is hard. IT Recruitment puts emphasize more on sourcing. It assumes that IT companies need to find their candidates, not just waiting for applicants. Because in IT industry the jobs are looking for candidates, not viceversa. So, the purpose of this topic is to explain why IT Recruitment is so different from other industries and what is the biggest challenge for an IT Recruiter, nowadays.

# The Opportunity to Implement the Concept of Information System Management in Higher National Education

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## **ABSTRACT**

The article reveals the importance and opportunity of emphasizing the formation of a modern and complex information system which has all the premises to support the efficient functioning of the management process in higher education institutions in the context of higher education reform and the entry of our country into the implementation phase of sustainable development postulates, also in the educational segment.



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# Electronics Session

# Nanoparticles as Building Units for Bio-Inspired Electronics –Switching and Sensing

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**Abstract**— Owing to their high surface-to-volume ratio, their small size and the high number of intrinsic defects, nanoparticleless (NPs) exhibit properties that go beyond typical bulk materials. Consequently, nanogranular systems, with NPs as their fundamental building units, differ in many aspects from their atom-assembled counterparts. In this work, gas phase synthesis of NPs is applied as it offers the benefit of a high purity, surfactant free deposition that is compatible with a broad range of substrates. At the example of three fundamentally different NP assemblies it is showcased, how the unique properties of NPs make them promising building units for electronic devices with neuron-inspired functionalities. First, metal-insulator-metal structures with sparse embedding of AgAu alloy NPs inside a dielectric matrix are investigated for their diffusive memristive switching with distinct, well-separable resistance states. Secondly, the dynamic transitions between multiple resistance states in highly interconnected multi-terminal Ag NP networks are described. Lastly, illumination-dependent resistance states are investigated in two-terminal TiO<sub>2</sub> NP sensor devices.

**Keywords**—nanoparticles; gas phase synthesis; sensors; memristive switching; nanoparticle networks; neuromorphic engineering

## I. INTRODUCTION

The transformation towards a data driven society goes hand in hand with the rapid development of artificial intelligence and machine learning that enable the processing of the ever-increasing amount of big data. Despite the immense growth in the computational capabilities within the past decade(s), current technology still largely relies on silicon-based digital computers, that accommodate to contemporary highly parallel data processing tasks at the expense of power efficiency. Thus, novel, energy efficient device architectures and computing concepts are in high demand. A potential inspiration can

be drawn from the earths most abundant, widely distributed computing devices – neuronal networks such as, e.g. the human brain. These systems have been evolutionarily optimized to accomplish highly robust, power efficient and adaptive information processing and can be found, in different variants and complexities, in organism throughout different scales. In contrast to digital computers, neuronal networks combine processing and memory at the local synaptic level and are arranged in highly parallel, dynamic networks.[1,2] Another striking feature of neuronal networks is the close connection of sensing (stimulus detection) and processing (data processing). The growing field of neuromorphic engineering draws inspiration from the features of neuron assemblies to engineer bio-inspired devices and circuits that are capable to perform complex tasks at high efficiency.[3]

Memristive devices with their intrinsic capabilities of memory and processing are often considered for the reproduction of synaptic features, such as spike time dependent plasticity and long-term potentiation.[4] Parallel crossbar arrays of memristive devices are frequently reported in applications in in-memory computing and hardware-based deep learning.[5–7] The unique electronic properties of memristive devices inspire applications that go beyond conventional electronics, e.g. to realize logics for in array computing or in neuromorphic engineering.[8] NPs have recently attracted attention as building blocks for memristive switching devices and are readily employed, either to enhance the reproducibility by tailoring the electrical field inside the dielectric matrix or to act as a source of mobile metallic cations.[9–12] Diffusive memristive switching, synonymously termed threshold switching, has been observed in a variety of devices with Ag or Ag-containing (alloy) NPs, including Ag:HfO<sub>x</sub>, Ag:MgO, Ag:SiO<sub>x</sub>, AgAu:SiO<sub>2</sub> or AgPt:SiO<sub>2</sub>. [10,11]

Typical memristive devices are metal-insulator-metal structures with the insulator thickness in the low nm range, mainly governed by the transport of metal cations or oxygen vacancies across the nm gap. In contrast, recently a particular research interest lies in massively parallel, self-organized structures, for example nanowire or NP networks at or beyond the percolation threshold.[13–17] Here, a common feature is that the dynamic transitions are found to be scale-invariant, with probabilities for resistance change, inter-spike interval, avalanche duration and avalanche size governed by power laws.[14,15] In many aspects the dynamic transitions show striking similarities to avalanche dynamics and long-range temporal correlations in neural systems.[14,18] For this reason, self-organized NP networks are considered as an interesting next-gen device candidate for reservoir computing and in neuromorphic engineering.

The close connection of sensing and processing, known from biological systems, has attracted increasing attention in material science and electrical engineering recently. Memristive devices have been combined with a variety of sensor devices to enable applications such as artificial skin or as optically modulated synapses.[19–22] Wide band gap transition metal oxides, such as  $\text{TiO}_2$ , are well known for their sensing capabilities towards photons (with sufficient photon energy to generate electron-hole pairs) and towards gas molecules (via adsorption of gas molecules on the sensor surface).[23–26] A promising approach to achieve distributed processing of the sensor information is to combine sensor elements with memristive devices, whose reconfigurable resistance serves as a means to pre-process the sensor data, e.g. by adaptation.[27]

In this work, the viability of NPs as building units for bio-inspired devices will be elucidated at the example of multistack memristive devices with diffusive memristive switching characteristics, as highly interconnected Ag NP networks and as  $\text{TiO}_2$  NP assemblies with photon-sensitive resistance states.<sup>1</sup>

## II. MATERIALS AND METHODS

The fabrication of NP-based devices was realized by physical vapour deposition (PVD) processes in custom-build high vacuum (HV) deposition systems. NPs were deposited using gas phase synthesis approaches, namely magnetron-based Haberland-type gas aggregation source in case of the Ag NPs from metallic Ag target and alloy AgAu NPs via multicomponent target approach and supersonic cluster beam deposition from pulsed microplasma cluster source (PCMS), using a metallic Ti rod, in case of  $\text{TiO}_2$  NPs.[28,29] Post deposition heat treatment was performed in an muffle furnace (controlled by PID Fuji Electric PXZ) at 600°C for 1h to safeguard

complete oxidation of the Ti NPs. Details on the fabrication process are reported elsewhere.[10,30–32] To embed the metallic NPs and achieve a sparse arrangement of the AgAu NPs in the multistack devices, dielectric  $\text{SiO}_2$  matrix was deposited by pulsed DC reactive magnetron sputtering.[10] Electrical characterization of lateral and horizontal NP arrangement was performed via a source measure unit (Keithley, 2400 Source Measure Unit; Agilent, E52790B). The contacting of multistack devices is reported in full details elsewhere[10]. Contacting of the Ag NP network device was done by a four point probe station (Signatone, H150W) with micromanipulators and conventional tungsten tips (Signatone, SE-T). Contacting of  $\text{TiO}_2$  NP network sensors was achieved using custom-made positioners featuring spring contacts (SS-40-J-1.8-G-N/L D/C). To measure the electrical characteristics, DC voltage sweeps as well as constant voltage were applied and the current response of the respective device was recorded. On the basis of the IV-data, the resistance was estimated using Ohm's law. No electroforming steps were performed for the measurements.

## III. RESULTS AND DISCUSSION

In the AgAu NP multistack memristive device, the individual NPs are separated by a dielectric  $\text{SiO}_2$  matrix, resulting in a sparse distribution of the metallic NPs within the matrix. For these devices, reproducible diffusive memristive switching is commonly observed and has been reported previously.[10] The main characteristic of memristive switching in these multistack devices is that the separation of the metallic NPs leads to an initially high electrical resistance. Upon application of a sufficiently high voltage, Ag atoms from the alloy NPs are ionized and transported alongside the electrical field. Following a reduction to metallic silver, a conductive metallic filament is formed, effectively bridging the dielectric matrix in the multistack device and substantially reducing the electrical resistance. Due to the limited availability of Ag species from the alloy NPs as well as the tendency to conserve surface energy, the metallic filaments are prone to spontaneous decay, resulting in the dissolution of the filament and consequently restoring of the initial high electrical resistance.[10,11]

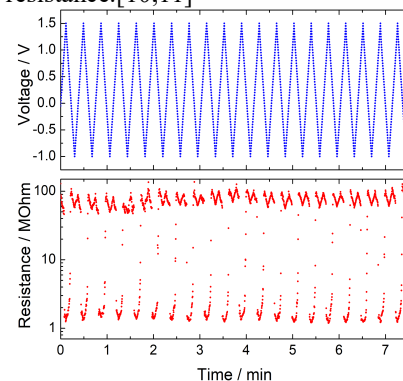


Figure 1. Resistance over time (bottom) for a AgAuNP multistack memristive device under application of a sawtooth voltage ramp (top)

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In case a sawtooth voltage is applied to the AgAu NP multistack device, commonly a IV hysteresis loop is recorded. In an alternative representation, the time dependent resistance response can be obtained from the recorded IV data (cf. Fig. 1). Here, the transitions between two distinct resistance states become immediately obvious. In Fig. 1, 20 consecutive switching cycles of a AgAu NP multistack device are depicted. For each cycle, the device switches between a low resistance state (LRS) and a high resistance state (HRS). There are only very few data points in between both resistance states, indicating that the switching is very fast compared to the data acquisition rate, which lies in the range of 100 ms in the presented measurement. From the  $R$  vs  $t$  data in Fig. 1, the resistance levels for the LRS and HRS state can be obtained. In the histogram (as depicted in Fig. 2) of the resistance states that are occupied within the operational window between 0.5V and 0.75V, a clear separation between the LRS and HRS can be observed. In case of this AgAu NP multistack device, a serial resistance of 1 M $\Omega$  was applied during the electrical characterization to limit the overall current.[10] This serial resistance dominates the LRS, while the HRS exhibits a resistance that is higher by more than one order of magnitude.

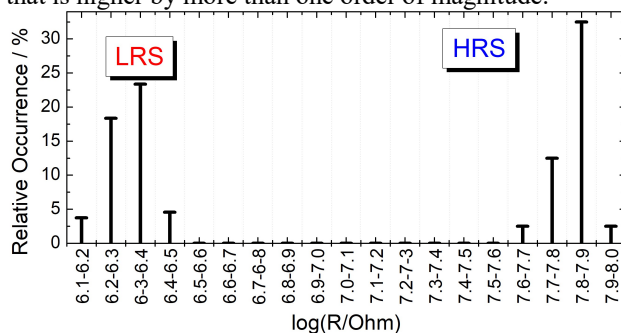


Figure 2. Histogram of resistance states in the diffusive switching window between 0.5V and 0.75V for a AgAuNP multistack memristive device

In addition to the AgAu NP multistack device with its sparse arrangement of NPs inside a dielectric matrix, another interesting device class using metallic NPs as building units are highly interconnected NP networks. To achieve such nanogranular assemblies, commonly surfactant-free gas phase synthesis methods such as the magnetron-based Haberland-type gas aggregation source [14] or the pulsed microplasma cluster source (PCMS) [15] are applied. In contrast to typical, predefined structural arrangements such as cross-bar arrays in the field of memristive devices, the NP networks are deposited onto substrates in a lateral geometry, with two or more prestructured electrodes. The statistical nature of the deposition process and the low impact energy of the NPs that arrive at the substrate result in a random assembly of connections and resistive switching gaps between the NPs. A schematic snapshot of a NPs network between two contacts is shown in Fig. 3 (a). At this time of the deposition, there is a considerable number of open

gaps between connected arrangements of NPs. Compared to the multistack NP devices, the sparseness of the NP arrangement is reduced with increasing deposition time. The more NPs are deposited onto the substrate, more and more NPs are in direct contact with each other, resulting in an increase in potential current paths. In Fig. 3 (middle) a schematic percolation curve, i.e. the dependency of the electrical resistance over the deposition time, is depicted. For an underpercolated arrangement of NPs (at low deposition time), a low number of connections between individual NPs is prevalent, resulting in a high number of gaps, schematically shown in Fig. 3 (a), which leads to a high resistance. In the later stages of the deposition, a fully connected network with a high number of parallel conduction pathways is present, resulting in a low electrical resistance. In the intermediate regime, when the gaps between individual NP arrangements become closed, drastic changes in the electrical resistance are present, corresponding to the steep slope in Fig. 3. A SEM micrograph of an Ag NP network close to the percolation threshold is depicted in Fig. 3 (b).

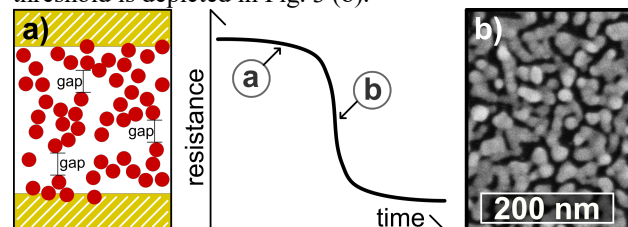


Figure 3. Typical *in-situ* measurement of the resistance in dependence of the lateral covering with NPs (middle). For low coverage, schematically shown in (a), a large amount of gaps between the NPs results in a large resistance. With increasing NP deposition, the onset of percolation goes alongside a steep slope, indicating the decrease in resistance, as shown for a SEM micrograph of a Ag NP network at percolation threshold (b).

In this work, NP networks of Ag NPs were fabricated via gas aggregation source and the electrical resistance was monitored during the deposition in order to obtain networks that fall into the intermediate regime (cf. Fig. 3 (b)). These highly interconnected networks of metal NPs are by no means limited to a purely linear ohmic I-V characteristic. In contrast, in nanogranular assemblies the high number of particle-particle interfaces and defects enables multiple resistance levels and dynamic transitions therein[15,33,34]. In Fig. 4 the time-dependent current response of an interconnected network of Ag NP is shown. Under application of a constant voltage, a rich transition between multiple resistance states can be observed. Each resistance state relates to a distinct configuration of the connectivity within the network, and the transition between two resistance states is mediated by local reconfigurations of Ag species from the Ag NPs. Similar to the limited lifetime of metallic filaments in the diffusive memristive devices, the transition between two resistance levels in the complex Ag network also underlies an intrinsic variability. Comparable electrical characteristics have been reported for a variety of NP

networks, ranging from Sn/SnO<sub>x</sub> NP networks[14] close to the percolation threshold to Au NP networks well above the percolation threshold.[15] This implies that the complex switching between a variety of resistance levels is inherently related to the nanogranular assembly and can be achieved by a variety of materials.

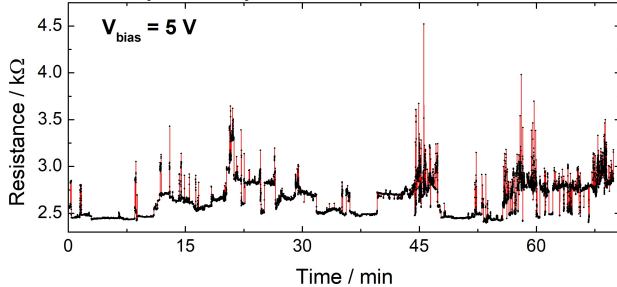


Figure 4. Resistance over time for 5 V applied to a AgNP network. In contrast to the individual diffusive switching in low dimensional NP arrangements, a high number of different resistance states is occupied.

The  $R$  vs.  $t$  measurement exhibits a high number of transitions between resistance states. To visualize the occurrence of the multitude of resistance states, the histogram corresponding to the time-dependent measurements at constant bias is depicted in Fig. 5. In contrast to the multistack NP device, here there is a spread of occupiable resistance states and no clear separation between distinct HRS and LRS can be observed. Notably, the network dynamics show separated periods of burst-like activity and periods of silence, which in many aspects resembles avalanche dynamics and long-range temporal correlations in neural systems.[14,18] For this reason, the electrical characteristics of self-organized NP networks makes them an interesting next-gen device candidate for neuromorphic engineering and reservoir computing, which requires interacting non-linear elements in a complex arrangement, able to map input information into temporal dynamics in the network.

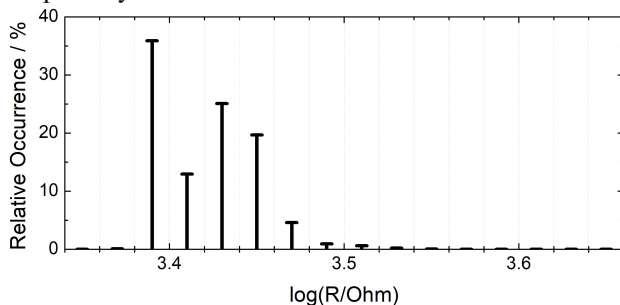


Figure 5. Histogram of the resistance states that are occupied in a AgNP network sample. Compared to the histogram of diffusive memristive switching in sparse AgAu NP arrangements, here a continuous spectrum of occupiable resistance states is observed.

Nanogranular assemblies are by no means limited to noble metal NPs. In contrast, the extension of lateral NP networks towards transition metal oxide NPs opens up the potential for additional functionalities, for example sensing. As such, an interesting parallel to biological systems can be found, in which sensing and data

processing are closely connected. With the junction of memristive switching and sensing it is possible to obtain accommodation to constant stimuli via adaptation.[27] An interesting application of NPs as functional building blocks in the field of sensing is the surface decoration of semiconducting metal oxide thin film sensors for gas sensing applications.[25] For semiconducting metal oxide gas sensors, the presence of metallic NPs at the sensor layer surface is commonly reported to result in a change in the sensitivity and selectivity of the sensor.[35–37]

In this section, the UV sensing properties of networks of TiO<sub>2</sub> NPs fabricated using supersonic cluster beam deposition from PCMS are discussed. The electrical response of a TiO<sub>2</sub> NP network between two Au electrodes (spacing 1mm) at a voltage bias of 10V is depicted in Fig. 6.

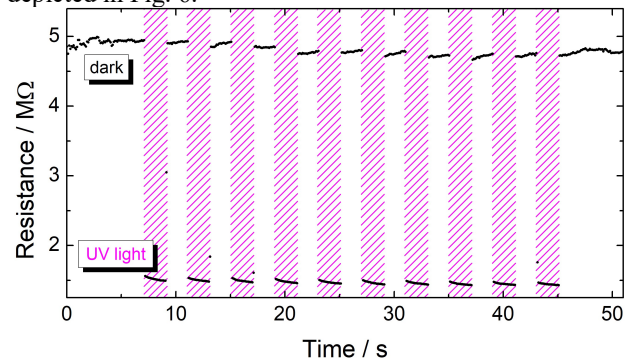


Figure 6. Resistance behaviour of a TiO<sub>2</sub> NP network, post-deposition heat treated for 1h at 600°C in air, UV illumination is applied in 10 pulses of 2s each (constant voltage of 10V applied).

While the resistance in the dark state (without illumination) lies in the range of 4.9 MΩ, the application of UV illumination (for 10 pulses with 2 s duration each) leads to a significant reduction in the resistance down to roughly 1.5 MΩ.

In analogy to the histograms of the resistance states in the multistack AgAu NP device and the Ag NP networks, the resistance states with and without UV illumination are depicted in the histogram in Fig. 7. Here, the clear separation between the dark and the illuminated state becomes clear. It has to be pointed out, that the resistance state “UV on” strongly depends on the illumination intensity.

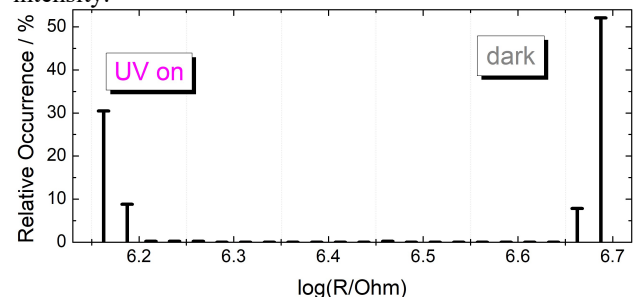


Figure 7. Histogram of the resistance states under illumination (UV on) and without illumination (dark)

#### IV. CONCLUSION

NPs are promising functional building blocks for a variety of (nano)electronic devices. Three use cases for nanoparticulate assemblies are discussed. The well-defined local confinement of memristive action due to the field enhancement between NPs and the limited reservoir of Ag-species in the AgAu alloy NPs results in reproducible diffusive memristive switching in sparse AuAu NP multistack devices with clearly separated resistance states. Dynamic transitions between multiple resistance states were observed in highly connected lateral Ag NP networks. Here, the high number of connections and interfaces enable complex behaviour and results in a plethora of accessible resistance states that do not show a clear separation like in the sparse AgAu NP multistack device. The usage of semiconducting metal oxide NPs, at the example of TiO<sub>2</sub> NPs, extends the usage of interconnected NP networks towards two-terminal sensor devices with well-separated illumination dependent resistance states. Owing to the broad application potential, nanogranular systems with NPs as their building units are a promising candidate for the development of bio-inspired computing architectures.

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# New Vapor Deposited Dielectric Polymer Thin Films for Electronic Applications

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**Abstract**—Dielectric materials are of great interest in a vast amount of applications ranging from cable insulation to advanced electronic devices. The emerging trend of device minituarization is creating an increased demand for dielectric thin films that can be produced precisely on the nanometer scale. In addition, special mechanical properties are often required, for example in the field of flexible organic electronics. Polymers are first-choice materials for this purpose. However, it is extremely difficult to produce precise nanoscale thin films, which have a low defect density and are free of e.g. residual solvent, by wet chemistry approaches. Initiated chemical vapor deposition (iCVD) is a solvent-free polymer thin film deposition process which can be used to produce high quality dielectric thin films with nanoscale control and circumvents thus these problems. This work demonstrates the versatility of the iCVD process in the field of electrical applications by some new application examples of iCVD coatings.

**Keywords**—Polymers, Initiated Chemical Vapor Deposition, Electronic Materials, Dielectrics, Electrets, Gas Sensors

## I. INTRODUCTION

The current advent of polymer thin films enabled by the combination of chemical vapor deposition (CVD) with organic chemistry provides a variety of new pathways in the field of organic electronics and electronic applications. In particular, oxidative chemical vapor deposition (oCVD) and initiated chemical vapor deposition (iCVD) variants developed by Gleason et al. facilitate the precise deposition of new electronic materials from a few nanometers to several micrometers in film thickness. [1] While in oCVD a step growth reaction allows the preparation of conjugated polymers such as PEDOT or

PANI [2], iCVD usually results in insulating films due to the underlying free radical polymerization. In the latter, the polymer backbone is sp<sup>3</sup>-hybridized and the polymer films can be used as dielectrics. Due to the solvent-free nature of iCVD, the dielectric layers are of very high quality and have no defects that accelerate e.g. dielectric breakdown [3]. Thanks to the CVD-typical growth character, the iCVD process can easily be scaled up and integrated into modern microelectronic process lines. A schematic illustration of the iCVD process is shown in Fig. 1a. The respective monomer (M) and initiator (I) are introduced to the reactor. The reactor is equipped with a heatable filament array, located above a sample stage, which is cooled to room temperature. The monomer molecules adsorb at the substrate stage and once the filaments are heated the initiator molecules are decomposed into free radicals (R). These radicals meet e.g. a vinyl groups of the adsorbed monomer molecules. They start a free radical polymerization, which follows similar kinetics like the well-known kinetics for wet chemistry free radical polymerization [4] in order to produce high quality polymer thin films at the substrate surface. In this work, some new application examples of different tailored dielectric iCVD films are shown to demonstrate the versatility of the process in the field of electrical applications.

## II. RESULTS AND DISCUSSION

The application of iCVD thin films as dielectric film is reported by many authors. Especially organocyclosiloxanes like PV3D3 and PV4D4 and fluropolymers have demonstrated excellent performance [5][6][7]. The chemical structure of possible monomers and initiators are presented in Fig. 1b. One argument for

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using iCVD is the high film quality, because no organic solvent is used. Residual solvent and defects can cause

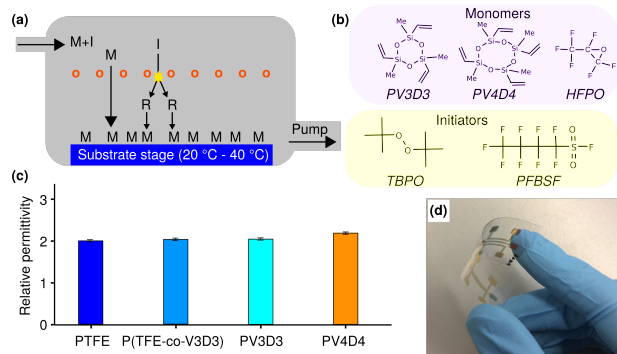


Figure 1. (a) Schematic illustration of the iCVD process. Monomer (M) vapor and Initiator (I) vapor are introduced to a hot wire CVD (HWCVD) reactor. Thermally decomposed I results in free radicals (R), which initiate a free radical polymerization with adsorbed M. (b) Possible monomers and initiators for dielectric thin films. (c) Measurement of relative permittivity for different iCVD thin films. (d) Photograph of flexible iCVD thin film on electronic device.

e.g. conductive paths and lower the dielectric breakdown strength of the material. For dielectric iCVD films the breakdown strength is extremely high, due to a low defect density and high film quality without residual solvent molecules [3]. Fig. 1c shows the relative permittivity of different dielectric thin films grown via iCVD. By using different monomers and initiators or by combining different comonomers the dielectric properties of the film can be individually tuned. The more the chemical composition changes to an organosilicon character the more the dielectric constant increases, as seen from the measurements of PTFE, P(TFE-co-V3D3) and PV3D3. By switching from a cyclotrisiloxane (V3D3) monomer to a cyclotetrasiloxane (V4D4) monomer, as well as different initiator (TBPO), the relative permittivity increases further. The polymer films can in this connection also be deposited on flexible substrates, as shown in the photograph in Fig. 1d and are thus also highly attractive for flexible organic electronics. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations. Since dielectric iCVD films exhibit high breakdown strength and high film quality, we also demonstrated the use of iCVD grown PTFE thin films as electret materials [3]. Electrets are dielectric materials with a quasipermanent surface charge. They are among others applied in portable electret condenser microphones, energy harvesting, air filters or magnetic field sensors [8][9]. Typically charged by corona discharge, contact electrification or electron beams [10], the surplus charge carriers are stored in the material in trap states. These are additional states in the bandgap of the polymer, as illustrated in Fig 2a. PTFE thin films, PV3D3 thin films and PEGDMA thin films have been charged in a corona

discharge under identical conditions and their charge stability is investigated via thermally stimulated discharge measurements. As shown in Fig. 2b, the PV3D3 films (red curve) show a significant lower charge stability, compared to the other polymers.

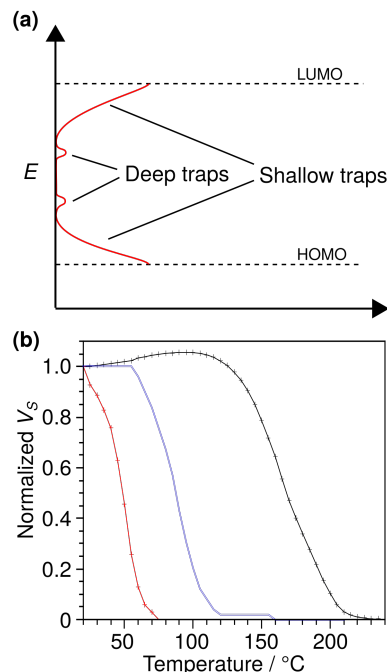


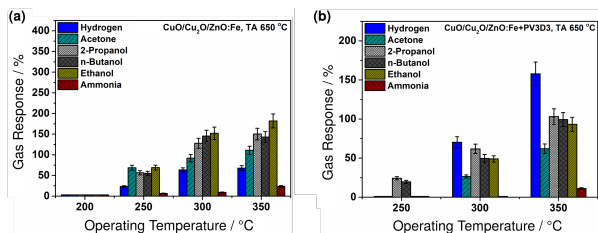
Figure 2. (a) Schematic illustration of deep trap and shallow trap states located in the gap between highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO). (b) Thermally stimulated discharge measurement for iCVD thin film electrets. Red: PV3D3, Blue: PEGDMA and Black: PTFE.

The surface charge vanishes here nearly directly after the charging. PEGDMA thin films (blue curve) show a better stability than PV3D3, but they are not as stable as PTFE thin films (black curve). This underlines the general observation, that fluoropolymers are one of the best materials for surface charge storage and thus the electret application, because they provide a lot of deep level traps [electretcharging]. Another way to use iCVD for electronic devices such as sensors is, for example, the chemical functionalization of the surface. Here, we have developed a conformal hydrophobic coating for metal-oxide gas sensors, so that the sensors can now be operated in high humidity, which was previously a major problem [11]. The dependence of the gas response (hydrogen, acetone, 2-propanol, n-butanol, ethanol and ammonia) versus operating temperature of the samples is shown in Fig. 3a,b. For comparison Fig. 3a shows the samples without PV3D3 coating and Fig. 3b the samples with PV3D3 coating. For the non-coated samples (Fig. 3a) the highest gas response is to ethanol vapors. After the coating with PV3D3 (Fig. 3b) in addition to the resistance to moisture the sample becomes selective for H<sub>2</sub> gas with the highest response at the operating

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temperature (OPT) 350 °C. The response value is here ~165%.



**Figure 3. The dependence of the gas response (hydrogen, acetone, 2-propanol, n-butanol, ethanol and ammonia) versus operating temperature for (a) uncoated samples and (b) hydrophobic PV3D3 coated samples.**

### III. EXPERIMENTAL DETAILS

ZnO:Fe nanostructured films were deposited on a pre-cleaned glass substrate microscope glasses 76 mm x 25 mm x 1 mm) by the chemical solutions based approach (SCS) and was reported in a previous work [12]. An ultra-thin layer of CuO/Cu<sub>2</sub>O with a thickness of 20 nm was deposited on the ZnO:Fe film with a custom system with DC and RF magnetron and then followed by a heat treatment in the furnace at 420 °C for 30 minutes. The hydrophobic PV3D3 thin films were deposited in a home-made ring-inlet iCVD reactor described in detail in our previous works [3][13][14]. Finally, Au electrodes were deposited on top of the CuO/Cu<sub>2</sub>O/ZnO:Fe heterojunctions coated with a layer of PV3D3 polymer through a meandering mask [15]. For sensor performances a computer-controlled Keithley 2400 sourcemeter at 0.2 V applied bias voltage was used. The details on the sensing experiments can be found in our previous works on gas sensing [16][17].

### ACKNOWLEDGMENT

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# Al<sub>2</sub>O<sub>3</sub>/CuO non-planar heterostructures for VOCs vapors detection

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**Abstract**—In this work, the gas sensing properties of the non-planar heterostructures based on CuO thin films, grown by the direct ink writing and covered with an ultra-thin Al<sub>2</sub>O<sub>3</sub> layer, are presented as a function of the operating temperature. The obtained results demonstrates the excellent selectivity to volatile organic compounds (VOCs) vapors, namely n-butanol and 2-propanol in a operating temperature range of 200 – 350 °C. The relatively low gas response was observed at room temperature, which is very important for low-power operation. The dynamic gas response showed an ultra-fast response time of 2 – 3 s. The obtained results demonstrates the excellent potential of non-planar heterostructures based on metal oxides for use in high-performance environmental monitoring applications.

**Keywords**—heterostructures; gas sensor; volatile organic compounds; metal oxide

## I. INTRODUCTION

The gas sensors based on metal oxides can become the key elements in real-time and wireless monitoring of gases and VOCs levels in environment [1,2]. Metal oxide nano- and microstructures demonstrated a high sensitivity and selectivity to a wide range of reducing and oxidizing gases [1,3]. The combination of different *n*-type and *p*-type metal oxides in form of non-planar heterostructures opened new possibilities to design high-performance gas sensors due to the induced new synergic effects [4,5,6]. Another interesting effect that can be induced is the immunity of the parameters to the water vapors, which is critical for practical outdoor applications of real-time monitoring [7]. However, because there is a possibility to combine the metal oxides in different ways and by different principles, as example by type of conductivity (*n-n*, *n-p* and *p-p*), a lot of investigation in this domain still need to be performed.

In this context, the non-planar heterostructures of metal oxides presents the high interest due to the high-

surface area and unique interface properties that can be activated [3,8]. However, in this case there are some critical parameters, that can change radically the gas sensing properties. Recent investigations showed the importance of the top layer thickness in order to involve the heterostructure interface in gas sensing mechanism and in this way to achieve the higher performances [9,10]. In the case of interesting non-planar CuO:Zn/Cu<sub>2</sub>O:Zn heterojunctions, where the top CuO:Zn layer was grown by rapid thermal annealing with different thicknesses (~24 and ~410 nm), it was demonstrated that the thickness of top layer comparable with the hall accumulation layer (HAL) is more preferable for gas sensing due to the involved interface which can enrich and enlarge the HAL [9]. As result, the modulation of HAL under adsorption/desorption of gas molecules is more efficient and the gas response is higher [11,12]. The same effect was also observed in the case of core-shell structures of ZnO-SnO<sub>2</sub> nanowires, where the optimal thickness of top layer was found to be about 40 nm in order to efficiently detect the reducing gases [13].

Using this strategy, the high gas sensitivity to reducing or oxidizing gases can be tuned by modulation of HAL in core material by formation of heterostructures using metal oxides with lower or higher work function [14]. As core material, the *p*-type CuO is very attractive sensing material with high oxygen adsorption and high reactivity to reducing gases due to the low stability associated with redox reactions promoted by variable oxidation states [15]. On the other hand, the *p*-type materials are less studied as gas sensing materials, compared to *n*-type materials, despite the fact that chemical or electronic sensitization can be performed in the same way [15]. For example, Lupan *et al.* reported on highly sensitive and selective hydrogen gas sensors based on CuO and CuO/Cu<sub>2</sub>O columnar films electronically sensitized by



controlled doping with Zn in the same process of growth [9].

In this work, the CuO thin films were grown using three-dimensional (3-D) printing by direct ink writing metal microparticle stripes of commercially available pure copper particles and further thermal annealing. The top ultra-thin layer of Al<sub>2</sub>O<sub>3</sub> was deposited using atomic layer deposition (ALD). The obtained results show the high efficiency of heterostructures formation to obtain high-performance gas sensors to VOCs vapors (n-butanol and 2-propanol), even at room temperature. The further optimization of technological parameters can be performed to extend the domain of applications.

## II. EXPERIMENTAL PART

Copper oxide films were prepared using direct ink writing with copper microparticles (diameter of 15 – 25 µm), purchased from Sigma Aldrich [3]. The ink composition is formed from copper microparticles, ethanol (96%) and polyvinylbutyral (PVB) in a mixing ratio of 1:3:1 by weight, respectively. More details on printing with such type of ink are presented in previous work [3]. The printed material was annealed at 425 °C in air for 30 min with a heating rate of 40 °C s<sup>-1</sup>, which can result in growth of nanowire and nanospikes on the surface of oxidized microparticles, which forms the highly porous networks [3]. This can lead to large surface-to-volume ration and a fast diffusion of gaseous species and therefore to a fast response and recovery of the signal, demonstrated in this work.

The Al<sub>2</sub>O<sub>3</sub> ultra-thin layer was deposited using thermal ALD method using Picosun's R200 with the deposition temperature during the process adjusted to 75 °C [7]. More details are presented in previous work [7]. The thickness of Al<sub>2</sub>O<sub>3</sub> layer in this study is about 6 nm.

The gas sensing properties were evaluated according to procedure described previously [7]. As carrier gas the ambient air with relative humidity of 30 – 40% was used, which was introduced in sealed chamber with a flow of 500 sccm. The concentration of VOCs was calculated using the following relation [7]:

$$V_x = (Vol \cdot C \cdot M) / (22.4 \cdot d \cdot p) \cdot [(273 + T_r) / (273 + T_c)] \cdot 10^{-9} \quad (1)$$

where  $V_x$  is the volume of the injected volatile organic compound liquid;  $Vol$  is the chamber volume, where the gas sensor structures are measured;  $C$  is the required VOC concentration in ppm;  $M$  is the molar mass of the VOC;  $d$  is the density of VOC (g/cm<sup>3</sup>);  $p$  the purity;  $T_r$  is the room temperature; and  $T_c$  is the chamber temperature. The gas response was calculated the following equation [7]:

$$S = [(R_{gas} - R_{air}) / R_{air}] \cdot 100\% \quad (2)$$

where  $R_{air}$  and  $R_{gas}$  is the electrical resistances of the gas sensor structure under atmosphere tested gas, respectively.

The operating temperature in test chamber was controlled using an standard industrial PID controller, connected to the resistive heater, while temperature was measured using a K-type thermocouple. The response and recovery times were calculated from dynamic response as the interval between 10% and 90% of the full response characteristic.

The gas sensing devices were fabricated by deposition of Au/Cr contacts on the surface of the sensing material, using a special designed mask. The resulted distance between contacts is 1 mm. As tested gases, the 2-propanol, n-butanol and ammonia with a concentration of 100 ppm were used.

## III. RESULTS AND DISCUSSIONS

Figure 1(a) shows the SEM image of copper oxide nanostructured film covered with ultra-thin Al<sub>2</sub>O<sub>3</sub> films with thickness of ~ 6 nm. The grown films are composed of nanometric interconnected spherical grains forming a microporous structure and resulting in high surface-to-volume ratio. This allow a easy diffusion of gas molecules even to inner layers of sensing material and theoretically can results in higher gas response due to higher coverage with oxygen species [3]. The top Al<sub>2</sub>O<sub>3</sub> layer is hard to observe with SEM due to ultra-thin thickness of ~ 6 nm, measured in previous work [7].

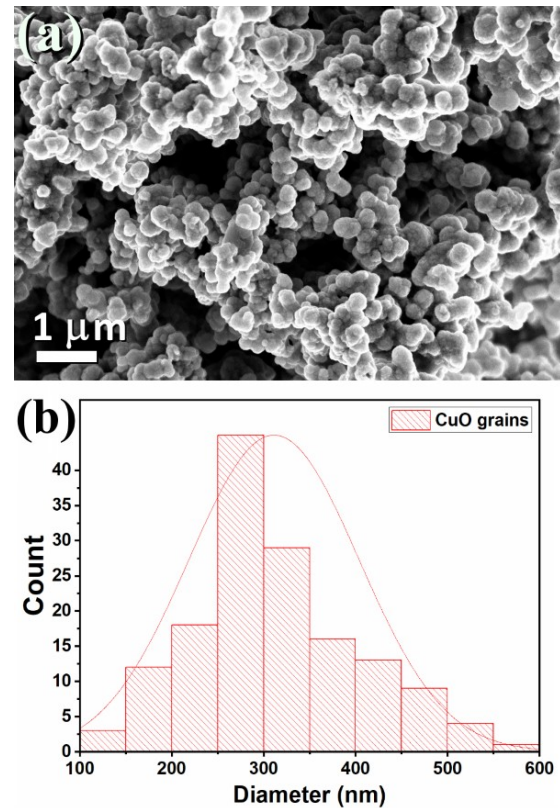


Figure 1. (a) SEM image of copper oxide nanostructured film covered with ultra-thin Al<sub>2</sub>O<sub>3</sub> films. (b) The grain diameter distribution for CuO film.

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The distribution of grains diameter for copper oxide nanostructured film, measured directly from Figure 1(a), is presented in Figure 1(b), being an important parameter for gas sensors based on thin films. Theoretically and experimentally, it was demonstrated that smaller grain size can result in higher gas response due to increased surface activity and formation of more potential barriers [5]. In our case, the grain diameter of CuO nanostructured film varies mainly from 200 nm to 400 nm.

Figure 2(a) shows the measured and calculated gas response of  $\text{Al}_2\text{O}_3/\text{CuO}$ -3D non-planar heterostructure in a wide range of operating temperature, namely from room temperature (25 °C) to 350 °C. From 200 °C to 350 °C the temperature was increased with a step of 50 °C. It can be observed that in all cases the highest response was detected for VOCs vapors, namely n-butanol and 2-propanol. In order to check the repeatability of the sensor, several measurements were performed under the same condition. The error bars indicate on the deviation of the obtained results. The optimal operating temperature is 250 – 300 °C, where the gas response to n-butanol and 2-propanol is ~ 60% and ~ 62%, respectively. The gas response at room temperature to 100 ppm of 2-propanol is ~ 4%. All tested sensor structures showed good repeatability and reproducibility. The measurements to hydrogen and methane gas showed no noticeable response, therefore were not included in this work and graph from Figure 2(a).

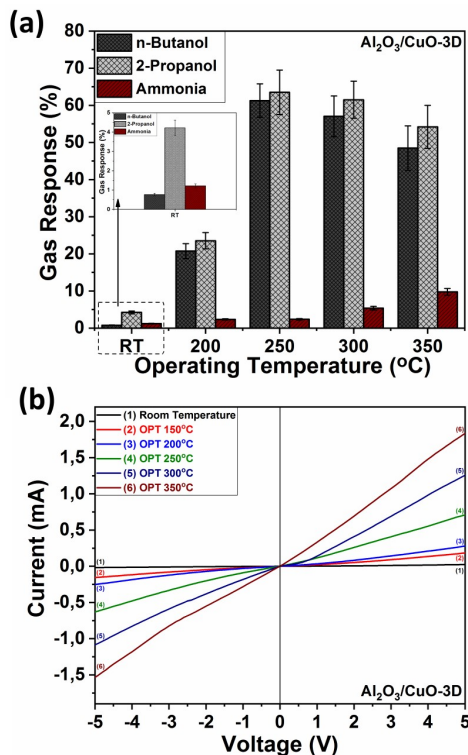


Figure 2. (a) Gas response of  $\text{Al}_2\text{O}_3/\text{CuO}$ -3D non-planar heterostructures to 100 ppm of ammonia, 2-propanol and n-butanol. (b)  $I$ - $V$  characteristic of heterostructures at different operating

temperatures.

Figure 2(b) shows the current – voltage ( $I$ - $V$ ) dependence of  $\text{Al}_2\text{O}_3/\text{CuO}$ -3D non-planar heterostructures at different operating temperatures (from room temperature to 350 °C). At all tested temperatures, all gas sensor structures showed formation of quasi-ohmic contacts. Therefore, we can conclude that gas sensing properties originate mainly from the sensing layer, while the interface at the contacts have minimum influence. Also, the increase in temperature gives the rise in current, typically for metal oxides.

Figure 3(a) shows the dynamic response of gas sensor structure based on  $\text{Al}_2\text{O}_3/\text{CuO}$ -3D non-planar heterostructures to 100 ppm of 2-propanol vapors at room temperature. The gas response of ~ 4% is quickly increased in 5 s with no evident saturation. The recovery of signal after evacuation of vapors from test chamber is much slower and takes about 20 – 25 s. The possibility to detect VOCs at room temperature is very important for practical applications because will exclude the necessity to use the microheaters.

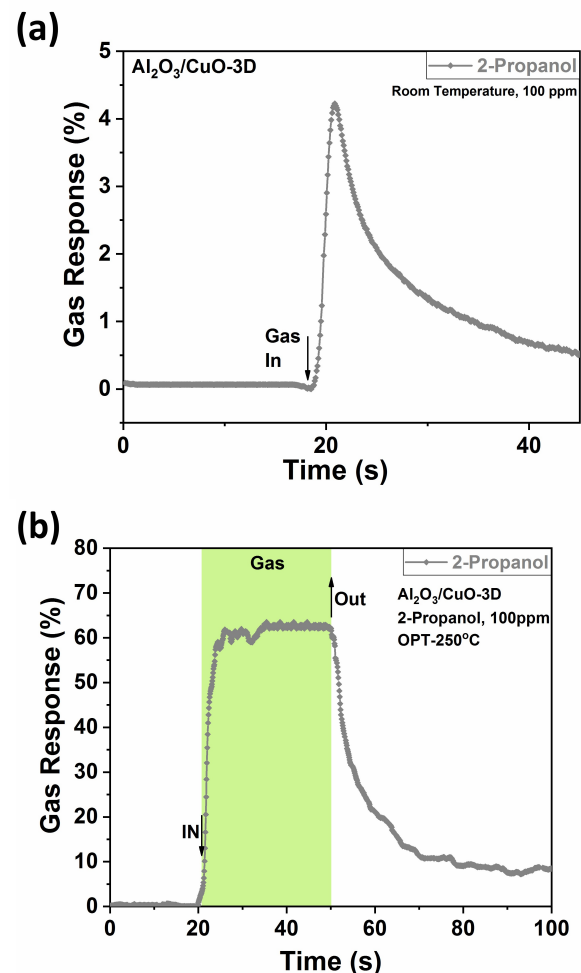


Figure 3. Dynamic gas response of  $\text{Al}_2\text{O}_3/\text{CuO}$ -3D non-planar heterostructures to 100 ppm of 2-propanol at: (a) room temperature; (b) 250 °C.

Figure 3(b) shows the dynamic response of the same gas sensor structure at operating temperature of 250 °C, showing the fast saturation of signal after 3 – 5 s. The recovery of signal in this case takes about 30 s. The similar values were obtained for response to 100 ppm of n-butanol. Such fast response is critical in the case of fast leakage detections. However, in the case of outdoor or indoor VOCs level monitoring this is not the most important parameter.

The higher selectivity of CuO nanostructured films to VOCs vapors compared to other gases can be explained based on many other reported results, which frequently demonstrates selective detection of VOCs, especially ethanol vapors [15]. CuO is oxide of transition metal and exhibit various oxidation states because of the electrons in the d shell of the metal atom [15]. Such type of sensing material posses distinctive catalytic activities that promote the oxidation of VOCs, such as 2-propanol and n-butanol [15]. Moreover, previous gas sensing investigations of undoped CuO films grown using chemical solutions based approach at a relatively low temperature < 95 °C and using the same 3-D printing based method showed the higher gas response to VOCs compared to such gases as H<sub>2</sub>, CH<sub>4</sub> and CO [3,9,12]. Therefore, it can be concluded that Al<sub>2</sub>O<sub>3</sub> ultra-thin layer have no important impact on selectivity of the films

#### IV. CONCLUSIONS

In this work, the gas sensing properties of Al<sub>2</sub>O<sub>3</sub>/CuO-3D non-planar heterostructures to 100 ppm of 2-propanol, n-butanol and ammonia were investigated. The experimental results clearly demonstrate the advantage of the heterostructure formation on the surface of sensing materials in order to obtain high-performance gas sensors with very fast response (3 – 5 s), high gas response and possibility to detect at room temperature. The obtained parameters will allow in future to integrate such sensors in portable devices for VOCs environmental monitoring.

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# Experience in creating nanosatellites of the "cubesat" "PolyITAN" standard in Igor Sikorsky Kyiv Polytechnic Institute: mission, development and exploitation results

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**Abstract.** This article gives general information about the goals, requirements of missions and describe show these requirements are expressed in the development of nanosatellites (NS) of the PolyITAN series of CubeSat standard. The report also discusses the integration of electronics with the design and payload, provides information on the applied manufacturing methods and tests of NS of various modifications for performing tasks in orbit. The analysis of the results of flight tests of the NS (PolyITAN-1 and PolyITAN-2) and potential capabilities of the developed NS "PolyITAN-3" (assessment of the quality of shooting when sensing the Earth from an altitude of 400 ... 350 km) and "PolyITAN-4" (features of simulating the environment and plant growth under microgravity and cosmic radiation).

**Keywords:** frame, honeycomb panel, Igor Sikorsky KPI, launch, nanosatellite (NS), nanosatellite testing, orientation, power budget, thermal vacuum tests.)

## I. INTRODUCTION (HEADING 1)

Leading universities of the world are now actively encouraging students to create nano-satellites - small spacecraft, the so-called international standard "CubeSat" (U1 format (single unit) corresponds to a mass of about 1 kg and dimensions of 10×10×10 cm). In addition to solving purely educational purposes, such spacecraft in the future may be used in the implementation of a number of scientific, technical and social projects for different purposes. Standard "CubeSat" makes it possible to create miniature satellites weighing 1-10 kg in a short period of time (1-3 years) and with relatively small means. Such work is carried out in dozens of scientific centers around the world. The rapid development of the element base gives hope for the commercial application of these spacecraft. The establishment of such satellites allows the

space research at relatively low financial cost and it is actual for Ukrainian conditions with its high potential in the field of designing and developing of space technology [1-4]. Ease of Use

## II. DEVELOPMENT, MANUFACTURE AND LAUNCH OF POLYITAN NANOSATELLITES

A thorough analysis of many options for real and design studies of microsatellites has shown the possibilities of implementation and the feasibility of creating nanosatellites of the CubeSat format for various purposes in higher technical educational institutions. Such spacecraft, of course, have undergone and are undergoing structural changes in comparison with spacecraft produced in the conditions of real aerospace technologies by large corporations. The main distinguishing features of university nanosatellites of the CubeSat format are:

- a) less stringent requirements for the payload and other onboard equipment;
- b) the possibility of using experimental samples of equipment not certified for work in space;
- c) support for radio communication with a CubeSat nano-satellite in radio amateur bands (for example, 144-435 MHz), which, in turn, does not require a special and expensive permit to operate these radio frequencies;
- d) the use of commercial (non-specialized) hardware in the payload and spacecraft subsystems;
- e) significantly lower financial costs for the production of nanosatellites;
- f) the possibility of launching in the form of a passing cargo by agreement with the provider of launch services.

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Such spacecraft are most often used by universities either for testing their own experiments or for practical training of students in educational programs of special disciplines.

### III. NANOSATELLITE POLYITAN-1

The PolyITAN-1 satellite was created by a group of young scientists and engineers of the thermal power and radio engineering faculties, the Faculty of Electronics, as well as the Institute of Telecommunication Systems NTUU “Igor Sikorsky Kyiv Polytechnic Institute” under the guidance Prof. Boris Rassamakin. The main goals of the PolyITAN-1 satellite launch were:

- development of technological flight modes;
- creation and research of solar sensors for small spacecraft;
- checking the energy of the solar power sources developed at the university;
- adaptation to space conditions and improvement for future flights of digital channels for transmitting information from the satellite to the Earth and commands to control it;
- study of the influence of outer space on the operation of satellite electronic subsystems;
- study of the functioning of GPS systems of the original design.

To track the flight of the spacecraft and carry out the planned research, the university has created a center with the necessary test equipment.

The first nanosatellite NTUU “Igor Sikorsky Kyiv Polytechnic Institute” - PolyITAN-1 - was launched on June 19, 2014 to work out technological flight modes and study the elements of the apparatus structure with the aim of their further improvement. It transmits telemetry signals to the university's flight control center (active as of 09/23/2021).

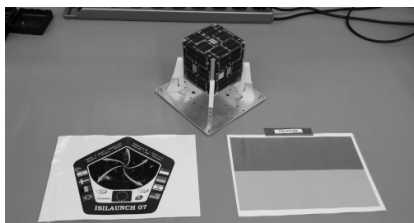


Figure 1. Flight model of the PolyITAN-1 nanosatellite

The results obtained during the flight are used, among other things, in the design of new structures of small satellites, the creation of which is stipulated by the agreements concluded by the NTUU “Igor Sikorsky Kyiv Polytechnic Institute” with other universities. This first launch was carried out through international cooperation NTUU “Igor Sikorsky Kyiv Polytechnic Institute” with Shenyang University (PRC). It should be noted that after

the presentation of the nanosatellite model (Figure 1.) at the Institute. Karman (Belgium) Kiev polytechnics were invited to participate in the QB50 International Project, in which several dozen universities have already taken part.

The first nanosatellite NTUU “Igor Sikorsky Kyiv Polytechnic Institute”- PolyITAN-1 - was launched into orbit using the Dnepr launch vehicle, created as part of the conversion on the basis of RS-20 (15A18) ICBMs (NATO classification - SS-18 Satan) and produced on Dnepropetrovsk enterprise “Yuzhmash”. The rocket was launched from the Yasny launch base (Orenburg region, Russia) on June 19, 2014 at 11:00 pm local time. In 16 minutes after the launch, all spacecraft successfully departed from the third stage and entered the specified orbits.

### IV. MODEL OF “POLYITAN-2-SAU NANOSATELLITE”

At present, the PolyITAN-2-SAU launched into the near-Earth orbit is part of the scientific space network of the QB50 project intended for studying the thermosphere. The main task of the QB50 project is to study the Earth's climate change. The NS carries a payload on board □ an experimental sensor for analyzing the oncoming gas flow FIPEX, capable of distinguishing and measuring the characteristics of atomic and molecular oxygen, which is the main element at altitudes of 90-420 km from the earth's surface. This is important for the assessment of thermosphere models.

### V. OBJECT OF STUDY

Structurally, NS “PolyITAN-2-SAU” is the successor of the previous model (NS “PolyITAN-1”) designed at NTUU “KPI” and launched into Earth orbit in 2017 (finished mission in 2019 when was burned in the Earth's atmosphere). The results of the first run and participation in QB50 mission allowed significant changes in the NS design. Thus, “PolyITAN-2-SAU” is a 2U (2-Unit) format, with a payload, which is a thermosphere composition analyzer FIPEX. This is the main difference compared to the first model (PolyITAN-1 is a 1U), which is caused by a special range of tasks to be carried out of the NS.

The key to finding innovative solutions is the need to comply with the requirements of the NS QB50 project, under which the payload is ready to be installed on the projected satellite. Thus these are size, layout, set of subsystems, which should provide integration, and the ability to manage the already developed FIPEX (Figure 2).

Payload is FIPEX (Flux-Probe-Experiment) – parser of the thermosphere composition, developed at Dresden Technical University, which is able to distinguish and

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measure the behavior of atomic oxygen, as a key element in the lower thermosphere, in the time domain.

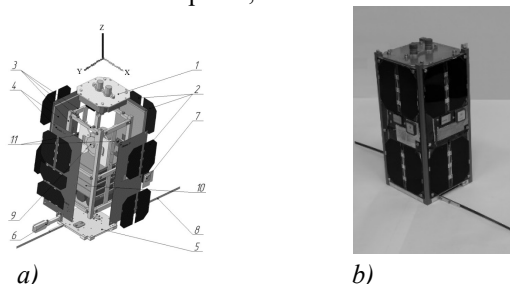


Figure 2. Engineered (a) and real (b) view of “PolyITAN-2-SAU”:

1 – payload (FIPEX); 2 – solar battery; 3 – satellite case; 4 – honeycomb panel; 5 – aerial module; 6 – magnetometer with deployment mechanism; 7 – GPS/GLONASS aerial; 8 – radio aerial; 9 – flywheel; 10 – electronic platform; 11 – Sun direction sensor.

## VI. THERMAL VACUUM TESTING

Thermal vacuum testing, during which was simulated the effect of space factors on the NS and its parts, is one of the important stages in the development of “PolyITAN-2-SAU”. Significant factors of space for the thermal vacuum test are: low temperature, vacuum, space blackness, Sunlight and reflected radiation from the Earth [5].

During its orbital motion, NS continuously falls under various influences – Sun radiation, Earth radiation etc., which significantly affect the thermal state and thermal mode of the NS systems, and thus the reliability and efficiency of the NS elements in flight.

At various intervals, the impact of these factors will vary: depending on the NS position in orbit and on the functioning conditions of its systems the carcasses surfaces will be exposed to variable heat flows of different intensity, which will determine the thermal state of subsystems and elements of NS, including its electronic equipment [5].

One of the main characteristics that determine the readiness of the NS PolyITAN-2-SAU to start is conformity of the temperature conditions of the electronic platform and equipment of the NS to their operating temperature range. Thus the result of thermal vacuum test should conclude that during the imitation of external and internal heat evolution, temperatures of NS elements do not exceed their permissible limits. Also during the test there was made the checkup of the functional ability of the satellite subsystems to perform their tasks at the orbit, and confirmation of the correct thermal regulation of NS systems. Also, tests are needed to fulfill international QB50 project requirements. This includes checking

performance and capability to control the payload under the impact of space factors.

To carry out the necessary tests simulating thermal vacuum chamber TVC-0.12 [5] was used, which is the single set of tools and equipment that provides the necessary space conditions simulation. This camera is designed specifically for the NS research, elements of space technology and small-sized spacecraft. This camera is located in the NTUU “KPI”.

As a result of the test, rotation of NS around the Earth was simulated and the temperature dependence of its components, on which temperature sensors were placed, was received. The Figure 3,a shows the temperature dependence of the inner sides of honeycombed structure which serves as frame, i.e. the temperature distribution on its planes.

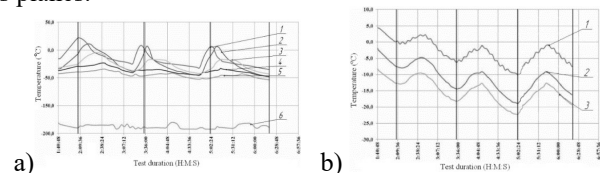


Figure 3, a. Distribution of temperatures on the inner sides of the NS honeycombs: 1 – side Z+; 2 – side Y–; 3 – side X–; 4 – side X+; 5 – side Y+; 6 – cryo shields.

Figure 3, b. Distribution of temperature on the electronics boards of NS: 1 – radio channel board; 2 – CPU board; 3 – FIPEX board.

Figure 3,b is a graph showing changes in temperature values on the control board of the payload, on the radio board and the CPU board. As can be seen from the chart, board temperature does not significantly dependent on external factors and changed slightly from the Sun to the shadow mode (2...3o). The maximum temperature is presented on radio board (+3...–10°), then the CPU board (–5...–20°) and the control board of payload (–10...–23°). Based on the data it can be stated that the electronic system of NS is within acceptable temperature limits.

Also worth noting the practical independence of temperature between the NS of orbital position, and fluctuations in the radio card, which can be observed in the course of the experiment — those are the results of the performance of this NS element. As a result, thermal vacuum tests:- studied the temperature distribution on the modules, assemblies and construction elements of the NS, electronic board surfaces, depending on the external radiant heat fluxes corresponding to movement of NS by the proposed orbit;- revealed the limits of temperature fluctuations of the NS elements caused by modeling of changes in its orbital position; - confirmed the performance of the NS equipment under conditions consistent with the orbital.

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According to test results, it can be concluded that the engineering model of the NS sustains thermal loads and can operate in space in normal mode.

## VII. THE FEATURE OF THE “POLYITAN-3” MISSION

The mission of the project “PolyITAN-3”(for Earth sensing) is creation of 3U CubeSat nanosatellite by developing, modeling and researching effective service subsystems to provide a payload □ an optoelectronic scanner with a capability of shooting in the range of up to 30 m when operating in orbit at altitudes up to 700 km.

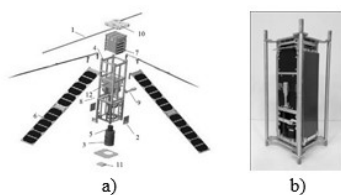


Figure 5. “PolyITAN-3”engineering model

(a): 1 – antenna 144/435 MHz, 2 – solar sensor, 3 – camera lens, 4 – frame, 5 – camera, 6 – solar panels, 7 – electronic platform, 8 – flywheel, 9 – magnetometer, 10 – antenna module, 11 – high-speed antenna, 12 – electromagnet board; and real photo (b).

“PolyITAN-3” (Figure 5) is 3U CubeSat satellite with camera for remote sensing. This feature is associated with new challenges in the thermal control system and the power supply of the satellite. Solar panels have the form of 4 wings, each wing consists of two modules of six elements. The modules are connected in the wing by the mechanism of opening and connected in series. In addition, a high-speed radio link module is used. It has the following properties: 5.7 GHz 800 kB, 2 W; and will be used for transfer of images to the earth station.

All previous work has been carried out, such as selection and development of equipment, electric and thermal calculations, etc. A thermal model of the nanosatellite was created, and a numerical calculation was also carried out in the ESATAN-TMS program. Now the satellite is being assembled, and scheduled to produce thermal-vacuum test.

## VIII. THE FEATURE OF THE “POLYITAN-4-BIO” MISSION.

The feature of the PolyITAN-4-BIO mission is current impossibility to give a positive forecast for the stability of higher plants in the conditions of space flight during long flights; since almost all vegetable objects that have been grown on space platforms are annual plants with a short

life cycle, and the duration of most of the experiments aboard the ISS did not exceed 30 days. Plants are considered as a source of food and oxygen in bioregenerative life support systems of long space missions.

Such an experiment can be carried out on the platform of a small satellite CubeSat, using the technology created and successfully tested in space conditions created by National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute” and microcosm technology □ growing plants in a closed gas environment, which was developed in the National Botanical Garden. M.M. Grishka NAS of Ukraine. In a unique experiment at this institution, the plants show the ability to grow in a closed gas environment for a long time (currently the duration of the experiment is 12 years).

Carrying out the experiment and promoting it in the media has a powerful image component and will promote the promotion of cosmonautics and the attraction of young people to pre-scientific space exploration.

The technology of the developed unit for long-term cultivation of plants in microgravity can be applied for the implementation of space experiments in the future, as well as being a tested basis for the creation of new cultivation chambers for growing plants aboard spacecraft. With plant life support system (temperature and lighting) from on-board telemetry and model experiments on plant growing is created in a stationary unit under stationary conditions with observation of the condition of plants growing in a stationary unit. Creating such a system will allow for various biological experiments on the CubeSat platform. The proposed space experiment is unparalleled and will be the first attempt at long-term exposure of several species of plants in space flight in a power unit. Information on the resilience of such an artificial ecosystem to the long-term impact of microgravity is a prerequisite for the creation of bioregenerative life support systems and the implementation of their long-term space missions. Plants are considered as a source of food and oxygen in bioregenerative life support systems of long space missions. The satellite design includes a hermoblock with a system for maintaining the viability of plants: fibrous substrate, grating for a substrate, NIR-camera for shooting (observing the state of plants), fan with protection, LED lighting, system for monitoring the environment inside.



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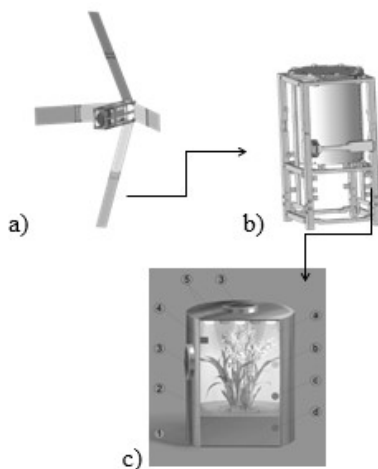


Figure 6. General view “PolyITAN-4-BIO” (a); Placing of hermoblock in the case of “PolyITAN-4-BIO” (b); Herm block composition (c) include plant’s life support systems: 1 – fibrous substrate, 2 – holding mesh for the substrate, 3 – NIR-camera (to monitor the state of the plant), 4 – fan with protection, 5 – LED light; and the environmental monitoring system inside the unit: a – light sensor, b – CO<sub>2</sub> sensor, c – temperature sensor, d – substrate humidity sensor.

Expected results: selection the optimal plant composition with the best growth characteristics and the value of the minimum-sufficient level of water with the mineral component for plant nutrition.

## IX. SUMMARY AND CONCLUSIONS

Aerospace technology and manufacturing techniques were used in the design and manufacturing of nanosatellites series “PolyITAN”. Architecture of “PolyITAN” nanosatellite allowed to avoid problems that occur with a reduction in scale structures of satellite systems for their use in small and nanosatellites. This was made possible thanks to realization of the key differences between large satellites and satellites CubeSat, the development of new sub-systems and systems specially designed for use in CubeSat format nanosatellites. “PolyITAN” nanosatellites provides high-performance electronic platform for testing new materials in space, carrying out scientific experiments and testing of technologies.

Benefits of “PolyITAN” Platform:

- High precision positioning using GPS + GLONASS (Galileo optional).
- The cost of mass production is lower by 40-60% than in the US and European counterparts.

- The presence of a complete set of satellite system at University (satellite into orbit and ground station).
  - Start services, support and maintenance.
  - The possibility of supply of separate components and subsystems.
  - Scalable platform in accordance with the Cubesat standard.
  - Using for a wide range of applications (radio communication, Earth sensing, scientific experiments, etc.).
  - Use of carbon fiber honeycombs for heat control and radiation protection.
  - The full nanosatellite development cycle
- Analysis of the functional characteristics of “PolyITAN-1” subsystems and test of the impact of external damaging factors are still going on in the orbit. However, all tests up to this day have been successful and the results are compared with the design.
- The PolyITAN-1 nanosatellite is active in the Earth's orbit at a height of 602 ... 607 km to the present time (site: <https://www.n2yo.com/?s=40042>).

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# The Experience of Preparing to Launch the TUMnanoSAT nanosatellite

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**Abstract**—In this paper, a brief overview of TUMnanoSAT's educational and scientific missions, the impact on system design and educational opportunities are presented. The main basic test procedures for the launch of this nanosatellite are described, including the structure, power supply and attitude control. The main mission of TUMnanoSAT is to provide practical experience to students not only in designing, building, but also testing the nanosatellite with various missions.

**Keywords**—nansatellite; TUMnanoSAT; testing procedures.

## I. INTRODUCTION

CubeSats are experiencing unprecedented growth, for instance, in 2020 the world registered 1260 new satellites and other space objects with the United Nations Office for Outer Space (UNOOSA) [2]. The National Center for Space Technologies (NCST) of Technical University of Moldova (TUM), like many universities focusing on the international CubeSat standard, has decided to develop a series of satellites with specific and efficient missions. The first general mission is TUMnanoSAT, the main objective of which is to verify in real conditions the functionality of the various satellite modules and subsystems for future missions. The concrete missions of TUMnanSAT are:

- space testing of sensors on nanostructures, developed by partners from the TUM Nanotechnology Center;
- establish an effective "satellite-to-ground station" communications subsystem with the possibility to modify the range of communication speeds and ensure high reliability, including verifying the communication protocol with different levels of access;
- searching for the optimal ways of distributing the

accumulated energy and testing the power supply system;

- in order to optimize the attitude of the process control satellite, testing the sensor subsystem to determine the attitude of the satellite (magnetometers, micro-gyroscopes, solar sensors);
- testing the operation of COTS electronic components under radiation conditions, including the on-board computer, digital memories.

It is known, that each spacecraft system involve always ground segment which basically consist of ground station and a monitor and control center. In this context in order to assure a successful mission, it is mention NCST was set up a whole infrastructure with two ground stations and a mission control center with the possibility of processing, command and control, including nanosatellite testing [5].

The paper deal with the experience of the NCST team obtained in the process of testing some satellite subsystems in preparation for its launch from the International Space Station (ISS).



Figure 1. TUMnanoSAT the first TUM 1U CubeSat

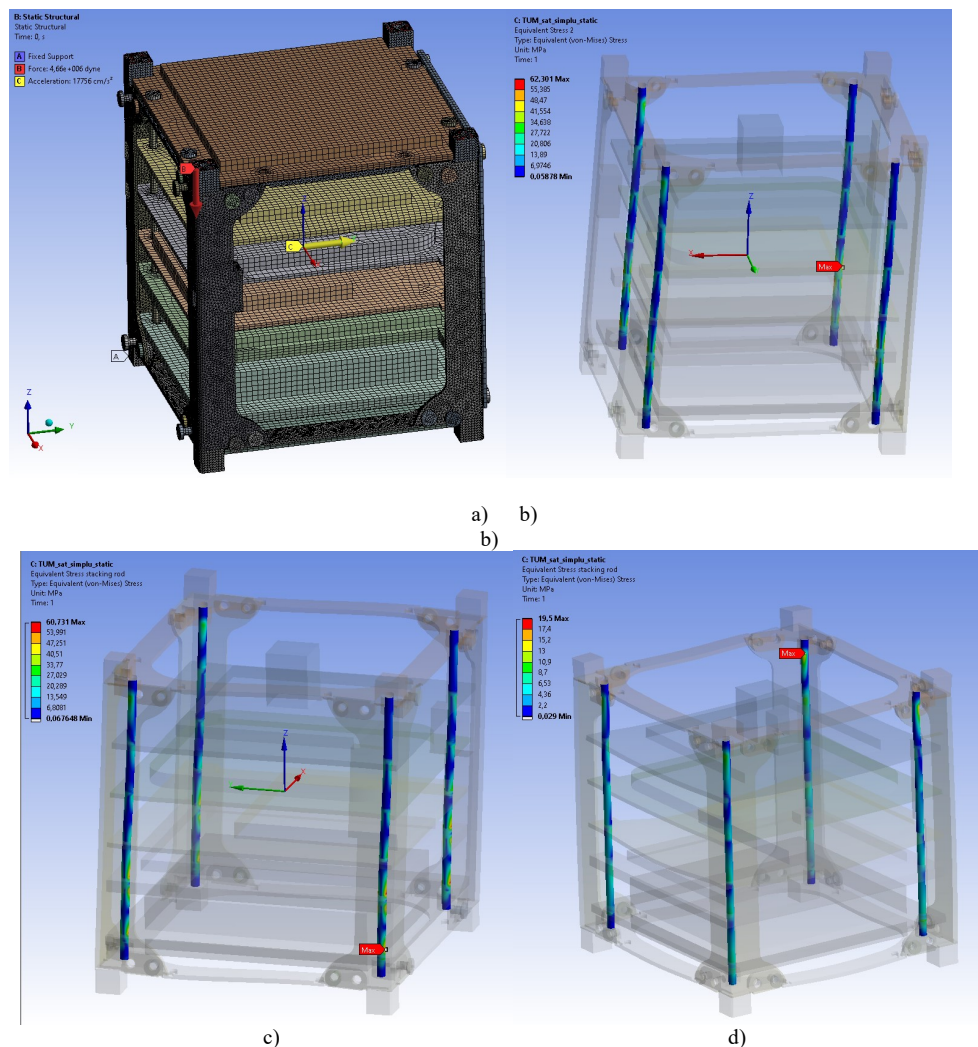
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## II. STRUCTURE OF TUMNANOSAT

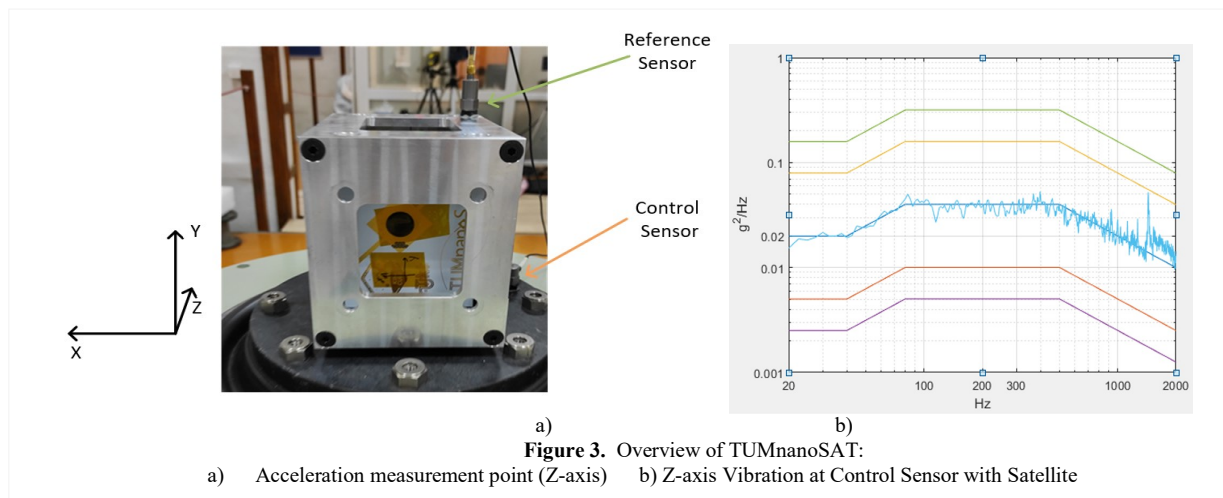
For each nanosatellite the main purpose of the structural subsystem is to provide a rigid and reliable structure that can withstand all harsh launch conditions. At the same time, in the design of structural subsystems is the maximization of usable interior space while minimizing the complexity of the subsystem. When designing the TUMnanoSAT structure, the constraints imposed were taken into account by the CubeSat Design Specifications and the Control Document of the implementation interface of small satellites for JEM payload accommodation.

In order to reduce the manufacturing costs and the mass of the structure, we opted for a structure consisting of several parts, despite the fact that the monolithic structure is much more rigid, and the material used in manufacturing in the structure TUMnanoSAT was proposed aluminum alloy 6061. On the other hand, due to the fact that TUMnanoSAT is designed to be launched from the International Space Station, three deployment switches have been added on the rails of the structure, that must physically interrupt all power lines in the satellite, so when the satellite is installed in the deployment device, early antenna deployment must not be activated.



**Figure 2.** TUMnanoSAT finite element model (a) and analysis results with :  
b) X direction acceleration; c) Y direction acceleration; d) Z direction acceleration

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**Figure 3.** Overview of TUMnanoSAT:

Initially the finite element model of the structure was created by using ANSYS Mechanical. The mass properties were used to construct a model with approximately equal mass as the components. The natural frequency and static load simulations by ANSYS Workbench Modal analysis results that it has revealed that minimum fundamental frequency is safety for the various components was computed using a factor of safety of 1.5 for yield strength ( $F_{ty}$ ) and 2.0 for ultimate strength ( $F_{tu}$ ). Real following vibration tests were performed along X, Y and Z axes, with low level sinusoidal sweep and random vibration. The verification points are: no breakage in main structure; main structure needs to satisfy specified natural frequency; natural frequency before and after tests need to remain unchanged; no improper antenna deployment, and no malfunction to cubesat; no breakage in grass material such as solar battery cover; no loosening in all fasteners. Low level sinusoidal sweep is adequate for model verification of simple structures with relatively rigid components, whose flexibility is confined to mounting jig or frequency isolation hardware. It is performed on each axis with the frequency 20~2000 [Hz] and amplitude 0,5 [G].

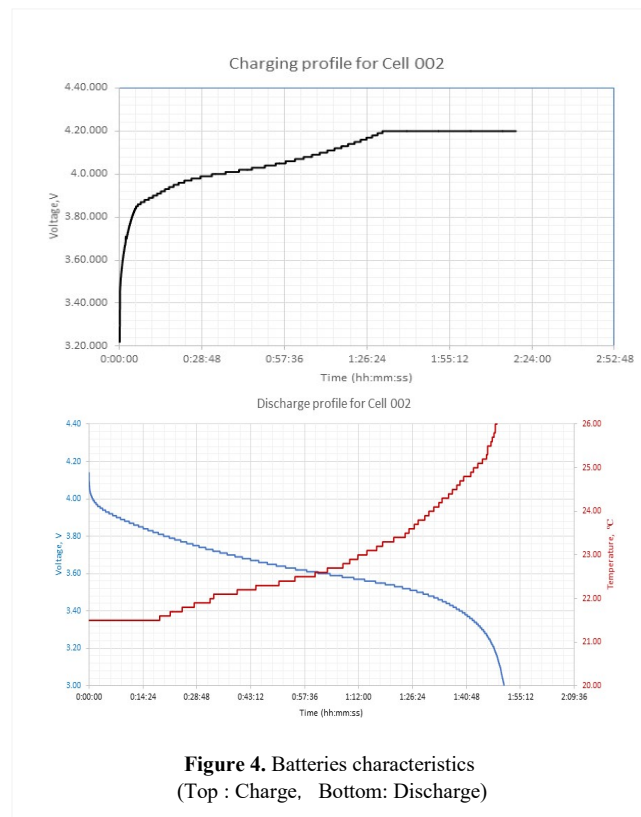
The random vibration test level It is performed with the frequency 20~2000 [Hz] and amplitude 02-04 [ $G^2/Hz$ ]. This level is the envelope of the environments for HTV, Space X Dragon and NG Cygnus (reference: JX-ESPC-101132). This test level was defined by Structure Fracture Control Evaluation Form. Some results are presented in the figure 3.

### III. POWER SUBSYSTEM of TUMnanoSAT

TUMnanoSAT subsystems require a nominal voltage stabilized by 3.3V or 5V for normal operation. The voltage on the battery can vary in the

366.57[Hz] which is higher than 60[Hz] and the maximum stress on the satellite was 94.5 MPa, 100.8 MPa and 19.5 MPa in the necessary limits of loads. Stress levels on various parts of the satellite are displayed in Figure 2 show the FEM with input load, acceleration and constraint condition for each analysis cases. The margin of

3.5V - 4.2V range, so for 3.3V voltage the DC-DC converter with the Buck (Step-Down) topology will be used, and for 5V - DC-DC converter with the Boost



**Figure 4.** Batteries characteristics  
(Top : Charge, Bottom: Discharge)

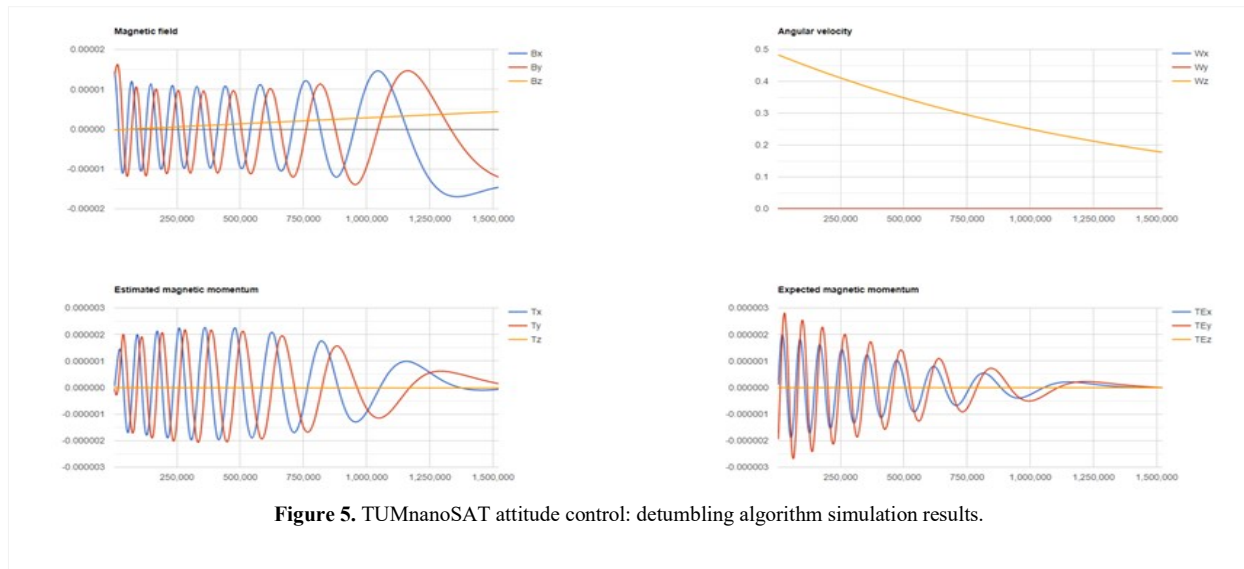


Figure 5. TUMnanoSAT attitude control: detumbling algorithm simulation results.

(Step-Up topology). Therefore, The power subsystem of TUMnanoSAT has one integrated Li-Po battery pack that contains two Varta Li-Po cells with a total capacity of 10 Wh. Also in EPS (Electrical Power Subsystem) are five solar panels. Each Solar Panel Channel has a DC-DC step-up converter with Maximum Power Point Tracking (MPPT). The output energy for each solar panel is monitored. The Solar Panel Channels can handle input voltages up to 5.5V and the current maximum threshold for overcurrent protection is set to 1.8A. The EPS subsystem was subjected to real tests, priority was given to the characteristics of the batteries, being COTS components. Therefore, charge and discharge characteristics tests are performed for each battery cells before and after the environmental tests. From these tests, it is confirmed that charge and discharge characteristics do not change due to the environmental and are within the nominal range (figure 4) It is important prior to handover after the environment tests for TUMnanoSAT Charge/Discharge Characteristic tests of battery inside nanosatellite is measured to see that there is no damage. To be mentioned that the Charge/Discharge Characteristics test was measured the range between maximum voltage and minimum voltage.

#### IV. ATTITUDE AND ORBIT CONTROL SUBSYSTEM

The TUMnanoSAT attitude control is a low-performance Attitude Determination and Control System (ADCS), that required to orient the nanosatellite to the Nadir direction, because the camera is low resolution and has a large aperture

angle (56 degree), on the other hand the antenna also has a transmit/receive diagram with an angle of 120 degrees. Based on these, there are a network of sensors and a magnetorquers on the solar panel PCB and they can be interfaced to an ADCS. The network can be all or a combination of the following: temperature sensor, Sun sensor, magnetorquer, and gyroscope. The temperature sensor and Sun sensor (photodiode) are positioned on the top surface of the solar panel whereas the magnetorquer and gyroscope are positioned within the solar panel and not visible. The magnetorquer is a series of large electrical coils positioned over several layers of a multi-layer PCB. Furthermore, the PCB is equipped with a connector for an external magnetorquer. To calibrate sensors and to test magnetorquers and attitude control algorithms was build a facility to simulate geomagnetic conditions for the satellite.

The verification of the attitude control algorithms was performed with the terrestrial magnetic field simulation stand that ensures in a computerized way the creation of the magnetic field as intensity and direction in any point of the orbit of the nanosatellite. The results obtained confirm the correctness and quality of the satellite orientation, which are partially shown in figure 5.

#### V. CONCLUSIONS

In this paper was presented the test experience of the first TUMnanoSAT nanosatellite within 4<sup>th</sup> round of the KiboCube program. The TUMnanoSAT missions are mainly with educational objectives, in the realization of which the students are involved and other objectives are with elements of research and technological verifications. The experimental tests in terrestrial conditions give us confidence in their efficient operation in space conditions.



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# Theoretical and Applied Physics Session

# Experimental and Computational Study of the Apparent Absorption Spectra of Nanostructured Manganese Tungstate Catalysts

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**Abstract**—The UV-Vis spectra of a series of  $\text{MnWO}_4$  nanorods with different Mn/W ratio represent the subject of the present study. Since the surfaces of the obtained catalysts are damaged to understand the observed spectra transformations with the change of the Mn/W content homometallic binuclear, trinuclear and tetranuclear linear manganese clusters, binuclear tungsten clusters and mixed manganese-tungsten clusters of different nuclearity are examined. The choice of the linear manganese clusters of different nuclearity for examination is dictated by the revelation of  $\text{MnO}_x$  units on the surface of the  $\text{MnWO}_4$  nanorods. The structures of these different nuclearity species have been optimized, and their absorption have been calculated with the aid of density functional theory (DFT). It has been shown that homonuclear tungsten clusters demonstrate only ligand-metal charge transfer, while manganese clusters demonstrate both ligand-metal and metal-ligand charge transfer. At the same time ligand-metal and manganese-tungsten electron transfers are characteristic for mixed manganese-tungsten clusters. A comparison of the calculated absorption spectra of the modeled clusters with those observed for  $\text{MnWO}_4$  nanorods showed, that chain-like manganese clusters mainly contribute to the high-energy part of the UV-Vis spectra, while the fall in the intensity of the observed spectra in the range of the longer wavelengths is connected not only with the decrease of the relative manganese content, but it also manifested due to decrease of the concentration of the mixed manganese-tungsten clusters, mainly contributing to this part of the spectra.

**Keywords**— $\text{MnWO}_4$  nanorods, UV-Vis spectra, ligand-metal and metal-ligand charge transfer

## I. INTRODUCTION

Transition metal tungstates  $\text{AWO}_4$  (A=Mn, Co, Ni, Cu, Zn) have recently attracted considerable interest due to their potential ability to be used for photochemical hydrogen gas production [1], as multiferroic materials [2], as photocatalysts for water splitting [3], as humidity

sensors [4], as optical fibers [5] or both photovoltaic electrochemical cells [6]. Wolframite-type tungstates demonstrate like other compounds from this series several interesting magnetic, multiferroic, photoluminescence and catalytic properties. Recently the electronic structures and optical properties of a series of  $\text{AWO}_4$  (A=Mn, Co, Ni, Cu, Zn) tungstates with wolframite structure have been characterized using a combination of UV-Vis spectroscopy and electronic structure calculations [7]. It has been obtained that in  $\text{MgWO}_4$  and  $\text{ZnWO}_4$  the lowest energy optical excitation represents a ligand to metal charge transfer (LMCT) excitation from oxygen 2p nonbonding orbitals to antibonding W 5d orbitals. At the same time in other compounds of this series the lowest energy charge transfer excitation is a metal-metal charge transfer (MMCT) transition from the partially occupied 3d orbitals of the  $\text{A}^{2+}$  transition metal ion to the unoccupied tungsten 5d orbitals.

About 10 years ago the interest of researchers switched to nanostructured  $\text{AWO}_4$  compounds. In [8]  $\text{MnWO}_4$  composed of a number of nano-plates in flower-like clusters was successfully produced. The authors of paper [9] described the morphology transitions from  $\text{W}_{18}\text{O}_{49}$  nanowires to  $\text{MnWO}_4$  hubnerite nano-cocoons by using mixed  $\text{MnCl}_2$  and  $\text{WCl}_6$  in a simple solvothermal process. A simple hydrothermal method to the shape-controlled synthesis of  $\text{MnWO}_4$  nanocrystals without any surfactants and templates was suggested in [10]. Single-crystal  $\text{MnWO}_4$  nanowires were successfully synthesized for the first time in [11]. In [12] it has been demonstrated that nanostructured, crystalline  $\text{MnWO}_4$  can be converted into a highly active and selective catalyst by stabilizing a defect-rich  $\text{MnO}_x$  surface phase. Terminating  $\text{MnO}_x$  zigzag chains on the (010) crystal planes were assumed to contain structurally site-isolated oxygen defects that most possibly assure good performance of the catalyst in

propane activation. To control the surface phase of rod-shaped  $\text{MnWO}_4$  nano-crystalline catalysts in [13] hydrothermal techniques in combination with *in situ* Raman spectroscopic and transmission electron microscopy studies were applied. The identification of the highly active  $\text{MnO}_x$  units on the surface of the  $\text{MnWO}_4$  nanorods definitely improved the understanding of the promotional effect of Mn in these catalytic systems. Information about the composition of the catalyst surface, i.e. about the presence of certain ions or clusters on it, can also be obtained from the study of the UV-Vis spectra, because for sufficiently strong electric dipole allowed transitions the intensity of the optical beam which traverses the material mainly reduces in its surface layer. With this in mind in the present paper it is performed the experimental study of the apparent absorption spectra of the  $\text{MnWO}_4$  nanorods with different content of manganese and tungsten. Since the surfaces of the nanorods, as it was earlier proved in [13], are not crystallographically ideal, and the structure of these surfaces cannot be identified in detail by X-ray analysis, in the present paper the observed changes in the UV-Vis spectra of samples with different W/Mn ratio will be qualitatively explained employing DFT modeling of clusters which represent constituent parts of the nanorods with different content of manganese and tungsten. The DFT calculations are also expected to give information about the types of charge transfer transitions (ligand-metal, metal-ligand or metal-metal), which mainly contribute to the observed spectra. On this basis an explanation of the spectra transformation with the change of the ratio Mn/W will be given.

## II. EXPERIMENTAL SECTION

The  $\text{MnWO}_4$  nanorods were obtained by hydrothermal synthesis, the procedure of which is described in detail in paper [13]. The UV-Vis diffuse reflectance spectra were recorded at room temperature in the range of 200-800 nm with an Agilent Cary 5000 instrument equipped with an *in situ* cell (Harrick Praying Mantis diffuse reflectance attachment DRP-SAP in combination with a HVC-VUV reaction chamber). The compound  $\text{BaSO}_4$  was used as a white standard. The apparent absorption spectra were calculated from the UV/Vis diffuse reflectance ones with the aid of the Kubelka-Munk formula. Briefly summarizing the experimental data on the apparent absorption spectra of the  $\text{MnWO}_4$  nanorods with different Mn/W content one can notice the following features: (i) the absorption of the catalysts independently of the Mn/W ratio mainly occurs in the range of wavelengths 200-450 nm; (ii) the intensity of the apparent absorption spectra of the nanorods in the whole spectra range falls with decrease of the relative manganese content; (iii) the absorption spectrum of the bulk sample significantly differs from those for nanorods. It spreads from 200 nm to 800 nm

and changes insignificantly in the range 200-420 nm. At longer wavelengths up to 500 nm the spectra intensity noticeably falls, and at about 560 nm a weak band is observed.

## III. COMPUTATIONAL DETAILS

Since the surfaces of the obtained series of catalysts are damaged [12,13] and, consequently, the translational symmetry of these samples is broken at least at the surface, which mainly participates in light absorption, to understand the observed spectra transformations with the change of the manganese/tungsten content we examine homometallic binuclear, trinuclear and tetranuclear linear manganese clusters, binuclear tungstate clusters and mixed manganese-tungstate clusters of different nuclearity. The linear manganese clusters of different nuclearity for examination are included in examination because  $\text{MnO}_x$  units have been revealed on the surface of the  $\text{MnWO}_4$  nanorods.

The optimization of the structures of the selected clusters, the calculation of the spectra of molecular vibrations as well as of the apparent absorption spectra were conducted with the aid of DFT, employing the ORCA suite of programs, version 4.2.1 [14]. For clusters containing  $\text{Mn}^{\text{II}}$  ions the DFT calculations were performed using the spin unrestricted formalism, while for clusters which only comprise  $\text{W}^{\text{VI}}$  ions the spin restricted open shell DFT formalism was employed. All calculations necessary to obtain the spectra shapes were carried out with the aid of the REVPBE functional [15,16], which has been proven to give reasonable results in the description of the spectroscopic characteristics of a series of clusters containing transition metal ions [17-19]. With the aid of the zero-order regular approximation (ZORA) [20], the scalar relativistic ZORA Hamiltonian was selected [14,20]. For heavy tungsten atoms the segmented all-electron relativistically contracted SARC-ZORA-TZVP basis set [14] is employed, while for all other atoms composing the cluster the ZORA-def2-TZVP functions are used. To considerably reduce the computation time of the exchange terms the combination of resolution of identity (Split-RI-J) and "chain of spheres" (COSX) approximation have been applied [21]. In the calculations the target precision of the energy and wavefunctions for all examined clusters was  $10^{-9}$  Hartree. The integration accuracy around the heavy tungsten atoms has been increased, using large integration grids in the radial part. Within the ORCA package the numerical values of the vibrational frequencies have been also calculated. The TDDFT method [14] within the ORCA package has been applied to obtain the excited state energies of the examined species. With the aid of these characteristics the absorption spectra arising from the Mn-, W- and mixed Mn-W clusters of different nuclearity have been calculated. The identification of the origin of the transitions in the observed spectra of Mn-W catalysts



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in different ranges of wavelengths was performed applying the following procedure. First, for a definite complex the molecular orbitals have been quantitatively calculated [14]. Then the transitions between the molecular orbitals, which give the main contribution to a definite peak in the calculated spectrum have been identified. Finally, analyzing the composition of these orbitals, a conclusion has been made about the type of the transition i.e. if it is of ligand-metal, metal-metal or ligand-metal origin.

#### IV. MODEL STRUCTURES

In the consideration model W, Mn and mixed W-Mn bi-, tri- and tetranuclear clusters are employed (Fig.1). These clusters will further allow us to correlate the electronic structure with the observed spectra transformations in the  $\text{MnWO}_4$  nanorods with different content of Mn and W. The initial structures of the clusters (Fig.1) are taken from the crystallographic data for the bulk  $\text{MnWO}_4$  compound [22]. As it is commonly accepted in DFT modeling, the charges of these complexes are neutralized by adding protons.

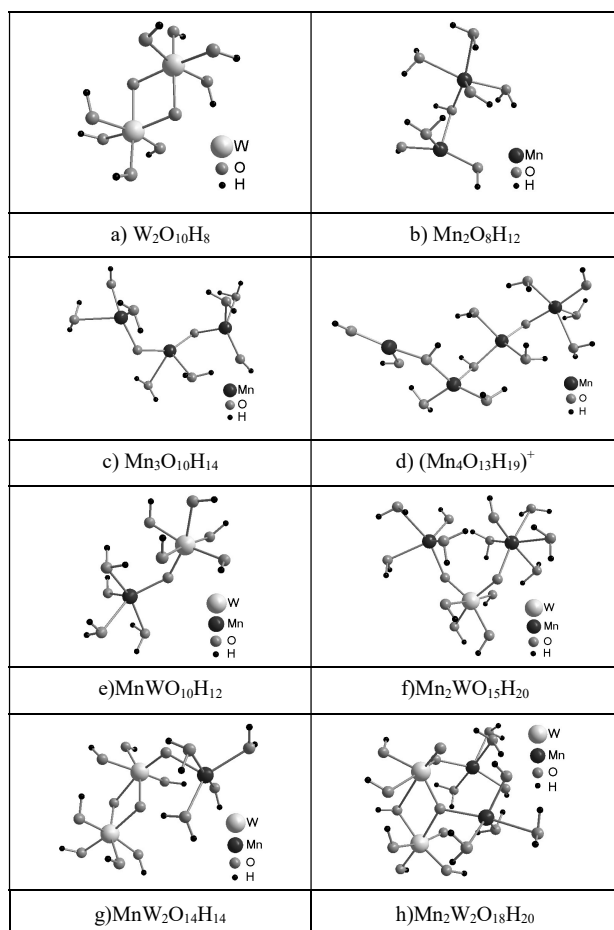


Figure 1. Geometric structures of homonuclear and heteronuclear model clusters containing Mn and W atoms. The composition of each cluster is indicated below its picture.

For binuclear tungsten and manganese clusters the initial structures represent dumbbells, which constitute parts of the structure of the bulk  $\text{MnWO}_4$  compound [22] and contain two metal ions with each of them surrounded by 6 oxygen ions. The optimized binuclear structures are depicted in Fig. 1a and Fig. 1b. From Fig.1a it follows that the binuclear  $\text{W}_2\text{O}_{10}\text{H}_8$  cluster keeps its dumbbell shape, and each  $\text{W}^{\text{VI}}$  ion remains octahedrally surrounded due to its high oxidation state. At the same time the manganese dumbbell after structure optimization transforms into a cluster in which the two metal ions are coupled through one oxygen instead of two in a dumbbell (Fig.1b). The surrounding of each Mn ion contains different number of oxygen ligands and it is not octahedral, confirming the formation of a defective structure. The initial geometry of the linear trinuclear  $\text{Mn}_3$  cluster represents octahedrally coordinated  $\text{Mn}^{\text{II}}$  ions which are connected through common oxygens to form a chain-like structure. In the result of the DFT optimization this structure taken for consideration to mimic the defect-rich  $\text{MnO}_x$  surface phase zigzag chains [12,13] transforms into the  $\text{Mn}_3\text{O}_{10}\text{H}_{14}$  species (Fig.1c) in which all Mn ions possess a distorted tetrahedral surrounding instead of an octahedral one. The structure of a linear tetranuclear cluster in which all manganese ions are in the octahedral surrounding as in the  $\text{MnWO}_4$  compound converts after the DFT optimization into a damaged chain-like one (Fig.1d) in which two Mn ions are tetrahedrally coordinated, while the number of the surrounding ligands of the edge Mn ions is equal to 3 and 5, respectively. The optimized tetranuclear manganese cluster bears a positive charge. This cluster is introduced in consideration to get a qualitative explanation of the observed spectra transformation with the change of the Mn/W ratio as well as to reveal the effect of the surface chains detected with aid of a series of different experiments [13].

In a further step we consider mixed manganese-tungstate clusters the optimized structures of which are also presented in Fig.1. The Mn-W fragment of the bulk compound neutralized by adding protons after DFT optimization gives the binuclear  $\text{MnWO}_{10}\text{H}_{12}$  species (Fig.1e), in which the tungsten ion remains octahedrally coordinated, while the nearest surrounding of the manganese ion becomes pentanuclear instead of the octahedral one in the initial  $\text{MnWO}_4$  compound. In the optimized structure of the trinuclear  $\text{Mn}_2\text{WO}_{15}\text{H}_{20}$  (Fig.1f) cluster with alternating W and Mn ions the tungsten ion is octahedrally coordinated, while the distorted ligand surroundings of the Mn ions are pentanuclear and hexanuclear, respectively. In the binuclear  $\text{MnW}_2\text{O}_{14}\text{H}_{14}$  (Fig.1g) and tetranuclear  $\text{Mn}_2\text{W}_2\text{O}_{18}\text{H}_{20}$  (Fig.1h) clusters the tungsten dumbbell keeps its form, while the surroundings of the manganese ions are damaged and not anymore octahedral as in the initial  $\text{MnWO}_4$  compound.

## V. QUALITATIVE INTERPRETATION OF THE OBSERVED SPECTRA OF NANORODS WITH DIFFERENT MANGANESE-TUNGSTEN CONTENT

In this section the DFT calculated spectra arising from different species (Fig.1) are compared with those observed for  $\text{MnWO}_4$  nanorods, the types of the species present in the surface layer of the catalysts and most probably contributing to these spectra are revealed. On this basis a qualitative explanation is given of the spectra transformations under the change of the W/Mn ratio.

The calculated spectrum of the  $\text{W}_2\text{O}_{10}\text{H}_8$  cluster (Fig.2,

curve 1) extensively expands in the UV part. The maximum of this spectrum, which arises from the strongest transition at 208 nm with the oscillator strength 0.14, was superimposed with the maxima of the experimental curves and put equal to unity like as those for the observed spectra. In the accepted scale the magnitudes of the intensities of the band maxima of other examined clusters were determined relative to the intensity of the main peak in the spectrum of the  $\text{W}_2\text{O}_{10}\text{H}_8$  cluster. From our calculations it follows that up to 220 nm (Fig.2) the main contribution to the observed spectra comes from O→W electron transfer. Then other clusters may also come into the play. The charge transfer transitions exhibited by the clusters  $\text{Mn}_2\text{O}_8\text{H}_{12}$  (Fig.1b),  $\text{MnWO}_{10}\text{H}_{12}$  (Fig.1e),  $\text{Mn}_2\text{WO}_{15}\text{H}_{20}$  (Fig.1f),  $\text{MnW}_2\text{O}_{14}\text{H}_{14}$  (Fig.1g),  $\text{Mn}_3\text{O}_{10}\text{H}_{14}$  (Fig.1c),  $(\text{Mn}_4\text{O}_{13}\text{H}_{19})^+$  (Fig.1d), as well as by the  $\text{Mn}_2\text{W}_2\text{O}_{18}\text{H}_{20}$  (Fig.1h) cluster may contribute to the range of wavelengths 220-290 nm. For this set of clusters the analysis of the molecular orbitals shows, that the transitions, forming the indicated part of the spectra, are of the type of O→Mn, Mn→(OH)<sup>-</sup> and O→W.

The oscillator strengths of the O→Mn and Mn→(OH)<sup>-</sup> transitions in the  $\text{Mn}_2\text{O}_8\text{H}_{12}$  species change from 0.0045 up to 0.011. As to binuclear tungsten  $\text{W}_2\text{O}_{10}\text{H}_8$  species in this range of wavelengths its contribution to the entire spectrum comes from a series of O→W transitions with the oscillator strengths in between 0.01-0.03. Therefore, the intensity of the spectra of the  $\text{W}_2\text{O}_{10}\text{H}_8$  cluster in the diapason 220-290 nm is appreciably higher than that of the  $\text{Mn}_2\text{O}_8\text{H}_{12}$  species. In the mentioned range of wavelengths the spectrum of the  $\text{MnWO}_{10}\text{H}_{12}$  cluster mainly originates from O→W transitions, the most intensive peak positions are situated in the range from 228 nm to 288 nm with the corresponding oscillator strengths in the diapason from 0.007 to 0.016. Only one transition of the type O→Mn at 236 nm with the oscillator strength 0.013 contributes to above mentioned range.

The highest in energy relatively strong transition of the  $\text{Mn}_2\text{WO}_{15}\text{H}_{20}$  cluster is situated at 244 nm, possesses the oscillator strength of about 0.006, and it is formed by the transfers O→Mn and O→W. The very close in energy

strong band at 248 nm with the oscillator strength  $f=0.092$  relates to ligand-metal O→W transfer. Then three close contributing transitions near 249 nm with oscillator strengths in the range 0.005-0.01 are of the Mn→(OH)<sup>-</sup> and O→Mn origin. The calculated transitions at 250 nm and 258 nm with oscillator strengths of 0.005 and 0.0125, respectively, refer to O→W transfer. A weaker in intensity transition at 260 nm with  $f=0.006$  arises from the Mn→(OH)<sup>-</sup> transfer.

For the  $\text{MnW}_2\text{O}_{14}\text{H}_{14}$  species (Fig.1g) up to 290 nm the charge transfer transitions with the following band

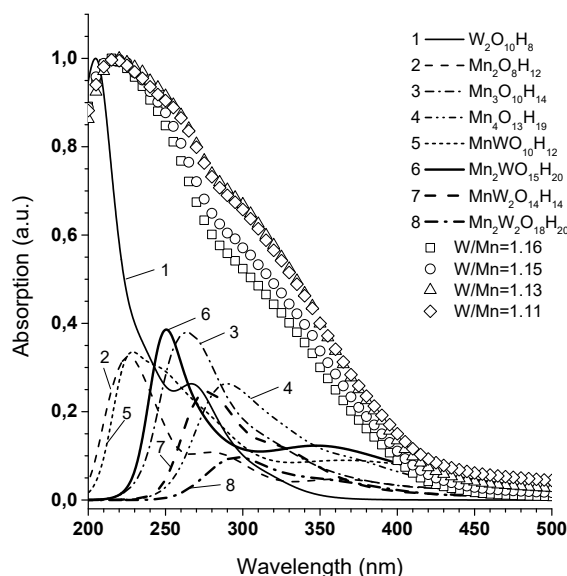


Figure 2. Observed spectra of nanostructured  $\text{MnWO}_4$  catalysts with different W/Mn content and DFT calculated spectra of manganese, tungstate and mixed manganese-tungstate clusters.

positions and oscillator strengths, given in parenthesis, contribute: 262nm (0.005), 267nm (0.004), 271nm (0.005), 277nm (0.006), 289nm (0.004). The first two transitions and the last two in this series refer mainly to the O→W electron transfer, while the third one corresponds to the excitation of an electron from the manganese ion to the (OH)<sup>-</sup> ligand. As to the  $\text{Mn}_2\text{W}_2\text{O}_{18}\text{H}_{20}$  cluster its contribution to the spectra in the range of 220-290 nm is small as compared with that of all clusters above discussed. The maximum of its band at 297nm corresponds to the excitations metal-metal in the two pairs Mn-W representing constituent parts of the cluster.

Finally, we notice that the clusters  $\text{Mn}_3\text{O}_{10}\text{H}_{14}$  and  $(\text{Mn}_4\text{O}_{13}\text{H}_{19})^+$  imitating the  $\text{MnO}_x$  chains detected on the catalyst surface [12,13] also contribute to the spectra range 220-290 nm. The spectra of these species are formed only by transitions between  $\text{Mn}^{2+}$  ions and the ligands  $\text{O}^{2-}$  and  $\text{OH}^-$  and can serve as indicators of manganese content on the surface layer. Here it should be

also noticed that in the range of wavelengths 220-290 nm the peak intensity of the band arising from the trinuclear manganese cluster is higher as compared with the bands arising from other clusters. At the same time in the range 220-290 nm in the spectra of all other heteronuclear species the contribution and the strength of the transitions involving manganese ions and, consequently, indicating, their content is not so high. Thus, from the performed analysis of the calculated spectra and qualitative considerations it follows that the chain like manganese clusters demonstrating the transitions  $O \rightarrow Mn$  and  $Mn \rightarrow (OH)^-$  ensure the spectra modification in the range 220- 290 nm.

The calculated intensities of the parts of the spectra of the examined clusters, which fall into the range of wavelengths 300-460 nm, are lower as compared to those in the range of shorter wavelengths. Most probably this may be the reason of the observed intensity fall in the indicated wavelength range for all samples. However, the most interesting is the result that along with the contribution of the chain-like bi-, tri- and tetranuclear manganese clusters a not negligible contribution to this part of the spectra comes from the heteronuclear Mn-W clusters. Again the performed analysis of the molecular orbitals, of the transitions, which form the spectra at longer wavelengths, shows that for the binuclear Mn-W species the metal-metal electron transfer is responsible for the absorption in the range of wavelengths 340-460 nm, which is in agreement with the results of paper [7]. The oscillator strengths of the most pronounced transitions contributing to this range change from 0.03 to 0.01. For the  $Mn_2W$  cluster the most intensive transitions in the range 320-404 nm also belong to the electron transfer between the manganese and tungsten ions. As to the  $MnW_2$  cluster the transitions in the range 303-335 nm can be mainly assigned to the type ligand-metal  $O \rightarrow W$  transfer. However, their oscillator strengths are weak and fall in between 0.005-0.008. Finally, the heteronuclear cluster  $Mn_2W_2$  contributes with the transitions of the type of  $Mn \rightarrow W$  to the range 290-615 nm, the oscillator strengths of these transitions fall in between 0.006 and 0.012. Thus, the heteronuclear manganese-tungsten and homonuclear manganese clusters may be responsible for the shape and intensity of the spectra of nanorods in the range 290-460 nm, and the main contribution to this spectra part comes from the  $O \rightarrow Mn$ ,  $Mn \rightarrow OH$  and  $Mn \rightarrow W$  electron transfers. From this it follows that the mentioned spectra range should undergo most pronounced changes under decreasing of the manganese content. As it is seen from Fig.2 this qualitative conclusion is in line with the observed transformations of the spectra shape.

## VI. CONCLUDING REMARKS

In the present paper the observed changes in the UV-Vis spectra of a series of  $MnWO_4$  nanorods with different Mn/W ratio are discussed and qualitatively explained. Taking into account, that the main contribution to the apparent absorption spectra of the catalysts comes from the surface layer the surface layer was modeled by three types of clusters. The first type of clusters contains only Mn or W ions. In the second type of clusters Mn and W ions alternate, while the third type clusters is formed by alternating manganese ions and tungsten dumbbells. With this aim the structure of bi-, tri- and tetranuclear manganese and binuclear tungsten species, as well of manganese-tungsten species of different nuclearity and architecture has been optimized, and the absorption spectra of these species have been calculated with the aid of the DFT method. It has been demonstrated that the manganese dumbbells representing a structural element of  $MnWO_4$  catalysts convert very easily into damaged binuclear clusters in which the manganese ions are connected through one common oxygen ion and the nearest surrounding of each Mn-ion is not anymore octahedral. Most probably this ability of manganese dumbbells to convert into clusters in which the Mn-ions share only one oxygen leads to the appearance on the surface of chains of these ions with damaged surroundings. Moreover, under certain conditions these chains can be easily broken, and single  $MnO_x$  species can be formed.

At the same time the high oxidation degree of the tungsten ions does not allow to destroy their octahedral surroundings, and the structure of the tungsten dumbbells remains unchanged under different external conditions. The DFT optimization of the structure of the tungsten dumbbell and calculation of its spectra allowed to reveal the range of wavelengths, to which oxygen-tungsten  $O \rightarrow W$  charge transfer transitions contribute. It has been demonstrated that the spectra of manganese species reveal two types of transfer and, namely, ligand-metal and metal-ligand electron transfer of the types of  $O \rightarrow Mn$  and  $Mn \rightarrow (OH)^-$ , respectively. The homonuclear clusters of tungsten demonstrate strong charge-transfer transitions  $O \rightarrow W$ , while for mixed manganese-tungsten clusters the electron transfers  $O \rightarrow Mn$ ,  $O \rightarrow W$  and  $Mn \rightarrow W$  are characteristic.

The performed calculations and the comparison of the spectra of the model clusters with those of the nanorods allowed to make several qualitative conclusions. The range of wavelengths, wherein the spectra of nanorods are observed, can be conditionally subdivided into two parts. In the range of wavelengths 220-290 nm the chain like manganese clusters are mainly responsible for the fall in the spectra intensity: the decrease in the relative manganese concentration provokes the fall in the spectra intensity. As to the range of the longer wavelengths the

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fall of the spectra transformations are also connected with decrease of the relative manganese content, which immediately leads to the fall in the intensities of the bands. However, this a bit more pronounced decrease is connected not only with the chain-like manganese clusters, but also with the mixed tungsten-manganese clusters which demonstrate metal-metal Mn→W transitions mainly contributing to this part of the spectra.

#### ACKNOWLEDGMENT

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# Solution-processed bulk heterojunction solar cells based on a zinc phthalocyanine: perylene dimide derivative

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**Abstract**—A solution processed ZnPc:PTCDI bulk heterojunction solar cells doped with iodine were fabricated and characterized. Photovoltaic properties of the solar cells were investigated by optical absorption, current density-voltage characteristic and external quantum efficiency. The absorption of ZnPc:I<sub>2</sub>:PTCDI was observed in the (300-800) nm region. Solar cells with a power conversion efficiency of about 2.4% has been obtained using simply drop casting and spin-coating methods without special treatment. The peak of the external quantum efficiency characteristics of the ITO/PEDOT:PSS/ZnPc:I<sub>2</sub>:PTCDI/Al solar cells is 10%.

**Keywords**—zinc phthalocyanine; iodine; N,N'-Bis(3-pentyl)perylene-3,4,9,10-bis(dicarboximide); solar cell

## I. INTRODUCTION

Organic solar cells based on bulk heterojunctions (BHJ) from solution are attracting more and more attention due to the potential for mass production on a flexible and lightweight substrate. In the recent years, significant improvements have been made in BHJ solar cells by combining the molecular design of active materials and interface layers, morphology control, manufacturing techniques. The power conversion efficiencies over 9% have been achieved.

Zinc(II) phthalocyanine (ZnPc) have been frequently used as a photo-active layer in photovoltaic applications. Most of these applications are related to structure of dye-sensitized solar cells (DSSC) [1-4]. These compounds have also been used as a donor in bilayer photovoltaic devices [5]. Many researchers have been attended to conductive polymer based organic solar cells due to their easily and cheaply production [6]. Researchers have concentrated their work on hybrid-structured (organic-inorganic, organic-MPCs, organic-inorganic nanoparticles or quantum dots) solar cells as a solution to enhance the power conversion efficiency of organic solar cells [7,8]. ZnPc is generally used in DSSC based solar cells owing to higher power conversion efficiency due to their high optical absorption in the visible region [9]. Moreover, perovskite solar cells (PSCs) devices produced using phthalocyanine compounds have achieved excellent power

conversion efficiencies. Higher PCEs values were obtained for unsymmetrically ZnPc compounds containing different substituents such as carboxyl and three tert-butyl groups [10,11] and symmetrically ZnPc compounds bearing four tertbutyl [12] or tetramethoxyltriphenylamine groups [13,14]. The perovskite solar cells containing ZnPc with one carboxyl and three tert-butyl groups show  $(16 \pm 1)$  mA/cm<sup>2</sup> photocurrent and  $(0.95 \pm 0.07)$  V open circuit voltage resulting in  $(13.0 \pm 0.7)\%$  PCE at 1 sun [15]. On the other hand, the dimeric Pcs are also used for this purpose with 14.4% PCEs values [16]. The solar cells based on a blend of ZnPc and Buckminster fullerene C60 reached value of PCE as high as 1.9% for single *p-i-n* structures [17].

The disadvantage of solar cells based on bulk heterojunction based on phthalocyanines-fullerenes is that fullerenes are essential as an electron-acceptor material, but they absorb poorly visible light, reducing the volume of the fraction occupied by the donor material with high absorption power. Moreover, fullerenes have a low tunneling capacity, leading to restrictions placed on the development of conjugate systems for many attractive electronic structures to create higher short circuit current density. In this paper we will replace these fullerenes with perylene dimides (PTCDIs) derivatives that would contribute to better electronic tunneling of carriers [18]. These substances also ensure good mobility of the carriers, are processable in solutions and have a good light absorption in the visible spectrum, a high fluorescence quantum yield, and high electron affinity. For these reasons they are very promising candidates for application in organic solar cells [19]. Due to these properties, the representatives of the given family of organic substances are potential competitors of fullerenes in the production of photovoltaic devices. PTCDIs are one class of the most explored organic fluorescent materials due to their high luminescence efficiency, optoelectronic properties, and ready to form well-tailored supramolecular structure.

In this study we use a PTCDI derivative that acts as an electron acceptor organic material, while ZnPc corresponds to a donor to form bulk heterojunctions from

chemical solution. From the available literature and to the knowledge of the authors the investigations have not been carried out on the solution processable zinc phthalocyanine-PTCDI bulk heterojunction thin films solar cells. In this paper, we are reporting the structural, optical properties of ZnPc-PTCDI blend and photovoltaic parameters of the Organic Solar Cells (OPV) based on ZnPc-PTCDI thin films bulk heterojunctions.

## II. SYNTHESIS OF ZnPc:PTCDI THIN FILMS AND DEVICES

Commercially available zinc phthalocyanine and N,N'-Bis(3-pentyl)perylene-3,4,9,10-bis(dicarboximide) (PTCDI) powders (98% purity) were purchased from Sigma Aldrich and were used without further purification. The formic acid (FA) (99% purity) also, purchased from Sigma Aldrich were selected as the solvent for ZnPc and PTCDI. The ZnPc powder was added to the solvent of 98% concentrations of formic acid (FA). In the ZnPc/FA solution the aggregation of undissolved ZnPc was observed. The solution was prepared by dissolving the ZnPc at a concentration of 1 mg/ml into FA solvent. The same procedure for solubilization of the N, N'-bis (3-pentyl) perylene-3,4,9,10-bis (dicarboximide) was used: 1.0 mg/ml in FA. To improve the conductivity of ZnPc and PTCDI thin films, they were doped with iodine. Both ZnPc and PTCDI solutions were sonicated for 1 hour and then were mixed in the different weight ratios. The structure of the films was analyzed by X-ray Bruker D8 advanced diffractometer (using CuK<sub>α</sub> radiation with λ=1.5406 Å). The crystallite size (D) was calculated from the XRD patterns according to the well-known Scherer equation [20]:

$$D = \frac{0.9 \lambda}{\beta \cos \theta}, \quad (1)$$

where β is the full-width at half-maximum (FWHM) peak for a Bragg angle θ, and λ is the wavelength of the X-ray radiation. The structure was also investigated with Raman spectroscopy at an excitation light wavelength of 532 nm. The optical absorption spectroscopy of the ZnPc:I<sub>2</sub>:PTCDI blend films at different composition was measured using a JASCO 7600 UV-Vis-NIR spectrophotometer. For the device fabrication the ZnPc:I<sub>2</sub>:PTCDI on ITO glass substrates (~8 Ω/□) were synthesized. To increase the work function of the ITO oxide and to improve the electrical connection between ITO and organic active layer, a layer of PEDOT:PSS was spin-coated. An Al electrode was thermally deposited onto the ZnPc:I<sub>2</sub>:PTCDI layer using a vacuum deposition system at a pressure of about 5 × 10<sup>-4</sup> Pa. The current density-voltage (J-V) characteristics were measured under 100 mW cm<sup>-2</sup> solar simulator using a Keithley 2400 Source-Meter-Unit. External quantum efficiency (EQE) measurements were measured using 90 W Xenon

lamp as light source connected *via* an optical fiber to an ACTON Spectra Pro150 monochromator and an EG&G 7260 DSP Lock-in amplifier. The key device photovoltaic parameters such as fill factor (FF) can be estimated by [21]:

$$FF = \frac{P_m}{J_{sc} V_{oc}} = \frac{J_m V_m}{J_{sc} V_{oc}} \quad (2)$$

where P<sub>m</sub> is the maximum power generated, with the current density and voltage marked as J<sub>m</sub> and V<sub>m</sub>, and J<sub>sc</sub> is the shortcircuit current density, V<sub>oc</sub> open-circuit voltage. The shunt R<sub>sh</sub> and serie R<sub>s</sub> resistances are the important factors that limit the FF of solar cells.

The power conversion efficiency (PCE) can be calculated by [21]:

$$\eta = \frac{P_m}{P_{in}} = \frac{J_m V_m}{P_{in}} = \frac{J_{sc} V_{oc} FF}{P_{in}} \quad (3)$$

where P<sub>in</sub> is the incident light power on the device.

## III. STRUCTURAL AND OPTICAL PROPERTIES OF ZnPc:PTCDI THIN FILMS

The X-ray diffractograms of the undoped and ZnPc thin films doped with iodine (I<sub>2</sub>) deposited from FA solution and thermally annealed at different temperatures are presented in Figure 1.

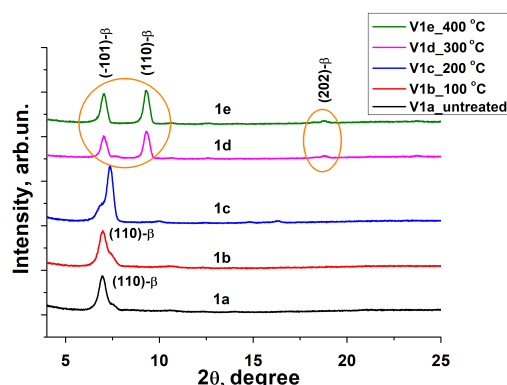


Figure 1. The XRD patterns of untreated and thermally annealed ZnPc:I<sub>2</sub> thin films at different temperatures: V1a- untreated, thermally annealed: V1b – 100 °C, V1c- 200 °C, V1d- 300 °C, V1e- 400 °C.

According to the data revealed in the Figure 1, it can be stated that the transition from α-β phases to a single stable β phase occurs in the temperature range of 200-300°C. Zinc phthalocyanine powder (purchased from Sigma Aldrich used without further purification) from which all the thin films were synthesized, was present in the β crystalline phase [22]. It seems that the protic solvent FA has an essential impact on the ZnPc. Likewise, doping with iodine influences the ZnPc component. Also in this temperature range, as can be seen from the diffractograms shown in Figure 2 (a) for the ZnPc:I<sub>2</sub>:PTCDI thin layers V3a, V3b, V3c, V3d and V3e, resulting from the disappearance of intense maxima at

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$2\theta=5.26$  degrees, that means complete elimination occurs of the PTCDI component from the thin layers. On the other hand, from the data presented in the XRD diffractograms from figure 2 (b) for thin layers V4a, V4b, V4c, V4d, V43, and from the comparative analysis of diffractograms for V3d and V4d samples, we revealed that iodine doping has a certain influence on the retention in the layers of PTCDI component even at temperatures above 300 °C. This suggests firstly the preservation of a certain amount of iodine (more likely the ionic type) in the analyzed systems, and secondly it indicates the intensification of interactions at the boundaries of the ZnPc and PTCDI phases.

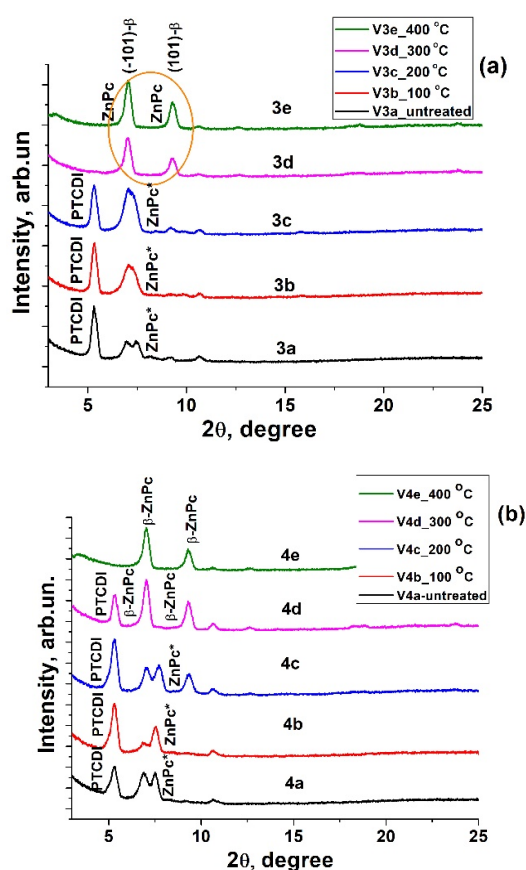


Figure 2 (a, b). The XRD patterns of untreated and thermally annealed ZnPc:I<sub>2</sub>:PTCDI thin films at different temperatures, V3a, V4a - untreated, thermally treated V3b, V4b – 100 °C, V3c, V4c – 200 °C, V3d, V4d- 300 °C, V3e, V4 e- 400 °C.

It follows that the stabilization of the  $\beta$ -phase of zinc phthalocyanine thin films during annealing and the simultaneous preservation of certain iodine species and the PTCDI perylene acceptor component due to the intensification of ZnPc and PTCDI interactions, should contribute to the facilitation of electrical charge transfer at the interface of these components in the volume of heterojunctions obtained on the basis of thin layers of the given type. To confirm the presence of iodine species in the doped thin layers, Raman

analysis was performed. In Fig. 3 it has been found that all Raman signals for ZnPc after iodine doping decrease. The presence of ZnI<sub>2</sub>(HCOO)<sub>2</sub>PcH<sub>2</sub> molecular complex in Fig. 3 is revealed by the signal located at 164 cm<sup>-1</sup>. Such a band has been observed in several publications [22-24]. In addition, iodine doping contributes to the broadening of the signal corresponding to the tensile vibrations of the isoindole units at 1335 cm<sup>-1</sup> and to the disappearance of the signal corresponding to the tensile vibrations of the pyrrole unit at 1580 cm<sup>-1</sup>.

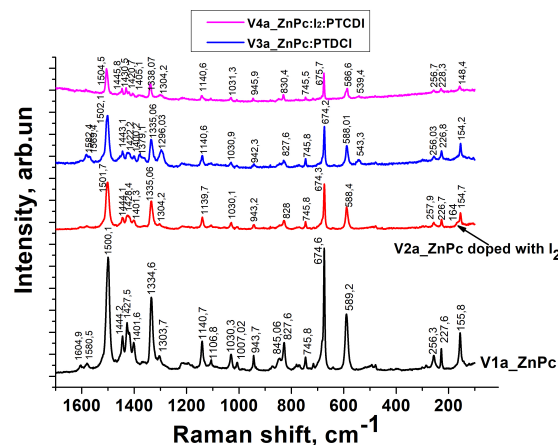


Figure 3. Raman spectra of undoped V1a, V3a ZnPc and ZnPc:PTCDI thin films and doped with iodine -V2a, V4a, respectively.

For the ZnPc thin layer doped with iodine and thermally annealed at 100°C for 30 minutes, the signal attenuation was recorded at 164 cm<sup>-1</sup> (Figure 4), and for those annealed at higher temperatures, the disappearance of this signal was found. These findings suggest the removal of molecular iodine from the thin films, and the gradual desorption of iodide ions from the ZnI<sub>x</sub>(HCOO)<sub>y</sub>PcH<sub>2</sub> complex during annealing.

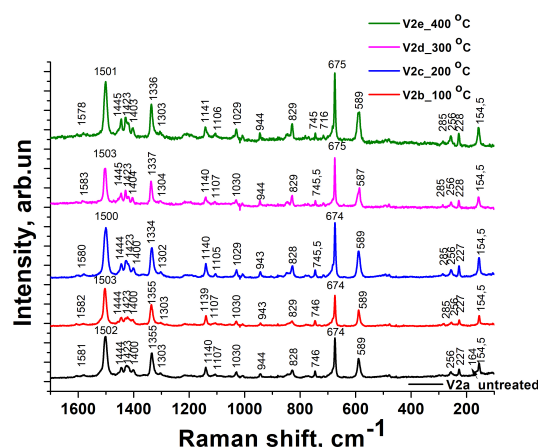


Figure 4. Raman spectra for untreated V2a and thermally annealed V2b, V2c, V2d and V2e ZnPc thin films obtained from doped 4ZnPc:I<sub>12</sub>/FA saturated solution.

The absorption spectra were measured for saturated solutions where molar concentration of ZnPc was  $4.32 \text{ mol} \cdot \text{m}^{-3}$ . The absorption spectra are presented in Fig. 5. The absorption spectrum of ZnPc thin film obtained by thermal evaporation in vacuum, the two solvatochromic bands Q and B presents [25].

The Q band occurs due to the transition from the ground state  $a_{1u}(\pi)$  HOMO to  $e_g(\pi^*)$  LUMO. The Q band splits into three distinct peaks. The splitting of the Q band is probably due to the vibration coupling in the excited state. [26]. The bands situated at 1.92 eV and 1.73 eV involve the transitions  $a_{1u}$  to  $e_g$  and  $2a_{2u}$  to  $7e_g$  in ZnPc macrocycle, and the one at 1.65 eV can be attributed to the excitonic transition or vibrational region. The appearance of the solvatochromic B Soret band with the two peaks located at 3.39 eV and 3.72 eV can be attributed to the  $\pi-\pi^*$  transition [25]. The absorbance spectrum for the saturated ZnPc/FA solution shows the same absorption Q and B bands, but they are wider and shifted to longer wavelengths, compared to those of the ZnPc layer obtained by vacuum thermal evaporation [27]. Probably, the shift of the solvatochromic bands are due to the interactions of zinc phthalocyanine with the FA solvent, resulting in the formation of supramolecular  $\text{Zn}(\text{HCOOH})_x\text{Pc}$  complexes.

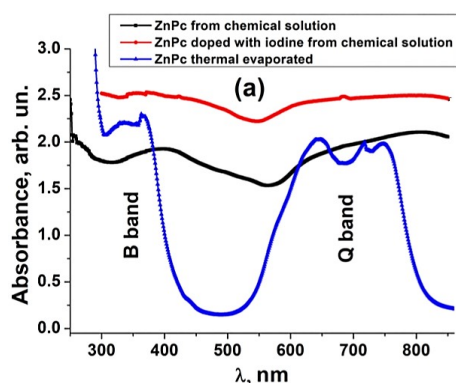


Figure 5. The absorption spectra for undoped and doped ZnPc thin films prepared from ZnPc/FA solutions and ZnPc thin film obtained by thermal vacuum evaporation.

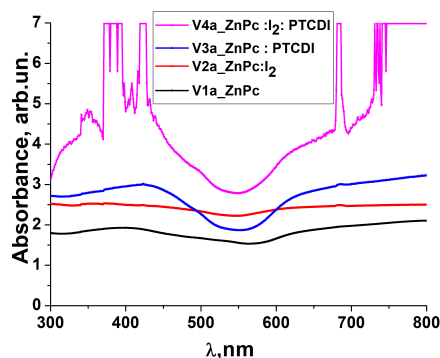


Figure 6. The absorption spectra for undoped ZnPc and ZnPc:PTCDI thin films and doped with iodine in formic acid.

The absorbance spectra of undoped ZnPc, ZnPc:PTCDI (ratio proportion (2:1)) and doped with iodine in formic acid are illustrated in Figure 6. It is observed that the absorption spectrum of ZnPc:I<sub>2</sub>:PTCDI is more structured than that of the undoped mixture. At the same time, we find that iodine doping contributes to the increase of the absorbance intensity and the spectrum shows more intense peaks in both Q and B solvatochromic bands. According to the reference [23], at a sufficiently high ratio of I: Zn in aqueous solutions it is possible to form complexes with changing  $\text{Zn}^{2+}$  coordination from the octahedral configuration to the tetrahedral configuration. The presence of these well-pronounced peaks demonstrates the formation of the supramolecular complex due to the self-assembly of ZnPc:I<sub>2</sub> and PTCDI in saturated solutions.

#### IV. SOLAR CELLS CHARACTERIZATION

The ITO glass substrates with  $\sim 8 \Omega/\text{Square}$  resistivity were sonicated in acetone, in ethanol and dried under hydrogen flow. Then a 120 nm thick buffer layer of PEDOT: PSS was spin-coated onto a ITO substrate at 2500 rpm and subsequently annealed in vacuum at 150°C for 30 min. The absorber layer of the bulk heterojunction solar cell is made of ZnPc:I<sub>2</sub> donor and PTCDI acceptor molecules.

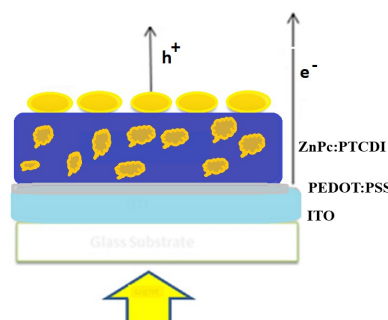


Figure 7. The schematic configuration of solution processable glass/ITO/ PEDOT:PSS/ZnPc:I<sub>2</sub>:PTCDI/Al solar cell.

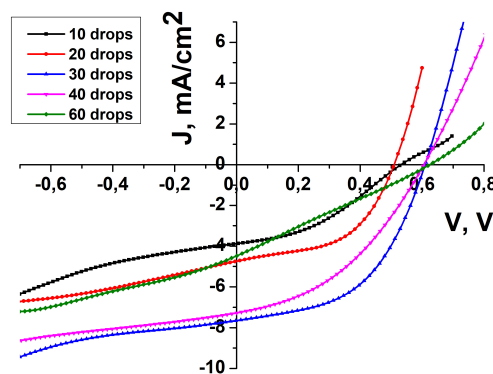


Figure 8. The current density–voltage ( $J-V$ ) characteristics of ITO/PEDOT:PSS/ZnPc:I<sub>2</sub>:PTCDI/Al solar cells.



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A solution of ZnPc:I<sub>2</sub>:PTCDI in 98% of FA was made and was dropped on the glass/ITO/PEDOT:PSS substrate. The solution-processable bulk heterojunctions solar cells consists of glass/ITO/PEDOT:PSS/ZnPc:I<sub>2</sub>:PTCDI structure. Finally, aluminum (Al) electrodes were higher vacuum thermally evaporated. The incident light enters in the device through transparent ITO side and is absorbed in ZnPc:I<sub>2</sub>:PTCDI. The absorbed photons result in the creation of bound electron-holes pairs in the absorbing layer, called excitons. Some of these excitons diffuse to the ZnPc:I<sub>2</sub>:PTCDI/Al interface where dissociate to electrons and holes. The schematic configuration of solution processable glass/ITO/ PEDOT: PSS/ZnPc: I<sub>2</sub>: :PTCDI/Al solar cell is shown in Figure 7.

The photovoltaic parameters are presented in Table 1.

TABLE I. The photovoltaic parameters: current-density ( $J_{sc}$ ), open circuit voltage ( $U_{oc}$ ), fill factor (FF) and efficiency ( $\eta$ ), series ( $R_s$ ) and shunt ( $R_{sh}$ ), resistances of ITO/PEDOT:PSS/ZnPc: I<sub>2</sub>: PTCDI/Al solar cells

drops	$J_{sc}$ , mA/cm <sup>2</sup>	$U_{oc}$ , V	FF, %	$\eta$ , %	$R_s$ , Ohm·cm <sup>2</sup>	$R_{sh}$ , Ohm·cm <sup>2</sup>
10	3.9	0.53	37.16	0.77	113.17	529.02
20	4.7	0.51	50.97	1.23	21.00	307.87
30	7.6	0.61	51.25	2.39	19.81	458.79
40	7.3	0.60	40.91	1.81	35.13	405.74
60	4.6	0.62	24.85	0.71	109.35	161.11

According to the Table 1 the photovoltaic parameters of ITO /PEDOT:PSS/ZnPc:I<sub>2</sub>:PTCDI/Al depend on the layer thickness (solution volume). It is observed that initially, with the increase of the layer thickness (number of drops), the open circuit voltage decreases, and then it starts to increase. The density of the short-circuit current increases with the increase of the thickness (number of drops) and at the highest thickness it decreases and reaches the value of 4.6 mA /cm<sup>2</sup>. This current-density corresponds to the highest value of the open circuit voltage of 0.62 V. It is well known that the behavior of the p-n junction is simulated by a diode, and the current losses (such as bulk resistances of materials and electrodes, or current leakage) can be modeled by series resistance ( $R_s$ ) and shunt resistance ( $R_{sh}$ ), respectively. It is widespread proved that the equivalent circuit model is applicable to organic solar cells. Therefore the shape of the J-V curves can be limited by the three elements in the equivalent circuit model. These are FF ,  $R_s$  and  $R_{sh}$ . The FF is the parameter that determine the PCE of organic solar cells.  $R_s$  induces a voltage drop on itself, so it can divide the applied voltage from the diode. Therefore the larger the  $R_s$  is, the less voltage drop on the diode, which results in a slower increase of J with V.  $R_{sh}$  has the effect of dividing current from diode, which makes it exhibit the opposite trend to that of  $R_s$ . When a reverse bias is applied, J should be small for the blocking effect of diode under reverse bias. However if  $R_{sh}$  is small, then the current under reverse bias will flow into  $R_{sh}$  and J will increase linearly with the increasing reverse voltage. This

will also lower FF. In the fabricated solar cells, reduction of  $R_s$  is effective means to improve the performance of the device. Also, the thickness of the blend layer, the interface between the active layer and electrodes, and the illumination intensity are three variables that can influence  $R_{sh}$  and ultimately impact on FF. The dominating contribution to the  $R_s$  is caused by the large resistivity of the ZnPc:I<sub>2</sub>: :PTCDI organic thin films. The best efficiency of conversion of solar energy into electricity for ITO/ PEDOT:PSS/ZnPc:I<sub>2</sub>: :PTCDI/Al solar cell reaches the value of about 2.4%.

The external quantum efficiency (EQE) for the ITO/ PEDOT:PSS/ZnPc:I<sub>2</sub>:PTCDI/Al structure is illustrated in Figure 9. The study of the distribution of external quantum efficiency showed that the photosensitivity range is between 300 nm and 800 nm wavelengths. Photosensitivity of the ITO/ PEDOT:PSS/ZnPc:I<sub>2</sub>: :PTCDI/Al structure is higher from 500 nm to 800 nm, and as the thickness of the ZnPc:I<sub>2</sub>:PTCDI layer increases, the external quantum efficiency decreases.

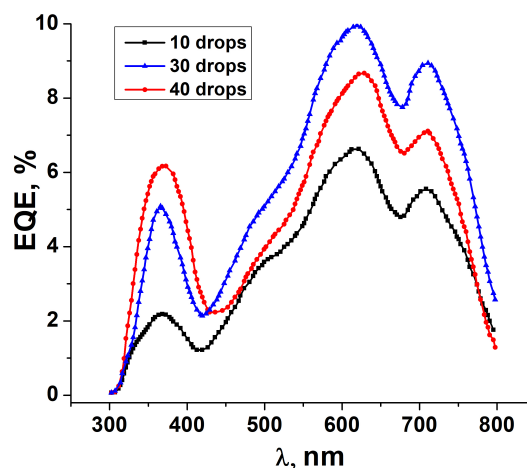


Figure 9. The external quantum efficiency characteristics of the ITO/ PEDOT:PSS/ZnPc:I<sub>2</sub>:PTCDI/Al solar cells.

The charge transfer (CT) is affected by recombination during the move of electrons and holes to the electrodes, especially if are transported by the same material.

## CONCLUSION

The solution-processable bulk heterojunctions solar cells with ITO/PEDOT:PSS/ZnPc:I<sub>2</sub>:PTCDI structures using low cost drop casting and spin coating methods were fabricated. The optimized solar cell composition in this investigation is the 2:1:1 of the ZnPc:I<sub>2</sub>:PTCDI mixture at which the  $J_{sc}$ ,  $V_{oc}$ , FF, and  $\eta$  are 7.6 mA/cm<sup>2</sup>, 0.61 V, 0.51, and 2.39 %, respectively. The  $R_s$  has a pronounced effect on the shape of J-V curve around  $V_{oc}$ , large  $R_s$  divide the voltage from the diode, leading to a slower rise of J with increasing positive V and FF decreases.

## ACKNOWLEDGMENT

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# Formation and Decay of Excitons and Biexcitons Excited in CdSe/CdS/CdZnS Colloidal Quantum Dots

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**Abstract**— The kinetics of a strongly nonequilibrium state of electrons and holes excited in quantum dots by a long laser pulse in the p-states are studied using the time-resolved photoluminescence. Three bands of the transient photoluminescence spectra were identified, and the ignition and decay of each of them was investigated. The complex picture of the time evolution of the bands is explained by the fast processes of cascade intraband relaxation and the Pauli exclusion principle. The durations of formation and decay for each of the photoluminescence bands are determined.

**Keywords**— quantum dots; photoluminescence; exciton; biexciton; binding energy

## I. INTRODUCTION

Multielectron states in semiconductor quantum dots (QDs) with two or more excited electron-hole (e-h) pairs play an important applied role in such devices as lasers, photodetectors, solar cells, light-emitting diodes, and photon-pair sources [1-6]. Owing to the enhanced interaction of charge carriers under conditions of quantum confinement, multielectrons in QDs are scattered mainly through a nonradiative Auger process, and effective photoluminescence (PL) can be realized only by single excitons [1,7]. In the simplest two-electron case, the biexciton in the ordinary CdSe QD can emit a photon during its subnanosecond Auger lifetime [8], which is much shorter than the radiation lifetime of tens of nanoseconds for the remaining single exciton. This transient presence of biexcitons is not pronounced in time-integrated (or *cw*) PL spectra and necessitates the use of ultrafast spectroscopic techniques and high-sensitivity experiments to detect their fundamental optoelectronic properties, such as PL lifetimes, spectral positions, and binding energies [9-15].

The relaxation kinetics of two, three, and four e-h pairs in CdSe QDs were studied in [1] using femtosecond transient absorption spectroscopy. It was shown that the relaxation cascades are mediated by Auger processes. The studies of ultrafast PL of colloidal CdSe/ZnS QDs were carried out in [10]. A new transient emission band

red shifted by about 10–30 meV relative to the band-gap luminescence was extracted. The authors attributed it to the neutral biexciton with very short measured lifetimes (100 ps for QD radius of 3.5 nm), in agreement with transient absorption studies of the two e-h pairs in [1]. The bands associated with the radiative decay of the single exciton, biexciton, and triexciton in the transient spectra of time-resolved PL were clearly observed in [11] for CdSe QD in hexane. The detailed study of the multielectronic effects in CdSe QDs, based on the energetics, the lifetimes, and the pump-power dependence of the various emission bands was presented in [12,13]. All measurements in [10-13] were performed at room temperature. We also draw attention to works [14-17] on this issue. As shown in [10,11,13], the positions of the exciton and biexciton bands do not depend on the pump power indicating that each of them is due to the emission from QDs in the well-defined one- and two-particle states.

To explain the time evolution of the system, the following scenario was expected. Initially, the sample is excited by an ultrashort laser pulse, so that in a selected QD some quantity of e-h pairs with the energy much higher than the QD energy gap is generated. For example, in [11] a pulse of 300 fs at 400 nm was used. After that, the system is left to itself (without any external influence). At the next stage the electrons and holes relax to the lowest states on a picosecond time scale [18-22] due to the fast intraband Auger-like and phonon emission processes. Then, at the third stage, a relatively slow process of recombination of e-h pairs occurs within a time interval from several tens of picoseconds to ten nanoseconds. This final stage of the time evolution of the system can be described by a simple set of coupled rate equations [11] and reflects in the time-resolved kinetics of PL studied in [10-13].

After rapid intraband relaxation, a quasi-equilibrium state is established in the sample. In different QDs from one (exciton) to several (multielectron) e-h pairs can be excited, depending on the excitation intensity. Their

number in the selected QD is described by the Poisson statistics [18]. The Poisson distribution is valid if the probability of generating the e-h pair in a QD is independent of the number of e-h pairs already existing in it [23]. Therefore, it is applicable for the case of ultrashort pulse excitation well above the PL band edge and makes it possible to supplement the set of rate equations by the initial conditions [11].

The population of the QD states can change very rapidly, and a high time resolution is needed to study its dynamics. Therefore, in the experiments [10-13] ultrashort laser pulses and high-resolution measuring equipment were used. In this paper we report that the PL from biexciton states in QD may be observed by more modest measuring means and with laser pulse, whose duration is comparable with the lifetime of biexcitons and far exceeds the intraband relaxation time.

## II. MAIN RESULTS

The time-resolved PL triggered by a ~30 ps long exciting pulse centered at the time 154 ps was investigated. The use of long pulses allows one not only to trace the decay of multi-exciton complexes, but also to study the process of their formation and, thus, to give a more complete picture of the physical processes occurring in the system. In addition, in contrast to [10-13], in order to achieve a fast relaxation to the lowest state, we excite electron-hole pairs by a laser directly near the p-states.

We obtained from the spectrogram with ~50 ps resolution the temporal trace of PL in the main (low-energy) spectral range. The entire process of the PL decay can be conventionally divided into three consecutive stages (I, II, and III) characterized by the different rates of the intensity decrease. We will assume that this difference is associated with sequential processes; in each of them the decay of a spectral component is accompanied by the excitation of the other, lower-lying energy state. However, unlike these works, we will not assume a single- or multi-exponential character of the decay, expecting that while some states are depleted, the filling of others may increase, and their decay will begin later. Therefore, the total radiation from these states will not have a simple form of decreasing exponents in the entire studied PL region.

The fitting function for the time-integrated PL spectrum can be decomposed into two Gaussian functions and a constant part that takes into account the noise background. The first of these functions, associated with the radiation from the s-states of electrons and holes, has a maximum at 1.98 eV and a full width at half maximum of the peak ~100 meV. The second function, associated with radiation from the p-states, significantly overlaps the first one and has a maximum at 2.1 eV and a width of ~340 meV. A strong overlap of the spectral bands occurs

due to the inhomogeneous broadening associated with the size dispersion of the QDs. Since the radiation of biexcitons is a fast transient process, the time-integrated PL spectrum does not contain any information about their presence. However, they can be detected by studying transient spectra at different points in time. This would make it possible to determine such parameters of biexcitons as the binding energy, excitation and decay times.

We obtained a series of transient PL spectra extracted at different delays relative to the center of the exciting laser pulse using a 50 ps integration window. The asymmetric fitting function can be presented as a sum of three Gaussian components  $F_i \exp\left(-(\varepsilon - \varepsilon_i)^2 / \gamma_i^2\right)$

centered at  $\varepsilon = \varepsilon_i$  ( $i = x, xx, xxx$ ) and some background constant  $F$ . We associate the broad peak in each transient PL spectrum described by the Gaussian function with a maximum at  $\varepsilon_{xxx} = 2.1$  eV with the radiative recombination of e-h pairs in p-states. It quickly disappears, but since its width is large, it also appears in the time-integrated spectrum. The high peak at  $\varepsilon_x = 1.98$  eV makes a major contribution to the time-integrated spectrum. We associate it with the decay of single excitons. And, finally, we explain the peak at  $\varepsilon_{xx} = 1.92$  eV, which first arises and then disappears, as the decay of biexcitons [11]. This peak is relatively low and is strongly overlapped by the other peaks; therefore, we can say that *biexcitons hide behind excitons*. The binding energy  $2\varepsilon_x - \varepsilon_{xx}$  of two excitons in the biexciton is 60 meV.

Comparing the spectral dependences we see that the parameters of the fitting function change with time. To find out how this occurs, let us study the temporal dependences of the amplitudes of Gaussian functions and their widths. The corresponding results are shown in Figs. 1 and 2.

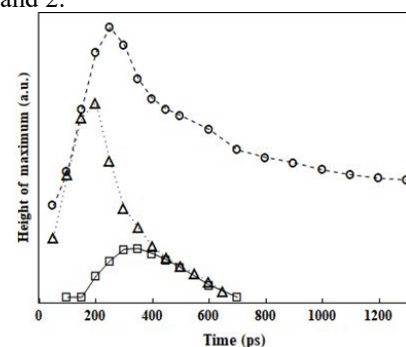


Figure 1. The temporal dependence of the height of the maximum of the fitting function at  $\varepsilon = \varepsilon_x$  (circles),  $\varepsilon = \varepsilon_{xx}$  (squares), and  $\varepsilon = \varepsilon_{xxx}$  (triangles).



As can be seen from Figs. 1 and 2, the laser pulse excites radiation, mainly from the  $p$ -states of electrons and holes, that occurs in a wide energy range and reaches a maximum value at 200 ps. Simultaneously, radiation appears from the  $s$ -states. It has an almost unchanged spectral range and reaches a maximum at 250 ps. The emission of biexcitons appears with even greater delay and much slower. Its growth ceases at 350 ps when two previous PL bands are already significantly reduced. The spectral range where this radiation occurs also does not almost change. Starting from 350 ps the decay of triexcitons is accompanied by the decay of biexcitons within  $\sim 140$  ps. The decrease of radiation from single excitons within this time interval slows down. After 700 ps only a very slowly decreasing emission of single excitons occurs that can be described by a simple exponential curve. Using the exponential function for fitting only at times greater than 700 ps we obtain a value of  $\sim 10$  ns for the decay time of a single exciton.

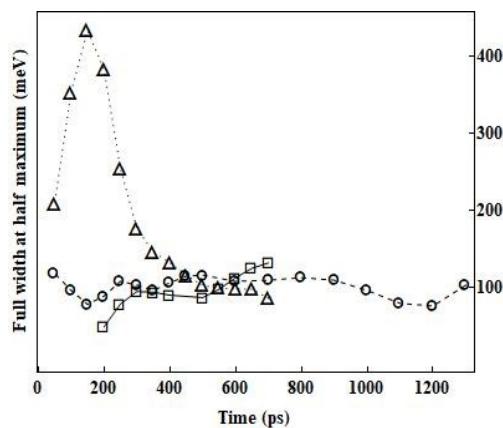


Figure 2. The temporal dependence of the width of the maximum of the fitting function at  $\mathcal{E} = \mathcal{E}_x$  (circles),  $\mathcal{E} = \mathcal{E}_{xx}$  (squares), and  $\mathcal{E} = \mathcal{E}_{xxx}$  (triangles).

We assume that all microscopic processes occurring in the system can be divided into fast and slow ones. The accuracy of the measurements does not allow us to follow the fast processes, but we can take into account the results of their actions. These processes involve an Auger-like scattering of the electron by the hole and subsequent intraband relaxation of the scattered hole with emission of phonons. This sequence of processes leads to the fact that e-h pairs excited by a laser pulse near the  $1P_e-1P_{3/2}$  state convert into e-h pairs in the lowest  $1S_e-1S_{3/2}$  state. Moreover, due to the described mechanism of intraband relaxation the creation of pairs in the  $s$ -states may continue even after the end of the action of the laser pulse if this is allowed by the filling of the  $1S_e-1S_{3/2}$  states of the e-h pairs in accordance with the Pauli Exclusion Principle. The number of pairs in  $p$ -states at this time

decreases. This explains the behavior of the curves in Fig. 1 within the time interval from 100 to 200 ps.

If there is only one e-h pair in the  $s$ -states, then taking into account the Coulomb interaction, we can speak about the formation of an exciton. If the number of e-h pairs in this state reaches a maximum value equal to two, we can speak about the formation of a biexciton. In this terminology, the appearance of the second pair in the state where one pair is already present automatically means the disappearance of both pairs (or two excitons) and the formation of a biexciton. The second pair, like the first one, can quickly transit to the  $s$ -state from the  $p$ -state as a result of fast intraband relaxation. In this case, the appearance of a biexciton means the disappearance of one pair from the  $s$ -state and one pair from the  $p$ -state. The corresponding behavior of the curves in Fig. 1 manifests itself within the time interval from 200 to 350 ps where the ignition of the biexciton band of PL is accompanied by a rapid decrease in both the radiation from the single excitons and the emission from the e-h pairs in the  $p$ -states.

By the time of 350 ps, the generation of biexcitons seems to reach saturation, and their decay begins. We can consider the annihilation of any constituent e-h pair of the biexciton as a decay of the biexciton resulting in the creation of an exciton and a photon. The remaining pair can also annihilate; this means a radiative decay of the exciton. Another channel for the biexciton's decay is associated with an Auger-like interband process where the annihilating e-h pair transfers its energy to an electron or hole of the second e-h pair. We see that the biexciton and exciton decay processes are slower than those indicated for the formation of excitons and biexcitons. Note, that the decay of the biexciton PL band in the interval from 350 to 700 ps is accompanied by almost the same decay of other bands. In our opinion, this also indicates the saturation of biexciton states. Electrons and holes in the  $p$ -states *do not hasten* to radiatively recombine, but wait for the opportunity to stay in a lower energy state.

Thus, the stage I of the PL decay corresponding to the peak is the shortest and fastest; it has the widest spectrum and is associated with the recombination of electrons and holes from the  $p$ -states. The stage II located at the foot of the peak is characterized by complex processes associated with both the formation and decay of biexcitons, as well as the slowing down of the decay of triexcitons and single excitons. And, finally, the slowest stage III located in the tail of the dependence is associated with the radiative decay of single excitons.

### III. CONCLUSION

We excited electrons and holes near the energy of the  $p$ -states expecting to get their fast relaxation in one step. However, the obtained results are very different from those previously presented in [10-13], where the

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excitation was high in the energy zone. We managed to trace not only the disintegration of the main PL bands, but also their ignition.

This gives evidence that taking account of the Pauli Exclusion Principle plays a significant role in the description of the temporal evolution of the system. An external pulse can excite only six e-h pairs in the  $p$ -state, while the  $s$ -states are ready to accept only two. Therefore, the pair conversion from the  $p$ - to the  $s$ -state does not occur until the  $s$ -state is at least partially vacant. The results presented by us show that in our case the Poisson distribution cannot be used as an initial condition for the rate equations at any fixed point in time. And the rate equations themselves cannot be linear, since one should take into account such a phenomenon as the saturation of the state of Fermi particles.

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# Superdense Coding of Information in Quantum Computer in the Paired Bosons Representation

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**Abstract** — An alternative approach to superdense coding of information in quantum computing is proposed on the basis of Schwinger's two-boson representation of angular momentum. Since the effective spin  $S = 2^{n-1} - 1/2$  corresponds to the  $n$ -qubit system, this representation can be used in the quantum computing. Operators of the logical elements of the quantum circuit were found, performing superdense coding of information in the paired bosons representation. It is shown that for superdense coding of information, the results obtained in the spinor representation and in the representation of paired bosons coincide. For one-qubit systems, one of the two representations cannot be favored. In the case of  $n$ -qubit systems for  $n \gg 1$ , the representation of paired bosons is probably more convenient for applications, since in this representation the explicit form of the Pauli operators  $X$ ,  $Y$ , and  $Z$  does not depend on  $n$ .

**Keywords** — entanglement, Bose fields, CNOT gate, Hadamard gate, qubit, spinor operators

## I. INTRODUCTION

Development of the information technologies have reached an effective methods of storing and processing of information. There is an essential difference between classical and quantum treatment of information, which became relevant after R. Feynman put forward the idea of simulating physics with computers [1]. Unlike the classical bit (0, 1), the qubit  $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$  ( $|0\rangle$  and  $|1\rangle$  denote basis vectors,  $\alpha$  and  $\beta$  are complex numbers that satisfy the relation  $|\alpha|^2 + |\beta|^2 = 1$ ) geometrically is presented by the unit vector, which has its origin in the center of the Bloch sphere and end on the surface. There is an infinite set of points on the spherical surface and correspondingly any qubit may be in one from infinite set of states. It would seem that using only one qubit it is possible to store an infinite quantity of information. For this it is necessary to obtain a set of clones of one arbitrary state  $|\psi\rangle$  and carry out measurements of the state of each copy, then with the probability  $|\alpha|^2$  the qubit will be found in the state  $|0\rangle$  and with the probability  $|\beta|^2$  it will be found in the state  $|1\rangle$ . Since  $|\alpha|^2$  and  $|\beta|^2$  can have infinitely many values, it would be possible to obtain infinitely many information

encoded in one qubit. However, it is impossible due to existence of no-cloning theorem of Wootters and Zurek [2].

Despite the restrictions caused by the no-cloning theorem, the number of publications in the field of quantum computing does not decrease, especially after the discovery of Deutsch-Jozsa [3], Shor [4] and Grover [5, 6] quantum algorithms. In all these investigations the spin algebra formalism is used in view of its simplicity. However, the Bose operators algebra is not more complicated than spinor algebra.

In this paper, we propose to implement the superdense coding of information using qubits and logical elements in the paired bosons (PB) representation. In Sect. II the logical elements given in the PB representation are found. The superdense coding of information in the paired bosons representation is theoretically studied in Sect. III. Concluding remarks are made in Sect. IV.

## II. THE QUBIT BASIS VECTORS AND LOGICAL ELEMENTS IN PAIRED BOSONS REPRESENTATION

The basis vectors of any qubit traditionally are represented using the spin wave functions corresponding to an effective spin  $S = 1/2$ :

$$|0\rangle = |1/2, 1/2\rangle, |1\rangle = |1/2, -1/2\rangle. \quad (1)$$

Therefore all logical operations, including superdense coding of information, are given in terms of spinorial algebra. On the other hand, spin operators and spin wave functions can be defined in the Schwinger's paired bosons (PB) representation [7]. The superdense coding of information can be described in the PB representation, if needed for such investigation logical elements are given in the same representation. The rationale for this alternative approach is that in the spinor representation, the dimension of the matrices of spin operators increases with an increase in the number of qubits, while in the PB representation it does not depend on the number of qubits. In this case, all the specificity of multi-qubit system is

contained in the structure of spin wave functions in the PB representation.

• *Basis vectors of the qubit*

In the PB representation, the components  $|0\rangle$  and  $|1\rangle$  of the qubit (1) has the form

$$|0\rangle = A^+ |1\rangle_1 |0\rangle_2, |1\rangle = B^+ |0\rangle_1 |1\rangle_2, \quad (2)$$

where  $A^+$  and  $B^+$  are the creation operators of Bose fields 1 and 2, which satisfy the relation

$$U_{1/2}^+ U_{1/2} = A^+ A + B^+ B = I, \quad (3)$$

where  $I$  is an unit operator given in two- dimensional space.

• *Pauli X, Y, and Z gates*

Let  $U_{1/2} = \begin{pmatrix} A \\ B \end{pmatrix}$  is an unitary spinor operator which satisfy the relation (3).

Let us subject each of the Pauli matrices  $\sigma_x, \sigma_y$ , and  $\sigma_z$  to a unitary transformation using the spinor operators  $U_{1/2}^+$  and  $U_{1/2}$ :

$$\begin{aligned} U_{1/2}^+ \sigma_x U_{1/2} &= A^+ B + B^+ A = X, \\ U_{1/2}^+ \sigma_y U_{1/2} &= i(B^+ A - A^+ B) = Y, \\ U_{1/2}^+ \sigma_z U_{1/2} &= A^+ A - B^+ B = Z \end{aligned} \quad (4)$$

Thus, X, Y, and Z are Pauli operators in the paired bosons representation. In the spinor representation Pauli operators are unitary operators. Therefore, in the representation of paired bosons, they are also unitary.

The eigenvectors of operators X, Y, and Z are  $\frac{1}{\sqrt{2}} \cdot (|1\rangle_1 |0\rangle_2 \pm |0\rangle_1 |1\rangle_2)$  for X,  $\frac{1}{\sqrt{2}} \cdot (|1\rangle_1 |0\rangle_2 \pm i |0\rangle_1 |1\rangle_2)$  for Y, and correspondingly  $|1\rangle_1 |0\rangle_2$  and  $|0\rangle_1 |1\rangle_2$  for Z operator. Unlike a one-qubit system, a system of n qubits is characterized by an effective spin  $S = 2^{n-1} - 1/2$  [8]. In this case, the relationship (3) takes the form

$$U_S^+ U_S = A^+ A + B^+ B = 2SI, \quad (5)$$

where  $I$  is the unit operator given in  $(2S+1)$  - dimensional space.

• *Hadamard logical element H*

Let us act by the operator H on the input qubit vector

$$|\psi\rangle = \alpha |1\rangle_1 |0\rangle_2 + \beta |0\rangle_1 |1\rangle_2, \quad (6)$$

where  $\alpha$  and  $\beta$ , as stated in Section I, are complex numbers that satisfy the condition

$$|\alpha|^2 + |\beta|^2 = 1. \quad (7)$$

As a result of this action, we obtain

$$\begin{aligned} H|\psi\rangle &= \frac{1}{\sqrt{2}} [A^+ (A+B) + B^+ (A-B)] \\ &\times (\alpha |1\rangle_1 |0\rangle_2 + \beta |0\rangle_1 |1\rangle_2) = \\ &= \frac{1}{\sqrt{2}} [(\alpha + \beta) |1\rangle_1 |0\rangle_2 + (\alpha - \beta) |0\rangle_1 |1\rangle_2]. \end{aligned} \quad (8)$$

The Hadamard operator H from (8) is a unitary operator since

$$H = \frac{1}{\sqrt{2}} (X + Z), H^+ = H, \quad (9)$$

$$H^+ H = (1/2)(X^2 + Z^2 + iY - iY) = I$$

The normalized eigenvectors of the operator H were calculated in [9] in the spinor representation:

$$|\psi_1\rangle = \frac{1}{\sqrt{4-2\sqrt{2}}} \begin{pmatrix} 1 \\ a \end{pmatrix}, |\psi_2\rangle = \frac{1}{\sqrt{4-2\sqrt{2}}} \begin{pmatrix} 1 \\ b \end{pmatrix}, \quad (10)$$

$$\text{where } a = \sqrt{2} - 1, b = -\sqrt{2} - 1.$$

Moving on from the spinor representation to the paired bosons representation, we obtain

$$|\psi_1\rangle = \frac{1}{\sqrt{4-2\sqrt{2}}} [ |1\rangle_1 |0\rangle_2 + (\sqrt{2}-1) \times |0\rangle_1 |1\rangle_2 ], \quad (11)$$

$$|\psi_2\rangle = \frac{1}{\sqrt{4+2\sqrt{2}}} [ |1\rangle_1 |0\rangle_2 - (\sqrt{2}+1) \times |0\rangle_1 |1\rangle_2 ]. \quad (12)$$

Formulas (4) and (8) define the operators of the logical elements X, Y, Z, and H in the paired bosons representation.

### III. SUPERDENSE CODING OF INFORMATION IN PAIRED BOSONS REPRESENTATION

Superdense coding is a quantum protocol, which allows increasing the information content using such a key resource of quantum systems as entanglement. The central idea is that two bits of classical information can be transferred with a single qubit participating in communication [10].

Let us imagine that Alice intends to send two classical bits of information to Bob using qubits. Without relying on entanglement, Alice has to send two qubits in order to transfer two bits of information. However, the advantage appears provided Bob prepares two entangled qubits and sends only one of them to Alice. Alice encodes information in this qubit by applying one single- and one two-qubit gates (Hadamard- and CNOT-gates) and this qubit is then sent back to Bob. Bob performs Bell measurements of both qubits and extracts two classical



bits of information despite of the fact that only the single qubit has been utilized in quantum communication.

It should be noted that the four entangled quantum states, discussed for the first time by Einstein, Podolsky and Rosen [11], are called EPR states. The properties of these states were studied by Bell [12], in connection with which they are also called Bell states.

On the first step two qubits are prepared by the Bob in an entangled states. He initially start the two qubits in the basis state  $|1\rangle_1|0\rangle_2$ . He applied the Hadamard gate (H) to the first qubit to create superposition of the states  $|1\rangle_1|0\rangle_2$  and  $|0\rangle_1|1\rangle_2$ . He then applied CNOT gate  $U_{CN}$  using the first qubit as a control and the second as a target (Fig. 1).

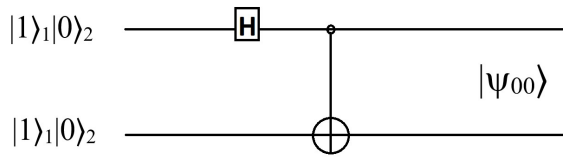


Figure 1. Quantum scheme described by the operator  $L = I \otimes H \cdot CNOT$  for obtaining the Bell state  $|\psi_{00}\rangle$ .

At the output of the quantum circuit shown in Fig. 1, after the original signal passes through the Hadamard gate H, and then through the CNOT gate, the entangled state is formed (the Bell or EPR state  $|\psi_{00}\rangle$ ):

$$|\psi_{00}\rangle = \frac{1}{\sqrt{2}}(|3\rangle_1|0\rangle_2 + |0\rangle_1|3\rangle_2). \quad (13)$$

Really, let the basis vectors  $|1\rangle_1|0\rangle_2$  be fed to both inputs of the quantum circuit. Let us find the state vector after passing through the Hadamard gate:

$$H|1\rangle_1|0\rangle_2 = \frac{1}{\sqrt{2}}(X + Z)|1\rangle_1|0\rangle_2 = \frac{1}{\sqrt{2}}(|1\rangle_1|0\rangle_2 + |0\rangle_1|1\rangle_2) \quad (14)$$

where X and Z are given in (4). We got a vector coming to the control input of the CNOT element. The base vector arrives at the controlled input of the CNOT element is  $|1\rangle_1|0\rangle_2$ . Thus, the input of the CNOT element receives the vector  $|\psi\rangle$ , which in the spinor representation has the form [3]

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle) \otimes |0\rangle = \frac{1}{\sqrt{2}}(|0\rangle \otimes |0\rangle + |1\rangle \otimes |0\rangle) \quad (15)$$

In the paired bosons representation the vector  $|\psi\rangle$  is converted to the form

$$|\psi\rangle = \frac{1}{\sqrt{2}}(|3\rangle_1|0\rangle_2 + |1\rangle_1|2\rangle_2). \quad (16)$$

The action of the CNOT operator on such an input vector results in the Bell state  $|\psi_{00}\rangle$  from (19):

$$U_{CN}|\psi\rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} I & 0 \\ 0 & X \end{pmatrix} (|3\rangle_1|0\rangle_2 + |1\rangle_1|2\rangle_2) = \frac{1}{\sqrt{2}}(|3\rangle_1|0\rangle_2 + |0\rangle_1|3\rangle_2) \quad (17)$$

If basis vectors  $|1\rangle_1|0\rangle_2$  and  $|0\rangle_1|1\rangle_2$  are applied to the control and controlled inputs of the quantum circuit, then at the output of the circuit, after passing through the Hadamard and CNOT gates, another Bell state will be formed:

$$|\psi_{01}\rangle = \frac{1}{\sqrt{2}}(|1\rangle_1|2\rangle_2 + |2\rangle_1|1\rangle_2). \quad (18)$$

In a similar way, one can obtain the remaining two Bell states  $|\psi_{10}\rangle$  and  $|\psi_{11}\rangle$ , if in the first case the basis vectors  $|0\rangle_1|1\rangle_2$  and  $|1\rangle_1|0\rangle_2$  are fed to the control and controlled inputs of the quantum circuit, and in the second case two  $|0\rangle_1|1\rangle_2$  are fed to both inputs:

$$|\psi_{10}\rangle = \frac{1}{\sqrt{2}}(|3\rangle_1|0\rangle_2 - |0\rangle_1|3\rangle_2), \quad (19)$$

$$|\psi_{11}\rangle = \frac{1}{\sqrt{2}}(|2\rangle_1|1\rangle_2 - |1\rangle_1|2\rangle_2). \quad (20)$$

All four cases (13), (18) - (20) can be written briefly in the form

$$|\psi_{ab}\rangle = (I \otimes H) \cdot CNOT |ab\rangle; a, b = 0, 1. \quad (21)$$

The end goal is for Alice to send two classical bits of information to Bob using one qubit. But before she does that, she needs to apply a set of quantum gates to her qubit, depending on which two bits of information she is going to send. Alice encodes each pair of consecutive bits ab using the  $L_{ab}$  operator and acts on her pair qubit. She matches pairs 00, 01, 10, and 11 with the operators  $L_{00}=I$ ,  $L_{01}=X$ ,  $L_{10}=Z$ , and  $L_{11}=iY$ , where I, X, Z, and Y are

defined by (3) and (4). Alice can only affect her pair qubit. Therefore, Alice's influence on any pair  $ab$  is described by the operator  $L_{ab} \otimes I$ . Taking into account (13), the following relations can be obtained:

$$\begin{aligned}(L_{00} \otimes I)|\psi_{00}\rangle &= \frac{1}{\sqrt{2}}(|3\rangle_1|0\rangle_2 + |0\rangle_1|3\rangle_2) = |\psi_{00}\rangle, \\(L_{01} \otimes I)|\psi_{00}\rangle &= \frac{1}{\sqrt{2}}(|2\rangle_1|1\rangle_2 + |1\rangle_1|2\rangle_2) = |\psi_{01}\rangle, \\(L_{10} \otimes I)|\psi_{00}\rangle &= \frac{1}{\sqrt{2}}(|3\rangle_1|0\rangle_2 - |0\rangle_1|3\rangle_2) = |\psi_{10}\rangle, \\(L_{11} \otimes I)|\psi_{00}\rangle &= \frac{1}{\sqrt{2}}(|2\rangle_1|1\rangle_2 - |1\rangle_1|2\rangle_2) = |\psi_{11}\rangle\end{aligned}\quad (22)$$

Thus,

$$(L_{ab} \otimes I)|\psi_{00}\rangle = |\psi_{ab}\rangle; a, b = 0, 1. \quad (23)$$

After encoding the information, Alice sends her qubit to Bob. If she sends Bob a sequence of  $ab$  qubits, then Bob has an entangled pair of qubits in the Bell state  $|\psi_{ab}\rangle$ . To decode this signal, it is necessary to apply a quantum circuit presented on the **Figure 2**.

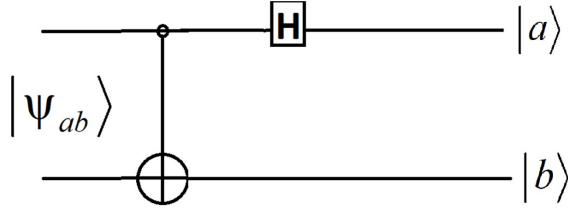


Figure 2. Decoding scheme of the method of superdense coding of information

The action of the decoding operator on the entangled Bell state  $|\psi_{ab}\rangle$  leads to the result. The action of the decoding operator on the entangled Bell state  $|\psi_{ab}\rangle$  leads to the result

$$((I \otimes H) \cdot CNOT)^{-1}|\psi_{ab}\rangle = |a\rangle \otimes |b\rangle = |ab\rangle. \quad (24)$$

Taking into account the unitarity properties of the operators  $I \otimes H$  and CNOT, we finally find:

$$\begin{pmatrix} I & 0 \\ 0 & X \end{pmatrix} \cdot (I \otimes H)|\psi_{ab}\rangle = |ab\rangle. \quad (25)$$

## CONCLUSIONS

1. Traditionally, in quantum informatics the qubits and logical elements are treated in terms of spinor algebra.

Along with this, quantum computing can be performed in the paired bosons representation.

2. Basic gates were found in the paired bosons representation.

3. Superdense coding of information in the representation of paired bosons was performed.

4. Superdense coding of information is closely related with quantum teleportation. To avoid confusion we need to clarify the difference. Superdense coding is a procedure that allows someone to send two classical bits to another party using just a single qubit of communication. Quantum teleportation is a process by which the state of qubit ( $|\psi\rangle$ ) can be transferred from one location to another, using two bits of classical communication and a Bell pair. We can say that teleportation is a process that destroys the quantum state of a qubit in one location and recreate it on a qubit at distant location. Thus, the teleportation protocol is a flipped version of the superdense coding protocol.

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# Thermoelectric Properties of a p-n Module Based on $\text{TTT}_2\text{I}_3$ and $\text{TTT}(\text{TCNQ})_2$ Organic Crystals

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**Abstract**—In this paper the thermoelectric properties of  $p - n$  thermoelectric module of organic nanostructured crystals is investigated. A thermoelectric module (TM) is a device designed for direct conversion of heat to electricity or for cooling effect by applying a small electrical current at the pairs legs. TMs are embedded in a various of devices: thermal generators for energy harvesting at industrial scale, personalized mini devices for power generation or local cooling effect for integrated circuits. In modern medical devices, TMs are used for accurate temperature control in PCR (polymerase chain reaction), biological samples and vaccines transportation, continuous temperature monitoring and others. However, most commercialized TMs nowadays are made of inorganic compounds with a low rate of energy conversion. By the other side, organic materials are more reliable, flexible with a higher efficiency at low temperature gradients. Earlier, it was established theoretically that organic crystals of  $\text{TTT}_2\text{I}_3$  of  $p$  - type and  $\text{TTT}(\text{TCNQ})_2$  of  $n$  - type are very prospective materials for thermoelectric applications at near-to-room temperature. For temperatures not exceeding  $\sim 400$  K, it is expected that crystals properties will not change significantly. The charge transport and thermoelectric properties are predicted to significantly enhance by some manipulations with carrier and impurity concentrations. In the following, the electrical conductivity, the output voltage, and the maximum power factor of a  $p$ - $n$  module made of these crystals is calculated numerically for different combinations of crystals parameters and temperature gradients.

**Keywords**—thermoelectricity; organic crystals;  $\text{TTT}_2\text{I}_3$ ;  $\text{TTT}(\text{TCNQ})_2$ ; thermoelectric module; Seebeck coefficient; thermoelectric efficiency

## I. INTRODUCTION

Thermoelectric (TE) phenomena are related with the electrochemical and thermal properties of a physical system (metal or semiconductor) leading to electrical current generation when a temperature gradient is applied or to local cooling effect when a difference of electrical potential is applied to the material [1]. The maximum

efficiency of the energy conversion process of a material at a given temperature is determined by the thermoelectric figure of merit  $ZT$  [2]:

$$ZT = \sigma S^2 T / \kappa \quad (1)$$

where  $\sigma$  is the electrical conductivity,  $S$  - thermopower (Seebeck coefficient),  $T$  - absolute temperature and  $\kappa$  - the total (electronic and phononic) thermal conductivity. For TMs used as temperature sensor, another quantity is very important, namely the power factor, describing the current power delivered by device for given temperature:

$$P = \sigma S^2 \quad (2)$$

Since the mid of 20<sup>th</sup> century, the main focus was on the TE properties of classic inorganic materials, such as  $\text{Bi}_2\text{Te}_3$ ,  $\text{PbTe}$ , and  $\text{SiGe}$  alloys. A threshold of  $ZT$  around 1 was achieved [3]. Over the last decades, the interest in this field has expanded rapidly, due to the novel techniques, such as low-dimensional structures, nanocomposites, band engineering and carrier filtering.

For instance, in  $\text{Pb}_{0.91}\text{Cr}_{0.09}\text{Te}$  codoped with Iodine, fabricated by melt growth process, values of  $\sigma = 625 \Omega^{-1}\text{cm}^{-1}$ ,  $S = 275 \mu\text{VK}^{-1}$ ,  $P = 47.3 \mu\text{Wcm}^{-1}\text{K}^{-2}$  and  $ZT \sim 2.2$  were reported at  $T = 550\text{K}$  [4]. In high-conductive  $\text{PbTeCd}_{0.02}$ ,  $\sigma = 2000 \Omega^{-1}\text{cm}^{-1}$ ,  $S = -143 \mu\text{VK}^{-1}$ ,  $P = 47.3 \mu\text{Wcm}^{-1}\text{K}^{-2}$  and  $ZT \sim 1.5$  was obtained by melt spinning and rapid induction hot pressing at  $T = 773\text{K}$  [5]. In skutterudites  $\text{Ba}_{0.09}\text{La}_{0.04}\text{Yb}_{0.14}\text{Co}_4\text{Sb}_{12}$  the effect of dopants, nanocomposites, and filler atoms has led to  $\sigma = 2220 \Omega^{-1}\text{cm}^{-1}$ ,  $S = -161 \mu\text{VK}^{-1}$ ,  $P = 57.5 \mu\text{Wcm}^{-1}\text{K}^{-2}$  and  $ZT \sim 1.4$  at  $T = 850\text{K}$  [6]. However, all the inorganic TE compounds reported in the last two decades are efficient at high temperatures, while for low, near-to room temperatures, their TE efficiency is very low.

Organic compounds, by the other side, offer the possibility to operate at low temperature, with high TE performance. The main advantage of organic TE materials is low thermal conductivity, leading to significant enhancement of  $ZT$  (see formula 1). In this sense,

materials with high electrical conductivity are desired. This can be obtained by using high-conducting organic crystals or by including carbon materials, particularly carbon nanotubes (CNT), in the structure of the polymer. From the recent advances, one can highlight the following:  $\sigma = 77000 \Omega^{-1}\text{cm}^{-1}$ ,  $S = 65 \mu\text{VK}^{-1}$ ,  $P = 176 \mu\text{Wcm}^{-1}\text{K}^{-2}$  and  $ZT \sim 0.12$  in PANI/SWCNT at  $T = 298\text{K}$  [7]. Simultaneous enhancement of electrical conductivity and Seebeck coefficient was obtained in organic thermoelectric SWNT/PEDOT:PSS nanocomposites ( $\sigma = 1700 \Omega^{-1}\text{cm}^{-1}$ ,  $S = 55.6 \mu\text{VK}^{-1}$ , resulting in a high power factor  $P = 526 \mu\text{Wcm}^{-1}\text{K}^{-2}$  [8].

The most successful p-type material developed to date is undoubtedly, poly(3,4-ethylenedioxy thiophene) polystyrene sulfonate (PEDOT:PSS) [9].

Thermoelectric devices, based on organic materials have been reported by many authors. For instance, an organic power generator consisting of 55 legs in a vertical architecture exhibits a maximum power output of 0.128  $\mu\text{W}$  at temperature difference of 10K [10]. By using metal-organic conducting polymers as the n-type and p-type materials Zhu's group reported a maximum power of 750  $\mu\text{W}$  and an output voltage of 0.26 V from a TM consisting of 35 legs under a temperature difference of 82K [11].

In this paper, we present the results of numerical modelling a p-n device made of highly conductive nanostructured organic crystals of  $\text{TTT}_2\text{I}_3$  and  $\text{TTT}(\text{TCNQ})_2$  under different temperature gradients. Earlier, theoretical investigations have revealed very promising TE properties of these crystals if carrier concentration is accurately tuned and the purification process is performed [12].

## II. THERMOELECTRIC COEFFICIENTS

Crystals of  $\text{TTT}_2\text{I}_3$  and  $\text{TTT}(\text{TCNQ})_2$  consist of stack-like packages of molecules, arranged in linear chains in perpendicular-to stack direction. This direction is considered below as x - direction of a cartesian coordinate system. The stack y and z axes are defining the stack plane. In x direction, the significant overlap of HOMO (higher occupied molecular orbitals) of neighboring molecules ensures high longitudinal electrical conductivity for both crystals, according to experimentally reported data [13, 14]. In y and z directions, the distance between neighbor molecules is of three or four times larger, the HOMO overlap is small and the transversal electrical conductivity is of three orders of magnitude lower than the longitudinal one. In crystals of  $\text{TTT}_2\text{I}_3$  the main charge carriers are holes, travelling along TTT chains. In crystals of  $\text{TTT}(\text{TCNQ})_2$  the carriers are electrons on TCNQ chains. Considering a small electric field and low temperature gradient, the transport processes can be derived by using the method of retarded, two-particle Green functions [12]. Thermoelectric coefficients can be calculated numerically as:

$$\sigma_{xx} = \sigma_0 R_0, S_{xx} = \pm 2 |w_1| / eT \cdot R_1 / R_0 \quad (3)$$

where

$$\sigma_0 = 2e^2 M v_{s1}^2 |w_1|^3 z / [\pi^3 \hbar abc (k_0 T)^2 w_1'^2] \cdot (T_0 / T)^2 \quad (4)$$

here  $k_0$  is the Boltzmann constant,  $e$  – elementary charge,  $z$  is the number of molecular chains per elementary cell.  $a, b, c$  are lattice constants,  $w_1$  is the transfer energy of a charge carrier from the given molecule to the neighbor, and  $w_1'$  is the derivative with respect to the intermolecular distance. The upper sign in  $S_{xx}$  is for p – type crystals and the lower – for n – type.  $R_n$  are the transport integrals:

$$\begin{aligned} R_n = & \iiint_{[-\pi, \pi]} dx dy dz |\sin x|^3 [1 - \cos x + d_1(1 - \cos y) + \\ & d_2(1 - \cos z) - (1 + d_1 + d_2) \varepsilon_F]^n n_k (1 - n_k) / \\ & \{ (1 \mp |\gamma_1| [1 + \beta_{xx}(T - T_0)]^5 \cos x)^2 + D_0 + D_1 e^{(-E_0/k_0 T)} + \\ & d_1^2(1 + 2 \sin^2 y \mp 2 |\gamma_2| \cos y + |\gamma_2|^2) / 8 \sin^2 x + \\ & d_2^2(1 + 2 \sin^2 z \mp 2 |\gamma_3| \cos z + |\gamma_3|^2) / 8 \sin^2 x \} \end{aligned} \quad (5)$$

here the upper sign in “ $\mp$ ” is for p – type crystals and the lower for n – type.  $n_k$  is the Fermi distribution function in terms of dimensionless quasi-momentum  $\mathbf{k} = (k_x b, k_y a, k_z c)$  and  $\varepsilon_F = E_F / 2w_1$  is the dimensionless Fermi energy. The parameters  $d_1 = w_2 / w_1$  and  $d_2 = w_3 / w_1$  describe the ratio of transfer energies.  $D_0$  describes the scattering on point-like impurities and  $D_1$  – the scattering on thermally activated lattice dislocations. The thermal expansion of the lattice is considered in the coefficient  $\beta_{xx}$  only for the direction of molecular chains.

The expressions for output voltage and the maximum power of a p - n module can be figured out as [15]:

$$U_0 = m(S_p - S_n) \Delta T, P_{\max} = U_0^2 / 4R_g \quad (6)$$

where  $m$  is the number of thermocouples in the module,  $S_p$  and  $S_n$  are the Seebeck coefficients of p, respectively, n legs and  $\Delta T$  is the temperature difference between hot and cold side. The expression for  $P_{\max}$  is obtained for the optimized case, when the internal electrical resistance of TM  $R_g$  and the load electrical resistance are equal. The internal electrical resistance can be calculated as:

$$R_g \cdot l = 1 / \sigma_p + 1 / \sigma_n \quad (7)$$

here  $\sigma_p$  and  $\sigma_n$  are longitudinal electrical conductivities and  $l$  is the length of legs.

## III. NUMERICAL RESULTS

The electrical conductivity and the Seebeck coefficient (3) were calculated by solving numerically the integrals (5) for the following crystals parameters:  $\text{TTT}_2\text{I}_3$ :  $M = 6.5 \cdot 10^5 m_e$  ( $m_e$  is the mass of the free electron),  $w_1 = 0.16 \text{ eV}$ ,  $w_1' = 0.26 \text{ eV \AA}^{-1}$ ,  $v_{s1} = 1.5 \cdot 10^3 \text{ m/s}$ ,  $z = 4$ ,  $d_1 = d_2 = 0.015$ ,  $D_0 = 0.001$ ,  $D_1 = 0.3$ ,  $E_0 = 0.024 \text{ eV}$ .  $\text{TTT}(\text{TCNQ})_2$ :  $M = 3.72 \cdot 10^5 m_e$ ,  $w_1 = 0.125 \text{ eV}$ ,  $w_1' = 0.22 \text{ eV \AA}^{-1}$ ,  $v_{s1} = 2.8 \cdot 10^3 \text{ m/s}$ ,  $z = 2$ ,  $d_1 = 0.01$ ,  $d_2 = 0.015$ ,  $D_0 = 0.001$ ,  $D_1 = 0.3$ ,  $E_0 = 0.024 \text{ eV}$ . The crystals parameters



were estimated by fitting the numerical results of electrical conductivity and Seebeck coefficient with experimentally reported ones [13, 14].

In Fig.1., the electrical conductivity and thermopower of TTT<sub>2</sub>I<sub>3</sub> crystals as a function of dimensionless Fermi energy are presented. It is observed that in case of stoichiometric concentration of conducting holes  $n_h = 1.25 \cdot 10^{21} \text{ cm}^{-3}$  (to which corresponds a dimensionless Fermi energy  $\varepsilon_F = 0.35$ ),  $\sigma_{xx} = 9 \cdot 10^3 \Omega^{-1} \text{ cm}^{-1}$  and  $S_{xx} = 60 \mu\text{V/K}$ , which is very close to the experimentally reported values in [13]. Bud, as it is observable from Fig.1., If  $\varepsilon_F$  is diminished down to 0.18 (which corresponds to the diminution of holes concentration by two times), the electrical conductivity decreases  $\sigma_{xx} = 3.6 \cdot 10^3 \Omega^{-1} \text{ cm}^{-1}$  and the Seebeck coefficient increases up to  $S_{xx} = 150 \mu\text{V/K}$ . This indicates on the enhancement of thermoelectric properties.

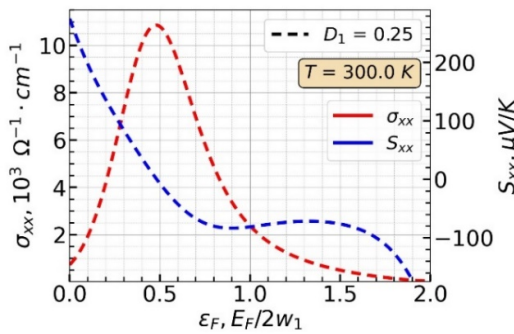


Figure 1. Electrical conductivity and Seebeck coefficient of TTT<sub>2</sub>I<sub>3</sub> crystals as function of dimensionless Fermi energy

In Fig.2., the electrical conductivity and Seebeck coefficient of TTT(TCNQ)<sub>2</sub> crystals are presented.

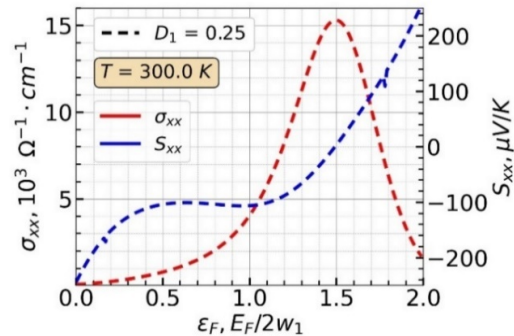


Figure 2. Electrical conductivity and Seebeck coefficient of TTT(TCNQ)<sub>2</sub> crystals as function of dimensionless Fermi energy.

In case of *n*-type crystals, the concentration of charge carriers has to be increased in order to achieve high thermoelectric voltage. For stoichiometric concentration of conducting electrons  $n_e = 1.22 \cdot 10^{21} \text{ cm}^{-3}$  (to which corresponds a dimensionless Fermi energy  $\varepsilon_F = 0.35$ ),  $\sigma_{xx} = 0.46 \cdot 10^3 \Omega^{-1} \text{ cm}^{-1}$  and  $S_{xx} = -120 \mu\text{V/K}$ . If additional doping with donors is performed, increasing the concentration  $n_e$  by 2 times with respect to the stoichiometric one (i.e.,  $\varepsilon_F = 1.05$ ), the Seebeck coefficient does not change significantly,  $S_{xx} = -110 \mu\text{V/K}$ , but electrical conductivity will increase with an order of

magnitude  $\sigma_{xx} = 4.6 \cdot 10^3 \Omega^{-1} \text{ cm}^{-1}$ . This is very promising, since according to (2), the delivered power factor will increase also. In the following, it is interesting to modelate a *p* - *n* pair (or a set of pairs) of these crystals in power generation regime.

In Fig.3. the output voltage and the maximum power output of a *p*-*n* module made of 10 pairs of legs under a temperature gradient  $\Delta T = 20\text{K}$  is presented. The length of a single leg was considered  $l = 0.05 \text{ m}$ . The modeling was performed as a function of the dimensionless Fermi energy of *n*-type TTT(TCNQ) crystals, considering stoichiometric TTT<sub>2</sub>I<sub>3</sub> crystals. The dimensionless parameter  $D_1$  was estimated by comparison with experimental data reported in [13], which correspond to crystals grown from gaseous phase. In the following, we have considered the same  $D_1$  value for TTT(TCNQ)<sub>2</sub>.

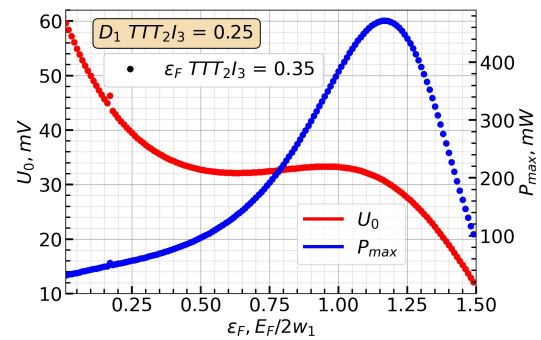


Figure 3. Output voltage and maximum power output generated by 10 *p*(TTT<sub>2</sub>I<sub>3</sub>) - *n*(TTT(TCNQ)<sub>2</sub>) pairs at temperature difference of 20K, as function of dimensionless Fermi energy of *n* leg. *p* leg - undoped.

It is observed that for stoichiometric concentration of conducting electrons in TTT(TCNQ)<sub>2</sub> (i.e.,  $\varepsilon_F = 0.35$ ) the TM can deliver an output voltage  $U_0 = 35 \text{ mV}$  with a maximum power  $P_{\max} = 70 \text{ mW}$ . If  $n_e$  is increased by two times (i.e.,  $\varepsilon_F = 1.05$ ), the output voltage practically does not change  $U_0 = 33 \text{ mV}$  but the maximum power increase by six times  $P_{\max} = 420 \text{ mW}$ . If the optimization procedure is applied to TTT<sub>2</sub>I<sub>3</sub> crystal (i.e.,  $\varepsilon_F = 0.18$ ), significant achievements can be obtained (see Fig.4).

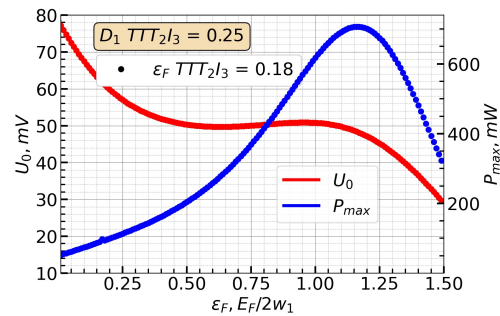


Figure 4. Output voltage and maximum power output generated by 10 *p*(TTT<sub>2</sub>I<sub>3</sub>) - *n*(TTT(TCNQ)<sub>2</sub>) pairs at temperature difference of 20K, as function of dimensionless Fermi energy of *n* leg. *p* leg - optimized.

In Fig.4. the same TM is modeled as a function of dimensionless Fermi energy of *n*-type TTT(TCNQ) crystals, considering optimized TTT<sub>2</sub>I<sub>3</sub> crystals. It is observed that in this case, high values of output voltage

and maximum power can be obtained:  $U_0 = 50$  mV and  $P_{\max} = 660$  mW.

Thus, the strategy for improving thermoelectric properties of a TM made of  $\text{TTT}_2\text{I}_3$  and  $\text{TTT}(\text{TCNQ})_2$  crystals consists of accurate tuning of charge carrier concentration. The purification process is very important, since the diminution of  $D_1$  leads to even more high values of  $U_0$  and  $P_{\max}$ . The temperature dependence of  $\sigma_{xx}$  and  $S_{xx}$  is very important, since when applying a temperature difference to the ends of  $p$  and  $n$  legs, the working temperature is distributed along the leg.

In Fig.5., the temperature dependence of electrical conductivity and Seebeck coefficient of  $\text{TTT}(\text{TCNQ})_2$  optimized crystals is presented.

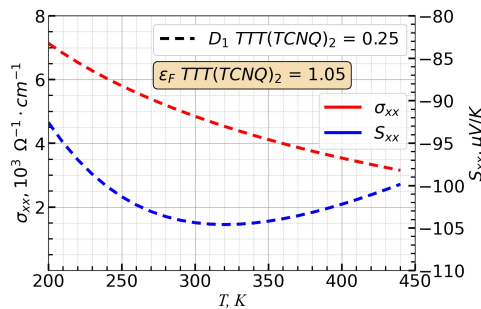


Figure 5. Electrical conductivity and Seebeck coefficient of  $\text{TTT}_2\text{I}_3$  crystals as function of dimensionless Fermi energy

As one can observe, the electrical conductivity decreases with the increase of temperature. This effect is linked to the intensification of electron-phonon scattering. The Seebeck coefficient is less sensible to the temperature variations and practically remains constant for a large range of temperatures. The domain below 200K was not considered, since for lower temperatures, a more detailed physical model has to be developed. For  $\text{TTT}_2\text{I}_3$  the temperature dependence was calculated in [16]. It was also revealed that for a temperature range from  $\sim 300\text{K}$  to  $400\text{K}$  the electrical conductivity and the Seebeck coefficient does not change significantly. From these reports results that at near-to room temperatures, the thermoelectric properties of the crystals practically remain unchanged.

#### IV. CONCLUSIONS

The electrical conductivity  $\sigma_{xx}$ , the Seebeck coefficient  $S_{xx}$  of  $p$  - type  $\text{TTT}_2\text{I}_3$  and  $n$  - type  $\text{TTT}(\text{TCNQ})_2$  crystals were calculated numerically and modeled as a function of dimensionless Fermi energy of charge carriers. It was obtained that the tuning of this parameter can lead to significant improvement in thermoelectric properties of the crystal. Also, a thermoelectric module made of 10  $p$  -  $n$  thermocouples of these organic crystals was modeled for different values of internal parameters of the crystals. A temperature difference of 10 K was assumed and the length of legs was considered as 0.05m. The output

voltage  $U_0$  and the maximum power delivered  $P_{\max}$  were calculated. It is predicted that one can achieve values of  $\sigma_{xx} = 3.6 \cdot 10^3 \Omega^{-1}\text{cm}^{-1}$  and  $S_{xx} = 150 \mu\text{V/K}$  for  $p$  - type and of  $\sigma_{xx} = 46 \cdot 10^3 \Omega^{-1}\text{cm}^{-1}$  and  $S_{xx} = -110 \mu\text{V/K}$  for  $n$  - type if the charge carrier concentration is tuned. In this case, the thermoelectric module should deliver  $U_0 = 50$  mV of voltage and  $P_{\max} = 660$  mW of maximum power. These results are very promising for high-efficient thermoelectric converters.

#### ACKNOWLEDGMENT

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## **For Notes**



# Computer Engineering Session



# Localization of Objects in 3D Space by Using a Stereoscopic Video System

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**Abstract**— This article describes two implementation models of an artificial vision for specific tasks of localization of objects in three-dimensional space using a stereoscopic system of two cameras.

The periscopic model provides means for objects localization relative to the position of the stereoscopic system. This can be used for both detecting the position of bodies in space and for performing the technical system orientation with an artificial vision. The orthogonal model is capable of executing a high-precision dynamic localization of objects in space.

**Keywords**— artificial vision; stereoscopic video system; absolute and relative coordinates; localization and identification of objects; periscope video system; orthogonal video system.

## I. INTRODUCTION

The implementation of computer vision is a part of many cyber-physical systems. Such systems perform the functions of monitoring the external environment and enable mobile devices to orient themselves to the terrain. The concept of artificial vision provides for the use of video units to obtain information about the exterior medium. It is often enough to have one video device to model artificial vision tasks. A fully functioning artificial vision is an integral part of a holonic artificial intelligence system and it is a useful aid to perform objects localization and identification tasks. The system must use at least two video devices to provide these functions by analogy with biological organisms [1-4]. This article suggests two strategies for artificial vision implementation, according to its tasks and additional requirements.

## II. PERISCOPIC MODEL OF ARTIFICIAL VISION

The periscopic model is a computer analogue of the biological organism's vision. The system consists of two closely-spaced video cameras. It is preferable to locate them on the same level, so that their centroidal observation axes are parallel (Fig. 1).

The distance between the cameras is defined as the periscopic base. The stereoscopic periscopic video system can be adjusted either by pointing both cameras at a sufficiently remote object or by using the setup plan (Fig. 1). Such a stereoscopic system is effective at distances at which there is a relative shift of objects in the images of two cameras. The variation of the distance to the object with respect to the offset value can be experimentally determined and tabulated in advance. A significant problem is the necessity of identifying objects in simultaneous images from two cameras in order to localize objects. This is possible when the object falls into the field of view of both cameras. In addition, the ability to localize several objects at the same time is an advantage of the periscopic method.

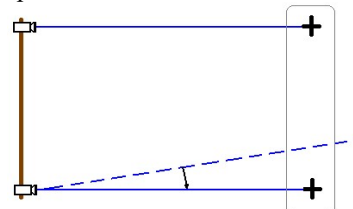


Figure 1. Periscopic video system model.

Thus, the work of the periscopic stereoscopic system consists of the following steps:

- machinal development of periscope system (Fig. 2) and its adjustment (Fig. 3);

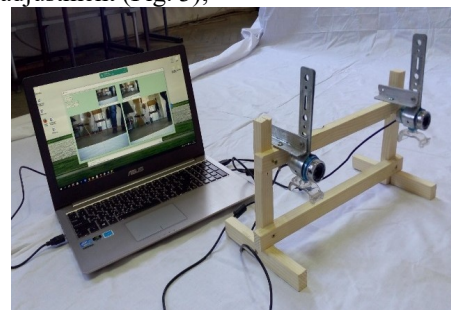


Figure 2. The development of periscopic video system.

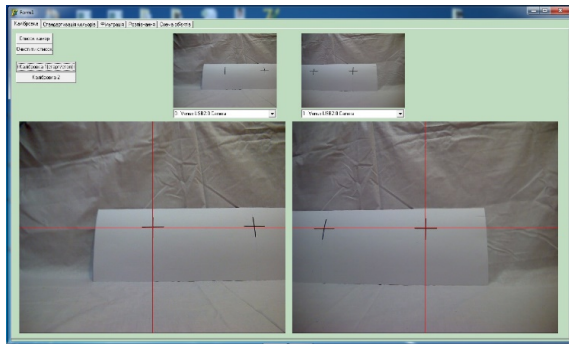


Figure 3. The adjustment of periscopic video system.

- tabling the variation of the distance to the object with respect to the offset value in the images from the two cameras (it is necessary for the cameras to have identical engineering data to get correct calculations);
- dynamical obtain of synchronous still images from two cameras (Fig. 4) and object identification (Fig. 5);

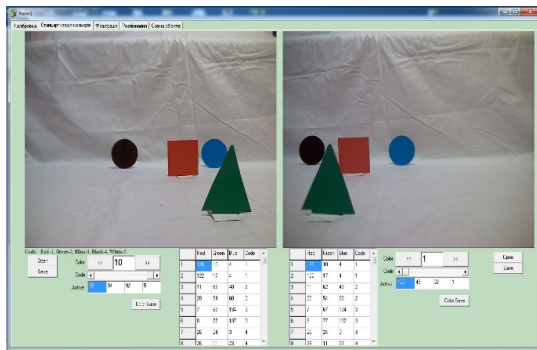


Figure 4. The obtain of synchronous still images from two cameras.

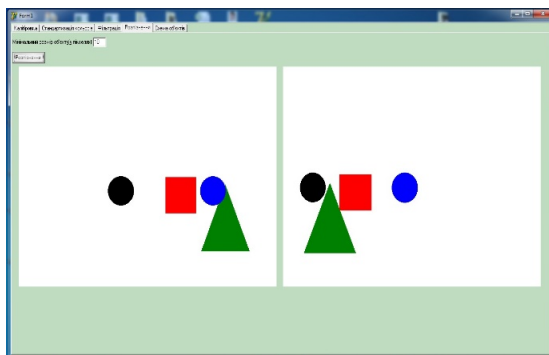


Figure 5. The obtain of synchronous still images object identification.

- objects localization and their placement on the "topographic scheme". As this takes place, one of the cameras is considered as the main one and determines the object's frontal coordinate, while the object's offset in another image determines the perspective coordinate according to the table (Fig. 6).

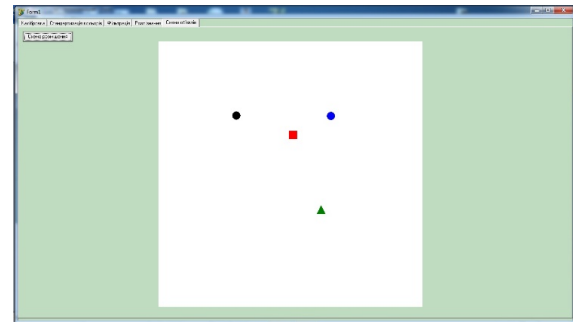


Figure 6. Localization scheme of identified objects.

### III. ORTHOGONAL STEREOSCOPIC MODEL OF AN ARTIFICIAL VISION

The periscope system is effective for localizing objects placed close to the artificial vision system. The orthogonal model can be used to observe and localize objects to high accuracy. This takes into account the fact that the video cameras can be placed as far apart from each other as from the "central organ" of the artificial intelligence system. To simplify the mathematical model, it makes more sense to place cameras in the same horizontal plane to intersect the central observation e right angle. The axes' cross-point is considered the center of the relative coordinate system (the third axis is placed perpendicular to the first two). We consider two model variations.

#### A. Orthogonal Model with Parallel Projecting

Let's assume that there is a fixed Cartesian reference system in a 3D space. Located on the x and y coordinate axes, cameras are directed toward the coordinate origin. The 3D space projection planes are at the right angles with the plane of the cameras' location and cut the x and y axes. Cameras are located at a far distance from the coordinate origin, thus we assume that projection rays are vertical to the projection plane (parallel projection) (Fig. 7). In this case, the geometric centers of the cameras' view windows will align with the center of the coordinate system in 3D space, while the field of view has the form of a rectangular parallelogram and which is limited to the size of the camera window.

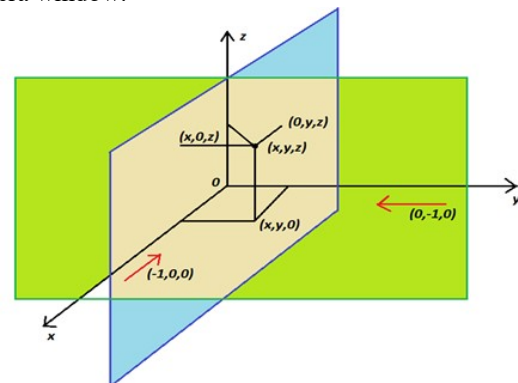


Figure 7. The model of 3D coordinate system and projective

planes.

Triaxial coordinates of “moving” point  $(x, y, z)$  in space are calculated using the formulas:

$$x = X1 - Cx1$$

$$y = X2 - Cx2$$

$$z = -Y2 + Cy2,$$

where:  $X1$  – the point coordinate  $X$  in the first camera’s view window;

$X2$  – the point coordinate  $X$  in the second camera’s view window;

$Y2$  – the point coordinate  $Y$  in the second camera’s view window;

$Cx1$  – the center point coordinate  $X$  in the second camera’s view window;

$Cx2$  – the center point coordinate  $X$  in the second camera’s view window

$Cy2$  – the center coordinates  $Y$  of the second camera’s view window.

### B. Orthogonal model with perspective projection

The parallel projection model ignores the resizing of the object and angular values in relation to the distance between the object and the camera. Such dependence is taken into account in the mathematical model of localization, based on the conception of perspective projection. The location of the coordinate systems on the projective planes is analogous to the model of parallel projection. The difference between these models is that cameras are located on coordinate axes at relatively small focal distances while perspective projection (we assume that both focal distances are the same to simplify the model). Projective perspective coordinate transformations are shown in Fig. 8.

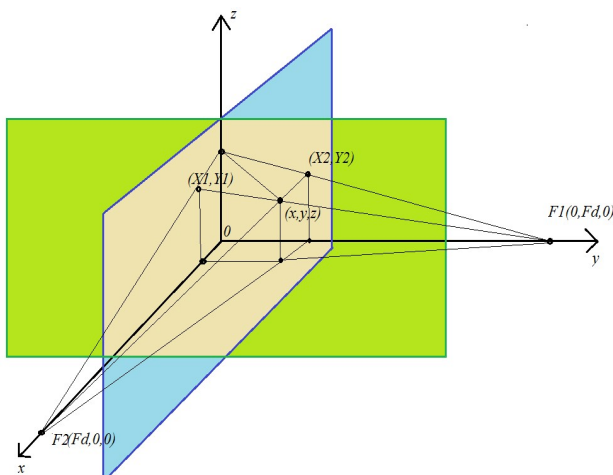


Figure 8. The model of stereometrical perspective projective transformations.

In Figure 8, there are the coordinates and the position of an observable object in the still images from the first and the second cameras after matching up 3D space coordinate systems and coordinate systems of still images.

The projective plane contains all information necessary for coordinate’s localization (Fig. 9).

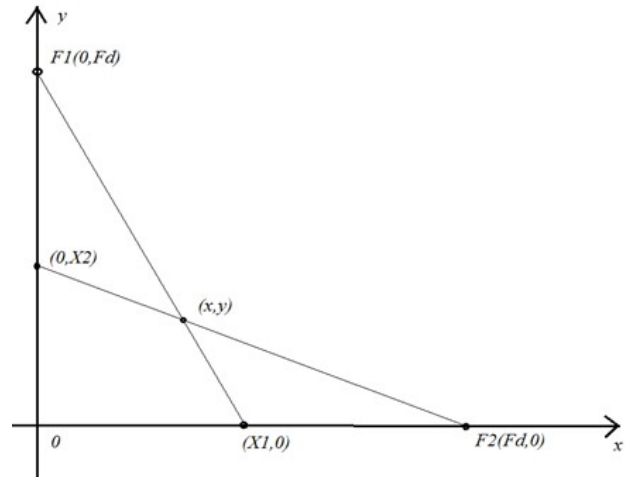


Figure 9. Projection of localization model on a plane  $xOy$ .

To determine the coordinates  $(x, y)$  it is necessary to perform the following actions:

1) Determine two intercept equations of a line (all wanted coordinates are known):

$$\begin{cases} \frac{x}{Fd} + \frac{y}{X2} = 1 \\ \frac{x}{X1} + \frac{y}{Fd} = 1 \end{cases} \quad (1)$$

2) Pass on to the general equations of a line:

$$\begin{cases} X2 * x + Fd * y = X2 * Fd \\ Fd * x + X1 * y = X1 * Fd \end{cases} \quad (2)$$

3) Solve simultaneous equations using Cramer’s rule:

$$\begin{aligned} x &= \frac{X2 * Fd * X1 - Fd^2 * X1}{X1 * X2 - Fd^2} \\ y &= \frac{X2 * Fd * X1 - Fd^2 * X2}{X1 * X2 - Fd^2} \end{aligned} \quad (3)$$

The coordinate  $z$  is calculated straight from the 3D localization model, according to the still image from any video camera, for instance, from the ratio:



$$\frac{z}{Y1} = \frac{Fd - x}{Fd}, \quad (4)$$

so

$$z = Y1 * \frac{Fd - x}{Fd}, \quad (5)$$

**Note:** the cases when there are zero values among coordinates  $(X1, Y1)$  and  $(X2, Y2)$  should be analyzed individually.

#### CONCLUSION

This study shows two models of objects localization in 3D space using a stereoscopic system of two video cameras. A perspective model can be used to simulate the artificial vision of the "biological" type. The model does not guarantee high localization accuracy but it allows to estimate the mutual arrangement of several "familiar" objects, and it helps to perform "terrain orientation" while placing an artificial vision system on a mobile autonomous platform, thus, determining its position

within a certain area of 3D space. In the presence of remote video cameras, an orthogonal model can perform real-time high precision localization of moving objects in certain field of view. The accuracy of the object's localization in the orthogonal model dominantly depends on the accuracy of the geolocation of the involved cameras and their mutual orthogonal orientation. The GPS localization results can be reasonable for localization of relatively remote cameras. The cameras orientation can be easily and accurately done using theodolite or dip compass.

Consequently, both video location models are not complicated for technical implementation, they are reasonably priced and accessible for completing practical tasks using artificial vision systems.

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# Comparative Analysis of the PID Algorithm Synthesis at the Object Model with Astatism and Dead Time

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**Abstract** - The paper presents the comparative analysis of the synthesis methods of the PID tuning algorithm for the model of the object with first degree astatism and dead time. In the practice of industrial and technological process automation, mathematical models attached to processes are considered models with first degree astatism and dead time. It analyzes the methods that can be applied for tuning algorithms to these types of process models. Systems with dead time transfer elements do not have finite dimensional systemic achievements, but have an infinite number of poly-zeros. In practice, these models are approximated with rational forms known as Pade approximations with minimal and non-minimal phase. The method of tuning the PID controller shall be analyzed using analytical method of maximum degree of stability and method of maximum degree of stability with iterations. In the object model the dead time component is approximated with Pade approximations with minimal phase and for these models the PID algorithm is synthesized according to the method of the maximum degree with iterations. The PID algorithm is synthesized according to the proposed methods for two examples of values of the parameters of the model of the control object with astatism and dead time and the obtained results are analyzed. The advantages of the method of maximum stability with iterations are highlighted.

**Keywords** - Object models with astatism and dead time; Pade approximations; PID algorithm, tuning methods; method of maximum degree of stability with iterations

## I. INTRODUCTION

When automating different industrial and technological processes, mathematical models attached to processes are considered as models with astatism and dead time described by the transfer function [1-7]:

$$H(s) = \frac{ke^{-ds}}{Ts}, \quad (1)$$

where  $k$  is the transfer coefficient,  $T$  - integration time constant,  $d$  - dead time.

The presence in the automatic system of the dead time transfer element leads to difficult problems in developing control algorithms. Systems with dead time transfer elements do not have finite dimensional systemic achievements - they have an infinite number of poly-zeros. In practice these elements are approximated with rational forms known as Pade approximants [1-3, 5, 7]. Further, for the transfer element with astatism and dead time, non-minimal phase Pade approximations are used and model (1) is presented with the transfer functions of the form:

$$H(s) = \frac{ke^{-ds}}{Ts} \approx \frac{k - \frac{kds}{3}}{Ts(1 + \frac{2ds}{3} + \frac{d^2s^2}{6})} = \frac{-b_0s + b_1}{a_0s^3 + a_1s^2 + a_2s}, \quad (2)$$

$$H(s) = \frac{ke^{-ds}}{Ts} \approx \frac{k - \frac{kds}{2}}{Ts(1 + \frac{ds}{2})} = \frac{-b_0s + b_1}{a_0s^2 + a_1s}, \quad (3)$$

$$H(s) = \frac{ke^{-ds}}{Ts} \approx \frac{k - \frac{kds}{2} + \frac{kd^2s^2}{12}}{Ts(1 + \frac{ds}{2} + \frac{d^2s^2}{12})} = \frac{b_0s^2 - b_1s + b_2}{a_0s^3 + a_1s^2 + a_2s}, \quad (4)$$

where the coefficients in (2)-(4) are expressed by the parameters  $k$ ,  $T$ ,  $d$  of the object (1) as:



in (2)  $b_0 = kd/3$ ,  $b_1 = k$ ,  $a_0 = Td^2/6$ ,  $a_1 = 2Td/3$ ,  $a_2 = T$ ;

in (3)  $b_0 = kd/2$ ,  $b_1 = k$ ,  $a_0 = Td/2$ ,  $a_1 = T$ ;

in (4)  $b_0 = kd^2/12$ ,  $b_1 = kd/2$ ,  $b_2 = k$ ,  $a_0 = Td^2/12$ ,  $a_1 = Td/2$ ,  $a_2 = T$ .

For tuning the parameters of the PID controller to the model of the object with astatism and dead time (1) can be used methods: empirical methods, frequency methods, parametric optimization, etc. [1, 3-7]. By empirical methods the calculations are reduced, but low performances are also obtained. Frequency methods contain a large volume of calculations with graphical representations in the frequency domain. The method widely used to tune PID-type controllers as the Ziegler-Nichols method cannot be applied [1, 2]. The parametric optimization method is performed in MATLAB.

It is proposed to use analytical method of maximum stability (AMSD) and method of maximum stability with iteration (MSDI) [8-11] for tuning the PID controller to the initial model of the control object with astatism and dead time (1) and approximate models (2)-(4).

The procedure for tuning the PID controller to two models of control object model with astatism and dead time with known parameters and to three approximate models with approximations of non-minimum phase Pade is analyzed.

## II. PID CONTROLLER TUNING ALGORITHMS

The study it is used the structural block scheme of the automatic system (AS) made up of the model of the object with transfer function  $H_P(s)$  and controller with transfer function  $H_R(s)$  given in Fig. 1.

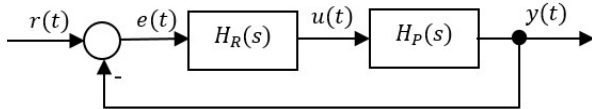


Figure 1. Structural block scheme of the automatic system.

The standard PID tune algorithm is described with the transfer function:

$$H_{PID}(s) = k_p + \frac{k_i}{s} + k_d s = \frac{k_d s^2 + k_p s + k_i}{s}, \quad (5)$$

where  $k_p$ ,  $k_i$ ,  $k_d$  are tuned parameters of the proportional, derivative and integrative component of the PID algorithm.

Applying the analytical method of the maximum degree of stability, the calculation expressions of the PID controller parameters for the models of the control object (1)-(4) in the form [9-11] are presented.

For model (1) the analytical relations are obtained:

$$d^2 J^2 - 4dJ + 2 = 0, \quad (6)$$

$$k_d = \frac{T e^{-dJ}}{2k} (-d^2 J^2 + 4dJ - 2) = f_d(J) \approx 0.206T/k, \quad (7)$$

$$k_p = \frac{T e^{-dJ}}{k} (-dJ^2 + 2J) + 2k_d J = \frac{T e^{-dJ}}{k} (-d^2 J^3 + 3dJ^2) = f_p(J) \approx 0.7836T/kd, \quad (8)$$

$$k_i = -\frac{TJ^2 e^{-dJ}}{k} - k_d J^2 + k_p J = \frac{T e^{-dJ}}{2k} (-d^2 J^4 + 2dJ^3) = f_i(J) \approx 0.0803T/kd^2, \quad (9)$$

Solving (6) it is determined the maximum value of the degree of stability  $J = 1.268/d$  and in the relations (7)-(9) the expressions are given after which the optimal values of the parameters  $k_p$ ,  $k_i$ ,  $k_d$  of the PID controller are calculated.

For model (2) the analytical expressions are obtained:

$$k_d = \frac{-d_0 J^5 - d_1 J^4 - d_2 J^3 - d_3 J^2 + d_4 J - d_5}{2(b_0 J + b_1)^2}, \quad (10)$$

where  $d_0 = 6a_0 b_0^3$ ,  $d_1 = 22a_0 b_0^2 b_1 - 2a_1 b_0^3$ ,  $d_2 = 28a_0 b_0 b_1^2 - 8a_1 b_0^2 b_1$ ,  $d_3 = 12a_0 b_1^3 - 12a_1 b_0 b_1^2$ ,  $d_4 = 6a_1 b_1^3 - 2a_2 b_0 b_1^2$ ,  $d_5 = 2a_2 b_1^3$ ,

$$k_p = \frac{d_0 J^4 + d_1 J^3 - d_2 J^2 + d_3 J}{(b_0 J + b_1)^2} + 2k_d J, \quad (11)$$

where  $d_0 = 3a_0 b_0$ ,  $d_1 = 4a_0 b_1 - 2a_1 b_0$ ,  $d_2 = 3a_1 b_1 - 2a_0 b_0$ ,  $d_3 = 2a_2 b_1$ ,

$$k_i = \frac{-a_0 J^4 + a_1 J^3 - a_2 J^2}{b_0 J + b_1} - k_d J^2 + k_p J. \quad (12)$$

For model (3) the analytical expressions are obtained:

$$k_d = \frac{-d_0 J^4 - d_1 J^3 - d_2 J^2 + d_3 J + d_4}{2(b_0 J + b_1)^4}, \quad (13)$$

where  $d_0 = 2a_0 b_0^3$ ,  $d_1 = 8a_0 b_0^2 b_1$ ,  $d_2 = 12a_0 b_0 b_1^2$ ,  $d_3 = -6a_0 b_1^3 + 2a_1 b_0 b_1^2$ ,  $d_4 = 2a_1 b_1^3$ ,

$$k_p = \frac{-d_0 J^3 + d_1 J^2 + d_2 J}{(b_0 J + b_1)^2} + 2k_d J, \quad (14)$$

where  $d_0 = 2a_0 b_0$ ,  $d_1 = -3a_0 b_1 + a_1 b_0$ ,  $d_2 = 2a_1 b_1$ ,

$$k_i = \frac{a_0 J^3 - a_1 J^2}{b_0 J + b_1} - k_d J^2 + k_p J. \quad (15)$$

For model (4) the analytical expressions are obtained:

$$k_d = \frac{-d_0J^8 - d_1J^7 - d_2J^6 - d_3J^5 - d_4J^4 - d_5J^3 - d_6J^2 - d_7J - d_8}{2(b_0J^2 + b_1J + b_2)^4}, \quad (16)$$

where  $d_0 = 2a_0b_0^3$ ,  $d_1 = 8a_0b_0^2b_1$ ,  $d_2 = 8a_0b_0^2b_2 + 12a_0b_0b_1^2$ ,  
 $d_3 = 28a_0b_0b_1b_2 + 2a_1b_0^2b_2 + 6a_0b_1^3 - 2a_1b_0b_1^2 - 2a_2b_0^2b_1$ ,  
 $d_4 = 18a_0b_0b_2^2 + 22a_0b_1^2b_2 - 4a_1b_0b_1b_2 - 2a_1b_1^3 - 2a_2b_0b_1^2 -$   
 $- 6a_2b_0^2b_2$ ,  $d_5 = 28a_0b_1b_2^2 - 4a_1b_0b_2^2 - 8a_1b_1^2b_2 - 8a_2b_0b_1b_2$ ,  
 $d_6 = 12a_0b_2^3 - 4a_2b_0b_2^2$ ,  $d_7 = 2a_2b_1b_2^2 - 6a_1b_1^3$ ,  $d_8 = 2a_2b_2^3$ ,

$$k_p = \frac{d_0J^5 + d_1J^4 + d_2J^3 + d_3J^2 + d_4J}{(b_0J^2 + b_1J + b_2)^4} + 2k_dJ, \quad (17)$$

where  $d_0 = 2a_0b_0$ ,  $d_1 = -3a_0b_1 - a_1b_0$ ,  $d_2 = 4a_0b_2 - 2a_1b_1$ ,  
 $d_3 = -3a_1b_2 + a_2b_1$ ,  $d_4 = 2a_2b_2$ ,

$$k_i = \frac{-a_0J^4 + a_1J^3 - a_2J^2}{b_0J^2 + b_1J + b_2} - k_dJ^2 + k_pJ. \quad (18)$$

The PID control algorithm is synthesized for the object model (1) with known parameters, using the analytical MSD method and MSD method with iterations [9-11], and for models (2)-(4) the MSD method with iterations is used.

PID controller tuned parameters  $k_p$ ,  $k_i$ ,  $k_d$  are analytical functions of the known parameters of the object and of the unknown degree of stability  $J$  of the system:  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$ . According to the relations (7)-(9), (10)-(12), (13)-(15), (16)-(18) the curves  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  are constructed respectively.

In order to obtain the desired system performance with the PID controller on curves  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  sets of values of the parameters of the PID controller  $J_i - k_{pi}$ ,  $k_{ii}$ ,  $k_{di}$  are chosen and the automatic system is simulated on the computer. The transient responses of the system are raised and the the highest performances of the system are determined.

### III. COMPUTER APPLICATIONS AND SIMULATIONS

To verify the proposed method of synthesis of the PID controller in the object model (1), two variants of numerical values of the object parameters are used:

- 1)  $k=1$ ,  $T=0.1s$ ,  $d=0.5s$ ,
- 2)  $k=0.5$ ,  $T=10s$ ,  $d=2s$ .

It is calculated the numerical values of the parameters for models (1)-(4).

*Example 1.* For the data  $k=1$ ,  $T=0.1s$ ,  $d=0.5s$  of the model the values of the parameters are obtained:

in (2)  $b_0 = kd/3 = 1 \cdot 0.5/3 = 0.1667$ ,  $b_1 = k = 1$ ,  $a_0 = Td^2/6 = 0.1 \cdot 0.5^2/6 = 0.0042$ ,  $a_1 = 2Td/3 = 2 \cdot 0.1 \cdot 0.5/3 = a_2 = T = 0.1$ ;

in (3)  $b_0 = kd/2 = 1 \cdot 0.5/2 = 0.25$ ,  $b_1 = k = 1$ ,  $a_0 = Td/2 = 0.1 \cdot 0.5/2 = 0.025$ ,  $a_1 = T = 0.1$ ,

in (4)  $b_0 = kd^2/12 = 1 \cdot 0.5^2/12 = 0.0208$ ,  $b_1 = kd/2 = 1 \cdot 0.5/2 = 0.25$ ,  $b_2 = k = 1$ ,  $a_0 = Td^2/12 = 0.1 \cdot 0.5^2/12 = 0.00208$ ,  $a_1 = Td/2 = 0.1 \cdot 0.5/2 = 0.025$ ,  $a_2 = T = 0.1$ .

According to the relations (7)-(9), (10)-(12), (13)-(15), (16)-(18) for both variants of numerical data of the parameters of models (2)-(4) were calculated and constructed the respective curves  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  which are given in Fig. 2 (curves: a) for model (2), curves b) for model (3), curves c) for model (4).

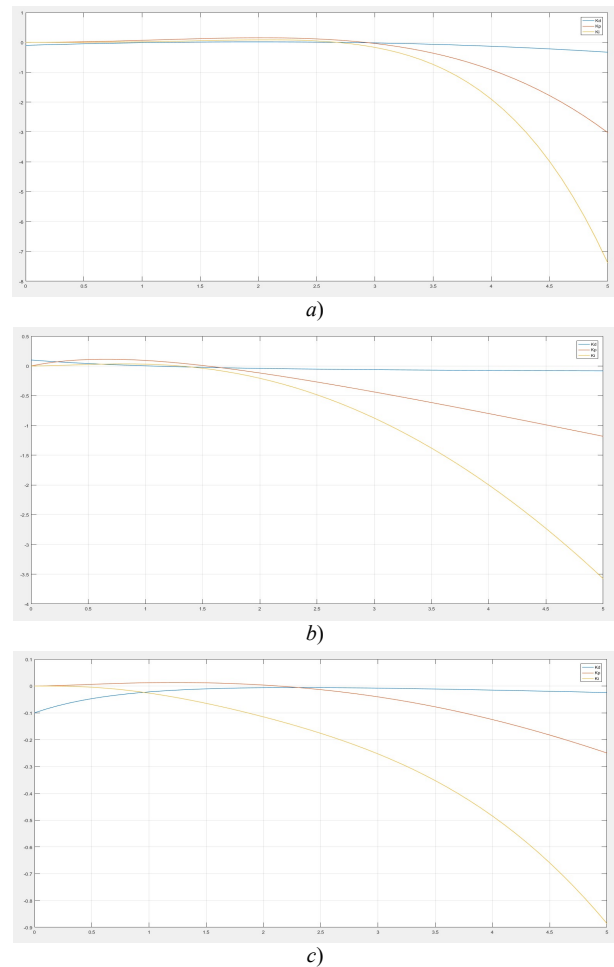


Figure 2. Dependencies  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  of the PID algorithm.

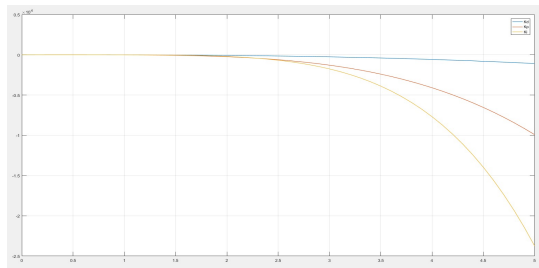
*Example 2.* For the data  $k=0.5$ ,  $T=10s$ ,  $d=2s$  of the model the values of the parameters are obtained:

in (2)  $b_0 = kd/3 = 0.5 \cdot 2/3 = 0.3333$ ,  $b_1 = k = 0.5$ ,  $a_0 = Td^2/6 = 10 \cdot 2^2/6 = 6.6667$ ,  $a_1 = 2Td/3 = 2 \cdot 10 \cdot 2/3 = 13.3333$ ,  $a_2 = T = 10$ ;

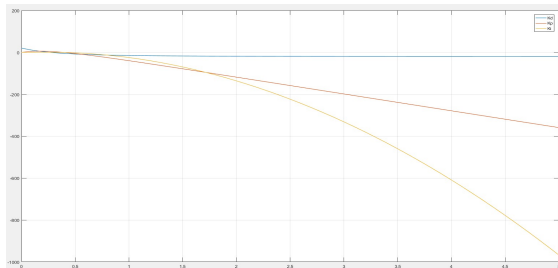
in (3)  $b_0 = kd/2 = 0.5 \cdot 2/2 = 0.5$ ,  $b_1 = k = 0.5$ ,  $a_0 = Td/2 = 10 \cdot 2/2 = 10$ ,  $a_1 = T = 10$ ;

in (4)  $b_0 = kd^2/12 = 0.5 \cdot 2^2/12 = 0.1667$ ,  $b_1 = kd/2 = 0.5 \cdot 2/2 = 0.5$ ,  $b_2 = k = 0.5$ ,  $a_0 = Td^2/12 = 10 \cdot 2^2/12 = 3.3333$ ,  $a_1 = Td/2 = 10 \cdot 2/2 = 10$ ,  $a_2 = T = 10$ .

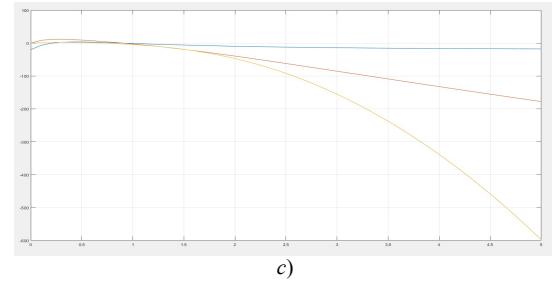
According to the relations (7)-(9), (10)-(12), (13)-(15), (16)-(18) for both variants of numerical data of the parameters of models (2)-(4) were calculated and constructed the respective curves  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  which are given in Fig. 3 (curves: a) for model (2), curves b) for model (3), curves c) for model (4)).



a)



b)



c)

Figure 3. Dependencies  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  of the PID algorithm.

On the curves  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  iterations were chosen and the automatic system was simulated in the MATLAB software package. The simulation scheme is given in Fig. 4.

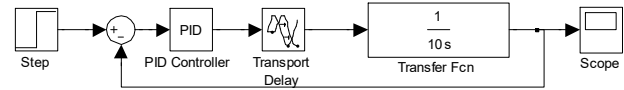


Figure 4. Computer simulation scheme of the automated system.

The transient responses - in Fig. 5, a) for the parameters of model 1 and b) for the parameters of model 2. The numbering of the curves corresponds to the numbering in Table I.

TABLE I. CONTROLLER PARAMETERS AND PERFORMANCE OF AUTOMATIC SYSTEM

№	Model object	Tuning method	Controller parameters				Performances of the system			
			$J$	$k_p$	$k_i$	$k_d$	$t_c$	$w$	$t_r$	$n$
	Data for example 1									
1	(1)	AMSD	2.536	0.1567	0.0839	0.0206	0.93	47.74	3.48	1
2	(1)	MSDI	0.3	0.0151	0.0008	0.0195	11.6	15.91	51.19	1
3	(2)	MSDI	1.3	0.1029	0.0387	0.0039	1.37	37.29	5.52	1
4	(3)	MSDI	0.4	0.0990	0.0185	0.0503	1.98	11.84	9.65	1
5	(4)	MSDI	-	$k_p > 0$	$k_i < 0$	$k_d < 0$	unstable system			
6	(1)	EM	-	0.22	1.0	0.2	unstable system			
7	(1)	PO	-	0.157	0.0023	0.034	1.02	11.00	10.5	1
	Data for example 1									
1	(1)	AMSD	0.634	7.836	1.0495	4.12	3.71	45.00	14.29	1
2	(1)	MSDI	0.9	6.4268	0.4820	3.2399	4.51	24.35	23.59	1
3	(2)	MSDI	0.4	5.0091	0.4451	0.6879	5.61	34.43	23.55	1
4	(3)	MSDI	0.2	5.4815	0.4370	3.1481	5.35	23.83	25.53	1
5	(4)	MSDI	0.7	5.0143	0.0476	2.0929	6.95	3.62	6.95	1
6	(1)	EM	-	11	0.25	0.8	3.63	64.40	25.51	5
7	(1)	PO	-	8.029	0.311	5.0562	1.48	23.7	43	1



<https://doi.org/10.52326/ic-ecco.2021/CE.02>



Table I shows the numerical data variant (examples 1 and 2), the object model, the degree of stability and the values of the controller parameters at which the highest system performance was obtained and they are shown in Table 1 in rows 1-5.

In rows 6 (ex. 1) and 6 (ex. 2) of the Table I are presented the values of the tuned parameters according to the empirical method (EM) and the system performances. The transient responses are given in Fig. 5, a) - curve 6 and b) - curve 6.

To verify the results obtained when tuning the PID controller to the models of objects (1)-(4) according to the MSD method with iterations, the parametric optimization method (PO) is used and the calculated controller parameters are given in table 1, rows 7 (ex. 1) and 7 (ex. 2). The transient responses are given in Fig. 5, a) - curve 7 and b) - curve 7 (the numbering of the curves corresponds to the numbering in Table I).

Analyzing the performances of the automatic systems with the PID controller tuned according to the methods indicated at the 5% error of the steady state regime from table 1, the following is found.

The system with PID controller tuned to model (1) according to the analytical MSD method for the data in examples 1 and 2 the performance of the overshoot  $w$  is obtained at the value 47.74% and 45% respectively, and the settling time  $t_r$  has reduced values at 3.48 and 14.29 respectively.

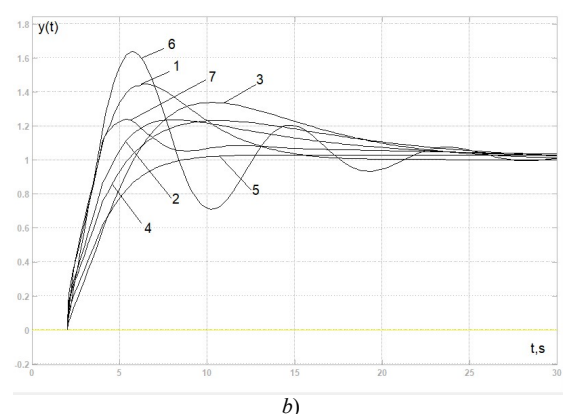
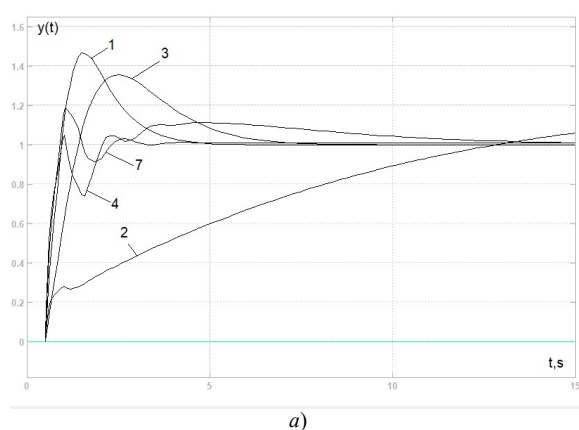


Figure 5. Transient responses of automatic system with PID controller

For the system with PID controller tuned to the model (1) according to the MSD method with iterations for the data in examples 1 and 2 the performance of the overshoot  $w$  was reduced by 3 and 1.85 times respectively and the settling time  $t_r$  was increased by 14.71 and 1.65 times respectively compared to the system with the PID controller tuned to model (1) according to the analytical MSD method.

For example 1 with the numerical values of the parameters of the object model  $k=1$ ,  $T=0.1$ ,  $d=0.5$  the system with the controller tuned to models (2)-(4) only the system with the controller tuned to model (3) has the performance overshoot  $w$  by 4.03 times lower and the settling time  $t_r$  is by 2.77 times longer than the same system performance with the controller given in model (1) according to the analytical MSD method. The controller system assigned to model (4) is unstable.

The system with the controller tuned to model (1) with the empirical method is unstable.

For example 2 with the numerical values of the parameters of the object model  $k=0.5$ ,  $T=10$ ,  $d=2$  the system with the controller tuned to models (2)-(4) only the system with the controller tuned to model (4) has higher performance the overshoot  $w$  12.43 times and the settling time  $t_r$  by 2.06 times compared to the same system performance with the controller tuned to model (1) with the analytical MSD method. The system with controller tuned to model (4) has higher performance overshoot  $w$  by 6.73 times and the settling time  $t_r$  by 3.39 times compared to the same performance of the system with controller tuned to model (1) according to the MSD with iterations method.

The system with the controller tuned to the model (1) with the empirical method has low performance: the

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overshoot by 2.71 times and the settling time by 1.11 times longer than the respective performances of the system with the controller tuned to the model (1).

#### IV. CONCLUSIONS

Analyzing the results of the study of the tuning of the PID regulator to the models (1)-(4) from Table I it was found:

- For the automatic system with the PID controller tuned to model (1)-(3) with the parameters from example 1 the performance of the overshoot and the settling time are contradictory. It is recommended to tune the controller to model (3) with the MSD with iterations method.

- For the automatic system with the PID controller tuned to model (1)-(4) with the parameters from example 2 it is recommended to tune the controller to model (4) with the MSD method with iterations.

- Tuning the PID controller to model (1) with the data from example 1 ( $d > T$ ) is more difficult than tuning the controller to the model with the data from example 2 ( $d < T$ ).

#### ACKNOWLEDGMENT

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# Synthesis the PID Control Algorithm for Speed Control of the DC Motor based on the Genetic Algorithm

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**Abstract**—In this paper, it is proposed to use the genetic algorithm for synthesis the PI and PID control algorithms for speed control of the DC motor, according to the imposed performance, namely settling time. The obtained results were compared with maximum stability degree method with iterations and to demonstrate the efficiency of proposed algorithm the computer simulation was done. The designed algorithm searches for the controller tuning parameters:  $k_p$ ,  $k_i$ , and  $k_d$ , so that performance for the closed-loop step response to be satisfied.

**Keywords**—PID controller; genetic algorithm; automatic control system; maximum stability degree method with iterations

## I. INTRODUCTION

The industrial or technological process, directed to achieve a specified goal, represents an organized and ordered set of activities, or operations, which are divided into two main categories: actuation operations and control operations. Actuation operations include activities that are necessary to carry out a process according to the nature laws, which are carried out on the technological installations that involves mass and energy transfer. In order to achieve the correct dynamic of the process and ensure the high performance, there are required the control operations. Both operations types can be developed on the automation equipment.

An important element in terms of actuation on the industrial or technological process are the electrical motors, which are used as actuator elements [5-7].

Electric motors have a wide range of applications in the fields of servo automation and robotics. Electric motors can be classified by the type of electric current: DC motors and AC motors. Due to the linearity of its

features and relatively simple speed control methods, DC motor is a power actuator which transforms electrical energy into mechanical energy and it is the most used motor as actuator or as a control object in the automatic control systems, where in both situations it is necessary to control its speed, which is solved by using a typical control algorithm.

One of the most used control algorithms in industrial applications is the PID control algorithm and its variation P, PI, PD. Proportional-Integral-Derivative (PID) control algorithm has been used for several decades in different industrial applications, due to its simplicity, good robustness and performance, that it ensures to the automatic control systems.

The PID control algorithm is characterized by three parameters - proportional (P), integral (I) and derivative (D). The proportional component P depends on the present error, the integral component I depends on the accumulation of past error, and the derivate component D presents the prediction of the future error, based on current rate of error change, Fig. 1 [8].

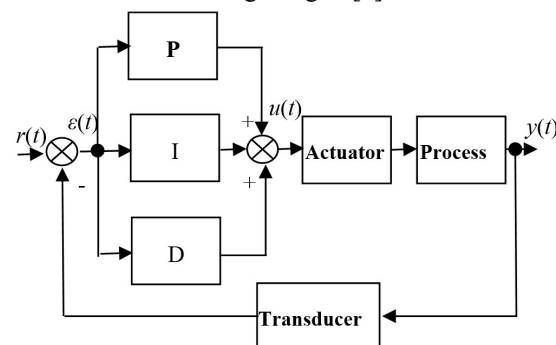


Fig. 1. Block scheme of the automatic control system

Nowadays, there are developed many methods for synthesis the typical control algorithms as: experimental methods; the graph-analytical methods, which involves to be known the mathematical model that approximates the industrial process; the optimization methods and the artificial intelligence approaches such as evolutionary algorithms are widely used in case of optimization problem of synthesis the PID control algorithm [1-2].

In this paper, it was proposed to use the genetic algorithm for synthesis the PI and PID control algorithms for speed control of the DC motor, according to the imposed performance. The designed algorithm searches for the controller tuning parameters:  $k_p$ ,  $k_i$ , and  $k_d$ , so that the performance imposed to the system to be satisfied.

## II. DESCRIPTION OF THE DESIGNED SYSTEM

As DC motor, it was used the FK130SH motor for testing several reaction wheels. The system was implemented based on the NUCLEO-F303K8 platform from ST Microelectronics and the reaction wheel is coupled directly to the motor, Fig. 2. The speed of the motor coupled with the reaction wheel is controlled by the STM32F303K8 microcontroller. As the speed sensor, the EE-SX4235A-P2 transmissive photo sensor is used.

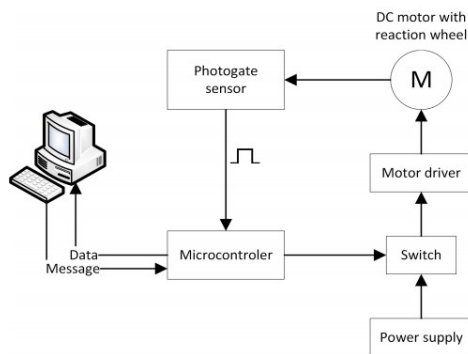


Fig. 2. Block diagram of the designed system

It was proposed to be done the experimental identification of the mathematical model that approximates the dynamics of the DC motor. It was done the data acquisition, so that the experimental variation of the DC motor speed at the reference speed of 8500 rpm is presented in the Fig. 3.

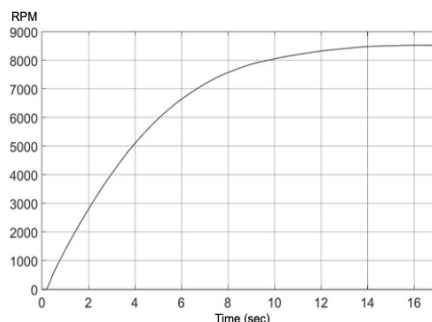


Fig. 3. Experimental curve

To estimate the mathematical model, it was proposed to be used the System Identification Toolbox from MATLAB. The experimental curve it was approximated with model of object with inertia second order [4]:

$$H(s) = \frac{k}{(T_1s + 1)(T_2s + 1)} = \frac{1.0069}{3.1695s^2 + 5.0289s + 1}. \quad (1)$$

## III. SYNTHESIS OF THE PI AND PID CONTROL ALGORITHMS USING GENETIC ALGORITHM

Genetic algorithm (GA) is inspired by biological phenomena (principles of natural selection and genetics) and particle swarm optimization algorithm. It has a strong search capability being a stochastic global search method, that mimics the process of natural evolution, where is evolving a population of candidate solutions to a target problem.

Genetic algorithm manipulates not just with one potential solution to a problem but with a collection of potential solutions, that are known as population. Every solution corresponds to a chromosome and each parameter represents a gene, where genetic algorithm evaluates the fitness of each individual in the population using a fitness (objective) function. The genetic algorithm use the genetic operators such as selection, crossover and mutation for the generation of the new chromosomes from the existing population. Genetic algorithm consists from the following steps:

**Step 1.** Random generation of the populations of  $n$  chromosomes.

**Step 2.** Evaluating of the success of each  $x$  chromosome using the fitness function  $f(x)$ .

**Step 3.** Creating a new population by applying the following evolutionary operations until the new population is complete:

- Selection - Selection of two parents chromosomes from a population according to the function  $f(x)$ .
- Crossover - Two individual agents combine to produce an offspring. The main objective of crossover is to explore new areas within the search space.
- Mutation - During mutation individual agents endure the small random changes of genes that lead to the generation of new individuals.

**Step 4.** The above-mentioned steps are repeated until the swarm converges to an optimal or sub-optimal solution [3].

The synthesis procedure implementation of the PI and PID control algorithms based on the genetic algorithm, starts with definition of the chromosome representation.

It was used the PI control algorithm in the standard form that is described by the following transfer function:

$$H_{PID}(s) = k_p + \frac{k_i}{s} = \frac{k_p s + k_i}{s}, \quad (2)$$

where  $k_p, k_i, k_d$  – are the tuning parameters of the PID control algorithm.

It was used the PID control algorithm in the standard form, that is described by the following transfer function:

$$H_{PID}(s) = k_p + \frac{k_i}{s} + k_d s = \frac{k_d s^2 + k_p s + k_i}{s}, \quad (3)$$

where  $k_p, k_i, k_d$  – are the tuning parameters of the PID control algorithm.

In this case, the chromosome is formed by the following parameters that correspond to the tuning parameters:  $k_p, k_i$  – for PI control algorithm;  $k_p, k_i, k_d$  – for PID control algorithm [2].

The objective function is proposed to be settled according to the settling time that was proposed to be equal with 2 seconds.

The obtained results of tuning the PID controller by the genetic algorithm were compared with maximum stability degree method with iterations (MSD).

The values of the tuning parameters of the PI and PID control algorithm are presented in the Table I and the obtained performance of the automatic control system is presented in the Table II.

TABLE I. TUNING PARAMETERS

No	Controller	Method	Iterations	Tuning parameters		
				$k_p$	$k_i$	$k_d$
1	PI	GA	200	4.891	1.07	
2	PI	MSD		1.64	0.46	
3	PID	GA	55	20.402	4.58	9.12
4	PID	MSD		10.226	4.07	5.29

TABLE II. PERFORMANCE OF AUTOMATIC CONTROL SYSTEM

No	Controller	Method	Performance of the system			
			$t_r$	$t_s$	$\sigma$	$\lambda$
1	PI	GA	1.39	4.56	12.044	1
2	PI	MSD	3.66	11.55	3.55	1
3	PID	GA	0.55	2.00	3.99	1
4	PID	MSD	0.93	5.039	7.83	1

The simulation results of control system with PI and PID control algorithms are presented in the Fig. 4 and 5, where curve 1- for the case of tuning the controller by the genetic algorithm, curve 2 – for the case of tuning the controller by the maximum stability degree method with iterations.

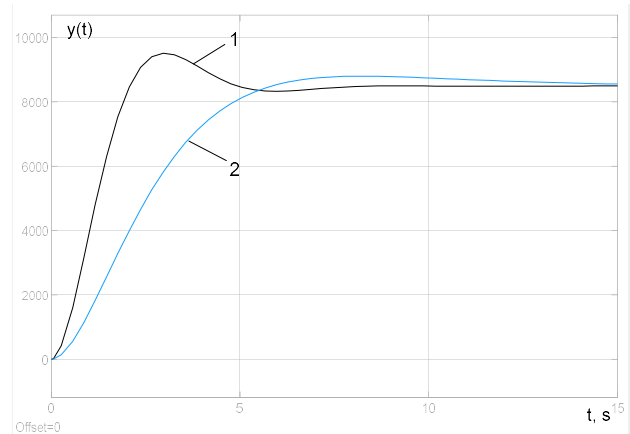


Fig. 4. The step responses of the control system with control object (1) and PI control algorithm

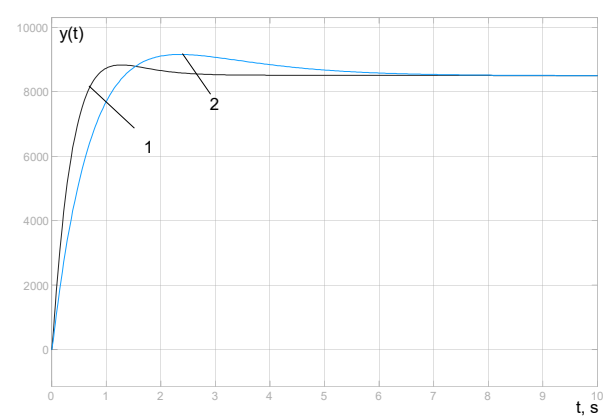


Fig. 5. The step responses of the control system with control object (1) and PID control algorithm

In the Fig. 6 and 7, it is presented the distribution of poles and zeros of the closed loop system with PI and PID controller in the complex plan, where the numbering of the poles 1- for the case of tuning the PI controller by the genetic algorithm, 2 – for the case of tuning the PID controller by the maximum stability degree method with iterations.

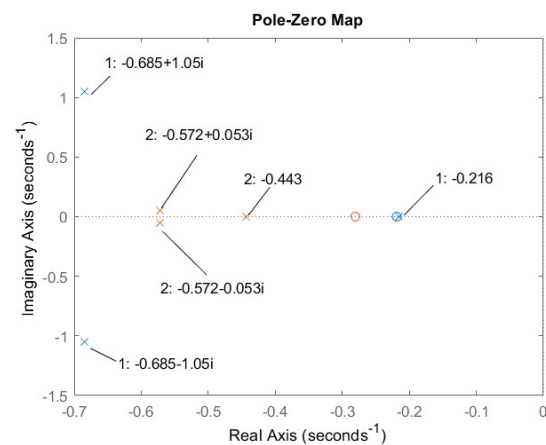


Fig. 6. The distribution of poles-zeros of the closed loop system



with PI controller

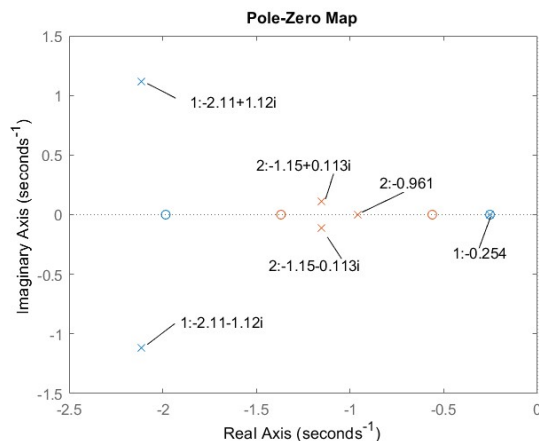


Fig. 7. The distribution of poles-zeros of the closed loop system with PID controller

#### IV. CONCLUSIONS

In this work, it was proposed to use the genetic algorithm for speed control of the DC motor. As DC motor it was proposed to use the FK130SH motor and the system was implemented based on the NUCLEO-F303K8 platform from ST Microelectronics. It was done the experimental identification of the mathematical model, that approximates the dynamics of the DC motor and to the obtained model of object was tuned the PI and PID controller by the genetic algorithm. It was done the comparison of the obtained results with maximum stability degree method with iterations.

Analyzing the obtained results, it was observed that for the case of tuning the PI and PID controllers by the genetic algorithm it was obtained the transient processes that satisfied the imposed performance. But for the case of using the MSD method the control system didn't

satisfy the imposed performance, but it has the higher robustness in comparison with genetic algorithm.

#### ACKNOWLEDGMENT

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# Multi-Agent System for Decision Making Based on Temporal Logic

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**Abstract**— The paper presents the results of the conceptual and structural design of a Multi-Agent system for decision making based on temporal logic. The decision making system has a Multi-Agent structure that forms a mesh network with broadcast communication, which ensures the organization of knowledge exchange between them. Functional elements and temporal logical operators are defined in the form of mathematical models, which allows their implementation based on hardware devices or software products. The functionality of the temporal logic is determined by the time function that calculates the credibility coefficient of the event and its influence on the decisions taken by the Agents.

**Keywords**— Multi-Agent system; decision making; temporal logic; operator; operand; event; knowledge.

## I. INTRODUCTION

Conceptually, the Multi-Agent for decision making system has a complex structure that has the ability to learn and develop new knowledge. A decision making system can be presented in the form of a person, a group of people, an organization, an Agent, a computer or a combination of these. The purpose of the decision making system is to provide services to enhance cognitive abilities of human agents (human intelligence) to select optimal solutions in solving problems in various fields of science [1, 2, 3].

As mentioned in papers [4, 5, 6] the most effective solutions in solving complex problems are offered by distributed computing, parallel computing and cloud computing systems. This work provides knowledge in modeling distributed computing systems, cloud platforms, clustering technologies. Methods for improving

performance in terms of scalability and reliability are analyzed. All the characteristics mentioned above are also specific for the design of Multi-Agent systems [7, 8] or of collective/collaborative decision making systems [9], based on Artificial Intelligence.

The decision making process is an evolutionary process that involves the analysis of a set of knowledge already known so far in order to generate new knowledge based on which optimal decisions can be made. This mechanism can very well be achieved by applying temporal logic [10, 11, 12], which allows to highlight the temporal relationship between past, present and future.

## II. STATEMENT OF THE RESEARCH PROBLEM

Modern technologies offer a wide range of solutions that allow the development of distributed computing decision making systems that ensure the solution of complex problems for different application areas. It can be mentioned papers: [13, 14, 17, 19] in which were researched Multi-Agent systems oriented towards collective calculation, and [15, 16, 18] where cognitive systems based on knowledge with application in various fields are researched.

This paper proposes the conceptual and structural design of a Multi-Agent system for decision making based on temporal logic. The architecture of the system presents lots of Agents that form a mesh network with broadcast communication and it is oriented towards making collective decisions based on the knowledge accumulated over time. At the basis of the process of knowledge formation is the set of rules defined by temporal logic that establishes the connection between past, present and future.

### III. SYNTHESIS OF THE MULTI-AGENT SYSTEM

It is defined the decision making system of collective calculation consisting of the set of Agents  $A = \{A_i, i = \overline{1, I}\}$  (Fig. 1).

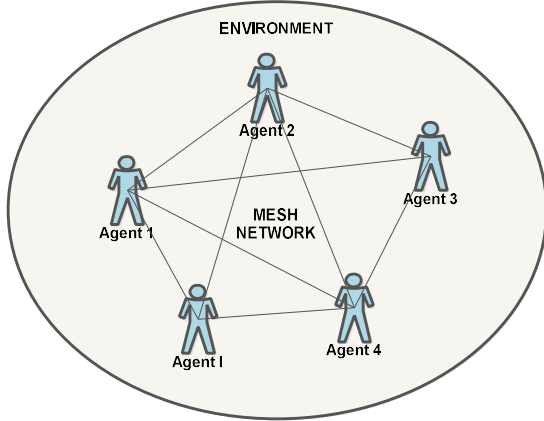


Figure 1. Multi-Agent system diagram

The functional model of an Agent is defined by expression (1), its diagram is presented in Fig. 2:

$$A_i = \left\{ \begin{array}{l} KB[T], \\ LC : (Ev, Pp, TLP, DMP, Ac) \end{array} \right\}_i, \quad (1)$$

where:  $KB[T]$  - Knowledge Base at time  $T$ ;  $LC$  - Logic Control for synchronizing the data processing operations performed by the Agent;  $Ev$  - the set of external events perceived by the Agent and generated by the activity environment;  $Pp$  - Pre-processor for conditioning the signals generated by external events;  $TLP$  - Temporal Logic Processor that through the application of Temporary Operators processes the data from the knowledge base  $KB[T]$  and input data generated by external events to generate new knowledge  $KB[T+1]$ ;  $DMP$  - Decision Making Processor that generates new decisions based on knowledge;  $Ac$  - Actions on the activity environment.

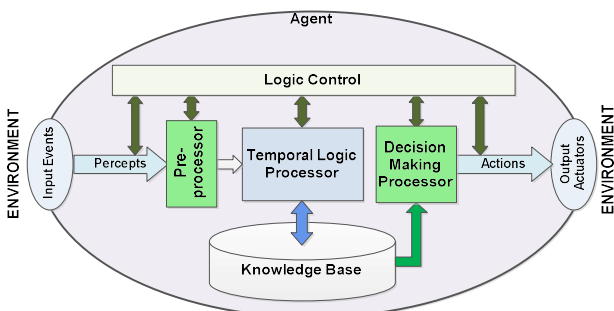


Figure 2. Agent diagram

### Definition of functional elements for synthesis of Multi-Agent system:

#### A. Event:

$$Ev[T]_i = \{X[T], KB[T]\}_i, i = \overline{1, I}$$

where  $Ev[T]_i$  - the set of events that took place at the time  $[T-1, T]_i$ , but perceived by the Agent at the time  $T$ ;  $X[T]_i$  - the set of events generated by the activity environment;  $KB[T]_i$  - the multitude of knowledge received from all Agents involved in decision making.

#### B. Decision:

$$D[T]_i = \{DMP : KB[T] \rightarrow (Ac, Qu, Dec, Con)\}_i, i = \overline{1, I}$$

where  $D[T]_i$  - the set of decisions made by the Agent at the time  $T$ ;  $Ac$  - decisions on action on the activity environment;  $Qu$  - generating questions to all the Agents;  $Dec$  - declaratory decisions communicated to all the Agents;  $Con$  - confirmatory decisions communicated to all the Agents.

#### C. Action:

$$Ac[T]_i = \{DMP : KB[T] \rightarrow (Ac[T]_{i,1}, \dots, Ac[T]_{i,j_i})\}_i, i = \overline{1, I}$$

where  $Ac[T]_i$  are the set of actions generated by Agent  $A_i$  on the activity environment as a result of processing the decision making block  $DMP$  of data from the knowledge base  $KB[T]$ .

#### D. Question:

$$Qu[T]_i = \{DMP : KB[T] \rightarrow (Qu[T]_{i,1}, \dots, Qu[T]_{i,j_i})\}_i, i = \overline{1, I}$$

where  $Qu[T]_i$  are the multitude of questions addressed by the Agent  $A_i$  to the set of the Agents  $A$  as a result of processing the decision making block  $DMP$  of data from the knowledge base  $KB[T]$ .

#### E. Declaration:

$$Dec[T]_i = \{DMP : KB[T] \rightarrow (Dec[T]_{i,1}, \dots, Dec[T]_{i,j_i})\}_i, i = \overline{1, I}$$

where  $Dec[T]_i$  are the set of declarative information transmitted by the Agent  $A_i$  to the set of Agents  $A$ .

#### F. Confirmation:

$$Con[T]_i = \{DMP : KB[T] \rightarrow (Con[T]_{i,1}, \dots, Con[T]_{i,j_i})\}_i, i = \overline{1, I}$$

where  $Con[T]_i$  is the set of confirmatory information transmitted by the Agent  $A_i$  to the group of Agents  $A$  as a result of processing questions  $Qu[T]$  generated by the Agents  $A$ .



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### G. Temporal Logic Processor:

$TLP_i = \{O(\tau)_{i,1}, \dots, O(\tau)_{i,I}\}$ ,  $i = \overline{1, I}$ , where  $O(\tau)$  are the set of temporal logic operators defined for the Agent  $A_i$  and implemented in a processor basis. The application of the set of temporal logic operators determines the cognitive properties of the distributed computing system.

### H. Operator:

$$O(\tau)_i : \{Ev[T]_i, KB[T]_i\} \rightarrow \{KB[T+1]_i\}, i = \overline{1, I}$$

where:  $Ev[T]_i$  are the set of events perceived from the activity environment;  $KB[T]_i$  the content of the knowledge base at the time  $T$ ; and  $KB[T+1]_i$  knowledge base after application of the temporal logic operator  $O(\tau)_i$ .

## IV. DEFINITION OF THE TEMPORAL LOGIC OPERATORS

The time function for temporal logic operators  $O(\tau)_i$  is determined by the expression (2):

$$x(t) = x[T] / \left( k * x[T] + (t - T)^2 / s \right), t = \overline{T, \infty}, \quad (2)$$

where:  $x(t)$  is the value of the decisional influence (credibility) of the event on the content of the knowledge base  $KB[T]$ ;  $k$  - the attenuation coefficient of credibility;  $s$  - stability coefficient of decision making influence (decision making credibility).

The structure and basic components of the operator are determined by the expression (3):

$$O(\tau) : \{Op_1, Op_2, \dots, Op_J\}, \quad (3)$$

where  $Op_j, j = \overline{1, J}$  is the set of operands that are part of the operator structure  $O(\tau)$ .

The format of the operand is determined by the expression (4):

$$Op(\tau) = \{Name, X[T], k, s\}, \quad (4)$$

where  $Name$  is the name of the operand or its content (State, Question, Confirmation, Declaration).

Table 1 presents the initial data for model validation (2). The modeling results are shown in the Fig. 3 for past events, and in the Fig. 4 for future events.

TABLE I. INITIAL DATA FOR MODEL VALIDATION (2)

Graphic number	$x[T]$	$k$	$s$
1	1	1	1

2	1	1	10
3	1	1	20
4	1	2	1
5	1	2	20

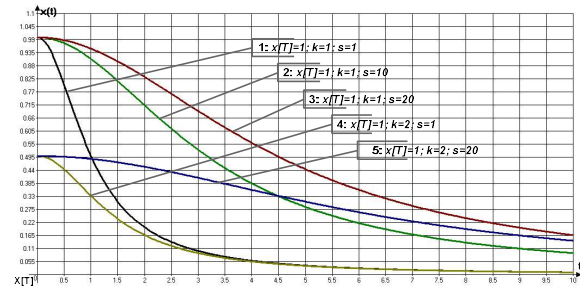


Figure 3. Model (2) validation results for past events

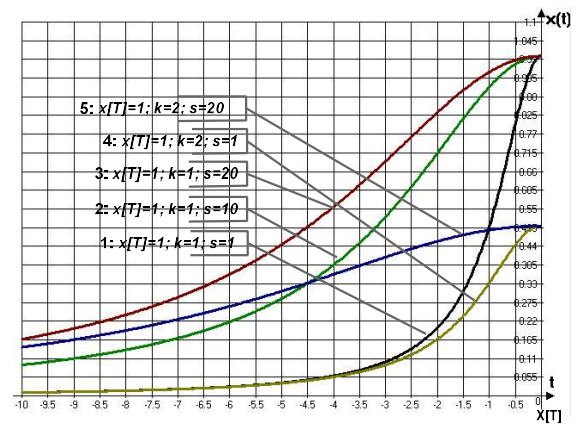


Figure 4. Model (2) validation results for future events

## V. EXAMPLES OF DEFINING TEMPORAL LOGIC OPERATORS

The list of temporal logical operators is determined by the functionality and field of activity of the Multi-Agent system for decision making. The following are presented some examples of temporal logical operators:

- 1)  $O(\vee^\tau) = \max \{Op_1, Op_2, \dots, Op_J\}$  ;
- 2)  $O(\wedge^\tau) = \min \{Op_1, Op_2, \dots, Op_J\}$  ;
- 3)  $O(\neg^\tau) = NOT \{Op_1, Op_2, \dots, Op_J\}$  ;
- 4)  $O(\cup^\tau) = \cup \{Op_1, Op_2, \dots, Op_J\}$  ;
- 5)  $O(\cap^\tau) = \cap \{Op_1, Op_2, \dots, Op_J\}$  ;
- 6)  $O(\Sigma^\tau) = \Sigma \{Op_1, Op_2, \dots, Op_J\}$  ;
- 7)  $O(\Pi^\tau) = \Pi \{Op_1, Op_2, \dots, Op_J\}$  ;

The number and complexity of operators for temporal logic can be extended in relation to the solved problem.

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## VI. CONCLUSION

This paper presents the results of the conceptual and structural design of a Multi-Agent system for decision making based on temporal logic. The system is defined as a group of Agents that forms a network of computing devices with mesh topology. The communication between the Agents ensures the organization of the knowledge exchange which allows the implementation of the calculation models with collective decision.

The functionality of the Agents is based on the application of temporal logic models and includes: operations to perceive the state of the activity environment, communication with other Agents for the purpose of knowledge exchange, updating knowledge, calculating decisions and acting with these decisions on the activity environment, or their communication to other Agents.

The paper proposes the synthesis of the Multi-Agent system for decision making, which includes: the functional model of Agents and its diagram, the functional elements are defined in the form of mathematical models (Event, Decision, Action, Question, Declaration, Confirmation, and Temporal Logic Processor).

Temporal Logic Processor is defined as a set of operators that performs operations on a set of operands. The purpose of the operators is to update the knowledge base, thus offering cognitive capabilities for the system. An operand is a functional description of an event and includes its name or content, the initial state of the event, its credibility attenuation coefficient and its credibility stability coefficient.

In order to validate the model for calculating the credibility coefficient of the event, its modeling was performed for different attenuation and stability coefficients. The results are presented in the form of graphs.

The implementation of the Agents in the form of hardware computing architectures and software products is planned for the future.

The results of this paper will be applied in the development of Multi-Agent systems with calculation and collective decisions.

## ACKNOWLEDGMENT

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# Synthesis of the PID Algorithm for Models of Objects with Double Astatism and Dead Time

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**Abstract**-The paper summarizes the tuning algorithm for models of objects with inertia and astatism of the second degree and dead time, which describe the dynamics of various technical objects and technological processes. These models of tuned objects have the original double pole and a negative pole and an infinity of poly-zeros due to the dead time component. In order to tune the PID controller algorithm to the model of the given object, the algorithm was elaborated based on the analytical method of the maximum degree of stability. The dead time component approximates by the Pade approximants with nonminimal phase. For the approximate object model, the PID algorithm is synthesized using the maximum degree method with iterations. In order to verify the results obtained at the synthesis of the PID algorithm by the analytical method and method with iterations of the maximum degree of stability, the synthesis of the tuned algorithm was performed using the method of polynomial equations. An example of a system with the control object model and the controller synthesized according to these methods with computer simulation in the MATLAB package was examined and the system performance was analyzed. The advantages of the method of the maximum degree of stability with iterations through reduced calculations and minimum time are highlighted, which lead to the simplification of the procedure for tuning the PID algorithm for these object models and higher system robustness.

**Keywords**- Model of the tuned object with inertia; double astatism and deadtime; transfer function, PID algorithm; tuning of the controller parameters; method of maximum degree of stability with iterations; system performance

## I. INTRODUCTION

In the practice of automation there are a variety of technical objects such as automobile, spacecraft, rocket, telescope, plotter, laser, elevator, nuclear reactor electrode, linear drives, etc., industrial and technological processes, which require automatic control [1, 2] and which are described by the mathematical models with

inertia, double integration and dead time presented with the transfer functions of the form:

$$H(s) = \frac{ke^{-ds}}{s^2(Ts+1)} = \frac{ke^{-ds}}{Ts^3+s^2} = \frac{ke^{-ds}}{a_0s^3+a_1s^2}, \quad (1)$$

where  $k$  is the transfer coefficient,  $T$  - the inertia time constant,  $d$  - the dead time, and  $a_0=T$ ,  $a_1=1$  are the generalized coefficients.

The presence in the model of the control object (1) of the second degree astatism and dead time raises difficult problems, when tuning the PID controller to these models. Several methods for tuning controllers such as the Ziegler-Nichols method, the poly-zero method, the frequency method, etc. can not be applied or are difficult [1-4].

In the paper it was proposed to use the method of analytical maximum degree of stability (AMSD) and the GMS method with iterations (MSDI) of the automatic system for the synthesis of the PID algorithm [7-10].

## II. PID CONTROLLER TUNING ALGORITHMS

The study uses the structural scheme-block of the automatic system (AS) consisting of the controller with transfer function  $H_R(s)$  and the model of the object with transfer function  $H_P(s)$  as given in Fig. 1.

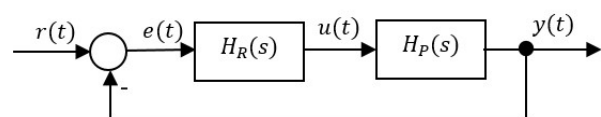


Figure 1. Structural block scheme of the automatic system.

The standard PID tune algorithm is described with the transfer function:

$$H_{PID}(s) = k_p + \frac{k_i}{s} + k_d s = \frac{k_d s^2 + k_p s + k_i}{s}, \quad (2)$$

where  $k_p$ ,  $k_i$ ,  $k_d$  are the tuning parameters of the PID algorithm.

Applying the method of the maximum degree of stability of the system, the calculation expressions of the PID tuning parameters for the model of the control object (1) are presented in the form [8-10]:

$$-d^3a_0J^4 + (12d^2a_0 + d^3a_1)J^3 - (36da_0 + 9d^2a_1)J^2 + (24a_0 + 18da_1)J - 6a_1, \quad (3)$$

$$k_d = \frac{e^{-ds}}{2k} (-d^2a_0J^4 + (8da_0 + d^2a_1)J^3 - (12a_0 + 6da_1)J^2 + 6a_1J) = f_d(J), \quad (4)$$

$$k_p = \frac{e^{-ds}}{k} (-da_0J^4 + (4a_0 + da_1)J^3 - 3a_1J^2) + 2k_dJ = f_p(J), \quad (5)$$

$$k_i = \frac{e^{-ds}}{k} (-a_0J^4 + a_1J^3) - k_dJ^2 + k_pJ = f_i(J), \quad (6)$$

At the known values of the model of the tuned object (1) the optimal degree of stability  $J$  from (3) is determined and using the expressions (4)-(6) the optimal parameters  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  of the PID algorithm are calculated.

The maximum degree of stability  $J$  is the smallest value of the real root or the real part of the complex root of the equation (3).

If the values of  $k_p$ ,  $k_i$ ,  $k_d$  for the optimal parameters of the PID algorithm do not satisfy the performance of the system, it is proposed to use the MSD method with iterations for calculus.

Variation  $J = 0 \dots \infty$  are calculated and then are constructed the curves (4)-(6)  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  for the PID algorithm. On these curves  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  is chosen a set of values of the parameters of the PID controller  $J_i - k_{pi}$ ,  $k_{ii}$ ,  $k_{di}$  and it is simulated on the computer the automatic system and are risen the transient response of the system after which the highest performances of the system are determined.

### III. SIMULATION AND ANALYSIS OF AN EXAMPLE

The parameter values of the tuned object model are considered to be known for two cases:

- 1) transfer coefficient  $k = 1$ , time constant  $T = 0.1s$ , dead time  $d = 0.5s$ ;
- 2) transfer coefficient  $k = 0.5$ , time constant  $T = 10s$ , dead time  $d = 2s$ .

The performance of the automatic system is required: the stationary error  $e = \pm 5\%$  of the stationary value of the output value  $y_{st}$ , the rise time  $t_c = 2s$ , the settling time  $t_r = 10s$  and the overshoot  $w = 10\%$ .

For the object model (1) it is proposed to synthesize the PID controller algorithm tuned according to the analytical MSD method and MSD method with iterations.

It is proposed to analyze the performance and robustness of the automated system with the PID controller given by the analytical MSD method and the MSD method with iterations to the variation of the object model parameters by  $\pm 50\%$  from the model values to step signal perturbation action.

The analytical MSD method is used for the case when the parameters of the object model have the values  $k = 1$ ,  $T = 0.1s$ ,  $d = 0.5s$ , it is determined the maximum degree  $J$  from (3) and is calculated the optimal values of the parameters  $k_p$ ,  $k_i$ ,  $k_d$  according to the expressions (4)-(6), which are given in table 1, row 1. The automatic system was simulated on the computer in MATLAB and the transient response is given in Fig. 2, a, curve 1, and the performances are given in Table I, row 1.

For the model (1) with parameters  $k = 1$ ,  $T = 0.1s$ ,  $d = 0.5s$ , the PID controller was tuned using the parametric optimization method in MATLAB and the controller parameters are given in Table I, row 2, the transient process is given in Fig. 2, a, curve 2, and the performances are presented in Table I, row 2.

TABLE I. CONTROLLER PARAMETERS AND PERFORMANCE OF AUTOMATIC SYSTEM

Nr.	Model parameters	Controller parameters				Performances of the system			
		$J$	$k_p$	$k_i$	$k_d$	$t_c$	$w$	$t_r$	$n$
1	Nom. 1A	0.6784	0.3374	0.0536	0.8315	1.62	58.27	11.95	2
2	PO	Not applicable							
3	$T^+$	0.6784	0.3374	0.0536	0.8315	1.66	63.79	11.57	2
4	$T^-$	0.6784	0.3374	0.0536	0.8315	1.58	53.09	12.25	2
5	$k^+$	0.6784	0.3374	0.0536	0.8315	1.29	73.17	3.39	1
6	$k^-$	0.6784	0.3374	0.0536	0.8315	Oscillating process			
7	$d^+$	0.6784	0.3374	0.0536	0.8315	1.82	92.49	9.31	2

8	$d^-$	0.6784	0.3374	0.0536	0.8315	1.54	39.19	13.11	2
9	Nom. 1I	0.9000	0.2571	0.0203	0.7828	1.74	44.4	7.37	1
10	$T^+$	0.9000	0.2571	0.0203	0.7828	1.76	48.76	7.09	1
11	$T^-$	0.9000	0.2571	0.0203	0.7828	1.71	40.47	7.6	1
12	$k^+$	0.9000	0.2571	0.0203	0.7828	1.35	58.24	6.92	2
13	$k^-$	0.9000	0.2571	0.0203	0.7828	Oscillating process			
14	$d^+$	0.9000	0.2571	0.0203	0.7828	1.91	71.31	8.26	1
15	$d^-$	0.9000	0.2571	0.0203	0.7828	1.71	30.61	8.26	2

The MSD method with iterations is applied for the case when the parameters of the object model have the values  $k=1$ ,  $T=0.1s$ ,  $d=0.5s$  and the independent variable  $J$  was varied. Using relations (4)-(6) the calculus of curves  $k_p=f_p(J)$ ,  $k_i=f_i(J)$ ,  $k_d=f_d(J)$  parameters of the controller were performed and they are given in Fig. 2, b.

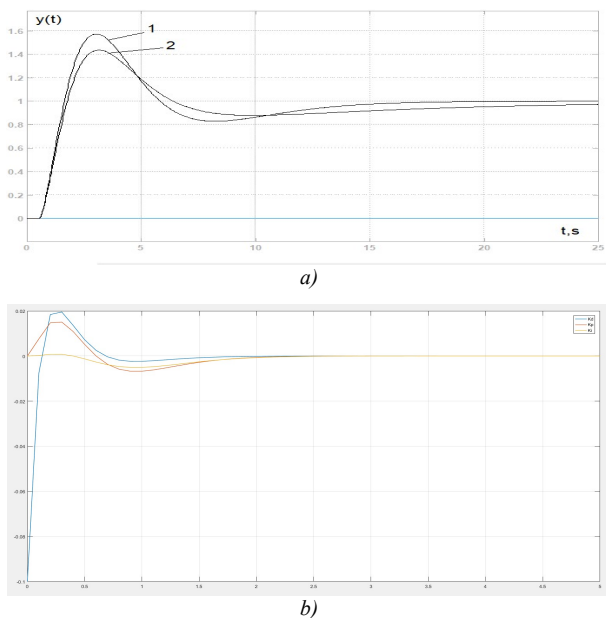


Figure 2. Transient responses a) and curves:  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  b) of the automatic system.

On these curves, sets of values  $J_i - k_{pi}$ ,  $k_{ii}$ ,  $k_{di}$  were chosen (three data variants were analyzed and in table 1, row 8 is given the variant for the highest performances) and using this values the automatic system was simulated on the computer in MATLAB with the parameters of the PID controller according to Table I, row 9 and the transient response is presented in Fig. 2, a, curve 3, and the performances of the automatic system are given in Table I, row 9.

The analytical MSD method is also used for the case when the parameters of the object model have the values  $k=0.5$ ,  $T=10s$ ,  $d=2s$ , it is determined the maximum degree  $J$  from (3) and it is calculate the optimal values of the parameters  $k_p$ ,  $k_i$ ,  $k_d$  also using the expressions (4)-(6), which are given in Table II, row 1. The automatic system was simulated on the computer in MATLAB and the results for transient response is given in Fig. 3, a, curve 1, and the performances are given in Table II, row 1.

For model (1) with parameters  $k=0.5$ ,  $T=10s$ ,  $d=2s$  the PID controller was tuned using the parametric optimization method in MATLAB and the controller parameters are given in Table II, row 2, the transient process is given in Fig. 3, a, curve 2, and the performances are presented in Table II, row 2.

TABLE II. CONTROLLER PARAMETERS AND PERFORMANCE OF AUTOMATIC SYSTEM

Nr.	Model parameters	Controller parameters				Performances of the system			
		$J$	$k_p$	$k_i$	$k_d$	$t_c$	$w$	$t_r$	$n$
1	Nom. 2A	0.0232	0.00101	5.61	0.0671	41.79	42.70	310.09	2
2	PO	Not applicable							
3	$T^+$	0.0232	0.00101	5.61	0.0671	44.69	54.14	289.39	2
4	$T^-$	0.0232	0.00101	5.61	0.0671	40.19	33.13	325.00	2
5	$k^+$	0.0232	0.00101	5.61	0.0671	26.69	43.32	95.79	1
6	$k^-$	0.0232	0.00101	5.61	0.0671	Oscillating process			
7	$d^+$	0.0232	0.00101	5.61	0.0671	41.99	45.10	306.49	2



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8	$d^-$	0.0232	0.00101	5.61	0.0671	41.79	39.52	317.19	2
9	Nom. 2A	0.03	0.00073	1.793	0.0618	46.67	35.36	211.19	1
10	$T^+$	0.03	0.00073	1.793	0.0618	49.31	41.65	191.51	1
11	$T^-$	0.03	0.00073	1.793	0.0618	45.83	25.6	226.91	1
12	$k^+$	0.03	0.00073	1.793	0.0618	35.03	32.16	166	1
13	$k^-$	0.03	0.00073	1.793	0.0618	Oscillating process			
14	$d^+$	0.03	0.00073	1.793	0.0618	46.67	34.30	207.29	1
15	$d^-$	0.03	0.00073	1.793	0.0618	46.79	30.97	214.31	1

The MSD method with iterations is applied when the parameters of the object model have the values  $k = 0.5$ ,  $T = 10s$ ,  $d = 2s$  and the independent variable  $J$  was varied and using the relations (4)-(6) the calculations of the curves  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  parameters of the controller were performed and the result are given in Fig. 3, b. On these curves, sets of values  $J_i - k_{pi}$ ,  $k_{ii}$ ,  $k_{di}$  were chosen (three data variants were analyzed and in Table II, row 9 is given the variant for the highest performances), the automatical system was simulated on the computer in MATLAB with the set of parameters for the PID controller according to Table II, row 9 and the transient process is presented in Fig. 3, b, curve 3, and the performances of the automatic system are given in Table II, row 9.

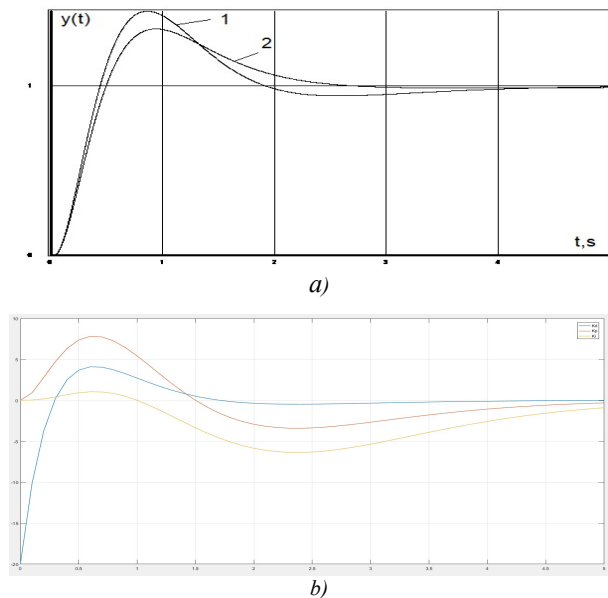


Figure 3. Transient responses a) and curves:  $k_p = f_p(J)$ ,  $k_i = f_i(J)$ ,  $k_d = f_d(J)$  b) of the automatic system.

The polynomial method is used to compare the results obtained by applying the analytical MSD method and

MSD method with iterations when tuning the PID controller to the object model (1) [5,6] and calculations have shown that this method does not apply.

For examples 1) and 2) the values of the model parameters (1) were varied and the automated system with PID controller tuned according to analytical MSD method and MSD method with iterations was simulated in MATLAB and the systems performances are given in tables 1 and 2, rows 3-7 and 9-15 respectively.

The parametric optimization method for both examples is not applicable.

For the automatic system with the object model with the parameters  $k = 1$ ,  $T = 0.1s$ ,  $d = 0.5s$  and with the PID controller tuned according to the analytical MSD method with increasing  $T$  by 50%  $T^+ = 0.15$  the time value  $t_c$  increases 2.5 times and the value of settling time  $t_r$  decreases 1.03 times and overshoot value increases 1.09 times. In case when the value  $T$  is reduced by 50%  $T^- = 0.05$ , the time value  $t_c$  decreases 2.5 times and the time value  $t_r$  increases 1.025 times, and the overshoot value is reduced 1.09 times.

With the increase of value  $k$  by 50%  $k^+ = 0.75$  the time values  $t_c$  and  $t_r$  are reduced by 1.26 times and 3.53 times respectively and the overshoot value increases by 1.26 times. In case of reduction of  $k$  by 50%  $k^- = 0.25$  the process becomes very oscillating. With increasing dead time  $d$  by 50%  $d^+ = 3$  the time value  $t_c$  increases 1.12 times,  $t_r$  decreases 1.26 times and the overshoot value increases 1.59 times. When the value of  $d$  is reduced by 50%, the value  $d^- = 0.05$ , time value  $t_c$  decreases 1.05 times,  $t_r$  increases 1.1 times and the overshoot value is reduced 1.49 times.

For the automatic system with the object model with the parameters  $k = 1$ ,  $T = 0.1s$ ,  $d = 0.5s$  and with the PID controller tuned according to the GMS method with iterations with increase of  $T$  by 50%  $T^+ = 0.15$ , the

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time value  $t_c$  remains unchanged, the settling value  $t_r$  is reduced by 1.04 times and the overshoot value is reduced by 1.12 times. In case when value  $T$  is reduced by 50%  $T^- = 0.05$ , the time value  $t_c$  remains unchanged, the settling value  $t_r$  increases 1.03 times, and the overshoot value is reduced 1.14 times.

With the increase of  $k$  by 50%  $k^+ = 0.75$ , the time values  $t_c$  and  $t_r$  increase 1.29 times and 1.07 times respectively and the overshoot value increases 1.31 times. With the reduction of  $k$  by 50%  $k^- = 0.25$  and the process becomes very oscillating. With the increase of the dead time by 50%  $d^+ = 3$  the time values  $t_c$  and  $t_r$  are reduced 1.1 times and 1.12 times respectively and the overshoot value increases 1.61 times. In case of reduction  $d$  by 50%  $d^- = 0.05$ , the time values  $t_c$  and  $t_r$  practically remain unchanged and the overshoot value is reduced by 1.45.

For the automatic system with the object model with the parameters  $k=1$ ,  $T=0.1s$ ,  $d=0.5s$  and with the PID controller tuned according to the MSD method with iterations the performance are higher: the settling time  $t_r$  by 1.62 times and the overshoot by 1.31 times than the system performance with the controller tuned according to the analytical MSD method.

For the case of the automatic system with the object model with parameters  $k=0.5$ ,  $T=10s$ ,  $d=2s$  and with the PID controller tuned according to the MSD method with iterations also the performances are higher: settling value  $t_r$  by 1.47 times and overshoot value by 1.21 times than the system performances with the controller tuned according to the analytical MSD method.

At the action of the perturbation  $p(t)=\pm 1(t)$  on the object with  $T=0.1s$  and  $T=10s$  the transient response of the system is restored during the settling time.

#### IV. CONCLUSIONS

Analyzing the results obtained when tuning the PID algorithm to model (1) according to the MSD method with iterations, it is found:

- For the automatic system with the object model with the parameters  $k=1$ ,  $T=0.1s$ ,  $d=0.5s$  and with the PID controller tuned according to the MSD method with iterations the performance are higher: the settling time  $t_r$  by 1.62 times and the overshoot by 1.31 times

than the system performance with the controller tuned according to the analytical MSD method.

- For the case of the automatic system with the object model with parameters  $k=0.5$ ,  $T=10s$ ,  $d=2s$  and with the PID controller tuned according to the MSD method with iterations also the performances are higher: settling value  $t_r$  by 1.47 times and overshoot value by 1.21 times than the system performances with the controller tuned according to the analytical MSD method.

#### ACKNOWLEDGMENT

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# Multi-Criteria Distributed Decision-Making System Based on Genetic Algorithms

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**Abstract**—This thesis comprises the results of designing a distributed decision-making system in multi-criteria areas. The distributed decision-making system is the architecture of homogenous data-processing devices that form a Wireless network with Mesh topology. The decision-making process is based on finding an optimal solution that is implemented through the use of genetic algorithms. Aiming to identify the initial population of the genetic algorithm, there shall be calculated the partial derivative for each variable for the ordered process. The results of partial derivative serve as an identifier of values from the Chromosome structure.

There have been developed in this thesis: general algorithm of system functioning; population structure formed of Chromosomes and Genes; methodology of calculation of component values of the initial population; and an example of implementation of the distributed decision-making system based on Node MCU ESP32 devices.

**Keywords**—distributed computing; decision-making systems; multi-criteria optimization; genetic algorithms.

## I. INTRODUCTION

The notion of artificial life predominates more and more often in the course of development of decision-making systems for solving complex problems.

The phenomenon of artificial life is based on the fundamental elements, which are specific to biological life, such as: reproduction, evolution, adaptation, self-organisation, parasitism or exploitation of others, cooperation and competition/concurrence.

The model of evolutive calculation [1], which was based on genetic algorithms, was proposed in the last century to optimise certain complex processes,

particularly, multi-criteria ones [2]. Such models were based on treating nonlinear functions as genotypes, which were subject to the operations of mutation, crisscrossing, coupling and selection that were specific to natural evolution of live biological species [3,4,5].

An important role in development of distributed calculation systems used to collective decision-taking is provided by the possibility to standardise the data processing nodes. This factor may be compared with object-oriented programming technology, where the same object may be used in different events and circumstances, thus providing a considerable reduction of costs for an implementation process. Thus, there may be also reduced the algorithmic and architectural complexity of calculation systems, through uniform distribution of data processing tasks [6].

An example of development of decision-taking systems is provided in this thesis [7], where there are applied the optimisation techniques aimed to implementation in complex systems, which are the emerging phenomena formed of a collection of interacting objects that can be self-organised and adapt their behaviour depending on their history and feedback.

Complex systems are a large class of processes, for instance: social, economic, technological and manufacturing ones, industrial companies and enterprises, and so on. All the above can be defined as multi-criteria decision-making systems, where decision-making factors shall comply with certain global quality criteria (global minimum or global maximum) [8,9,10,11].



Since complex multi-criteria systems have a distributed and concurrent nature, they need methods of parallel data processing to be applied. Such performances for parallel data processing may be reached through use of model based on genetic algorithms [12]. Genetic algorithms are adaptative algorithms of heuristic search, based on evolutive ideas of natural and genetic selection. The main concept of genetic algorithms is to simulate processes of the natural system, which are required for evolution, particularly those ones that follow the principles of survival of the best individuals [13].

This thesis proposes to design and to carry on functional research of a distributed decision-making system for multi-criteria areas, as based on genetic algorithms. The system architecture is composed of a lot of devices for parallel data processing [14,15,16], which interact and settle the problem of finding an optimal value for the activity area [17,18].

## II. PROBLEM FORMULATION

Whether in a multicriteria space, the process is defined  $P = \{X, U, t\}$ , where:  $P \in R^N$  and  $N$  are the number of process definition criteria  $P$ ;  $X = \{x_i, \forall i = \overline{1, N}\}$  - the state vector of the process  $P$  and  $X \subset R^N$ ;  $U = \{u_i, \forall i = \overline{1, N}\}$  - the decision vector for the process command  $P$  and  $U \subset R^N$ ;  $t \in [0, T]$  - the time parameter that determines the activity interval of the process  $P$ .

For the process command  $P$  the mathematical model (1) that generates the decision vector  $U$  is defined to ensure conditions (2) and (3), if necessary.

$$U = g(X^{Opt}) \quad (1)$$

Where:  $X^{Opt} = X^{\min} \cup X^{\max}$  are the values of the optimal state of the process  $P$ ,  $X^{\max}$  and  $X^{\min}$  are respectively the maximum or minimum state values;  $g$  are the set of decision-making functions for action on the process  $P$ .

$$f(X^{\min}) = \min_{X \in R^N} (f(X)), \quad (2)$$

$$f(X^{\max}) = \max_{X \in R^N} (f(X)), \quad (3)$$

where:  $f(X)$  - non-linear function that ensures the selection of optimal decision solutions for process control  $P$ .

## III. SYNTHESIS OF THE ALGORITHM OF OPERATION OF THE DECISION-MAKING SYSTEM

The sequence of operations performed by the distributed decision-making system based on genetic algorithms is shown in Figure 1, where the following are mentioned:

$f(X)$  - defining the non-linear function that will ensure the selection of the optimal decision solutions for process control  $P$ ;

$\partial(f(X))/\partial x_i$  - calculation of the partial derivative of the function  $f(X)$  on the variable  $x_i, \forall i = \overline{1, N}$ ;

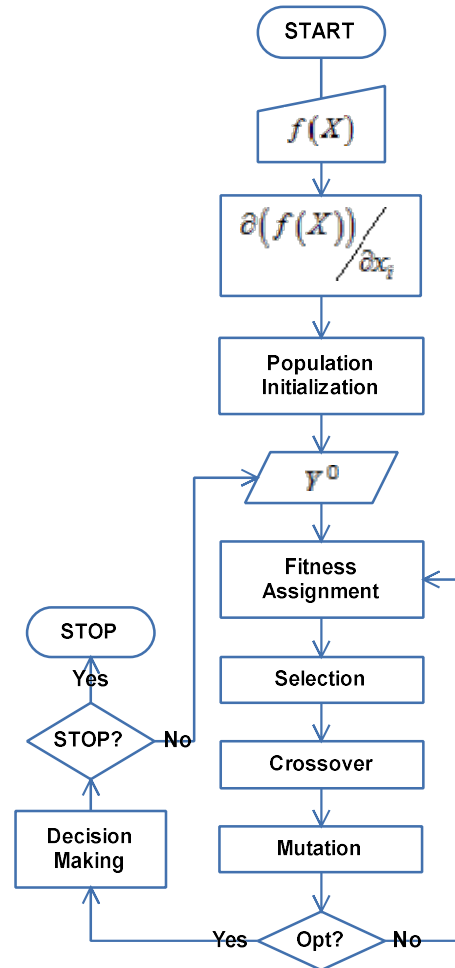


Figure 1. The operating algorithm of the decision-making system)

*Population Initialization* - application of the initial population calculation algorithm  $Y^0$ ;

$Y^0$  - the initial population for the genetic algorithm, where:

$$Y^0 = [Y_i^0, \forall i = \overline{1, N}]^T - \text{the set of Chromosomes}$$

of the population  $Y^0$ ;

$$Y_i^0 = [y_{i,j}^0, j = \overline{1, M}], \forall i = \overline{1, N} - \text{the set of}$$

Genes  $M$  which forms the Chromosome  $i$ ;

**Fitness Assignment** - The fitness function determines how fit an individual is. It gives a fitness score to each individual. The probability that an individual will be selected for reproduction is based on its fitness score;

**Selection** - the idea of selection phase is to select the fittest individuals and let them pass their genes to the next generation. Two pairs of individuals (parents) are selected based on their fitness scores. Individuals with high fitness have more chance to be selected for reproduction;

**Crossover** - Crossover is the most significant phase in a genetic algorithm. For each pair of parents to be mated, a crossover point is chosen at random from within the genes;

**Mutation** - In certain new offspring formed, some of their genes can be subjected to a mutation with a low random probability. This implies that some of the bits in the bit string can be flipped;

**Opt?** - The iteration terminates if the population has converged. Then it is said that the genetic algorithm has provided a set of solutions to our problem;

**Decision Making** - calculation of decisions  $U$  for action on process  $P$ ;

**Stop?** - Checks the expiration of the time interval  $t \in [0, T]$  of the process activity.

#### IV. THE ALGORITHM FOR GENERATING THE INITIAL POPULATION $Y^0$

Based on the optimization conditions (2) and (3), the initial populations for the genetic algorithm are also obtained.

Figure 2 shows the general structure of a population.

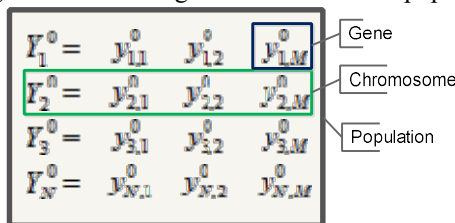


Figure 2. Population structure

$$\text{Gene } y_{i,j}^0 \in \{0, 1\};$$

**Chromosome**  $Y_i^0$  has a series of genes (0 or 1) whose values are calculated based on the algorithm defined by Figure 3;

**Population**  $Y^0$  is the set of Chromosomes defined for the genetic algorithm that will provide optimal solutions in making ordering decisions with the process  $P$ .

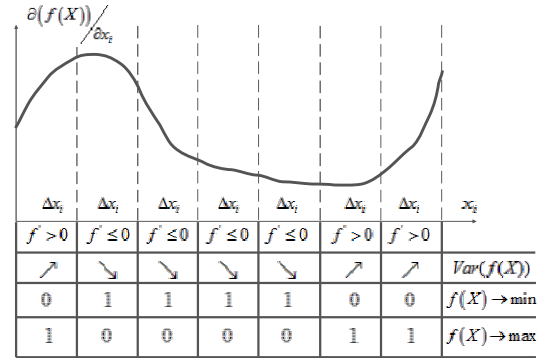


Figure 3. Calculation of gene value

$$\frac{\partial(f(X))}{\partial x_i} - \text{is the partial derivative of the}$$

function  $f(X)$  on the variable  $x_i, \forall i = \overline{1, N}$ . As a result of performing the partial derivation operation we will obtain:

$$\left[ \frac{\partial(f(X))}{\partial x_1} \quad \frac{\partial(f(X))}{\partial x_2} \quad \dots \quad \frac{\partial(f(X))}{\partial x_N} \right]^T,$$

respectively  $N$  graphs (Figure 3) for identifying the value of Genes and Chromosomes;

$\Delta x_i$  - the step of variation of the variable  $x_i, \forall i = \overline{1, N}$ ;

$f'$  - the value of the partial derivative;

$Var(f(X))$  - variation of the control function. If the function it increases then  $Var(f(X)) \approx \nearrow$ , else  $Var(f(X)) \approx \searrow$ ;

$f(X) \rightarrow \max$  - the value of the Gene identification bit for vector definition conditions  $X^{\max}$ ;

$f(X) \rightarrow \min$  - the value of the Gene identification bit for vector definition conditions  $X^{\min}$ .

#### V. DISTRIBUTED DECISION-MAKING SYSTEM SYNTHESIS

We will consider Figure 4 the structure of the distributed decision-making system consisting of homogeneous computing devices (Node MCU ESP32) configured in a Wireless communication network with

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mesh topology and programmed to calculate decision values based on model (1) taking into account the conditions generated by formulas (2) and (3).

**Way of operation.** The distributed decision-making system based on genetic algorithms, consisting of Node MCU ESP32 devices, performs identical operations in parallel:

- Acquires the state value  $x_i, \forall i = \overline{1, N}$  of the process  $P$  forming the state vector  $X$ ;
- Performs the exchange with the values of the state vector  $X$ ;
- Process the data according to the algorithm shown in Figure 1;
- Performs the exchange with the values of the set of chromosomes of the population  $Y^0$ ;
- Calculates decision  $u_i, \forall i = \overline{1, N}$  for the action on the  $P$  process.

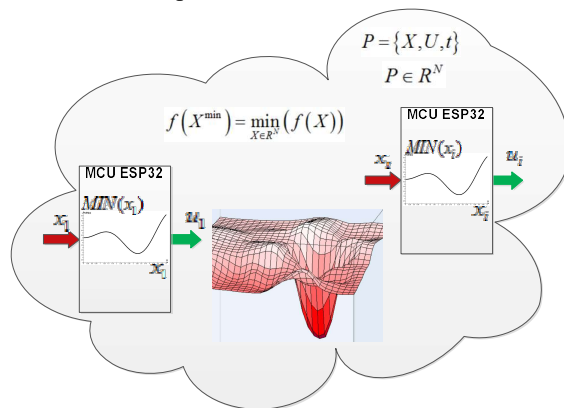


Figure 4. Distributed Decision-Making System Diagram

## CONCLUSION

This thesis provides the results of designing a distributed decision-making system in the course of ordering process, in multi-criteria areas. This system includes a lot of homogenous data-processing devices that form a network with Mesh topology. Aiming to apply genetic algorithms for finding optimal solutions, there is proposed to calculate the partial derivative for each state variable that serves as a generator of initial population.

There are provided in this thesis: general algorithm of system functioning; population structure; methodology of obtaining the population; and a chart of a distributed decision-making system.

## ACKNOWLEDGMENT

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# Computer Science Session

# The Cauchy problem for quasilinear pseudodifferential equation with integral coefficients

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**Abstract**—We consider a quasilinear pseudodifferential evolution equation with the derivative of order one with respect to the time variable  $t$  and the pseudodifferential operator this symbol  $a_\gamma(\sigma)$ ,  $\sigma \in \mathbb{R}$ , homogeneous order  $0 < \gamma \leq 2$ , by space variable  $x$  with integral coefficients. Such equations describe diffusion on inhomogeneous fractals.

**Keywords**—Cauchy problem; fractal diffusion; integral coefficient; quasilinear equation

## I. INTRODUCTION

The first result about solvability of the Cauchy problem for one linear equation of the form (6), (7) were obtained in [3 – 6]. However, completely correct and final, in some cases, results were obtained for one equation, where for the first time the pseudodifferential operator is treated as a hypersingular integral. For systems of such equations, similar results were obtained for the first time in [9, 10]. Professors S.D. Eidelman and Ya.M. Drin are authors of a new direction in mathematics - "Parabolic pseudodifferential equations with non-smooth symbols". These equations are characterized by the fact that their fundamental solutions have power estimates and are proved by them for the first time.

## II. FORMULATION OF THE PROBLEM

Before you begin to format your paper, first write and save the content as a separate text file.

We should determine the solution of the Cauchy problem

$$u_t(t, x) - A_\gamma u(t, x) + \int_0^1 u(t, \xi) d\xi u_x(t, x) = f(t, u),$$

$$(t, x) \in \mathbb{R}_+^2 \equiv \mathbb{R}_+ \times \mathbb{R}, 0 < \gamma \leq 2, \quad (1)$$

and initial condition

$$u(0, x) = \varphi(x), x \in \mathbb{R}, \quad (2)$$

where  $f: \mathbb{R}_+^2 \rightarrow \mathbb{R}$  are known function with such properties [1]

1)  $f$  is continuous function;

2) for any  $t \in \mathbb{R}_+$  and  $\{u, u_1, u_2\} \subset \mathbb{R}$  satisfy the conditions

$$|f(t, u)| \leq C_1 |u|^{1+\beta}, \quad (3)$$

$$|f(t, u_1) - f(t, u_2)| \leq c_2 |u_1 - u_2| \max\{|u_1|^\beta, |u_2|^\beta\}, \quad (4)$$

Where  $c_1, c_2$  and  $\beta$  are some positive constants, and  $\beta > 1$ ,  $A_\gamma$  is pseudodifferential operators with symbol  $a_\gamma(\sigma)$ ,  $\sigma \in \mathbb{R}$  [2, 7, 8].

We study existence and the only solution of problem (1), (2).

Assume the function  $u(t, x)$ ,  $(t, x) \in \mathbb{R}_+^2$ , is a solution of the problem (1), (2), and  $u(t, x) \in C^{1,1}(\mathbb{R}_+^2)$ . A constitute the substitution

$$u(t, x) = v(t, y), \quad (5)$$

$$y = x - \int_0^1 \int_0^t u(\eta, \xi) d\xi d\eta, (t, y) \in \mathbb{R}_+^2.$$

So long as

$$u_t(t, x) = v_t(t, y) + v_y(t, y) \frac{\partial y}{\partial t} =$$

$$= v_t(t, y) - \int_0^1 u(t, \xi) d\xi v_y(t, y),$$

$$A_\gamma u(t, x) = A_\gamma v(t, y),$$

then the problem (1), (2) acquire appearance

$$v_t(t, y) - A_\gamma v(t, y) = f(t, v(t, y)), \quad (6)$$

$$(t, y) \in \mathbb{R}_+^2, \\ v(0, y) = \varphi(y), y \in \mathbb{R}. \quad (7)$$

### III. A SOLVING OF THE PROBLEM (6), (7)

The solution of the problem (6), (7) where  $v \in C^{1,1}(\mathbb{R}_+^2)$  will be found as

$$v(t, y) = \int_{-\infty}^{\infty} G(t, y - \xi) \varphi(\xi) d\xi + \\ + \int_0^t d\tau \int_{-\infty}^{\infty} G(t - \tau, y - \xi) f(\tau, v(\tau, \xi)) d\xi, \quad (8)$$

$$(t, y) \in \mathbb{R}_+^2,$$

then  $G(t, x)$ ,  $(t, x) \in \mathbb{R}_+^2$  is fundamental solution of the pseudodifferential equation [3, 4]

$$\frac{\partial v(t, x)}{\partial t} - A_\gamma v(t, x) = 0, (t, x) \in \mathbb{R}_+^2,$$

and then  $\gamma = 1$ ,  $a_\gamma(\sigma) = |\sigma|$ ,  $\sigma \in \mathbb{R}$ , and

$$G(t, x) = \frac{1}{\pi} \frac{t}{t^2 + x^2}, (t, x) \in \mathbb{R}_+^2.$$

Integral equation (8) we unbind by consecutive approximate method:

$$v_0(t, y) = \int_{-\infty}^{+\infty} G(t, y - \xi) \varphi(\xi) d\xi, \\ v_k(t, y) = v_0(t, y) + \int_0^t d\tau \int_{-\infty}^{\infty} G(t - \tau, y - \xi) \times \\ \times f(\tau, v_{k-1}(\tau, \xi)) d\xi, k \geq 1, (t, y) \in \mathbb{R}_+^2. \quad (9)$$

We denote  $H(\mathbb{R}_+^2)$  a space of continuously functions where  $\langle \cdot \rangle_{\mathbb{R}_+^2}$  denotes norm in this space [11]

$$\langle \psi(t, x) \rangle_{\mathbb{R}_+^2} \equiv \sup_{(t, x) \in \mathbb{R}_+^2} \frac{|\psi(t, x)|}{G(t + \chi, x)},$$

where  $\chi$  is a positive number.

Obviously what

$$|f(t, v(t, y))| \leq \\ \leq C_1 \frac{|v(t, y)|^{1+\beta}}{G^{1+\beta}(t + \chi, y)} G^{1+\beta}(t + \chi, y) \leq \\ \leq C_1 \langle v(t, y) \rangle_{\mathbb{R}_+^2}^{1+\beta} G^{1+\beta}(t + \chi, y), (t, y) \in \mathbb{R}_+^2. \quad (10)$$

At that time

$$|(Mv)(t, y)| = \\ = \left| \int_0^t d\tau \int_{-\infty}^{\infty} G(t - \tau, y - \xi) f(\tau, v(\tau, \xi)) d\xi \right| \leq \\ \leq c_1 \int_0^t d\tau \int_{-\infty}^{\infty} \langle v \rangle_{\mathbb{R}_+^2}^{1+\beta} G^{1+\beta}(\tau + \chi, \xi) \times \\ \times G(t - \tau, y - \xi) d\xi \leq \\ \leq c_1 \langle v \rangle_{\mathbb{R}_+^2}^{1+\beta} \int_0^t \frac{d\tau}{\pi^\beta (\tau + \chi)^\beta} \times \\ \times \int_{-\infty}^{\infty} G(t - \tau, y - \xi) G(\tau + \chi, \xi) d\xi = \\ = c_3 \langle v \rangle_{\mathbb{R}_+^2}^{1+\beta} G(t + \chi, y) \frac{(\tau + \chi)^{1+\beta}}{1 - \beta} \Big|_0^\infty = \\ = c_4 \langle v \rangle_{\mathbb{R}_+^2}^{1+\beta} G(t + \chi, y), \quad (11)$$

where  $1 - \beta < 0$  or  $\beta > 1$ ,  $c_4 = c_3 \chi^{1-\beta} (\beta - 1)^{-1}$ , and use a roll up formula

$$\int_{-\infty}^{\infty} G(t - \tau, y - \xi) G(\tau + \chi, \xi) d\xi = \\ = G(t + \chi, y), \tau < t, y \in \mathbb{R}.$$

So from inequality (11) we obtain inequality

$$\langle Mv \rangle_{\mathbb{R}_+^2} \leq C_4 \langle v \rangle_{\mathbb{R}_+^2}^{1+\beta}. \quad (12)$$

Further, for the arbitrary  $\{v, w\} \subset H(\mathbb{R}_+^2)$  like that

$$\langle v \rangle_{\mathbb{R}_+^2} \leq K, \langle w \rangle_{\mathbb{R}_+^2} \leq K \text{ we have}$$

$$|(Mv - Mw)(t, y)| = \\ = \left| \int_0^t d\tau \int_{-\infty}^{\infty} G(t - \tau, y - \xi) [f(\tau, v(\tau, \xi)) - \right. \\ \left. - f(\tau, w(\tau, \xi))] d\xi \right| \leq \\ \leq C_2 \int_0^t d\tau \int_{-\infty}^{\infty} G(t - \tau, y - \xi) \times \\ \times \max\{|v|^\beta, |w|^\beta\} |v - w| \times \\ \times G^{1+\beta}(t + \chi, \xi) G^{-(1+\beta)}(\tau + \chi, \xi) d\xi \leq$$



$$\begin{aligned} &\leq C_2 \int_0^t d\tau \int_{-\infty}^{\infty} \max\left\{\left(\frac{|v(\tau, \xi)|}{G(\tau + \chi, \xi)}\right)^\beta, \left(\frac{|w(\tau, \xi)|}{G(\tau + \chi, \xi)}\right)^\beta\right\} \times \\ &\quad \times \frac{|v(\tau, \xi) - w(\tau, \xi)|}{G(\tau + \chi, \xi)} G(t - \tau, y - \xi) \times \\ &\quad \times G^{1+\beta}(\tau + \chi, \xi) d\xi \leq \\ &\leq C_2 K^\beta \langle v - w \rangle_{\mathbb{R}_+^2} \frac{1}{\pi^\beta} \int_0^\infty \frac{d\tau}{(\tau + \chi)^\beta} \times \\ &\quad \times \int_{-\infty}^\infty G(t - \tau, y - \xi) G(\tau + \chi, \xi) d\xi = \\ &= C_5 K^\beta \langle v - w \rangle_{\mathbb{R}_+^2} G(t + \chi, y), (t, y) \in \mathbb{R}_+^2, \end{aligned}$$

and we obtain inequality

$$\langle Mv - Mw \rangle_{\mathbb{R}_+^2} \leq C_5 K^\beta \langle v - w \rangle_{\mathbb{R}_+^2}. \quad (13)$$

We estimate the norm  $\langle v_0 \rangle_{\mathbb{R}_+^2}$ . We have

$$\begin{aligned} &|v_0(t, y)| = \\ &= \left| \int_{-\infty}^\infty G(t, y - \xi) G(\chi, \xi) \frac{\varphi(\xi)}{G(\chi, \xi)} d\xi \right| \leq \\ &\leq \langle \varphi \rangle_{\mathbb{R}} G(t + \chi, y), (t, y) \in \mathbb{R}_+^2 \end{aligned}$$

and that is why

$$\langle v_0 \rangle_{\mathbb{R}_+^2} \leq \langle \varphi \rangle_{\mathbb{R}}. \quad (14)$$

Assume then the function  $\varphi$  is a continual and  $\langle \varphi \rangle_{\mathbb{R}} < \delta$  and have a small  $\delta > 0$ .

At that time from (9) and (12) swim out, what

$$\langle v_R \rangle_{\mathbb{R}_+^2} \leq \delta + c_4 \langle v_{k-1} \rangle_{\mathbb{R}_+^2}^{1+\beta}, k \geq 1. \quad (15)$$

Therefore

$$\begin{aligned} \langle v_1 \rangle_{\mathbb{R}_+^2} &\leq c_4 \delta^{1+\beta} + \delta \equiv N_1(\delta), \\ \langle v_2 \rangle_{\mathbb{R}_+^2} &\leq \delta + c_4 N_1^{1+\beta}(\delta) \equiv N_2(\delta), \\ &\dots\dots\dots \\ \langle v_k \rangle_{\mathbb{R}_+^2} &\leq \delta + c_4 N_{k-1}^{1+\beta}(\delta) \equiv N_k(\delta), k \geq 1. \end{aligned} \quad (16)$$

From (16) swim out, that to small  $\delta$

$$\langle v_k \rangle_{\mathbb{R}_+^2} \leq N(\delta), k \geq 1, \quad (17)$$

and  $N(\delta) \rightarrow 0$  if  $\delta \rightarrow 0$ .

From the inequalities (13) and (17) we obtain

$$\begin{aligned} \langle v_k - v_{k-1} \rangle_{\mathbb{R}_+^2} &= \langle Mv_{k-1} - Mw_{k-2} \rangle_{\mathbb{R}_+^2} \leq \\ &\leq c_2 N^\beta(\delta) \langle v_{k-1} - v_{k-2} \rangle_{\mathbb{R}_+^2}, k \geq 2. \end{aligned}$$

Let's assume that exists a constant  $\delta > 0$  that  $c_5 N^\beta(\delta) < 1$ . The sequences  $\{v_k, k \geq 1\}$  is a component sum to the functional row

$$v_0 + (v_1 - v_0) + \dots + (v_k - v_{k-1}) + \dots$$

what valuing (in norm space  $H(\mathbb{R}_+^2)$ ) to the number row.

Then exist  $\lim_{k \rightarrow \infty} v_k = v \in H(\mathbb{R}_+^2)$ , and  $v$  is continuous function in  $\mathbb{R}_+^2$ . If in (9)  $k \rightarrow \infty$  therefore  $v$  is solution of the equation (8).

#### IV. THE MAIN RESULT

**Theorem** Assume that the function  $f$  is a continuity and satisfy the conditions (3) and (4). Then exists the numbers  $\delta > 0$ ,  $c > 0$  so if  $\varphi \in H(\mathbb{R})$  and  $\langle \varphi \rangle_{\mathbb{R}^2} \leq \delta$ , then exist only solution  $u$  of the problem (1), (2), where  $u \in H(\mathbb{R}_+^2)$  and  $\langle u \rangle_{\mathbb{R}_+^2} \leq c$ .

#### V. CONCLUSION

Fractional calculus is a branch of mathematics that with the study of integrals and derivatives of non-integer orders, plays an outstanding role and have found several applications in large areas research during the last decade. Behaviour of many dynamical systems can be described and studied using the fractional order system. Fractional derivatives cribe effect of memory.

The Cauchy problem (1), (2) described diffusion on inhomogeneous fractals.

The equation (1) is essentially nonlinear and solution of the problem (1), (2) can be investigated by numerical methods.

The investigated problem can be generalized in case  $n > 1$  variables, as well as variables depending on  $t$  or  $t, x$ ,  $t > 0, x \in \mathbb{R}^n$ .

For this it is necessary to spend appropriate research.

The fast result about solvability of the Cauchy problem for linear equation in form (6) were obtained by S.D. Eidelman and Y.M. Drin, who are authors of a new direction of mathematics - "Parabolic pseudodifferential equations with non-smooth symbols".

The problem of physical content and admissibility of differentiation of fractional order is considered in [12]. The generalizing character of the apparatus of derivative and integrals of fractional order, it is demonstrated in describing the model of a medium with the elasticity viscoelasticity-viscous liquid properties.

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# Once again about the reliability of serial-parallel networks vs parallel-serial networks

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**Abstract**— The paper addresses the issue of comparing the reliability of two standard types of networks: serial-parallel and parallel-serial. Four variants of dynamic mathematical models are analyzed depending on the lifetime cumulative distribution function of each units of the network, the non-random / random character of the number of units in each subnet and of the number of subnets. Sufficient conditions have been determined for serial-parallel networks to be more reliable than parallel-serial networks. The main result is that these conditions do not imply the lifetime distribution of each unit but only the probabilistic distribution of the numbers of units and subsystems of the networks.

**Keywords**—lifetime distribution; reliability; power series distribution; serial-parallel/parallel-serial networks

## I. INTRODUCTION

In the case of networks whose structure (topology) is a complex one, in many cases, the subnets that are part of them have a series-parallel or parallel-series structure. This means that when designing networks, not infrequently, we will need to we know, possibly, which of the mentioned sub-networks is preferable in terms of their reliability.

Based on mathematical models in various hypostases of such subnets, we aim to find the most reliable subnet.

## II. SERIES-PARALLEL AND PARALLEL-SERIES NETWORKS IN VARIOUS HYPOSTASES

When in our paper we talk about the reliability of series-parallel / parallel-series networks we consider dynamic mathematical models in various situations depending on the number of units in each subnet, the number of subnets, but also the lifetime distribution of each unit of network.

The figure below shows how the two networks *A* and *B* look schematically.

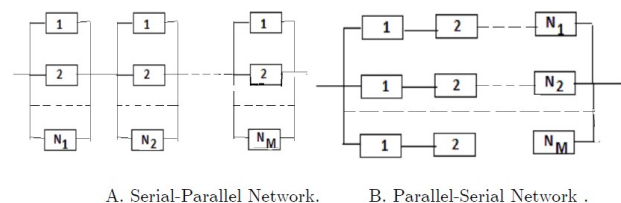


Figure 1. Schematic representation of series-parallel / parallel-series networks

We will consider, thus, that the network (regardless of its type, *A* or *B*) consists of  $M$  subnets, the subnet  $k$  consists of  $N_k$  units,  $k = 1, 2, \dots, M$ , and the lifetimes of all units are independent, identically distributed random variables (i.i.d.r.v.) with the cumulative distribution function (c.d.f.)  $F(x)$ .

Even if the numbers  $N_k$ ,  $k = 1, 2, \dots, M$ , or / and  $M$  are random, we consider that they are independent of the lifetimes of all units.

Furthermore, the reliability of type *A* and *B* networks will be compared in the following variants.

**Variant 1.** The number of units  $N_k$  in the subnet  $k$ ,  $k = 1, 2, \dots, M$  is constant, the number of subnets being constant too.

**Variant 2.** The number of units  $N_k$ ,  $k = 1, 2, \dots, M$  in the subnets  $k = 1, 2, \dots, M$  are i.i.d.r.v. with 0-truncated Power Series Distribution (PSD) but the number of subnets being constant.

**Variant 3.** The number  $N_k$  of units in the subnet  $k$ ,  $k = 1, 2, \dots, M$  is constant, in addition,  $N_1 = N_2 = \dots = N_M = N$ , and the number  $M$  of the subnets is 0-truncated PSD r.v.

**Variant 4.** The numbers of units  $N_k$ ,  $k = 1, 2, \dots, M$  in the subnets  $k = 1, 2, \dots, M$  are independent, identically,  $0$ -truncated PSD r.v., and the number  $M$  of subnets is  $0$ -truncated PSD r.v., independent of r.v.  $N_k$ ,  $k = 1, 2, \dots, M$ .

We recall that, according to [1], r.v.  $Z$  with values from the set  $\{0, 1, \dots, n, \dots\}$  is a power series distributed (PSD) r.v. with parameter  $\vartheta$  and power function  $A(\vartheta) = \sum_{k \geq 0} a_z \vartheta^z$  if  $P(Z = z) = a_z \vartheta^z / A(\vartheta)$ ,  $a_z \geq 0$ , where the power series is convergent with the convergence radius  $\tau \in (0, +\infty)$ . Shortly,  $Z \in \text{PSD}$ .

The PSD used in our paper are  $0$ -truncated ones, because the real networks consists from at least one unit. The following assertion assure us that the operation of  $0$ -truncations does not alter the initial quality of distribution to be of PSD class.

**Proposition 1** [2]. If  $Z \in \text{PSD}$  with parameter  $\vartheta$  and power series function  $A(\vartheta) = \sum_{k \geq 0} a_z \vartheta^z$ , then his  $0$ -truncation is a r.v.  $Z^* \in \text{PSD}$  with parameter  $\vartheta$ ,  $\vartheta \in (0, \tau)$ ,  $\tau \in (0, +\infty)$  and power series function  $A^*(\vartheta) = \sum_{k \geq 1} a_z \vartheta^z = A(\vartheta) - a_0$ , i.e.,  $P(Z = z) = a_z \vartheta^z / A^*(\vartheta)$ ,  $a_z \geq 0$ ,  $z = 1, 2, \dots$ .

**Example 1.** The following Table 1, from [2], shows the form of PSD parameters of  $0$ -truncated distributions of some classical discrete distributions as  $\text{Bin}(n; p)$ ,  $\text{Geom}(p)$ ,  $\text{Poisson}(\lambda)$ ,  $\text{Log}(p)$ ,  $\text{NegBin}(k; p)$ ,  $\text{Pascal}(k; p)$ ; marked by symbol "\*", if their  $0$ -truncation change form as a PSD.

TABLE I. 0-TRUNCATED DISTRIBUTIONS OF SOME CLASSICAL DISCRETE DISTRIBUTIONS

Distribution	$a_z$	$\theta$	$A(\theta)$	$\tau$
$\text{Bin}^*(n; p)$ , $n \in \{1, 2, \dots\}$ , $0 < p < 1$	$\begin{cases} \binom{n}{z}, \text{ for } z = \overline{1, n}, \\ 0, \text{ for } z = 0 \text{ or } z > n. \end{cases}$	$\frac{p}{1-p}$	$(1+\theta)^n - 1$	$+\infty$
$\text{Poisson}^*(\lambda)$ , $\lambda > 0$	$\begin{cases} \frac{1}{z!}, \text{ for } z = 1, 2, \dots, \\ 0, \text{ for } z = 0. \end{cases}$	$\lambda$	$e^\theta - 1$	$+\infty$
$\text{Log}(p)$ , $0 < p < 1$	$\begin{cases} \frac{1}{z}, \text{ for } z = 1, 2, \dots, \\ 0, \text{ for } z = 0. \end{cases}$	$p$	$-\ln(1-\theta)$	$1$
$\text{Geom}^*(p)$ , $0 < p < 1$	$\begin{cases} 1, \text{ for } z = 1, 2, \dots, \\ 0, \text{ for } z = 0. \end{cases}$	$1-p$	$\frac{\theta}{1-\theta}$	$1$
$\text{NegBin}^*(k; p)$ , $k \in \{1, 2, \dots\}$ , $0 < p < 1$	$\begin{cases} \binom{z+k-1}{k-1}, \text{ for } z = 1, 2, \dots, \\ 0, \text{ for } z = 0. \end{cases}$	$p$	$(1-\theta)^{-k} - 1$	$1$
$\text{Pascal}(k; p)$ , $k \in \{1, 2, \dots\}$ , $0 < p < 1$	$\begin{cases} \binom{z-1}{k-1}, \text{ for } z = k, k+1, \dots, \\ 0, \text{ for } z = 0, k-1. \end{cases}$	$1-p$	$\left(\frac{\theta}{1-\theta}\right)^k$	$1$

### III. COMPARING THE RELIABILITY OF NETWORK OF TYPE A vs NETWORK OF TYPE B.

We denote by  $R_{S-P}(x)$  the reliability of the type  $A$  network and by  $R_{P-S}(x)$  the reliability of the type  $B$  network, by the reliability (also called the survival function) of a

system understanding the function  $R(x) = 1 - L(x)$ , where  $L(x)$  is the lifetime c.d.f. of this system.

The following two statements highlight the conditions under which the type  $A$  network is more reliable than the type  $B$  network.

**Proposition 2.** For any mathematical model (in variants 1-4), the property of one network to be more reliable than the other network does not depend on lifetime c.d.f.  $F(x)$  of each unit of the network.

**Proposition 3.** For any mathematical model (in variants 1-4), the series-parallel network is more reliable than the parallel-series network, i.e.,  $R_{S-P}(x) > R_{P-S}(x)$  as soon as  $P(N_1 > M) = \dots = P(N_M > M) = 1$ .

In other words, it is sufficient that  $P(N_1 > M) = \dots = P(N_M > M) = 1$ , which in the case of variant 1 this means that  $\min(N_1, N_2, \dots, N_M) > M$ , to guarantee that  $R_{S-P}(x) > R_{P-S}(x)$ . Otherwise, this means that not always  $R_{S-P}(x) > R_{P-S}(x)$ . Moreover, Proposition 2 shows that this property takes place regardless of the lifetime c.d.f.  $F(x)$  of each unit in the network. So, to illustrate graphically this property is sufficient to take the uniform distribution on  $[0, 1]$  as the c.d.f.  $F(x)$ , i.e.  $F(x) = xI_{[0,1]}(x) + I_{(1,+\infty)}$ , where  $I_D(x) = 1$  if  $x \in D$ , otherwise  $I_D(x) = 0$ .

For the mathematical models in variants 1-2, our statements being a consequence of the results of the [3], we will bring illustrative examples for variants 3-4.

**Example 2.** We consider the networks of type  $A$  and  $B$  according to the mathematical model from variant 3, i.e., the number of units in each subnet is constant and equal to the same number  $N$ , while the number of subnets is a r.v.  $M \in \text{PSD}$  with parameter  $\omega$  and power series function  $B(\omega)$  with radius of convergence  $r \in (0, +\infty)$ .

As a consequence of Proposition 2, we will consider that lifetime c.d.f. of each unit is given by  $F(x) = xI_{[0,1]}(x) + I_{(1,+\infty)}$ . Under these conditions it is valid

**Proposition 4.** Reliability of type  $A$  and  $B$  networks in variant 3, when lifetime c.d.f.  $F(x) = xI_{[0,1]}(x) + I_{(1,+\infty)}$  are given respectively by the functions

$$R_{S-P}(x) = [B(\omega(1-x^N)) / B(\omega)] I_{[0,1]}(x) \text{ and } R_{P-S}(x) = [1 - B(\omega(1-(1-x)^N)) / B(\omega)] I_{[0,1]}(x),$$

where  $B(\omega)$  is a power series function of r.v.  $M \in \text{PSD}$  with parameter  $\omega$ .

So, to exemplify, we will take a few cases when  $M \sim \text{Bin}^*(n; p)$ , i.e.  $\omega = p/(1-p)$  and  $B(\omega) = (1+\omega)^n - 1$ .

$N=5$ ,  $n=3$ ,  $p=1/2$ , i.e.,  $\omega=1$  and  $P(N>M)=1$ . Then  $R_{S-P}(x) = \{[(1+(1-x^5))^3 - 1] / (2^3 - 1)\} I_{[0,1]}(x)$  and  $R_{P-S}(x) = \{[1 - (1-(1-x)^5)^3 - 1] / (2^3 - 1)\} I_{[0,1]}(x)$ .

<https://doi.org/10.52326/ic-ecco.2021/CS.02>



Their graphical representation below (Fig. 2) shows that

$R_{S-P}(x) > R_{P-S}(x)$ , which confirms the statement of Proposition 3.

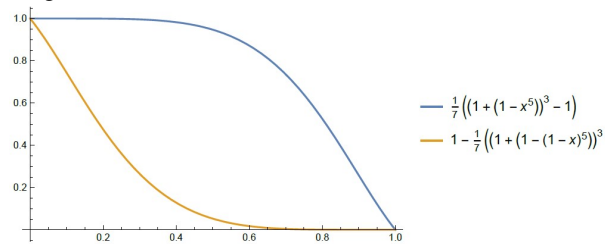


Figure 2.

$N=5, n=34, p=1/2$ , i.e.,  $\omega=1$  and  $P(N>M)<1$ . Then  $R_{S-P}(x) = \{[(1+(1-x^5))^{34}-1] / (2^{34}-1)\} I_{[0,1]}(x)$  and  $R_{P-S}(x) = \{[1+(1-(1-x)^5)^{34}-1] / (2^{34}-1)\} I_{[0,1]}(x)$ .

Their graphical representation below (Fig. 3) shows that inequality  $R_{S-P}(x) > R_{P-S}(x)$  is not sure for all  $x$ , which also confirms conclusions from the Proposition 3.

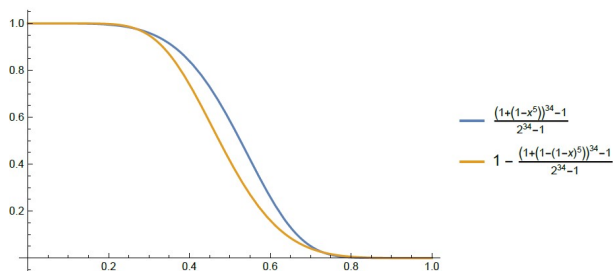


Figure 3.

Moreover, in the following case,  $R_{S-P}(x) < R_{P-S}(x)$ , when

$P(N>M) < 1$ .

$N=5, n=100, p=1/2$ , i.e.,  $\omega=1$ . So,  $P(N>M)<1$ . Then

$R_{S-P}(x) = \{[(1+(1-x^5))^{100}-1] / (2^{100}-1)\} I_{[0,1]}(x)$  and

$R_{P-S}(x) = \{[1+(1-(1-x)^5)^{100}-1] / (2^{100}-1)\} I_{[0,1]}(x)$ .

From the graphic representation below (Fig. 4) we see that, indeed,  $R_{S-P}(x) < R_{P-S}(x)$ . This also confirms conclusions from the Proposition 3.

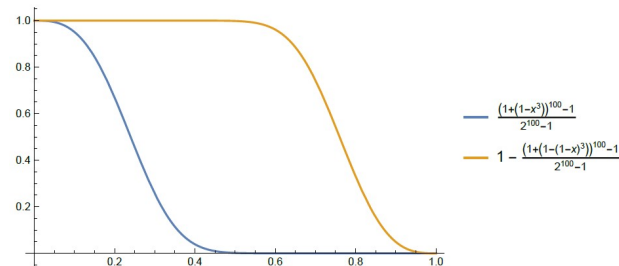


Figure 4.

**Example 3.** Now, let's consider the networks of type  $A$  and  $B$  according to the mathematical models which correspond to variant 4, i.e., the numbers  $N_i$  of units in each subnet,  $i=1, 2, \dots$  are i.i.d.r.v. of 0-truncated PSD type with the parameter  $\vartheta$  and power function  $A(\vartheta)$  with radius of convergence  $\tau \in (0, +\infty)$ , while the number of subnets  $M$  is a r.v. independent of numbers  $N_i, i=1, 2, \dots$  and  $M \in PSD$  with the parameter  $\omega$  and power series function  $B(\omega)$  with radius of convergence  $r \in (0, +\infty)$ .

Also, as a consequence of Proposition 2, we will consider that lifetime c.d.f. of each unit is given by  $F(x) = xI_{[0,1]}(x) + I_{(1,+\infty)}$ . Under these conditions it is valid

**Proposition 5.** Reliability of type  $A$  and  $B$  networks in variant 4, when lifetime c.d.f.  $F(x) = xI_{[0,1]}(x) + I_{(1,+\infty)}$  are given respectively by the functions

$R_{S-P}(x) = [B(\omega(1-A(\vartheta x)/A(\vartheta)))/B(\omega)] I_{[0,1]}(x)$  and  $R_{P-S}(x) = [1-B(\omega(1-A(\vartheta(1-x)/A(\vartheta)))]/B(\omega)] I_{[0,1]}(x)$ ,

where  $A(\vartheta)$  and  $B(\omega)$  are the power series functions of r.v.  $N_i, i=1, 2, \dots$ , and  $M$ , with parameters  $\vartheta$  and  $\omega$ , respectively.

Now, we consider the following cases.

R.v.  $N_i \sim \text{Pascal}^*(k;p), i=1, 2, \dots, M, k=5, p=1/2$  and  $M \sim \text{Bin}^*(n; q), n=4, q=1/2$ . So, from the Table 1, we deduce that  $\theta=1/2$  for  $p=1/2$  and  $\omega=1$  for  $q=1/2$ ,  $A(\theta) = (\theta/1-\theta)^5=1$  for  $\theta=1/2$  and  $B(\omega)=(1+\omega)^4-1=2^4-1$  for  $\omega=1$  and  $P(N_i>M)=1, i=1, 2, \dots, M$ . This implies that for  $x \in [0,1]$

$R_{S-P}(x) = \{[2-(x/(2-x))^5]-1\}/(2^4-1)$  and

$R_{P-S}(x) = 1 - \{[2-((1-x)/(1+x))^5]-1\}/(2^4-1)$ .

The graphical representation below (Fig. 5) shows that

$R_{S-P}(x) > R_{P-S}(x)$ , which confirms the statement of Proposition 3.

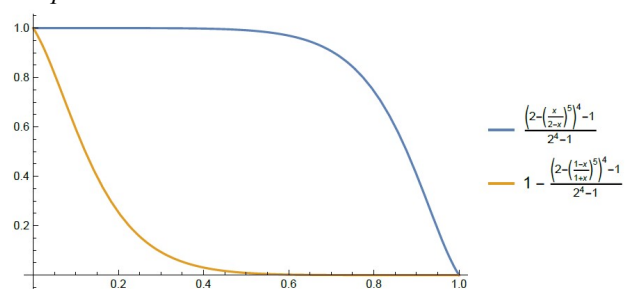


Figure 5.

R.v.  $N_i \sim \text{Bin}^*(n; q), n=4, q=1/2, i=1, 2, \dots$ , and  $M \sim \text{Pascal}^*(k;p), k=5, p=1/2$ . So, from the Table 1, we deduce that  $\theta=1$  for  $p=1/2$  and  $\omega=1/2$  for  $q=1/2$ ,  $A(\theta) = (1+\theta)^4-1=2^4-1$  for  $\theta=1$  and  $B(\omega)=(\omega/(1-\omega))^5=1$  for  $\omega=1/2$  and  $P(N_i>M)=0, i=1, 2, \dots, M$ . This implies that for  $x \in [0,1]$

$$R_{S-P}(x) = \{ [2^4 - (1+x)^4] / [2(2^4-1) - (2^4 - (1+x)^4)] \}^5 \text{ and}$$

$$R_{P-S}(x) = 1 - \{ [2^4 - (2-x)^4] / [2(2^4-1) - (2^4 - (2-x)^4)] \}^5.$$

The graphical representation below (Fig. 6) shows that

$R_{S-P}(x) < R_{P-S}(x)$  because  $P(N_i > M) = 0$ ,  $i = 1, 2, \dots, M$ , which also confirms consequences from the statement of Proposition 3.

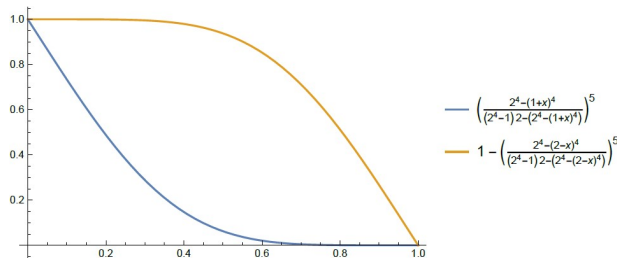


Figure 6.

Finally, also, if there is at least one  $i$  for which  $P(N_i > M) < 1$ , do we have that inequality  $R_{S-P}(x) > R_{P-S}(x)$  it becomes uncertain. Really

R.v.  $N_i \sim \text{Bin}^*(n; q)$ ,  $n=20$ ,  $q=1/2$ ,  $i=1, 2, \dots$ , and  $M \sim \text{Pascal}^*(k; p)$ ,  $k=100$ ,  $p=1/2$ . So, from the Table 1, we deduce that  $\theta = 1$  for  $p=1/2$  and  $\omega = 1/2$  for  $q=1/2$ ,  $A(\theta) = (1+\theta)^{20} - 1 = 2^{20} - 1$  for  $\theta = 1$  and  $B(\omega) = (\omega / (1-\omega))^{100} = 1$  for  $\omega = 1/2$  and  $P(N_i > M) < 1$ ,  $i=1, 2, \dots, M$ . This implies that for  $x \in [0, 1]$

$$R_{S-P}(x) = \{ [2^{20} - (1+x)^{20}] / [2(2^{20}-1) - (2^{20} - (1+x)^{20})] \}^{100} \text{ and}$$

$$R_{P-S}(x) = 1 - \{ [2^{20} - (2-x)^{20}] / [2(2^{20}-1) - (2^{20} - (2-x)^{20})] \}^{100}$$

(Fig. 7).

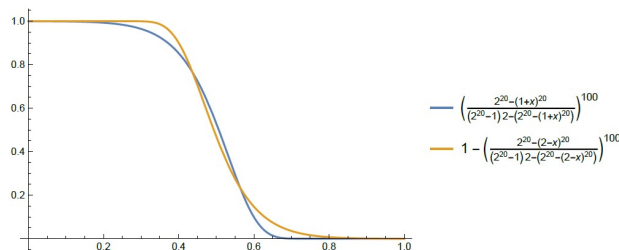


Figure 7.

**Conclusions.** Comparing the reliability of the serial-parallel type networks with the reliability of the parallel-serial type networks represented in fig. 1 we have shown the following.

Due to the specific / characteristic properties of c.d.f. this comparison does not depend on lifetime c.d.f. of the units that are part of the network.

As a result, we can make the proposed comparison, taking as lifetime c.d.f.  $F(x)$  the uniform distribution on the segment  $[0, 1]$ .

We also showed that, finally, in any of the 4 dynamic mathematical models (variants 1-4) the parallel series network is more reliable than the parallel series network as soon as the probability that the number of units in each subnet will be greater than the number of subnets is equal to 1. Otherwise, the comparison is not unambiguous.

This last statement is also confirmed by graphic methods.

Moreover, in the case of mathematical models 3 and 4, the calculation formulas for reliability / survival function are brought.

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# Cultural Heritage Digitisation Using Game with a Purpose

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**Abstract** — The digitisation of cultural heritage is a priority area in the European Union. This task requires a close collaboration between researchers in humanities and computer scientists. The paper presents our effort to create a training set of recognized handwritten text. To this mean we propose an online game with a purpose (GWAP). This is a human-based computing technique in which some stages of a computational process are transmitted to humans in a form of an online game. The input of the game is a line of handwritten text and the user has to type in its transcription. We investigated how to make this in an attractive and enthralling way in order to involve more users and obtain a large set of transcribed texts.

**Keywords** — cultural heritage digitisation, automate manuscript recognition, training set, games with a purpose

## I. INTRODUCTION

The digitisation of cultural heritage is a priority area on the European Union's digital agenda. The Commission Recommendation on digitisation, online accessibility and digital preservation of cultural material [1] represents a milestone in digital cultural policy. The Recommendation invites the States to pool their resources and involve the private sector in digitising cultural material, in order to increase online accessibility of European cultural heritage, boost engagement of citizens and growth in Europe's creative industries. Furthermore, digitised material should be made accessible through the European cultural platform providing access to a wide array of digital content from Europe's libraries, archives and museums.

Huge collections of old documents stored in the museums and libraries cannot be made easily available for the large public as they need to be preserved in special conditions of temperature, humidity and light. Today, there is a solution for this problem. Plenty of old documents are already published by online digital libraries around the world for preservation and for making them available online for everyone who is interested [8].

Our republic is also working towards digitisation of our cultural treasures, in order to facilitate its preservation, online access and re-use. The decision no. 478 of July 4, 2012 on the National Program for computerization of the sphere of culture for the years 2012-2020, published in the Official Gazette [2] described in details the plans of our cultural heritage digitisation and its online access.

Multiple cultural organizations have been involved in this process including museums, libraries, research centres on history and arts, everyone who is working with valuable historical objects. This work, however cannot be done without computer scientists, who are able to perform the necessary operations and organize online access to the digitised content.

We present our effort to create a training set of recognized handwritten text. To this mean we propose an online game with a purpose (GWAP). This is a human-based computing technique in which some stages of a computational process are transmitted to humans in a form of an online game (this process is called gamification) [7].

## II. DIGITISATION OF OUR CULTURAL HERITAGE

The digitisation of the cultural heritage is necessary for two major reasons:

1. Historical cultural objects preservation. All old objects have been gradually destroying, especially if they are exposed for the large public.
2. Free access for everyone who is interested. Digital copy of the historical documents uploaded online are easily accessible by anyone to explore without additional damage to fragile originals.

The term "digitisation" (we use British spelling, in USA "digitization" is used) is defined in the Collins dictionary as "turning information into a form that can be read easily by a computer" or "transformation of data into a digital form so that it can be directly processed by a computer"<sup>1</sup> and this is only the first step for digital

<sup>1</sup><https://www.collinsdictionary.com/dictionary/english/digitize>



preservation. Digital preservation is to maintain something over a long period of time in digital form [10]. However, there is the other goal of the digital preservation activities, namely, organization of the free access to the digital copies of the historical objects. This is especially important for the historical documents: old books, letters, manuscripts and other texts; they are of great importance for the researchers in the fields of history and arts.

The Institute of Mathematics and Informatics of the Moldavian Academy of Science took part in the research project "Information technologies and resources for digitizing the Romanian historical-literary heritage from the 17th-20th centuries printed in Cyrillic alphabet" within the State Program "Development of e-Infrastructure data in the field of research, development and innovation in the Republic of Moldova", the years 2018-2019 [9]. The aim of the project was the development of an instrument to support the digitisation and transliteration of texts printed in Romanian with Cyrillic characters. In their report they listed the main steps of the digitisation process for these documents:

- Obtaining the image by scanning of the original physical documents from the library, using the software provided by the scanner. The desired quality is 600 DPI (Dots Per Inch) or more.
- Preparing images for OCR (Optical Character Recognition) with a software, which performs massive automatic corrections of image defects, for example, corrects the tilt angle of the page or cleans some small spots. This work is quite laborious when processing large volumes of text.
- Optical recognition of the Cyrillic characters of the scanned texts.
- Transliteration of the results obtained in modern Latin script.
- Manual or automated processing of the result obtained for the final correction of the text.

Thus, the whole process cannot be completed without manual verification of the final text even for the printed sources and we worked with handwritten texts. At the moment, handwritten texts are still a great problem for the automate systems. In order to create systems able to read handwritten text we need a large volume of training material that have to be created manually.

### III. PREPROCESSING OF THE OLD TEXTS

In our work, we used a limited set of manuscripts already scanned and published on the online portal "National Digital Treasure" of the Republic of Moldova, [www.digi.emoldova.org](http://www.digi.emoldova.org)

Scanned old documents are the result of the first step in the process of their digitisation; in addition to the steps mentioned in the previous section, there is one more important step: image segmentation for the further optical character recognition and its post-processing [3]. In comparison to printed texts, the process of manuscripts'

recognition is considerably more difficult. The causes of the difficulties are:

- The text is written on various types of paper, which has lost its quality over time;
- All manuscripts have different writing style, depending on the period in which they were written;
- The use of different alphabets, such as Cyrillic, Latin and so called alphabets of transition [13];
- The texts are written disorderly, various signs being placed above and below the line;
- Abbreviations and other special marks.

Various machine learning algorithms are used for this task including recent neural network architectures. Even a small set of training data can significantly improve the model's performance on corresponding test data [4].

At the text segmentation stage the whole text on the page is split in rows for further recognition. This process is described in [5]. Then, the rows are presented to online users for recognition in a fun way. The answers, introduced by users are stored along with the original handwritten row forming the labeled instances for training a machine learning model [6].

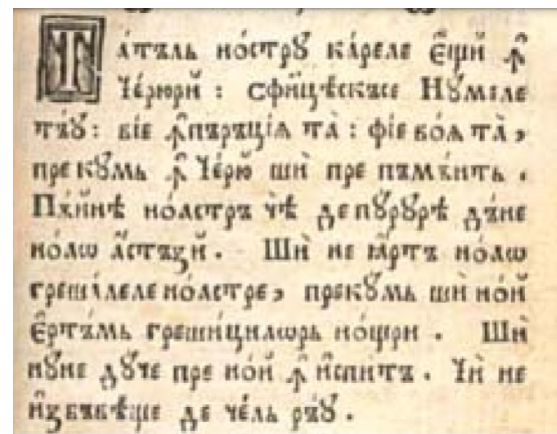


Figure 1. An example of old printed text. [3].

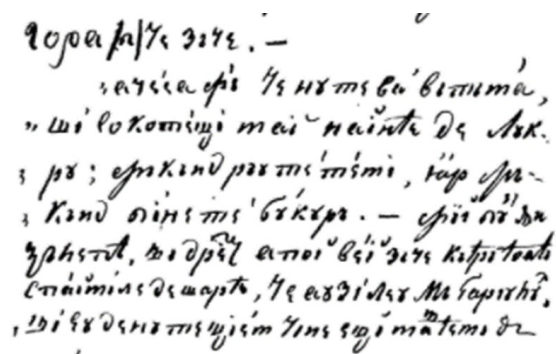


Figure 2. An example of old handwritten text. [5]

Figure 1 presents an example of old printed text and Figure 2 contains an example of old handwritten text.

<https://doi.org/10.52326/ic-ecco.2021/CS.03>



Both texts are old and difficult to read and understand by a modern person, but printed text is seemingly easier.

Before the text can be recognized it should be segmented in rows and words. This task is complicated by different height of the letters and various symbols that appear above and below the letters of the text: it is seen on the picture on figures 1 and 2.

Figure 3 presents a process of text segmentation described in [5]. The output of this step are separate rows of text that should be recognized.

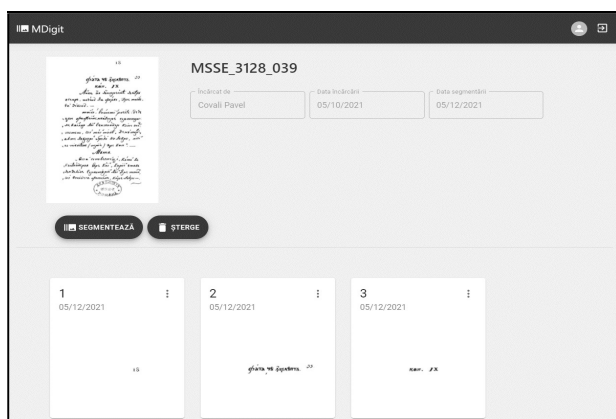


Figure 3. An example text image segmentation. The whole page with text is above and the pages with extracted rows of the text are below. [5]

#### IV. USING THE GAME WITH A PURPOSE

Even after segmentation in rows the handwritten text is extremely difficult to recognize. The modern machine learning methods can be trained to perform this task with some acceptable accuracy but they need a training set to be trained. A training set is a set of examples with the answers for the given task. The bigger is the training set the better is the model of a machine learning method, the better are the results of text recognition. For the task of handwritten text recognition, a training set is a volume of handwritten text fragments with their transcriptions in printed words. These transcriptions are made manually by the specialists. However, there are not many such specialists and they are not able to make a set of transcriptions large enough for the training. We decided to organize crowdsourcing of such transcriptions.

The word "crowdsourcing" is a combination of "crowd" and "outsourcing" and it is a sourcing model in which individuals or organizations obtain goods or services including ideas, voting, micro-tasks, and finances from a large, relatively open, and often rapidly evolving group of participants. It typically involves using the internet to attract and divide work between participants to achieve a cumulative result [11].

In our case we planned to create a web interface in which web users can transcribe the rows of handwritten texts adding pieces of data to the training set. In order to

attract more users to the transcription process we use game with a purpose (GWAP).

A human-based computation game or game with a purpose is a human-based computation technique of outsourcing steps within a computational process to humans in an entertaining way (gamification) [14]. The tasks presented in these games are usually trivial for humans, but difficult for computers. One of the first games with a purpose was ESP Game, also known as Google Image Labeler "an online game in which players label images with words that describe them" [14]. In this game people provided meaningful and accurate tags for web images as a side effect of the game; for example, an image of a man and a dog was labeled 'dog', 'man' and 'pet'. The game was fast, enjoyable and competitive.

It is well known that there are a large number of web users who play online games. If a game is fun, there is a good chance that enough online users will play it [12].

The Entertainment Software Association reported that "over 200 million hours are spent every day playing computer and video games in the United States." Indeed, by the age of 21, the average American had spent more than 10,000 hours playing such games, the equivalent of five years of full-time work 40 hours a week.

People play not because they are interested in solving a computational problem, but because they want to have fun. The GWAP approach is characterized by three motivating factors: an increasing proportion of the world's population has access to the Internet; certain tasks are impossible for computers, but easy for people; and people spend a lot of time playing computer games.

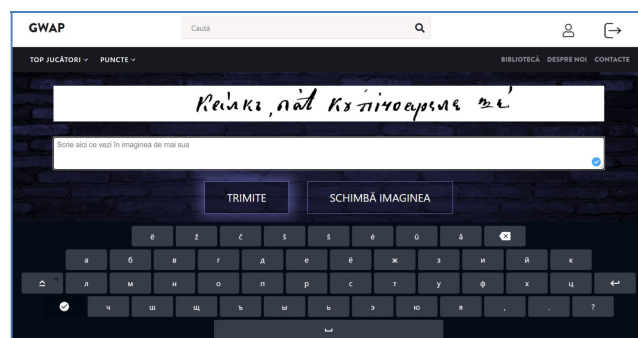


Figure 4. An example of the game interface. [6]

One of the most important aspects of GWAP is the ability to be enjoyable. The fact that people enjoy the game makes them want to continue playing, producing in turn more useful results. Setting time limits for game sessions introduces the challenge into a game in the form of a timed response. The timed response is effective for introducing the challenge as long as the goal is not trivial for the players.

One of the most direct ways to motivate players is to award points for each successful exit produced during the game. For the ESP game, pairs of players receive points for each image for which they successfully agree on a

<https://doi.org/10.52326/ic-ecco.2021/CS.03>



word (which then becomes a label for the image). Using points increases motivation by providing a clear connection between effort in the game, performance (obtaining the winning condition) and results (points). A summary of the score after each game also provides players with performance feedback, making it easier to assess progress on score-related goals (such as exceeding a previous game score and completing all task instances within the set time limit).

The designed game is a Game with Exit Agreement similar to ESP game.

Initial configuration: Two users are randomly chosen by the game itself from all potential players.

Rules: In each round, both are given the same input and they must produce outputs based on the input. The game instructions indicate that players should try to produce the same result as their partners. Players cannot see each other's results and cannot communicate with each other.

Winning condition: Both players produce the same output; they are not synchronized in time, but they have to produce a result at some point while the input is displayed on the screen.

The application is written in PHP, uses JQuery, its database is MySQL. The database contains data about users, games and images.

The main modules of the application are:

- Enrollment and authentication of the user;
- Visualisation of the user account information;
- Game rounds;
- Assignment of ranks and motivation points for players; visualization of the ranking.

The game interface presented on Figure 4 contains a row of handwritten text to be recognized, a input field where the player should introduce the response and a virtual keyboard with the necessary letters as the letters used in the handwritten documents are specific and some of them cannot be found on the standard keyboard.

The main purpose of the game is to produce a large amount of useful and clean data. Each of these three objectives ("large", "clean" and "useful") has important implications for the design of the proposed game. First, to collect large amounts of data, the game must be attractive to users. The next requirement is that the data be clean. First, players must be able to produce high quality annotations and the game should encourage users to enter relevant data. We award points as a motivating factor, but this can cause players to enter irrelevant data.

There may not always be enough players available online to match a human player with another human player. Therefore, an important part of designing an online game is building a bot that can work instead of a player.

## V. CONCLUSION AND FUTURE WORK

The presented work is a part of the project dedicated to our cultural heritage digitisation, namely old

manuscripts written in transitional alphabet. Scanned manuscripts have to be transcribed and transliterated in modern romanian. Our task is to create a large set of manually transcribed handwritten examples in order to train a machine learning method. Game with a purpose (GWAP) is a good way to solve this problem with the help of users which playing online will transcribe the handwritten texts. In the paper, we present a game developed for this purpose.

Our future plans include uploading the game on the web, attracting users to this game, collecting a set of transcribed rows of handwritten texts and experimenting with machine learning models trained on this set of data.

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# Context Free Grammar Representation by the Colored Petri Net

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**Abstract**— Specification technique like Colored Petri Net (CPN) allows for the formal description and analysis of the discrete event systems. In this paper, it is presented the methodology for Context Free Grammar design, specification and analysis by the using Colored Petri Net technique. It is proposed the approach for representation of the Context Free Grammar by the Colored Petri Net language.

**Keywords**—Colored Petri Net; Context Free Grammar, discrete event systems

## I. INTRODUCTION

Agent-based systems are one of the most important areas of research and development that have been developed in information technology for the last 30 years. The concept of multi-agent systems can be found in a range of domains and offers the strong models for representing complex and discrete event systems. The multi-agent systems can be described and modelled by the formalism that is used for design of the discrete-event systems as Finite Automata, Petri Nets etc.

Petri Nets is one of the powerful modeling formalism in computer science, system engineering and many other domains. Petri Nets combine a well defined mathematical theory with a graphical representation of the dynamic behavior of systems. The graphical representation of Petri nets enable visualization of the modeled system state changes [6].

In 1991 by the Jensen and Rozenberg, the Petri Nets was extended to the Colored Petri Net (CPN), that is a powerful and recognized modelling tool that can be seen as one of the most advanced behavior modeling techniques that is used to model and specify the behavior of concurrent and distributed systems [1].

An important topic in the field of multi-agent systems is the concept of ‘environment’. The environment in which a multiagent system is acted, is fundamental in the analysis, design and operation of the system. In the

literature, there are developed the environment based model for formalizing multi-agent systems by means of formal languages, where is specified the way of interaction of the agent with its environment by the formal language theory [3].

The field of formal language theory it was initiated by Noam Chomsky in the 1950s—provides a measuring stick for linguistic theories that sets a minimal limit of descriptive adequacy. Chomsky suggested a series of massive simplifications and abstractions to the empirical domain of natural language. The immense success of this framework—influencing not only linguistics to this day, but also theoretical computer science and, more recently, artificial intelligence domain—suggests that these abstractions can essentially improve the design of the multi-agent systems and the way of interaction of the agents with environment [2, 9-10, 12].

By the classical classification, that is called Chomsky hierarchy, there are types of languages: regular, context-free, context-sensitive and computably enumerable languages. The each type of language specification can be defined by the grammar.

A context-free grammar is a set of recursive rules used to generate patterns of strings, that is studied in fields of theoretical computer science, compiler design, and linguistics. It is a formal grammar which is used to generate all possible patterns of strings in a given formal language and can describe all regular languages and more [8,11], but it is a known, that context-free grammars are not able to cover all phenomena of natural and programming languages. Context-sensitive grammars are powerful enough, but have bad features in case of decidability problems. Therefore, the context free grammars has a wide applicability and it is a natural idea to introduce grammars which use context-free rules and have a device which controls the application of the rules [4].

In this paper, it is proposed a new approach for context free grammar design and analysis by the Colored Petri Net modeling formalism.

## II. COLORED PETRI NET

The Petri nets are graphical and mathematical modeling tools that are applicable to many concurrent, asynchronous, distributed systems and have been used in the study of the formal languages design and analysis [7].

A Petri Net is a directed bipartite graph defined by the 4-tuple  $(P, T, Pre, Post)$ , where [1]:

- $P$  is a finite set of places;
- $T$  is a finite set of transitions ( $P \cap T = \emptyset$ );
- $Pre$  is the backward incidence application;
- $Post$  is the forward incidence application.

Simulating the Petri Nets involves moving tokens from place to place by firing transitions according to predefined rules. Colored Petri Net is an extension of Petri Nets for modeling complex systems that adds another dimension for tokens as well as to selection criteria used in determining firing by the addition of different token types. In this case, tokens are represented by the different functions.

Colored Petri Net is a graphical language for constructing models of concurrent systems and analyzing their properties, where each place has an associated type determining the kind of data that the place may contain.

A Colored Petri Net is defined by the 9-tuple [1]

$$CPN = (\Sigma, P, T, A, Nod, Col, Grd, Expr, Init), \quad (1)$$

where:

- $\Sigma$  is a finite set on non-empty types;
- $P$  is a finite set of places;
- $T$  is a finite set of transitions;
- $A$  is a finite set of arcs such that:

$$P \cap T = P \cap A = T \cap A = \emptyset. \quad (2)$$

- $Nod$  is a node function. It is defined from  $A$  into

$$Nod : A \rightarrow (P \times T) \cup (T \times P). \quad (3)$$

- $Col$  is a color function. It is defined from  $P \cup T$  into  $\Sigma$  such that:

$$Col : P \rightarrow \Sigma. \quad (4)$$

- $Grd$  is a guard function. It is defined from  $T$  into expressions such that:

$$\forall t \in T : [Type(Grd(t)) = Bool \wedge Type(Var(Grd(t))) \subseteq \Sigma]. \quad (5)$$

The guard function is a logical expression that must take the true logical value for the transition to take place.

-  $Expr$  is an arc expression function. It is defined from  $A$  into expressions such that:

$$\forall a \in A : [Type(Expr(a)) = Col(p(a))_{MS} \wedge Type(Var(Expr(a))) \subseteq \Sigma], \quad (6)$$

where  $p(a)$  is the place of  $N(a)$ ;

-  $Init$  is an initialization function. It is defined from  $P$  into closed expressions such that:

$$\forall p \in P : [Type(Init(p)) = Col(p)_{MS}]. \quad (7)$$

$Type(v)$  – it is used for specification of the variable types,  $Type(expr)$  – is used for specification of the expressions and  $Var(expr)$  for the set of expressions' variables.

The syntactical elements of the Colored Petri Net are essentially places, transitions, arcs and inscriptions. The elements of the CPN are presented in the Fig. 1.

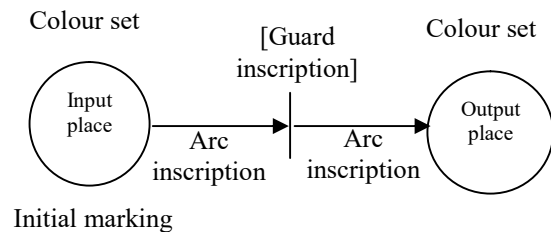


Figure 1. The elements of the Colored Petri Net [5].

The collection of tokens on the places determinate at any time the state of the discrete-event system. The arcs represent the relation between places and transactions and determinate a way how a state changes when an event occurs. The inscription above arcs are the functions, that determinate the actions and quantity of tokens moved between places. The transitions represent the possible actions and the guard function introduce the restriction to the possible actions that can occurs. The colored sets are the types of tokens attached to the respectively places and initial marking set the initial configuration of the Colored Petri Net [5].

## III. CONTEXT FREE GRAMMAR

A grammar by the Chomsky classification is defined as a quadruple [12]

$$G = (V, \Sigma, P, S), \quad (8)$$

where:

- $V$  - is a finite set of non-terminal symbols;
- $\Sigma$  - is a finite set of terminal symbols;

$$V_N \cap V_T = \emptyset,$$

- $S \in N$  is a start symbol;
- $P$  – is a finite set of productions of rules:

$$P \subseteq (V \cup \Sigma)^* V (V \cup \Sigma)^* \times (V \cup \Sigma)^* \quad (9)$$

The families of languages generated by context-sensitive, context-free, linear and regular grammars are denoted by CS, CF, LIN and REG, respectively. The next strict inclusions, named Chomsky hierarchy, hold [7, 9-10]:

$$\text{REG} \subset \text{LIN} \subset \text{CF} \subset \text{CS} \subset \text{RE}.$$

Usually, the rules  $(u, v) \in P$  are written in the form  $u \rightarrow v$ , and the rule  $u \rightarrow \varepsilon$  is called the erasing rule.

Let  $G = (V_N, V_T, P, S)$  is a grammar. The language generated by the grammar  $G$  is denoted by  $L(G)$  and represents the set of all strings of terminals that are derivable from the starting state  $S$ :

$$L(G) = \{x \mid S \rightarrow^* x, x \in \Sigma^*\}. \quad (10)$$

A string  $x \in (V \cup \Sigma)^*$  directly derives a string  $y \in (V \cup \Sigma)^*$  in grammar  $G$ , written as  $x \Rightarrow y$  if there is a rule  $u \rightarrow v \in P$ , such that  $x = x_1 u x_2$  and  $y = x_1 v x_2$  for some  $x_1, x_2 \in (V \cup \Sigma)^*$ .

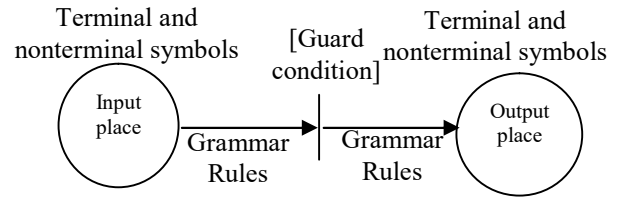
A grammar  $G = (V_N, V_T, P, S)$  is called a context free grammar if each rule

$$U \rightarrow v \in P \text{ has } u \in V \text{ and } v \in (V \cup \Sigma)^*. \quad (13)$$

## VI. CONTEXT FREE GRAMMAR REPRESENTATION BY THE COLORED PETRI NET

Forward reachability in Colored Petri Net, is a concept that a given marking  $M_f$  is reachable from  $M_0$ , where  $M_0$  is initial marking. The backward reachability, means that if a marking  $M_f$  is reachable from  $M_0$ ,  $M_0$  is backward reachable from  $M_f$ . To perform the backward and forward reachability analysis, it is done based on the defined CPN structure and given transformation rules according to the given guard functions and transition functions [1].

The representation of the context free grammar by the Coloured Petri Net is given in the Fig. 2.



Initial marking

Figure 2. The representation of the context free grammar by the Colored Petri Net.

The construction of the Colored Petri Net presented in the Fig. 2 is based on the idea of using similarity between the firing of a transition based on function attached to each arc and guard condition and with the application of a production rule in a derivation in which tokens represent nonterminal and terminal symbols.

A context-free Colored Petri Net is defined as the 10-tuple

$$\text{CPN} = (\Sigma, P, T, A, \text{Nod}, \text{Col}, \text{Grd}, \text{Expr}, \text{Init}), \quad (14)$$

where :

- $\Sigma$  is a finite set of terminal symbols;
- $P$  is a finite set of places;
- $T$  is a finite set of transitions;
- $A$  is a finite set of arcs such that:

$$P \cap T = P \cap A = T \cap A = \emptyset. \quad (15)$$

-  $\text{Nod}$  is a node function. It is defined from  $A$  into

$$\text{Nod} : A \rightarrow (P \times T) \cup (T \times P). \quad (16)$$

-  $\text{Col}$  is a color function. It is defined from  $P \cup T$  into  $\Sigma$  such that:

$$\text{Col} : P \rightarrow (V \cup \Sigma)^*, \quad (17)$$

where  $V$  is a set of nonterminal symbols.

$\Sigma$  is a set of terminal symbols.

-  $\text{Grd}$  is a guard function. It is defined from  $T$  into expressions such that:

$$\forall t \in T : [\text{Type}(G(t)) = \text{Bool} \wedge \text{Type}(\text{Var}(G(t))) \subseteq (V \cup \Sigma)^*]; \quad (18)$$

The guard function is a logical expression that must take the true logical value for the transition to take place.

-  $\text{Expr}$  is an arc expression function. It is defined from  $A$  into expressions such that:

$$\forall a \in A: [\text{Type}(\text{Expr}(a)) = \text{Col}(p(a))_{\text{MS}} \wedge \text{Type}(\text{Var}(\text{Expr}(a))) \subseteq (V \cup \Sigma)^*], \quad (19)$$

where  $p(a)$  is the place of  $N(a)$ ;

-  $\text{Init}$  is an initialization function. It is defined from  $P$  into closed expressions such that:

$$\forall p \in P : [\text{Type}(\text{Init}(p)) = \text{Col}(p)_{\text{MS}}]. \quad (20)$$

#### V. CONCLUSIONS

In this paper, it is proposed a new approach for context free grammar design and analysis by the Colored Petri Net formalism. Colored Petri Net is a powerful modelling tool, that can be seen as one of the most advanced behavior modeling techniques, that is used to model and specify the behavior of concurrent and distributed discrete event systems. This approach can be easily used for modeling and design the agent-based systems.

Grammar systems can be considered as a formal model for a phenomenon of solving a given problem by dividing it into sub problems (grammars) to be solved by several parts. The control of rules in grammar systems also allows increasing computational power grammar systems, but the context free grammar have the limitation in description of the concurrent or synchronous event and in these way the Colored Petri Net introduce the parallel firing strategy, which can define the concurrently parallelism situations in formal language theory.

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# A Second Order-Cone Programming Relaxation for Days-Off Scheduling Problem

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**Abstract**— This paper relates the numerical solution of one of the well-known problems related to production systems. Namely, it is about Days-Off Scheduling Problem, which is reformulated in terms of non-convex minimization problems with quadratic constraints. After relaxation of the above problem, a model based on second-order cone programming is obtained.

**Keywords**—days-off scheduling; binary quadratic programming; days-off scheduling; style; styling (key words)

## I. INTRODUCTION

One of the most frequent and at the same time most difficult organizational problems is the days off planning of the employees of the economic production units provision of services or trade such as IT companies, hospitals, restaurants, stores, public transport, etc. The problem is to minimize the number of working days, satisfying the working conditions and individual preferences of employees.

Such problems were first formulated in terms of integer linear programming by Danzig [1] in 1954. Over the years the problem of planning the working hours of employees in different companies has been addressed by many researchers: in the field of public transport services [2,3], hospital staff scheduling [4,5], scheduling days off [6,7,8,9]. The paper [10] presents a detailed study of the classification of workforce planning problems.

The issues discussed are part of the NP-hard class, being combinatorial optimization problems.

In practical situations the problem is an optimization problem in integers which makes it difficult and time consuming to build a good algorithm.

In this paper, the authors treat the model proposed in [11, 12] to maximize the number of consecutive days off for employees of an economic unit, which is based on the construction of a quadratic programming problem.

The following notation is used in this paper:

$$x^T y = \sum_i x_i y_i \quad (1)$$

for the inner product of column vectors  $x$  and  $y$ ;  
 $x^T$  denotes in (1) the transposition of  $x$  and  $x^T$  is a row vector;

$$\|x\|_2 = \sqrt{x^T x} \text{— the Euclidean norm of a vector } x;$$

$x_i$  - denotes the  $i^{\text{th}}$  component of  $x$ ;

$e_i$  - the vector with all components equal to zero, except the  $i^{\text{th}}$  component which is equal to one;

$I$  - the identity matrix.

## II. THE DAYS OFF PLANNING PROBLEM

This paper will focus on finding a solution for maximizing the number of consecutive days off of the employees of a specific IT company.

The following notation is used:

$p$  - number of employees

$T_i$  - number of days-off for the  $i$  employee of the week, in

$$i \in \{1, 2, \dots, p\}$$

$n_k$  - number of necessary employees in the day  $k$ ,

$$k \in \{1, 2, \dots, 7\}$$

the constraints for satisfying daily work requirements, such as a specific task to be assigned to a class of workers that have abilities for it

$$c = (c_1, c_2, \dots, c_7)$$

$c_k$  is the class of workers  $q_k$  that is necessary for accomplishing a specific task for the day  $k$

$$q_k \in \{1, 2, \dots, n_k\}, \quad n_k = \{1, 2, \dots, 7\}$$

For each  $i \in \{1, 2, \dots, p\}$  worker it is introduced 7 binary variables  $x_{ik}$ ,  $k \in \{1, 2, 3, \dots, 7\}$ , such that

$$x \in \begin{cases} 1, \text{ if the } k \text{ day is an off - day} \\ \text{for the } k \text{ worker} \\ 0, \text{ otherwise} \end{cases} \quad (2)$$

The matrix

$$X = \begin{pmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} & x_{16} & x_{17} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} & x_{26} & x_{27} \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ x_{p1} & x_{p2} & x_{p3} & x_{p4} & x_{p5} & x_{p6} & x_{p7} \end{pmatrix} \in R^{p \times 7}$$

The main objective is maximizing the number of consecutive days off in a week.

Then it can be defined the objective function as follows:

$$g(x) = \sum_{i=1}^p \left( \sum_{k=1}^6 x_{ik} x_{ik+1} + x_{i7} x_{i1} \right) =$$

$$= \sum_{i=1}^p \left( \sum_{k=1}^6 x_{ik} x_{ik+1} + x_{i7} x_{i1} \right)$$

The column vector is noted

$$x = (x_{11} x_{12} \dots x_{17}, x_{21} x_{22} \dots x_{27} \dots x_{p1} x_{p2} \dots x_{p7}) \in R^n$$

$$n = 7p$$

$$x \in R^n$$

The following notations are used

$$Q = \begin{pmatrix} 0 & \frac{1}{2} & 0 & 0 & 0 & 0 & \frac{1}{2} \\ \frac{1}{2} & 0 & \frac{1}{2} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{2} & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{2} & 0 & \frac{1}{2} & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{2} & 0 & \frac{1}{2} & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{2} & 0 & \frac{1}{2} \\ \frac{1}{2} & 0 & 0 & 0 & 0 & \frac{1}{2} & 0 \end{pmatrix} \in R^{7 \times 7} \quad (3)$$

$$Q = \begin{pmatrix} Q_0 & 0 & \dots & 0 \\ 0 & Q_0 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & Q_0 \end{pmatrix} \in R^{n \times n} \quad (4)$$

and

$$g(x) = x^T Q x$$

The following constraints are defined:

- I. For each day  $k$ , the number of workers who take this day off is  $p - n_k$ .

$$\rightarrow \sum_{i=1}^p x_{ik} = p - n_k, \quad k \in \{1, \dots, 7\} \quad (5)$$

The following notations are used

$$\bar{A}_0 = \begin{pmatrix} 1 & 0 & \dots & 0 & 1 & 0 & \dots & 0 & \dots & 1 & 0 & \dots & 0 \\ 0 & \backslash & \dots & 1 & 0 & \backslash & \dots & 1 & \dots & 0 & \backslash & \dots & 1 \\ \vdots & \backslash & \dots & 0 & \vdots & \backslash & \dots & 0 & \dots & \vdots & \backslash & \dots & 0 \\ 0 & \dots & 0 & 0 & 0 & \dots & 0 & 1 & \dots & 0 & \dots & 0 & 1 \end{pmatrix}, \quad (6)$$

$$\bar{b} = \begin{pmatrix} p - n_1 \\ p - n_2 \\ \vdots \\ p - n_7 \end{pmatrix} \quad (7)$$

so

$$\bar{A}_0 x = \bar{b}.$$

It is noted that



$$\bar{A}_0 = \left( \begin{pmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 1 \end{pmatrix} \right)$$

i.e.

$$\bar{A}_0 = (I \ I \ \dots \ I) \in R^{7 \times n}$$

II. Each worker has  $T_i$  days off during the week

$$\left. \begin{aligned} x_{11} + x_{12} + \dots + x_{17} &= T_1 \\ x_{21} + x_{22} + \dots + x_{27} &= T_2 \\ \dots + \dots + \dots + \dots &= \dots \\ x_{p1} + x_{p2} + \dots + x_{p7} &= T_p \end{aligned} \right\} \quad (8)$$

with the matrix

$$\bar{A}_1 = \begin{pmatrix} 1 & \dots & 1 & \dots & 10 & \dots & 0 & \dots & 0 & \dots & 0 & \dots & 0 & \dots & 0 \\ \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots \\ 0 & \dots & 0 & \dots & 0 & \dots & 1 & \dots & 1 & \dots & 0 & \dots & 0 & \dots & 0 \\ \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots & & \vdots \\ 0 & \dots & 0 & \dots & 0 & \dots & 0 & \dots & 0 & \dots & 1 & \dots & 1 & \dots & 1 \end{pmatrix}, \quad (9)$$

and the vector

$$T = \begin{pmatrix} T_1 \\ T_2 \\ \vdots \\ T_p \end{pmatrix}$$

Example, for  $p = 3$ ,

$$\left. \begin{aligned} x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} + x_{17} &= T_1 \\ x_{21} + x_{22} + x_{23} + x_{24} + x_{25} + x_{26} + x_{27} &= T_2 \\ x_{31} + x_{32} + x_{33} + x_{34} + x_{35} + x_{36} + x_{37} &= T_3 \end{aligned} \right\}$$

$$\bar{A}_1 = \begin{pmatrix} 1111111 & 0000000 & 0000000 \\ 0000000 & 1111111 & 0000000 \\ 0000000 & 0000000 & 1111111 \end{pmatrix},$$

and

$$A_i = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \leftarrow \text{the row } i$$

$$\bar{A}_1 = (A_1 \ A_2 \ \dots \ A_n) \in R^{p \times n}$$

$$\bar{A}_1 x = T$$

III. The constraints defined by the tasks of the day is a set:

$$c = (c_1, c_2, \dots, c_k).$$

Where  $c_k$  is the class of workers  $q_k \in \{1, 2, \dots, n_k\}$ , which is needed to perform the specific task for the day  $k \in \{1, 2, \dots, 7\}$ .

These classes are determined by the company and are represented by the matrix  $\bar{A}_2 \in \{0, 1\}^{2 \times n}$  such that

$$Q_{ik} = \begin{cases} 1, & \text{the presence of the worker } i \\ & \text{is required on day } k \\ 0, & \text{otherwise} \end{cases} \quad (10)$$

and

$$\bar{A}_2 x = 0$$

Considering the above restrictions and notations, the problem of scheduling consecutive days off of workers is reduced to solving a quadratic programming problem.

III. QUADRATIC PROGRAMMING MODEL [12]

Consider the quadratic programming problem:

$$y(x) = x^T Q x \rightarrow \max$$

subject to

$$\begin{cases} \bar{A}_0 x = b, \\ \bar{A}_1 x = T, \\ \bar{A}_2 x = 0, \\ x \in \{0, 1\}^n \end{cases} \quad (11)$$

The following notation is used

$$A = \begin{pmatrix} \bar{A}_0 \\ \bar{A}_1 \\ \bar{A}_2 \end{pmatrix} \in R^{m \times n},$$

$$m = 14 + p,$$

$$n = 7p$$

$$b = \begin{pmatrix} b^I \\ T \\ 0 \end{pmatrix} \in R_+^m$$

The problem can be formulated as follows:

$$f(x) = -g(x) = -x^T Q x \rightarrow \min$$

subject to

$$Ax = b,$$

$$x \in \{0,1\}^n$$

#### IV. SOLVING THE PROBLEM OF QUADRATIC PROGRAMMING

Because of their high level of difficulty, to solve these problems obtained by quadratic programming, there are many methods [12, 17, 18].

The authors propose to solve these problems using second order - cone programming relaxation.

#### V. A SECOND ORDER - CONE PROGRAMMING RELAXATION [13]

The conditions that  $x_i$  are binary are equivalent to the non-convex quadratic constraints:

$$x_i^2 - x_i = 0,$$

which in turn are equivalent to the following constraints:

$$\left. \begin{array}{l} x_i^2 - x_i \leq 0, \\ \sum_i (x_i - x_i^2) \leq 0, \end{array} \right\}$$

Define  $M_i = e_i e_i^T$  - the matrix whose all entries are zero, except the  $(i, i)$  entry which is one:

$$M_i = \begin{pmatrix} 0 & \dots & 0 & \dots & 0 \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ 0 & \dots & 1 & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & \dots & 0 & \dots & 0 \end{pmatrix} \leftarrow i$$

$\uparrow i$

The constraint  $x_i^2 - x_i \leq 0$  can thus be reformulated as:

$$x^T M_i x - e_i^T x \leq 0,$$

from which

$$x^T (M_i + I) x - e_i^T x - x^T x \leq 0, \quad (12)$$

where

$$x = (x_1, x_2, \dots, x_n)^T.$$

It easily observed the matrix  $M_i + I$  is positive definite that it can be rewritten using Cholesky decomposition as follows:

$$M_i + I = L_i^T L_i = L_i^2$$

where

$$L_i = \sum_{s \neq i} e_s e_s^T + \sqrt{2} e_i e_i^T.$$

$$L_i = \begin{pmatrix} 1 & 0 & \dots & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \sqrt{2} & \dots & 0 \\ \vdots & \vdots & \dots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & 0 & \dots & 1 \end{pmatrix}$$

Letting nonnegative variable  $t_0 = x^T x \geq 0$ , the relationship (12) can be rewritten as:

$$\omega_i^T \omega_i \leq \xi_i \eta_i \quad (13)$$

where

$$\omega_i = L_i^T y = \sum_{s \neq i} y_s e_s + \sqrt{2} y_i e_i, \quad \xi_i = 1$$

and

$$\eta_i = e_i^T y + t_0 \geq 0.$$

A hyperbolic constraint (13) is equivalent to the second-order cone constraints [14]:

$$\left\| \frac{1 - e_i^T y - t_0}{2L_i y} \right\|_2 \leq 1 + e_i^T y + t_0. \quad (14)$$

On the other hand it is observed that the condition



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$$\sum_i (x_i - x_i^2) \leq 0$$

implies the linear constraints:

$$\sum_i x_i - t_0 \leq 0 \quad (15)$$

Finally, it can be mentioned that the quadratic constraint

$$t_0 = y^T y, \quad (16)$$

used above in constructing second-order cones (9) and (10) are non-convex. The constraint (12) is relaxed such that:

$$y^T y \leq t_0.$$

The last constraints are equivalent to following second order cones constraint:

$$\left\| \frac{1 - t_0}{2y} \right\|_2 \leq 1 + t_0, \quad (17)$$

Thus, the problem (1)-(6) might be relaxed to the following second-order conic programming problem:

$$\sum_{i=1}^n x_i \rightarrow \min$$

subject to

$$Ax = b.$$

and the constraints (14), (15), (17).

## VI. CONCLUSIONS

This paper contains the numerical solving of the Days-Off Scheduling Problem reformulated in terms of non-convex minimization problems, to find a solution for days off scheduling problem with the constraints defined by the tasks of the day.

This paper has proposed a solution for scheduling the staff days off by a relaxation of the Days-Off Scheduling Problem in terms of second-order cone programming. This problem can be effectively solved by the interior point algorithm ([15]).

There is specialized software for solving conic optimization problems ([16]). Future work includes implementing the solution for scheduling days off for an IT company staff

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# Using Luong's attention mechanism and simple classifiers to make people overcome psychological illnesses

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**Abstract**—Conversational AI is the set of technologies behind automated messaging and speech-enabled applications that offer human-like interactions between computers and humans. It can communicate like a human by recognizing speech and text, understanding intent, deciphering different languages, and responding in a way that mimics human conversation. The objectives of this research are to explore the applicability of conversational AI technology in creating a chatbot for assisting people struggling with psychological illnesses and mental dysfunctions.

The main hypothesis is that having an NLP system containing an NLG submodule (module for generation of the Natural text) and an NLU submodule (module for recognizing the emotional state of the person using this chatbot. We use an NLU submodule because we can't rely only on the artificially generated text as a response for a person in an awful emotional state. Even more, we can use the information from the NLU submodule for stronger strategies generation to ensure emotional support.

The system represents a chatbot with two NLP modules, Natural Language Generation, being represented by a Seq2Seq Neural Network with the Luong's attention mechanism, and a Natural Language Understanding module represented by a classical classification NLP Pipeline that classifies the text in multiple emotional state classes. To interact with the user it uses the Telegram API and is able to save the user messages and the chatbot answers into a simple SQLite Data Base.

Even if this implementation wouldn't replace the real psychologists, with accurate management and maybe with additional inputs for professionals in psychology it may become a tool for detecting people with possible psychological and mental illnesses which can become the first step in further therapy with a real psychologist.

**Keywords**—Neural Networks; Natural Language Processing; Python; PyTorch; Luong's attention mechanism

## I. INTRODUCTION

In today's world full of high speed and stress, the psychological state of people has become more affected by psychological disorders. Even if going to a psychologist isn't a big deal, people are ashamed of this, especially men. In the era where people have a lot of trust in written software and Artificial Intelligence, a lot of technological solutions to this problem appeared. Woebot[1], Moodnotes[2], Wysa[3], Youper[4] just mention some, are chatbots oriented on helping and assisting people with psychological disorders.

This work is exploring the implementation in more technical details of a chatbot created to assist people with psychological disorders. The initial problem that this solution is addressing was that people who are struggling with bad feelings or psychological disorders don't always have enough courage to address them to a psychologist. That's why a chatbot that can handle a dialog with a person and at the same time can detect the emotional and psychological state of the person by how it is chatting and direct the communication in the direction that will bring the person to a more positive state was created.

## II. SOLUTION

### A. General description.

The system is constructed from the following elements: the telegram API (Initially, the first version of the chatbot was built on the telegram platform), the text classification pipeline, the emotional state to response mapper, the seq2seq model for text generation, and the database. The general scheme of the interaction between all modules of the chatbot is listed below:

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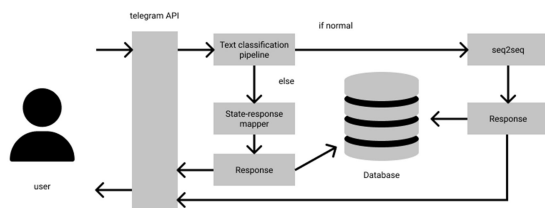


Figure 1: The architecture of the chatbot.

### B. Telegram API

The telegram platform offers a big range of possibilities to create a chatbot. However, for this project, was used the simplest way to do this - get requests. All interaction with the telegram is stored in the telegram\_bot class, which has the access token and the function for the interaction with it. Below are listed the links for the API interaction:

The endpoint for getting the messages sent to the bot:

<https://api.telegram.org/bot<token>/getUpdates?timeout=100&offset=<offset>>

The endpoint to send messages from the bot:

[https://api.telegram.org/bot<token>/sendMessage?chat\\_id=<chat\\_id>&text=<msg>](https://api.telegram.org/bot<token>/sendMessage?chat_id=<chat_id>&text=<msg>)

These endpoints are used by the chatbot to interact with the telegram users, however, it can be adapted to other messaging platforms too.

### C. The data sources

As was said the architecture of the chatbot includes 2 models: one for text classification and one for text generation. Each model had its data source. For the text generation model, was used the industry-standard - Cornell Movie-Dialog Corpus[5]. It contains a large metadata-rich collection of fictional conversations extracted from raw movie scripts, and it doesn't contain any sentiment label.

The emotional state classification model, were extracted through the Reddit API[6] redds from the following subreddits: rape, PTSD, anxiety, abuse, depression, and bullying. By adding 800 additional ham samples from the SMS Spam Collection Data Set[7] the data set for the emotional state classification task was created. Below are listed the number of samples per class:

**Table 1:** The number of samples of every class of emotional state classifier.

Class	Number of samples
rape	878
ptsd	811

normal	800
anxiety	720
abuse	709
depression	622
bullying	610

### D. The text classification pipeline

Unfortunately, we cannot pass simple text to a machine learning model. The text should be preprocessed and represented in an optimal numerical form. Usually, for that, an NLP pipeline is constructed. The pipeline is illustrated below:



Figure 2: A classic NLP classification pipeline.

The first step in this pipeline is the text normalization step. It is represented by bringing the text to lowercase, eliminating the special symbols like newline and additional spaces. In our case, an additional step was added: erasing from text everything that isn't text.

The second step is the word extraction step. Following Zipf's law, we must extract the most frequent tokens (a.k.a. stopwords) which we can obtain from the nltk library[8], and the hapaxes - the tokens that we find only once in the whole corpus.

The next step is text vectorization. During the vectorization step, we try to represent text in a vectorial form. One of the most popular ones is the TF-IDF one. TF-IDF vectorization was chosen because this representation gives low scores to words that are very frequent throw the corpus, lowering in such a way their impact on the model, and giving higher scores to the more rare tokens.

The final module of the pipeline is the Machine Learning model itself - in our case, it is the Logistic Regression model. It gave the highest accuracy. The accuracy of other models are listed below:

**Table 2:** The accuracy of the different pipelines.

Model	Accuracy
Bernoulli Naive Bayes	0.511

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Multinomial Naive Bayes	0.440
Logistic Regression	0.740
Support Vector Machines	0.726
Decision Tree	0.581
Random Forest	0.677

The text classification pipeline is returning one of the classes listed in table nr. 1. If the returned class is 'normal' then the response is generated by the text generation model, else it is chosen from the emotional state - response mapper.

#### E. The emotional state - response mapper

To be sure that the user of the chatbot is getting the messages that he or she needs in her emotional state, for every non-normal emotional state were created a list of 10 predefined responses. To add more interactivity whenever a non-normal emotional state is triggered a random response from its list of responses is chosen as a response.

#### F. The text generation model

The text generation model is represented by a seq2seq model. The goal of the seq2seq model is to take a variable-length sequence as an input and return a variable-length sequence as an output using a fixed-sized model.

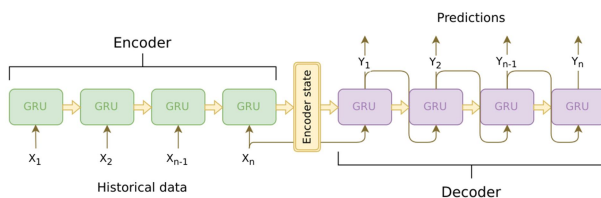


Figure 2: The seq2seq architecture.

Sutskever et al.[9] discovered that this can be achieved by using two separate recurrent neural networks together. One RNN acts as an encoder, which encodes a variable lengths input sequence to a fixed-length context vector. In theory, this context vector will contain semantic information about the query sentence that is input to the bot. The second RNN is a decoder, which takes an input word and the context vector, and returns a guess from the next word in the sequence and a hidden state to use in the next iteration.

At the heart of our encoder is a multi-layered Gated Recurrent Unit, invented by Cho et al.[10] in 2014. In this

project a bidirectional variant of the GRU, meaning that there are essentially two independent RNNs: one that is fed the input sequence in normal sequential order, and one that is fed the input sequence in reverse order. The outputs of each network are summed at each time step. Using a bidirectional GRU will give us the advantage of encoding both past and future contexts.

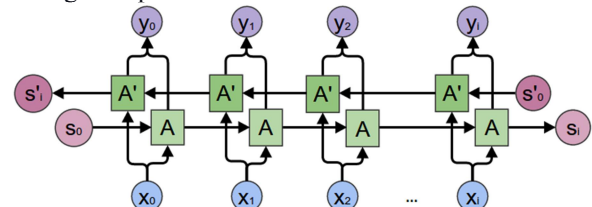


Figure 3: Bidirectional RNN.

The decoder RNN generates the response sentence in a token-by-token fashion. It uses the encoder's context vectors, and internal hidden states to generate the next word in the sequence. It continues generating words until it outputs an EOS (End Of Sequence) token. A common problem with a vanilla seq2seq decoder is that if we rely solely on the context vector to encode the entire input sequence's meaning, we will likely have information loss. This is especially the case when dealing with long input sequences, greatly limiting the capability of our decoder.

To combat this, Bahdanau et al.[11] created an "attention mechanism" that allows the decoder to pay attention to certain parts of the input sequence, rather than using the entire fixed context at every step.

Luong et al.[12] improved upon Bahdanau et al.'s groundwork by creating "Global attention". The key difference is that with "Global attention", we consider all of the encoder's hidden states, as opposed to Bahdanau et al.'s "Local attention", which only considers the encoder's hidden state from the current time step. Another difference is that with "Global attention", we calculate attention weights, or energies, using the hidden state of the decoder from the current time step only. Bahdanau et al.'s attention calculation requires knowledge of the decoder's state from the previous time step. Also, Luong et al. provide various methods to calculate the attention energies between the encoder output and decoder output which are called "score functions":

$$\text{score}(\mathbf{h}_t, \bar{\mathbf{h}}_s) = \begin{cases} \mathbf{h}_t^\top \bar{\mathbf{h}}_s & \text{dot} \\ \mathbf{h}_t^\top \mathbf{W}_a \bar{\mathbf{h}}_s & \text{general} \\ \mathbf{v}_a^\top \tanh(\mathbf{W}_a [\mathbf{h}_t; \bar{\mathbf{h}}_s]) & \text{concat} \end{cases}$$

Figure 4: The score function of Loung's model.

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Overall, the Global attention mechanism can be summarized by the following figure:

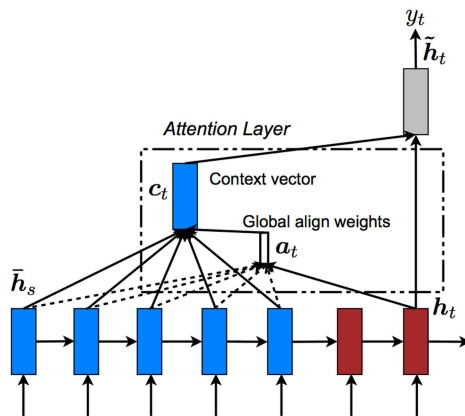


Figure 5: The Global attention mechanism.

The last step for an operating seq2seq model is the Greedy decoding. Greedy decoding is the decoding method that we use during training when we are not using teacher forcing.

#### G. The database

The last module of the Chatbot is the database. It has only 2 tables: messages and users. The first one is used to store the data about messages received by the chatbot, while the second one store the information about users that interact with it. When a new user is sending messages to the chatbot it is added to the database. The structure of the database is shown below:

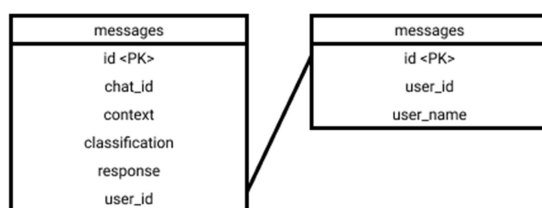


Figure 6: The database schema of the chatbot.

To make the interaction between the chatbot and the database easier, a database manager was created.

### III. THE RESULT

Below are shown some examples of the interaction of people with the chatbot:

**user:** Hi

**Bot:** hi

**user:** how are you feeling today?

**Bot:** fine

**user:** do you like chocolate?

**Bot:** yes

**user:** why do you like chocolate?

**Bot:** because i m a puppeteer it

**user:** What do you mean by that?

**Bot:** i don t know

Now let's see an example of a person that may go through some bad emotions:

#### Scenario 1:

**user:** I think that I will end my life

**Bot:** Do not worry, I am here to help

**user:** I don't see any sense in living my life

**Bot:** Don't cry, we're in this together

#### Scenario 2:

**user:** I got sick of bullying at school

**Bot:** Why do you think this is happening?

**user:** Because my fellows are hating me

**Bot:** you re not ? ? ?

**user:** No, I don't hate them

**Bot:** Remember you're not alone

**user:** Thank you so much

**Bot:** you re welcome

### IV. CONCLUSION

This work is exploring the implementation in more technical details of a chatbot created to assist people with psychological disorders. The initial problem that this solution is addressing was that people who are struggling with bad feelings or psychological disorders don't always have enough courage to address them to a psychologist. To handle normal dialogs were implemented a Seq2Seq Neural Network base on Loung's attention mechanism, which is generating responses based on the user's input, and a text classification pipeline to identify the emotional state of the person.

Right now the implementation made will never replace a professional psychologist because the models that are used in this chatbot aren't perfect. The text classification model isn't ideal, and a more sensitive model is needed. Also sometimes the text generated by the chatbot isn't always coherent enough. Besides, that in psychology text communication isn't always the unique way to find what is happening with the patient, a lot of information is extracted from non-verbal and para-verbal communication.

However, this experiment offers a new territory to explore, where we can try new models and maybe even new architectures of the chatbot itself.



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## **For Notes**



# Software Engineering & Cybersecurity Session



# Prioritization of Cybersecurity Measures

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**Abstract.** The considerable losses caused by the low level of cyber security of companies, institutions and so on and the limited financial resources available imply the need to prioritize the implementation of measures to counter cyber attacks. For this purpose, the respective optimization problem is formulated as a Boolean mathematical programming one. At large dimensions, the use of known methods of solving the problem requires a large volume of calculations. That's why, a simple rule for approximately solving the problem is obtained. By computer simulation, it is shown that the error of the solution when using this rule decreases considerably with the increase of the number of cybersecurity measures, more accurate – the more detailed such measures are. In order to reduce the error of solutions, three other simple algorithms are also proposed. The latter of these algorithms is more detailed and allows to reduce to a greater extent the solutions' error.

**Keywords:** algorithm; entity; cybersecurity means; ordering rule; optimization problem.

## I. INTRODUCTION

Information is a strategic resource. Many parts of it are confidential (personal data, commercial secret, state secret, e-transactions, etc.). Unauthorized access to such information, but also massive and targeted misinformation of the population, especially through Internet, leads to considerable losses, slowing the pace of economic growth and of advancing the well-being of the population.

For example, IT frauds cause losses of 0.5-5% of the total expenditure of public institutions [1]. Cybersecurity Ventures expects global cybercrime costs to grow by 15 percent per year over the next five years, reaching \$10.5 trillion USD annually by 2025 [2]. This is about 9,3% of the global GDP estimate of 113,5 trillion USD done by International Monetary Fund [3].

At the same time, global spending on cybersecurity products and services for defending against cybercrime is projected to exceed \$1 trillion cumulatively over the five-year period from 2017 to 2021 [4]. Part of it, the global information security market, is forecast to grow at a five-year CAGR of 8.5% to reach \$170.4 billion in 2022 [5].

So, the global losses caused by the low security of cyberspace are considerably higher than the costs of implementing and maintaining those means of

cybersecurity. Anyway, both are considerable and it is important the rational use of available resource for the efficient security of informatics infrastructures at all levels, especially of the critical ones. In this paper, some aspects of the prioritization of cybersecurity measures are systemized and discussed, taking into account the available financial resources.

## II. ESSENCE OF THE PROBLEM

They are considered  $n$  entities (cybersecurity measures, companies, subdivisions, components of informatics infrastructure, etc.) in terms of improving their cybersecurity. For the latter, in this paper, the term "informatics security" (i-security) usually is used. Each entity  $i \in G$ ,  $|G| = n$ , is characterized by:

$a_i$  – annual losses caused by the insufficient degree of i-security within entity  $i$ ;

$b_i$  – annual costs with the implementation and maintenance of needed degree of i-security within entity  $i$ . It is considered that at a such degree of i-security there is  $a_i = 0$ ;

$C$  – financial resources available for the implementation and maintenance of i-security means.

Obviously, the entities for which  $a_i \leq b_i$  ( $c_i = a_i - b_i \leq 0$ ) and also those for which  $b_i > C$  is not rational to include in set  $G$ . So, one has  $a_i > b_i$  and  $b_i \leq C$ .

It is necessary to determine the optimal set  $B \subseteq G$  of entities within which to ensure the necessary degree of i-security by minimizing the summary annual losses and costs involved

$$I = \sum_{i \in A} a_i + \sum_{k \in B} b_k \rightarrow \min \quad (1)$$

at

$$\sum_{k \in B} b_k \leq C, \quad (2)$$

$$A \cup B = G, \quad (3)$$

where  $A$  is the set of entities with insufficient degree of i-security, and  $B$  is the set of i-secure entities.

The problem  $\{(1)-(3)\}$  is one of mathematical programming. Taking into account its peculiarities, this problem can be formulated in another form. Let  $x_i$  is a Boolean variable that takes the value 0 if  $i \in A$  and the value 1 if  $i \in B$ . Then the summary annual losses and

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costs with i-security for entity  $i$  can be determined as  $(1 - x_i)a_i + x_i b_i$ ,  $i \in G$ , and relations (1) and (2) – as

$$I = \sum_{i \in G} [(1 - x_i)a_i + x_i b_i] \rightarrow \min \quad (4)$$

at

$$\sum_{i \in G} x_i b_i \leq C, \quad (5)$$

Thus, the problem  $\{(1)-(3)\}$  can be replaced by the  $\{(4), (5)\}$  one. The latter is a Boolean mathematical programming problem with the unknowns  $x_i$ ,  $i \in G$ .

To solve the problem  $\{(4), (5)\}$ , the respective well-known methods/computer applications can be used. But, first, at large dimension of the problem they need a considerable volume of calculations and, second, not always the respective means are available. Therefore, sometimes may be sufficient another, simplistic, approach.

### III. THE MAIN RULE TO PROBLEM SOLVING

Let's consider the problem in the form  $\{(1)-(3)\}$ .

**Statement 1.** It is preferable, in the meaning of (1), to ensure the needed degree of i-security within entity  $i$  than to ensure it within entity  $j$ , if at equal other conditions occurs  $a_i / b_i > a_j / b_j$ , that is

$$i > j, \text{ if } a_i / b_i > a_j / b_j. \quad (6)$$

Indeed, let's examine the case when sizes  $a_i$ ,  $b_i$ ,  $l \in G$  are natural numbers. If these sizes are financial data, for example losses and costs in euro cents or dollar cents, then they are natural numbers.

Let  $c_s = a_s - b_s$ ,  $s \in G$  and  $M$  is the greatest common factor of the natural numbers  $b_i$  and  $b_j$ , and  $z_i = b_i / M$ ,  $z_j = b_j / M$ . So, entity  $i$  can be considered as consisting of  $z_i$  unities to each of which corresponds (conventionally) the value  $M$  of annual costs for the implementation of necessary degree of i-security and, similarly, entity  $j$  can be seen as consisting of  $z_j$  unities to each of which corresponds (conventionally) the value  $M$  of annual costs for the implementation of necessary degree of i-security.

Then, because of  $M = b_i / z_i = b_j / z_j$ , if  $c_i / z_i > c_j / z_j$  and other conditions are equal, it is preferable to implement the i-security means within entity  $i$  than to implement them within entity  $j$ . By replacing  $z_i$  and  $z_j$  in this inequality, one has  $c_i / z_i = M c_i / b_i > c_j / z_j = M c_j / b_j$ , that is  $M c_i / b_i > M c_j / b_j$ , so  $c_i / b_i > c_j / b_j$  or  $a_i / b_i > a_j / b_j$ . ▽

Now, using the same approach, one can observe that the rule (6) is adequate also for real positive values of sizes  $a_i$ ,  $b_i$ ,  $l \in G$ , too. ■

### IV. A SIMPLE APPROXIMATE SOLUTION TO THE PROBLEM

The first step, when initiating the works on i-securing a set of entities, is to determine the parameters  $a_i$  and  $b_i$  values for each entity  $i$ . The second one, knowing the available in this purpose financial resources  $C$ , is to exclude from the project entities for which  $a_i \leq b_i$  ( $c_i = a_i - b_i \leq 0$ ) and also those for which  $b_i > C$ . So, one has to solve the problem (1)-(3).

Further, it is easy to observe that conditions (6) are transitive, that is if  $a_i / b_i > a_j / b_j$  and  $a_j / b_j > a_k / b_k$ , then

$a_i / b_i > a_k / b_k$ . Thus, the third step is to order and renumber the entities  $i \in G$  according to the rule

$$i > i + 1, \text{ if } a_i / b_i > a_{i+1} / b_{i+1}, i = \overline{1, n}. \quad (7)$$

The fourth step is to include in set  $B$  the first  $k$  entities of set  $G$ , where  $k := \max \{i \mid \sum_{j=1}^i b_j \leq C\}$ .

Usually, the probability that takes place the equality  $\sum_{i=1}^k b_i = C$  is very small. At the same time, in majority of cases the value of the difference  $C - \sum_{i=1}^k b_i > 0$  may be acceptable, because the remained financial resources  $C - \sum_{i=1}^k b_i$  can be used in other projects. In these cases, the ordering and renumbering of entities  $i \in G$  according to rule (7) and then determining the set  $B$ , i.e. of such an approximate solution, is sufficient. The described above procedure of four steps, further as algorithm  $A_1$  is addressed. In order to quantitatively estimate the dependence on various factors of the relative error of solutions, obtained when applying such a procedure, the computer simulation is performed. In calculations, the following initial data were used: simple size  $10^4$ ;  $C = 1000$  units;  $n = \{10, 15, 20, 30, 40, 50, 60, 80, 100\}$  entities; the value of parameters  $a_i$ ,  $b_i$ ,  $i = \overline{1, n}$  are generated stochastically at the uniform distribution in intervals described below.

For each pair  $\{a_i, b_i\}$ , the value of size  $b_i \in (0; C/d]$  is generated, where  $d \in \{2, 3, 4, 5, 6, 7, 10, 15, 20, 25, 30, 40, 50\}$  and additionally  $d < n$ , because at  $d = n$  the relation  $\sum_{i=1}^k b_i < C$  always takes place; then, the value of size  $a_i \in (b_i; 20 b_i]$  is generated. In the latter interval, the value 20 is obtained, taking into account (very approximately) the value of the ratio 6.0 trln USD (in 2021) / 0.2 trln USD (in 2021) = 30 (see section I); the value 30 is reduced to 20, because many of the areas are not yet covered by cybersecurity measures.

The relative deviation  $\delta$  (in %), equal to the average of the values  $100(C - \sum_{i=1}^k b_i)/C$ , usually can be used to compare the solutions. When calculating  $\delta$ , cases for which  $\sum_{i=1}^n b_i < C$  are not taken into account. At the same time, it is important to know the number of cases used when calculating  $\delta$ . For this purpose, the relative frequency  $\rho$  is used, where  $\rho = 100 \times (\text{number of cases used when calculating } \delta) / 10^4$ , %.

Some results of calculations, obtained using the SIMSEC application, are shown in Figures 1 and 2.

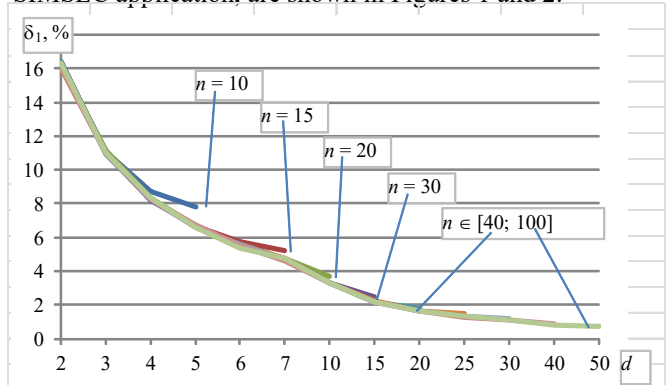


Figure 1. Dependence of error  $\delta_1$  on  $n$  and  $d$  at algorithm  $A_1$ .

From Figure 1, it can be seen that the deviation  $\delta_1$  of solutions, obtained by algorithm  $A_1$ , practically does not depend on the value of  $n$ , but decreases rapidly with the increase of  $d$ , becoming lower than 2% at about  $d \geq 15$  and lower than 1% at  $d \geq 40$ . The maximum value of  $\delta_1$ , equal to approx. 16%, is at  $d = 2$ , and the minimum value of  $\delta_1$ , from the specified above alternatives of initial data, is of 0.70% at  $d = 50$ .

As for the frequency  $\rho$  (see Figure 2), it increases with the increase of  $n$  at (approx.)  $n/3 < d < 2n/3$ , but decreases rapidly with the increase of  $d$ , becoming 0 at approx.  $d > 2n/3$ . The maximum value of  $\rho$ , equal to 100 %, is at (approx.)  $d < n/3$ . Also, it takes place  $\rho \geq 50\%$  at  $d \leq n/2$ . Therefore, from the performed other calculations they are taken into account only cases in which  $d \leq n/2$ .

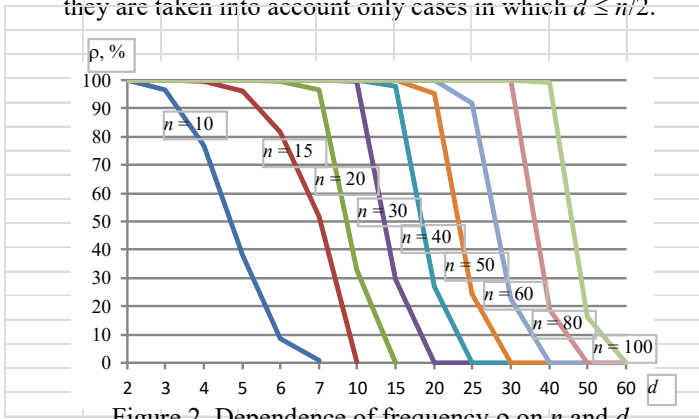


Figure 2. Dependence of frequency  $\rho$  on  $n$  and  $d$ .

Based on the results of performed calculations, it can be said that, in most cases, the use of the simplistic approach described above may be acceptable. In order to reduce the  $\delta$  deviation at the given value of  $n$ , it is necessary to increase the parameter  $d$  value, that is to reduce the upper limit for the  $b_i$ ,  $i = \overline{1, n}$  values. Another way is to increase the value of the number  $n$  of entities and also that of the parameter  $d$  (see Figures 1 and 2).

## V. REDUCING THE SOLUTIONS' ERROR

If  $\sum_{i=1}^k b_i \neq C$ , the question appear: how large can be the difference  $C - \sum_{i=1}^k b_i$ ? The answer is formalized by the requirement  $C - \sum_{i=1}^k b_i \leq \varepsilon$ . Thus, instead of requirement (2), the following one has to be used

$$\sum_{k \in B} b_k \leq C \leq \sum_{k \in B} b_k + \varepsilon, \quad (8)$$

and the problem  $\{(1)-(3)\}$  takes the form of  $\{(1), (3), (8)\}$ . Here, it should be noted that if the value of  $\varepsilon$  is too small, the solution may not exist.

In many cases, the value of  $\delta = C - \sum_{i=1}^k b_i$  can be reduced by checking and, if convenient, including in set  $B$  of some entities from set  $A = G/B$  so that  $C - \sum_{i \in B} b_i \geq 0$ . One such simple algorithm ( $A_2$ ) is the following.

1. Initial data:  $C; N; a_i, b_i, i \in G; n = |G|$ , where  $a_i > b_i, b_i \leq C, i \in G$ .
2.  $Z := \sum_{i \in G} b_i$ . If  $Z \leq C$ , then  $B_{\text{opt}} := G, I_{\text{opt}} := Z, Y := Z, \delta := 0$  and go to Step 14.

3. Determining the primary solution according to the  $A_1$  algorithm of Section IV.

3.1. Ordering and renumbering of entities  $i \in G$  according to the rule (7).

3.2.  $k := \max\{i \mid Z \leq C\}$ , where  $Z = \sum_{j=1}^i b_j$  (the first part of restriction (8) is followed).  $Z := \sum_{j=1}^k b_j$ ,  $B := \{1, 2, \dots, k\}$ ,  $D := \sum_{i=k+1}^n a_i$  and  $I := Z + D$ .  $I_{\text{opt}} := I, B_{\text{opt}} := B, \delta := C - Z$ .

4. Reducing the value of  $\delta$  by adding to set  $B$  of some entities from set  $A$ .

4.1. If  $k \geq n - 1$ , the value of  $\delta$  will not be reduced. Go to Step 5.

4.2.  $i := k + 2$ .

4.3. If  $b_i \leq \delta$ , then  $B_{\text{opt}} := B_{\text{opt}} \cup i, Z := Z + b_i, D := D - a_i, I_{\text{opt}} := Z + D$  and  $\delta := C - Z$ .

4.4. If  $i < n$ , then  $i := i + 1$  and go to Step 4.3.

5. The solution is:  $B_{\text{opt}}, A_{\text{opt}} := G \setminus B_{\text{opt}}, I_{\text{opt}}$  and  $\delta$ . Stop.

It should be mentioned that if at Step 4 of the  $A_2$  algorithm new entities were added to set  $B$  (from set  $A$ ), then the value of  $I_{\text{opt}}$  was reduced, too. At the same time, because for entities added to set  $B$  from set  $A$  are not followed the requirements of rule (7), it may be that the  $\delta$  value increases. So, when the  $A_2$  algorithm is applied, the value of  $I_{\text{opt}}$  can be reduced, and that of  $\delta$  can increase (but rarely) compared to those obtained by the  $A_1$  algorithm.

In order to comparatively analyze the  $A_1$  and  $A_2$  algorithms, for the latter were performed calculations at same initial data as for the  $A_1$  one. Some of the obtained results are shown in Figure 3.

Figure 3. Dependence of  $\delta_2$  on  $n$  and  $d$  at algorithm  $A_2$ .

Unlike the case of algorithm  $A_1$ , the deviation of solutions obtained when applying the  $A_2$  algorithm significantly depends on the value of the number  $n$  of entities, especially at relatively small its values (for example,  $n \leq 30$ ). At the same time, regardless of the value of  $n$ , it decreases on  $d$  at small their values and increases on  $d$  at large their values. At specified above alternatives of initial data, the maximum  $\delta_2$  value of 6.21% is at  $\{n = 10, d = 5\}$ , and the minimum  $\delta_2$  value of 0.06% is at  $\{n = 100, d = 20\}$  and  $\{n = 100, d = 25\}$ .

Comparing data in Figures 2 and 3, it can be seen that  $\delta_2 < \delta_1$ . In more details, the quantitative comparative

analysis of  $\delta_1$  and  $\delta_2$  deviations can be done based on  $m = \delta_1/\delta_2$  ratio, some values of which are shown in Figure 4.

According to Figure 4, the value of  $m$  is decreasing on  $d$  and is increasing on  $n$ . The maximum  $m$  value of 44.22 times is at  $\{n = 100, d = 2\}$ , and the minimum  $m$  value of 1.26 times is at  $\{n = 10, d = 5\}$ . Thus, in majority of cases, the  $\delta_2$  value is considerably smaller than the  $\delta_1$  one.

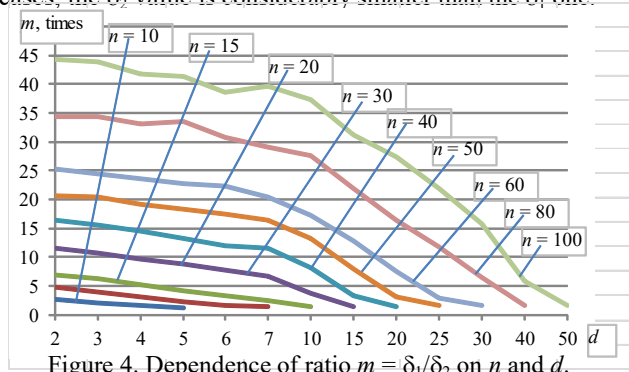


Figure 4. Dependence of ratio  $m = \delta_1/\delta_2$  on  $n$  and  $d$ .

## VI. AN IMPROVED APPROACH TO THE PROBLEM SOLVING

Finally, if  $C - \sum_{i=1}^k b_i > \varepsilon$ , it may be reasonable, in the meaning of criterion (1), to change by places some entities of set  $B$  with some entities of set  $A$ . If to consider all possible such alternatives, it can be obtained the optimal solution. But at relatively large values of  $n$ , many calculations may be necessary. That is why in this purpose are used, as mentioned above, special well-known methods/computer applications for solving problems of Boolean mathematical programming. At the same time, because of  $\varepsilon > 0$ , it can be sufficient to consider only few of such alternatives.

The  $A_3$  algorithm for roughly solving the problem  $\{(1), (3), (8)\}$  is described below. It checks the opportunity to replace a number of up to  $N$ , preponderantly last, entities of set  $B$  by some, preponderantly first, entities of set  $A$ . The accuracy of its solution does not depend on  $\varepsilon$ , but on the  $N$  value: the higher the value of  $N$ , the more accurate is the solution.

1. Initial data:  $C$ ;  $N$ ;  $a_i, b_i, i \in G$ ;  $n = |G|$ , where  $a_i > b_i$  and  $b_i \leq C, i \in G$ .
2.  $Z := \sum_{i \in G} b_i$ . If  $Z \leq C$ , then  $B_{\text{opt}} := G, I_{\text{opt}} := Z, Y := Z, \delta := 0$  and go to Step 14.
3. Determining the primary solution according to the algorithm  $A_2$  of Section V.
  - 3.1. Ordering and renumbering of entities  $i \in G$  according to the rule (7).
  - 3.2.  $k := \max\{i \mid Z \leq C\}$ , where  $Z = \sum_{j=1}^i b_j$  (the first part of restriction (8) is followed).  $Z := \sum_{j=1}^k b_j, B := \{1, 2, \dots, k\}, D := \sum_{i=k+1}^n a_i$  and  $I := Z + D, I_{\text{opt}} := I, B_{\text{opt}} := B$  and  $\delta := C - Z$ .
  - 3.3. If  $k \geq n - 1$ , then go to Step 4.
  - 3.4.  $i := k + 2, Z_1 := Z$  and  $D_1 := D$ .
  - 3.5. If  $b_i \leq \delta$ , then  $B_{\text{opt}} := B_{\text{opt}} \cup i, Z_1 := Z_1 + b_i, D_1 := D_1 - a_i$  and  $I_{\text{opt}} := Z_1 + D_1$  and  $\delta := C - Z_1$ .
  - 3.6. If  $i < n$ , then  $i := i + 1$  and go to Step 3.5.
4.  $N := \min\{N, k\}$ . Gradual replacement of up to  $N$ , preponderantly last, entities of set  $B$  ( $i = k - N + 1, k$ ) with some of the first entities of set  $A, k + 1 \leq i \leq \min\{k + N, n\}$  (Steps 5-12).  $t := 1$ , where  $t$  is the number of entities to be moved from  $B$  to  $A$  at the current value of  $v$  (see Step 5).
5.  $v := k$ , where  $v$  is the index of the first entity from the up to  $N$  entities of set  $B$  to be moved to set  $A$ .  $w := 0$ , where  $w$  is the number of entities already moved from  $B$  to  $A$  at the current value of  $v$ .
6.  $E := B, X := Z$  and  $R := D, l := v$ , where  $l$  is the index of the current entity to be moved from  $B$  to  $A$ .
7.  $E := E \setminus l, X := X - b_l, R := R + a_l$  and  $w := w + 1$ .
8. Identifying the entities from set  $A$  to replace the entity  $l$  in set  $E$ .  $g := 0$ , where  $g$  is a constant that specifies the difference between  $r$  and the index of the second entity (after the  $r$  one) to be moved from  $A$  to  $B$ .  $h := 1$ , where  $h$  is a variable that takes the value 0 or 1.
  - 8.1.  $r := k + 1$ , where  $r$  is the index of the first entity from those of set  $A$  to be moved to set  $B$ .
  - 8.2.  $u := r$ , where  $u$  is the index of the current entity to be moved from  $A$  to  $B$ .  $H := E, Y := X$  and  $V := R$ .
  - 8.3. Calculations for the current set  $H$ .  $Y := Y + b_u$ . If  $C - Y < 0$  (the first part of (8) is not followed), then go to Step 8.6 to modify the value of  $r$ .
  - 8.4. The first part of restriction (8) is followed.  $H := H \cup u, V := V - a_u$  and  $I := Y + V$ . If  $I < I_{\text{opt}}$ , then  $I_{\text{opt}} := I, B_{\text{opt}} := H$  and  $\delta := C - Y$ .
  - 8.5. If  $u < \min\{n, k + N\} - gh$ , then  $u := u + gh + 1, h := 0$  and go to Step 8.2.
  - 8.6. If  $r < \min\{n, k + N\} - gh$ , then  $r := r + 1, h := 1$  and go to Step 8.2.
  - 8.7. If  $g < \min\{N, n - k\} - 2$ , then  $g := g + 1, h := 1$  and go to Step 8.1.
9. Moving the next entity from  $E$  to  $A$ . If  $l = k - N + 1$ , then go to Step 11 to modify the value of  $v$ .
10. If  $w < t$ , then  $l := l - 1$  and go to Step 7.
11. If  $v > \max\{1, k - N + 1\}$ , then  $v := v - 1$  and go to Step 6.
12. If  $t < N$ , then  $t := t + 1$  and go to Step 5.
13. The solution is:  $B_{\text{opt}}, A_{\text{opt}} := G \setminus B_{\text{opt}}, I_{\text{opt}}$  and  $\delta$ . Stop.

- Some results of calculations by the  $A_3$  algorithm using the SIMSEC application are shown in Figure 5. Initial data are the same as in calculations by the  $A_1$  and  $A_2$  algorithms and, additionally,  $N = 10$ .
- Data in Figure 5 show that for some values of  $d$  the dependence of the  $\delta$  deviation on  $N$  is decreasing, and for



the others - is increasing for small and is decreasing for large values of  $N$ . Taken into account that  $2 \leq d \leq n/2$  and based on these and other calculations, it is identified that the dependence in question is decreasing at  $10 \leq n \leq 15$ ,  $\{n = 20, d \geq 4\}$ ,  $\{n = 30, d \geq 10\}$ ,  $\{n = 40, d \geq 15\}$ ,  $\{n = 50, d \geq 20\}$ ,  $\{n = 60, d \geq 25\}$ ,  $\{n = 80, d \geq 30\}$  and  $\{n = 100, d \geq 40\}$ , and is increasing at  $\{n = 20, d \leq 3\}$ ,  $\{n = 30, d \leq 7\}$ ,  $\{n = 40, d \leq 10\}$ ,  $\{n = 50, d \leq 15\}$ ,  $\{n = 60, d \leq 20\}$ ,  $\{n = 80, d \leq 25\}$  and  $\{n = 100, d \leq 30\}$ . At the same time, the dependence of costs  $I$  on  $N$  are always decreasing, regardless of the value of  $d$ .

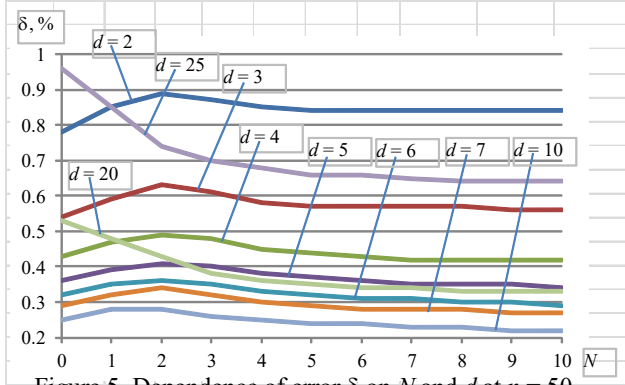


Figure 5. Dependence of error  $\delta$  on  $N$  and  $d$  at  $n = 50$ .

## VII. MORE DETAILED FORMULATION OF THE PROBLEM

The problem  $\{(1)-(3)\}$ , as well as the  $\{(4), (5)\}$  one not always is convenient. In practice, there are many cases when the i-security measures are opportune to be applied to entities gradually. Such an approach is closer to reality, more flexible and, at the same time, allows more efficient use of financial resources. In this case, it will be considered that each entity  $i \in G$ ,  $|G| = n$ , is characterized by:

$a_{ij}$  – annual losses caused to entity  $i$  ( $i = \overline{1, n}$ ) if within it there is implemented the i-security measure  $j$  ( $j = \overline{0, m_i}$ ). If  $j = 0$ , that is if there is no implemented any i-security measures, one has annual losses  $a_{i0}$ ;

$b_{ij}$  – annual costs with the implementation and maintenance within entity  $i$  of i-security measure  $j$  (i-security activity  $j$ ). Evidently,  $b_{i0} = 0$ ;

$x_{ij}$  – a Boolean variable that takes the value 1, if the i-security measure  $j$  is implemented within the entity  $i$  and the value 0 – otherwise;

$C$  – financial resources available for the implementation and maintenance of i-security measures within the  $n$  entities.

As in Case 1 (see Sections II-VI), the entities for which  $a_{i0} - a_{ij} \leq b_{ij}$  ( $c_{ij} = a_{i0} - a_{ij} - b_{ij} \leq 0$ ) and also those for which  $b_{ij} > C$  is not rational to be included in set  $G$ . So, one has  $a_{i0} - a_{ij} > b_{ij}$  and  $b_{ij} \leq C$ ,  $i = \overline{1, n}$ ,  $j = \overline{1, m_i}$ .

It is necessary to determine the i-security measures  $j = \overline{0, m_i}$ ,  $i = \overline{1, n}$  (the value of variables  $x_{ij}$ ,  $i = \overline{1, n}$ ,  $j = \overline{0, m_i}$ ), which implementation within the  $n$  entities

minimize the summary annual losses and costs with i-security

$$I = \sum_{i \in G} \sum_{j=\overline{0, m_i}} [(1 - x_{ij})a_{ij} + x_{ij}b_{ij}] \rightarrow \min \quad (9)$$

at

$$\sum_{i \in G} \sum_{j=\overline{0, m_i}} x_{ij}b_{ij} \leq C. \quad (10)$$

It should be noted that in problem  $\{(9), (10)\}$ , the i-security measure  $j$  for entity  $i$  ( $j\{i, j\}$ ) may differ from the i-security measure  $j$  for entity  $r$  ( $j\{r, j\}$ ).

The problem  $\{(9), (10)\}$  is one of Boolean mathematical programming with unknowns  $x_{ij}$ ,  $i = \overline{1, n}$ ,  $j = \overline{0, m_i}$  and can be solved by respective well-known methods/computer applications. A simplistic approximate approach, similar to that for the problem  $\{(1), (3), (8)\}$ , is described below.

**Statement 2.** Within entity  $i$ , it is preferable to implement the i-security measure  $p(i, p)$  than the i-security measure  $s(i, s)$ , if at equal other conditions occurs  $a_{ip} / b_{ip} > a_{is} / b_{is}$ , that is

$$p(i, p) > s(i, s), \text{ if } a_{ip} / b_{ip} > a_{is} / b_{is}. \quad (11)$$

The relevancy of this statement can be easily shown similarly as that for Statement 1, if to consider  $a_{ir}$  instead of  $a_i$  and  $b_{ir}$  instead of  $b_i$ . ■

**Statement 3.** It is preferable to implement the i-security measure  $p(i, p)$  within entity  $i$ , than to implement the i-security measure  $s(r, s)$  within entity  $r$ , if at equal other conditions occurs  $a_{ip} / b_{ip} > a_{rs} / b_{rs}$ , that is

$$p(i, p) > s(r, s), \text{ if } a_{ip} / b_{ip} > a_{rs} / b_{rs}. \quad (12)$$

The relevancy of this statement can be easily shown similarly as for Statement 1, if to consider  $a_{kj}$  instead of  $a_k$  and  $b_{kj}$  instead of  $b_k$ . ■

As in Case 1, in order to implement the simplistic approximate approach, the restriction (10) has to be substituted by

$$\sum_{i \in G} \sum_{j=\overline{0, m_i}} x_{ij}b_{ij} \leq C \leq \sum_{i \in G} \sum_{j=\overline{0, m_i}} x_{ij}b_{ij} + \varepsilon. \quad (13)$$

The  $A_4$  algorithm for roughly solving the problem  $\{(9), (13)\}$  is described below. The accuracy of its solution, as in the case of  $A_3$  algorithm, does not depend on  $\varepsilon$  but on the value of  $N$ : the higher the value of  $N$ , the greater the accuracy of the solution.

1. Initial data:  $C$ ;  $N$ ;  $a_{ij}$ ,  $b_{ij}$ ,  $i \in G$ ,  $j = \overline{0, m_i}$ ;  $n = |G|$  and  $a_{i0} - a_{ij} > b_{ij}$ ,  $b_{ij} \leq C$ ,  $i \in G$ ,  $j = \overline{1, m_i}$ .
2.  $Z := \sum_{i \in G} \sum_{j=\overline{1, m_i}} b_{ij}$ . If  $Z \leq C$ , then:  $x_{ij} := 1$ ,  $i \in G$ ,  $j = \overline{1, m_i}$ ;  $D := \sum_{i \in G} \sum_{j=\overline{1, m_i}} a_{ij}$   $I_{\text{opt}} := Z + D$ ,  $Y := Z$  and go to Step 15.
3. For each entity  $i \in G$ , ordering and renumbering the i-security means  $j = \overline{1, m_i}$  according to rule (11).
4. Ordering and numbering in a series  $K = \{k(i, j)\}$ ,  $k = \overline{1, |K|}$ , the i-security measures  $j = \overline{1, m_i}$  for all entities  $i \in G$  according to rule (12). Here  $|K| = \sum_{i \in G} m_i$ .
5.  $k := \max\{s \mid Z \leq C\}$ , where  $Z = \sum_{p=1}^s b_p$ , where  $b_p$  is the value of  $b_{ij}$  that corresponds to  $p(i, j)$ .  $Z := \sum_{p=1}^k b_p$ ,  $B := \{1, 2, \dots, k\}$ ,  $D := \sum_{p \in K} a_p$ , where  $a_p$  is the value of  $a_{ij}$  that corresponds to  $p(i, j)$  and  $I := Z + D$ .  $I_{\text{opt}} := I$ ,  $B_{\text{opt}} := B$ ,  $N := \min\{N, k\}$ .

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6. Gradual replacement of up to  $N$ , preponderantly last, i-security measures of set  $B$  ( $p = \overline{k - N + 1, k, N}$ ) with some of the first i-security measures of set  $A$ ,  $k + 1 \leq p \leq \min\{k + N, n\}$  (Steps 7-14).
7.  $v := k$ , where  $v$  is the index of the first i-security measure from the up to  $N$ , preponderantly last, i-security means of set  $B$  to be moved to set  $A$ .  $t := 1$ ,  $w := 0$ , where  $t$  is the number of i-security measures to be moved from  $B$  to  $A$  at the current value of  $v$ , and  $w$  is the number of i-security measures already moved from  $B$  to  $A$  at the current value of  $v$ .
8.  $E := B$ ,  $X := Z$  and  $R := D$ .  $l := v$ , where  $l$  is the index of the current i-security measure to be moved from  $B$  to  $A$ .
9.  $E := E \setminus l$ ,  $X := X - b_l$ ,  $R := R + a_l$  and  $w := w + 1$ .
10. Identifying the i-security measures from set  $A$  to replace the i-security measure  $l$  in set  $E$ .  $r := k + 1$ , where  $r$  is the index of the first i-security measure from, preponderantly last, i-security measures of set  $A$  to be moved to set  $B$ .  $g := 0$ , where  $g$  is a constant that specifies the difference between  $r$  and the index of the second i-security measure (after the  $r$  one) to be moved from  $A$  to  $B$ .  $h := 1$ , where  $h$  is a variable that takes the value 0 or 1.
  - 10.1.  $u := r$ , where  $u$  is the index of the current i-security measure to be moved from  $A$  to  $B$ .  $H := E$ ,  $Y := X$  and  $V := R$ .
  - 10.2. Calculations for the current set  $H$ .  $Y := Y + b_u$ . If  $C - Y < 0$  (the first part of restriction (13) is not followed), then go to Step 10.5 to modify the value of  $r$ .
  - 10.3. The first part of restriction (13) is followed.  $H := H \cup u$ ,  $V := V - a_u$  and  $I := Y + V$ . If  $I < I_{opt}$ , then  $I_{opt} := I$ ,  $B_{opt} := H$ ,  $A_{opt} := K \setminus B_{opt}$  and  $\delta := C - Y$ .
  - 10.4. If  $u < \min\{n, k + N\} - gh$ , then  $u := u + gh + 1$ ,  $h := 0$  and go to Step 10.2.
  - 10.5. If  $r < \min\{n, k + N\} - gh$ , then  $r := r + 1$ ,  $g := g + 1$ ,  $h := 1$  and go to Step 10.1.
11. Moving the next i-security measure from  $E$  to  $A$ . If  $l = k - N + 1$ , then go to Step 13 to modify the value of  $v$ .
12. If  $w < t$ , then  $l := l - 1$  and go to Step 8.
13. If  $v > \max\{1, k - N + 1\}$ , then  $v := v - 1$ ,  $t := t + 1$  and go to Step 7.
14. If  $t < N$ , then  $t := t + 1$  and go to Step 6.
15. The solution is:  $B_{opt}$ ,  $A_{opt} := K \setminus B_{opt}$ ,  $I_{opt}$  and  $\delta := C - Y$ . Based on  $p(i, j) = \overline{1, |K|}$ , determining  $B_{i_{opt}}$ ,  $A_{i_{opt}}$ ,  $i \in G$ ;  $a_{ij}$ ,  $b_{ij}$ ,  $i \in G$ ,  $j = \overline{0, m_t}$ ;  $Z_{i_{opt}}$ ,  $D_{i_{opt}}$  and  $I_{i_{opt}} := Z_{i_{opt}} + D_{i_{opt}}$ ,  $i \in G$ . Stop.

It should be noted that the  $A_4$  algorithm has many similarities to the  $A_3$  one. If in the case of algorithm  $A_3$

(and of the respective optimization problem  $\{(1), (3), (8)\}$ ) the security object (system of objects) is detailed to the level of entities – a single level, then in the case of algorithm  $A_4$  (and of the respective optimization problem  $\{(9), (13)\}$ ) the security object (system of objects) is detailed to the level of entities, and each entity, in their turn, to the level of cybersecurity measures. But in essence, there are no radical differences between them. At the same time, in the case of a large object (system of objects) the use of the  $A_4$  algorithm is more convenient, including in terms of reducing the error of solutions.

## VIII. CONCLUSIONS

Two cases of i-securing the informatics infrastructure are examined: Case 1 - one level entities (Sections II-VI) and Case 2 - two level entities (Section VII). For each of them, the respective optimization problem is formulated; they can be solved using the computer applications for Boolean mathematical programming. However, the use of such an application may require considerable calculations or it may not be available at the moment.

That is why some approaches for the approximate solution of the problem are also examined. To this end, a rule for prioritizing the explored cybersecurity measures is obtained. Based on this rule, four algorithms ( $A_1$ - $A_4$ ) for roughly solving the problem are proposed. They are numerated in the order of the reducing of deviation  $\delta$ . The  $A_1$ - $A_3$  algorithms are for Case 1, and the  $A_4$  algorithm is for Case 2.

For the quantitative estimation of the solution error, the computer simulation was performed using the SIMSEC application developed for this purpose.

The results of calculations confirm the veracity of the proposed algorithms. At the same time, the value of deviation  $\delta_2$ , obtained when using the  $A_2$  algorithm, usually is considerably smaller than the deviation  $\delta_1$ , obtained when using the  $A_1$  algorithm. Also, the solution error decreases rapidly with the lowering of the upper limit for the values of quantities  $b_i$ ,  $i = \overline{1, n}$ . Thus, the more detailed the cybersecurity measures in initial data, the lower the error of the solution.

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# Task Completion Time Evaluation in Moving Target Defense Cloud Environment Based on Matrix SRN With Z-Fuzzy Parameters

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**Abstract**—Moving Target Defense (MTD) has recently emerged as a game-changing technique in confronting cyber attacks and defending cloud computing systems (CCS) and computer networks (CN). A MTD technique randomly modifies the configurations of the attacked CCS, thus creating great uncertainties of the attack surface against cyber-intruders. In this paper, is proposed an analytical modeling approach based on the Matrix Stochastic Reward Nets (MSRN) with fuzzy parameters, that allows attacker's behaviors compact modeling and analysis of the impact in which the use of a MTD technique influences the completion processing time of a running task by CCS. A numerical case study is presented to analyze the impact of different parameters on the expected task completion time and other evaluation metrics.

**Keywords** — *moving target defense; fuzzy parameters; matrix stochastic reward net; task completion time*

## I. INTRODUCTION

Traditional computer networks (CN) and cloud computing systems (CCS) defense techniques such as IDS, firewalls, and antiviruses are increasingly ineffective in resisting new types of attacks due to the static properties of protected attack targets [1]. Intruders always have an advantage over time and can get enough information about the vulnerabilities of the CN's or CCS target system before launching an attack. To eliminate this disadvantage, the Moving Target Defense (MTD) approach [1] has emerged as a game changer for these interactions, as it *provides a proactive defense strategy* by creating asymmetric uncertainties in favor of defenders, constantly and variably changing CN configurations.

Designing CN and CCS security systems based on MTD techniques is a complex task, in which a large number of parameters must be taken into account. The influence of these parameters is often mutually opposite, often uncertain and weakly predictable. Depending on the content of the research associated with the use of MTD

techniques, they focused on one or more aspects of modeling, determining the parameters and efficiency of the CN and CCS defense systems, using different mathematical formalisms, which reflect their various behavioral aspects: continuous time Markov chains (CTMC), mathematical game theory and Stochastic Reward Nets (SRNs) [2, 3].

Existing research on the evaluation of MTD techniques focuses on the analysis of the effectiveness of MTD to assess the level of security or loss of performance of the system caused by the use of MTD. To our knowledge, only in the paper [4], based on SRN models, the impact of using the MTD technique on the damage of the task processing time on such a protected system is investigated. Nevertheless, in this type of models, the fuzzy epistemic uncertainties of the attacker's and defense's behavior are not taken into account. Also, it is easy to confirm from experience that SRNs [4] are often difficult to use in practice due to the problem of rapidly increasing graphical size of the model to describe the behavior of a real system. In this context, it is necessary to enhance the SRN formalism in order to fully represent more compactly and flexibly the models that describe complex processes in CN and CCS.

Here we present only some content of SRNs that is necessary to describe our quantitative analytical modeling approach based on the Matrix SRNs (MSRN) [5] with Z-fuzzy parameters, called FMSRN. This is needed to analyze how the use of a defense MTD technique affects the task completion processing time in a CCS, considering the real execution time of the entire task becomes longer than needed. More details on MSRN can be found in [5]. The FMSRN model, presented in this paper, describes both the processing of each task on several VMs, and the behavior of intruders in a CCS defended using MTD techniques. Also, the results presented in this paper can help defenders to choose a better MTD configuration and defense strategy to

complete the execution of the paper as soon as possible and evaluate some quantitative QoS (Quality of Service) metrics [2, 4, 5].

## II. MATRIX SRNs WITH Z-FUZZY PARAMETERS

### A. Elements of Z-Fuzzy Numbers

In [6], L. Zadeh proposed the concept of Z - numbers, which also allows us to take into account the inaccuracy of our knowledge of the membership function using a joint approach from the standpoint of probability theory and theory of possibility. The Z-numbers have more capability to describe the uncertain information. A fuzzy Z -number is an ordered pair of fuzzy numbers, denoted as  $Z = (\tilde{A}, \tilde{R})$ . The first component  $\tilde{A}$ , plays the role of a fuzzy restriction on the values, is a real-valued uncertain variable  $X$ . The second component  $\tilde{R}$  is a measure of reliability for the first component. Computing with Z-numbers can be realized by directly using Zadeh expansion principle, which requires very cumbersome calculations and is extremely difficult when solving complex applied problems. In [7], it was proposed a method of converting Z-numbers to *generalized fuzzy numbers*. Assume  $Z = (\tilde{A}, \tilde{R})$  is a Z-number. The left of Z is the part of restriction, and the right of Z is the part of reliability. Let  $\tilde{A} = \{ \langle x, \mu_{\tilde{A}}(x) \rangle \mid x \in [0, 1] \}$  and  $\tilde{R} = \{ \langle x, \mu_{\tilde{R}}(x) \rangle \mid x \in [0, 1] \}$ , where  $\mu_{\tilde{A}}(x)$  is a *trapezoidal* membership function and  $\mu_{\tilde{R}}(x)$  is a *triangular* membership function. In fact, the conversion of a  $Z = (\tilde{A}, \tilde{R})$  into a *regular* fuzzy number  $\tilde{Z}'$  is performed as follows:

- (1) Convert the  $\tilde{R}$  into a crisp number  $\delta = (\int x \cdot \mu_{\tilde{R}}(x) dx) / (\int \mu_{\tilde{R}}(x) dx)$ ; (2) Add the weight  $\delta$  of the  $\tilde{R}$  to  $\tilde{A}$ . The weighted Z-number can be denoted as  $\tilde{Z}^\delta = \{ \langle x, \mu_{\tilde{A}^\delta}(x) \rangle \mid \mu_{\tilde{A}^\delta}(x) = \delta \cdot \mu_{\tilde{A}}(x), x \in [0, 1] \}$ ;
- (3) Convert the *irregular* fuzzy number  $\tilde{Z}^\delta$  (weighted restriction) to *regular* fuzzy number :

$$\tilde{Z}' = \{ \langle x, \mu_{\tilde{Z}'}(x) \rangle \mid \mu_{\tilde{Z}'}(x) = \mu_{\tilde{A}^\delta}(x / \sqrt{\delta}), x \in [0, 1] \}.$$

*Example.* Let  $\tilde{A} = (a_1, a_2, a_3, a_4; 1)$  be the trapezoidal regular fuzzy number (TrFN) and  $\delta$  be the weight of  $\tilde{R}$  in  $Z = (\tilde{A}, \tilde{R})$ , then  $\tilde{Z}^\delta = (a_1, a_2, a_3, a_4; \alpha)$  and  $\tilde{Z}' = (a_1 \cdot \sqrt{\delta}, a_2 \cdot \sqrt{\delta}, a_3 \cdot \sqrt{\delta}, a_4 \cdot \sqrt{\delta}; 1)$  is TrFN.

According to [8], the average credibility value  $\bar{z}' = E[z']$  of TrFN is determined by the expression  $\bar{z}' = E[z'] = (\sqrt{\alpha}) \cdot (a_1 + a_2 + a_3 + a_4) / 4$ , will further be used to determine the *credible parameters* of a FMSRN model.

### B. Definition of MSRN with Z-fuzzy parameters

The definition and behavior of MSRN (SRN with matrix attributes) is presented in [5]. The MSRN inherits most of the SRN [3] characteristics. In a MSRN model, the matrix attributes of objects (arcs, places capacities,

guard functions and transition priorities, rewriting rules, firing rates of transitions, etc.) of the specified type  $z$ , depending on the current state of the network, are defined by a set of matrix  $A^z = [a_{ij}^z(s)]_{k \times n} \in \mathbf{A}$ . The values of the network attributes may be constant, variable or functions of the specified type and may depend on the current state of the MSRN model. The location of the current element  $a_{ij}^z(s)$  of the matrix  $A^z$  is specified by a set  $P_A^z \subset P$  of net *control places*. For example, for the selection of current elements position in  $A^z$ , two control places should be specified. Therefore, the current number of tokens  $i = m_l = M(p_l)$  and  $j = m_v = M(p_v)$  in control places  $p_l$  and  $p_v$  shows the position of the respective element of matrix  $A^z$ , and its values must be imported and taken into account when executing and analyzing the model. Furthermore, should be specified the capacity of the control places  $p_l \in P_A^z$  and place  $p_v \in P_A^z$  respectively.

Graphically, a matrix attribute of MSRN will be presented in a way that it will contain the matrix name in square brackets. So, for example, a direct arc matrix cardinality, denoted by  $\xrightarrow{A}$ , can take values that are contained in a specified matrix  $\mathbf{A}$ .

In order to model more realistically the uncertainty of the attackers' behavior and the defense reaction of the security system of CCS, it is necessary to consider the fuzzy aspects in MSRN.

Thus, the FMSRN, denoted  $FMT$ , is specified as a 3-tuple system so that  $FMT = \langle MSRN, \tilde{\Lambda}, \tilde{W} \rangle$ , where:

$MSRN$  is the underlying of  $FMT$ ;  $\tilde{\Lambda}: E_\tau \times IN_+^{|P|} \rightarrow IR^+$  is the matrix function that determines the Z-fuzzy firing rate  $0 < \tilde{\lambda}(t_j, M) < +\infty$  (the parameters of exponential-negative law) of timed transition  $t_j$ , that is enabled by current marking  $M$ ;  $\tilde{\omega}: E_0 \times IN_+^{|P|} \rightarrow IR^+$  is the matrix Z-fuzzy weight function  $0 \leq \tilde{\omega}(e, M) < +\infty$  which determines the firing probability  $q(t_l, M)$  of immediate transition  $t_l$ , enabled by current marking  $M$ , that describes a probabilistic selector.

## III. INFORMAL DESCRIPTION OF ATTACKED SYSTEM

We consider a scenario in which it is necessary for a critical task to be processed in a certain limited time  $\tau_{Ask}$  on a CCS [4]. However, given the existence of attacks, the actual time  $\tau_R$  taken to complete the processing of a task is longer than necessary. To eliminate security concerns and complete the processing of each task as soon as possible, a MTD technique is adopted to protect the processing of this task. As an example of MTD, we consider techniques based on the use of a dynamic computing platform (DCP) on the cloud computing, which allows, by dynamically changing the structure of



this platform, to considerably complicate the success of attacks [1, 2, 3].

The considered DCP consists of  $\gamma$  heterogeneous virtual machines (VMs) that can have the same or different system hardware / software environments. Each VM has some vulnerabilities and they can be exploited by intruders. To withstand attacks, the processing of each task is divided into  $L$  stages. In each stage, MTD randomly chooses a VM to perform (continue) the task processing. There are only two cases where a new VM needs to be elected. One is that the task at the current stage has been successfully processed. The other is that task processing is interrupted due to attacks at the current stage. In both cases the task will not be processed on the same VM if the next stage starts or the current stage will be reprocessed.

We consider a single determined and experienced attacker whose goal is to prevent the normal processing of the task in this CCS. Only one VM of the DCP can be used to process the task at a current stage. We assume that the attacker, before successfully attacking a VM and achieving the desired effect, cannot distinguish the process whether or not this VM is processing the target task during the attack. At the same time, we assume that the attacker can exploit all CCS vulnerabilities in order to have access to all VMs, but he can attack only one VM at a time. Based on these assumptions, typical attack behaviors can be summarized by the following steps. First, the attacker randomly selects a VM to attack. After a successful attack, the attacker gains access to a VM and he can determine if the target task is being processed by that VM. If so, the attacker will destroy the processing of this task and immediately reselect the next target VM. If not, the intruder waits a long time to determine if a task will arrive on this VM. This waiting time has an upper limit, noted  $\bar{\tau}_{\max}$ . As soon as this limit is reached, the attacker will abandon the current VM and return to selecting the next VM to be attacked. Regardless of how the VM is selected by the task, the process of choosing the target VM by the attacker is the one without memory. In the next attack stage, the same VM can be selected.

To form the modeling of the behavior of this attacked system by FMSRN, we adopt the following hypotheses: (i) the durations (delay) of the activities of the attacker's behavior and those of the task migration on DCP are exponentially distributed random variables; (ii) the correct processing time of the task at each phase by a VM, being a non-exponentially distributed random variable (eg deterministic), is approximated by the Cox-2 distribution [9]. This means that we have the values of the mathematical average  $\bar{u}$  and that of the coefficient of variation  $K^v$ ,  $0.5 \leq K^v < +\infty$  of the non-exponentially distributed random variable. Based on these two values, the parameters of the Cox-2 distribution are identified as

follows [9]: 1) if  $K^v < 1$  then  $\lambda' = 1/(\bar{u} \cdot K^v)$ ,  $\lambda'' = 2/\bar{u}$  and  $q = 2(1 - K^v)$ ; 2) if  $K^v > 1$  then  $\lambda' = 2/\bar{u}$ ,  $\lambda'' = 1/(\bar{u} \cdot K^v)$  and  $q = 1/(2 \cdot K^v)$ . Here  $\lambda'$  (resp.  $\lambda''$ ) is the processing rate at the first (resp. at the second) phase, and  $q$  (resp.  $1 - q$ ) is the probability that after the end of the first phase the second phase will performe (resp. not performe) the task.

#### IV. FMSRN MODEL OF TASK PROCESSING IN MTD ENVIRONMENT

In this section, we present the developed FMSRN model, which formally describes the processing of an attacked task in CCS, presented in the previous section. The places (resp. transitions) correspond to the local states (resp. activities) of the attacker and of the MTD security system.

##### A. Attack Sub-model of DCP

In Fig. 1 is presented the FMSRN1 sub-model, noted  $FMT_1$ , which describes the behavior of the attacker, who repeatedly randomly selects a VM to attack.

The meanings of places and transitions in attack  $FMT_1$  sub-model:

- **Places.**  $pa1$  - the initial marking  $M_0(pa1)$  describes the potential number of VMs in DCP;  $pa2$  - the control place indicating the number,  $j = M(pa2)$ , of the  $VM_j$  that is or can be selected to be attacked;  $pa3$  - passive attacker;  $pa4$  - intruder started to select target  $VM$ ;  $pa5$  - the target  $VM_j$  is attacked;  $pa6$  - the target  $VM_j$  has successfully attacked;
- **Timed transitions.**  $ta1$ , ( $ta2$ ) - incrementing (decrementing) the target number of  $VM_j$  to be attacked;  $ta3$  - attacking the CCS;  $ta5$  - successfully attacking the target  $VM_j$ ;  $ta8$  - indicates the maximum waiting time for the arrival of the task on the attacked VM;

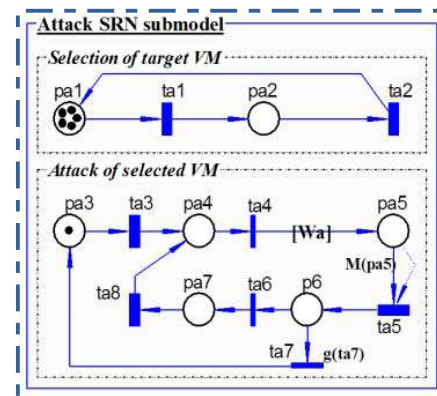


Figure 1. Attack  $FMT_1$  sub-model of DCP

- **Immediate transitions.**  $ta4$  - target selection;  $ta6$  - switching to waiting for the arrival of the task on the attacked VM;  $ta7$  - failure destruction of the current task processing process, complete the progress of the attack.

The weight  $W(ta4, pa5) = [W_a]$  of the arc  $(ta4, pa5)$  is a line vector  $W_a$  whose components are the serial number  $j = 1 + M(pa2)$  of selected target  $VM_j$ , i.e.  $W_a = [1, 2, \dots, N-1, N]$ , and the selection of the coordinate of an element  $W_{a_n}$  of this vector depends on  $n = M(pa2) = 0, 1, \dots, K(pa2)$ . Here  $K(pa2) = \gamma - 1$  is the capacity of the place  $pa2$  and  $2 \leq \gamma \leq N$ .

The guard functions  $g(ta6) := (M(pml) \neq N)$  and  $g(ta7) := (M(pm2) = 1)$  of attack  $FMI1$  sub-model are evaluated based on the current marking of the FMSRN2 sub-model, noted  $FMI2$  (see Fig. 2), which describes the processing and migration of a task among VMs on the DCP.

The "Selection of target VM" subnet of the  $FMI1$  sub-model (consisting of  $pa1$ ,  $pa2$  places, and transitions  $ta1$ ,  $ta2$ ) models the randomly attack selection of a  $VM_j$ . If the firing rates  $\lambda_{ta1} = \lambda_{ta2}$  of these transitions are equal to each other, the probability of attack of each VM is the same:  $q_{VM_j}^{attack} = 1/\gamma$ , where  $\gamma = K(pa2)$ .

#### B. Task migration sub-model in DCP

The  $FMI2$  sub-model, shown in Fig. 2, describes the processing and migration behaviors of a task between heterogeneous VMs of DCP.

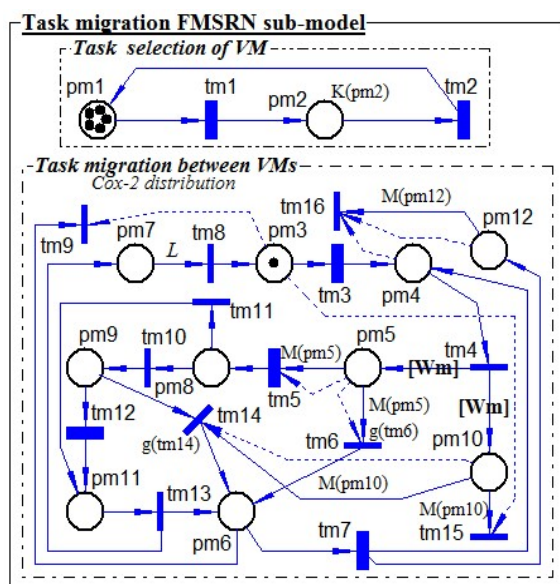


Figure 2.  $FMI2$  sub-model of task migration in DCP

The meanings of places and transitions in task migration  $FMI2$  sub-model:

- **Places.**  $pm1$  - the  $M_0(pm1)$  initial marking exhibit the potential number of VMs in the DCP;  $pm2$  - the control location indicating the number  $j = M(pa2)$ , of  $VM_j$ , which is selected to migrate the task and process a respective phase;  $pm3$  - the task is ready to be processed on the DCP;  $pm4$  - task started to select one VM;  $pm5$  - setting the processing of a stage of the task by  $VM_j$ ;  $pm6$  - wait migration task to another VM;  $pm7$  - the current marking shows the number of task stages successfully processed by VMs in DCP,  $M(pm7) \leq L$ ,  $L$  - numbers of stages;  $pm8$  - selecting phase 2 or finishing processing at phase 1 of the task according to the Cox-2 distribution by  $VM_j$ ;  $pm9$  - processing the task at stage 2 by  $VM_j$ ;  $pm10$  - the current serial number  $j = M(pm10)$  of  $VM_j$  which the current stage of the task is processing;  $pm11$  - task processing completion time indicator according to Cox-2 distribution;  $pm12$  - counter the actual number of migrations.

- **Timed transitions.**  $tm1$ , ( $tm2$ ) - incrementing (decrementing) the target number of  $VM_j$  to be attacked;  $tm3$  - arrival of the task processing request on DCP;  $tm5$  - task processing time at phase 1 of the Cox-2 distribution;  $tm7$  - the delay of the task migration to another VM;  $tm12$  - task processing time at phase 2 of the Cox-2 distribution.

- **Immediate transitions.**  $tm4$  - the selection of  $VM_j$  on which the task is processed;  $tm6$ ,  $tm14$  - disables the current task processing, if  $VM_j$  is attacked, respectively;  $tm8$  - DCP reset;  $tm9$  and  $tm15$  - the current task has completed the migration and processing process on DCP;  $tm10$  - moving to phase 2 of the Cox-2 distribution processing task;  $tm11$  and  $tm13$  - successfully complete the processing of a task stage on  $VM_j$ ;  $tm16$  - resetting of  $pm12$ .

The weights  $W(tm4, pm5) = W(tm4, pm10) = [W_m]$  of the arcs  $(tm4, pm5)$  and  $(tm4, pm10)$  are respectively rendered by a line vector  $W_m$ , whose components determine the serial number  $j = 1 + M(pm2)$  of the current  $VM_j$  on which the task is processed, i.e.  $W_m = [1, 2, \dots, N-1, N]$ , and the selection of the coordinate of an element  $W_{m_k}$  of this vector depends on the current marking of place  $pm2$ , i.e.  $k = M(pm2) =$

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$0, 1, \dots, K(pm2)$ . Here  $K(pm2) = K(pa2) = \gamma - 1$  is the capacity of the place  $pm2$ .

The guard functions  $g(tm6) := (M(pm5) = M(pa5))$  and  $g(tm14) := (M(pm9) = M(pa5))$  of the  $FMT2$  sub-model (see Fig.2), describing the processing and migration of a task among VMs, are evaluated based on the current marking of the  $FMT1$  shown in Fig. 1.

The “Task migration between VMs” subnet of the  $FMT2$  models the probabilistic selector of task migration between VMs, and its meaning is similar to that of the submodel  $FMT1$ . The difference between them is that  $\lambda_{ta1} = \lambda_{ta2} \neq \lambda_{tm1} = \lambda_{tm2}$ . Also, the probability of task migration between VMs is the same:  $q_{VM_j}^{migr} = 1/\gamma$ , where  $\gamma = K(pa2) = K(pm2)$ .

### C. Unfolding of FMSRN sub-models

It can be demonstrated that any model  $FMT$  type FMSRN can be unfolded in a SRN with fuzzy parameters (FSRN) model with the same attributes and behavioral properties. This allows to use the available Petri Nets Software Tools [10] to perform their analysis. In order to better understand the logic of the elaborated submodels, we present in Fig. 3 and Fig. 4, respectively the sub-models  $F\Gamma1$  and  $F\Gamma2$ , obtained by unfolding of sub-models  $FMT1$  and  $FMT2$ , respectively for the case  $\gamma = 3$ , i.e. the DCP has three available VMs.

The meaning of places and transitions in  $F\Gamma1$  (resp.  $F\Gamma2$ ) is clarified by those of  $FMT1$  (resp.  $FMT2$ ) sub-model as follows:  $pa0,1 := pa3$ ,  $pa0,2 := pa4$ ;

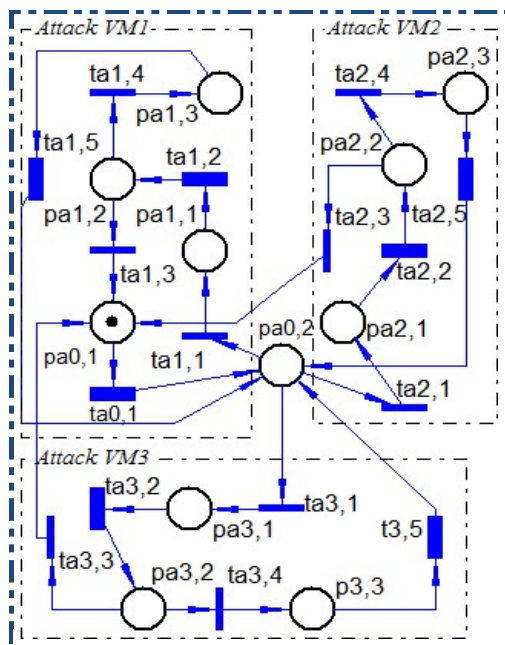


Figure 3. Attack  $F\Gamma1$  sub-model of 3 VMs

$pai,2 := pa6$ ,  $ta0,1 := ta3$ ;  $pai,1 := pa5$ ,

$pai,3 := pa7$  and  $tai,1 := ta4$ ,  $tai,2 := ta5$ ,  
 $tai,3 := ta7$ ,  $tai,4 := ta6$ ,  $tai,5 := ta8$ ;  $p0,1 := pm7$ ,  
 $p0,2 := pm3$ ;  $p0,3 := pm4$ ,  $p0,4 := pm12$ ,  $pi,1 := pm5$ ,  
 $pi,2 := pm8$ ,  $pi,3 := pm9$ ,  $pi,4 := pm11$ ,  $pi,5 := pm6$   
and  $t0,1 := tm8$ ,  $t0,2 := tm3$ ,  $ti,1 := tm4$ ,  $ti,2 := tm5$ ,  
 $ti,3 := tm6$ ,  $ti,4 := tm11$ ,  $ti,5 := tm10$ ,  $ti,6 := tm12$ ,  
 $ti,7 := tm14$ ,  $tmi,8 := tm13$ ,  $ti,9 := tm7$ ,  $ti,10 := tm9$ ,  
where  $i = 1, 2, \dots, \gamma$  represents the serial number of the  
attacked (resp. task migration)  $VM_i$  (here  $\gamma = 3$ ) which,  
in the  $FMT1$  and  $FMT2$  sub-models, is determined by the  
dynamic weight vector parameter  $W(ta4, pa5) = [W_a]$  and  
 $W(tm4, pm5) = [W_m]$ , respectively.

Thus, the number of graphical elements of the  $F\Gamma1$  and  $F\Gamma2$  unfolded sub-models depends on the number  $\gamma$  of VMs in DCP:  $N_1^P = 3 \cdot \gamma + 2$  and  $N_2^P = 6 \cdot \gamma + 4$  places,  $N_1^T = 5 \cdot \gamma + 1$  and  $N_2^T = 10 \cdot \gamma + 3$  transitions,  $N_1^A = 10 \cdot \gamma + 2$  and  $N_2^A = 21 \cdot \gamma + 7$  arcs, respectively, which leads to huge dimension and cumbersome FSRN models and thus complicates their analysis presentation.

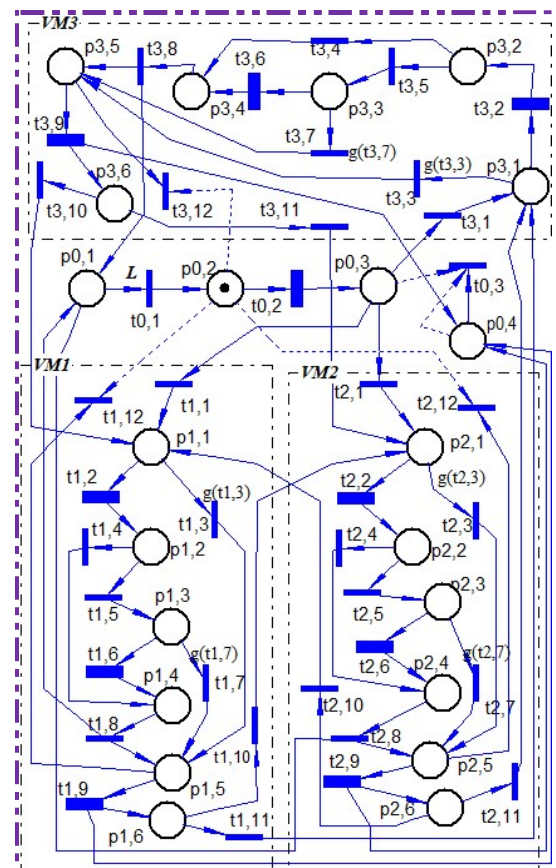


Figure 4.  $F\Gamma2$  sub-model of task migration between 3 VMs in DCP



## V. NUMERICAL CASE STUDY

Next we will present a numerical case study to show the use of the approach presented in this paper. The numerical analysis of some QoS metrics of this MTD security system is based on the unfolded  $FM1$  and  $FM2$  models, using the knowledge of the experts in the field [4]. As an example, we establish the parameters:

1) *crisp values*:  $\tau_{Ask} = 20 \text{ days}$  - task completion execution time without attack;  $L = 10$  - number of stages;  $\bar{u} = 2 \text{ days}$  - mean time to execute the task (with coefficient of variation  $K^v = 0.6$ ) by VM at a every stage, based on which we identify the firing rates  $[\lambda_{tm5}]_{1 \times \gamma} = [0.833]_{1 \times \gamma}$ ,  $[\lambda_{tm12}]_{1 \times \gamma} = [1]_{1 \times \gamma}$ ,  $[q_{tm10}]_{1 \times \gamma} = [0.8]_{1 \times \gamma}$ ;  $\lambda_{ta1} = \lambda_{ta2} = 1$ ,  $\lambda_{tm1} = \lambda_{tm2} = 2.5$ ,  $\lambda_{tm7} = \lambda_{tm8} = 48$ ,  $\lambda_{tm3} = 2$ .

2) *Z-TrNFs values*:  $[\tilde{\lambda}_{ta3}^{A_j}]_{1 \times \gamma} = [(\tilde{\lambda}_{ta3}^{A_j}, \tilde{\lambda}_{ta3}^{R_j})]_{1 \times \gamma}$  and  $[\tilde{\lambda}_{ta5}^{Z_j}]_{1 \times \gamma} = [(\tilde{\lambda}_{ta5}^{A_j}, \tilde{\lambda}_{ta5}^{R_j})]_{1 \times \gamma}$ , where  $[(\tilde{\lambda}_{ta3}^{A_j})]_{1 \times \gamma} = [(0.05, 0.08, 0.12, 0.20, 1)]_{1 \times \gamma}$ ,  $[\tilde{\lambda}_{ta5}^{A_1}]_{1 \times \gamma} = [(0.1, 0.2, 0.5, 0.8, 1)]_{1 \times \gamma}$ ,  $[\tilde{\lambda}_{ta5}^{A_2}]_{1 \times \gamma} = [(0.6, 1.0, 1.5, 2.5, 1)]_{1 \times \gamma}$  and  $[\tilde{\lambda}_{ta5}^{A_3}]_{1 \times \gamma} = [(3.0, 5.45, 7.0, 9.0, 1)]_{1 \times \gamma}$  with  $[\tilde{\lambda}_{ta3}^{R_j}]_{1 \times \gamma} = [\tilde{\lambda}_{ta5}^{R_j}]_{1 \times \gamma} = [(0.8, 0.9, 1, 1)]_{1 \times \gamma}$  for  $j = 1, 2, 3$ , respectively. For these Z-TrNFs parameters we obtain the weight  $\delta = 0.9$  of the  $[\tilde{\lambda}_{ta3}^{R_j}]_{1 \times \gamma} = [\tilde{\lambda}_{ta5}^{R_j}]_{1 \times \gamma}$ .

Conform [7], the average credibility values of Z-TrNFs parameters are:  $[\bar{\lambda}_{ta3}]_{1 \times \gamma} = [0.1]_{1 \times \gamma}$  and  $[\bar{\lambda}_{ta5}^1]_{1 \times \gamma} = [5.50]_{1 \times \gamma}$ ,  $[\bar{\lambda}_{ta5}^2]_{1 \times \gamma} = [1.25]_{1 \times \gamma}$ ,  $[\bar{\lambda}_{ta5}^3]_{1 \times \gamma} = [0.35]_{1 \times \gamma}$  which indicates the *strong*, *medium* and *weak* attack, respectively.

We used the VPNPtool [10] and PIPEtool [11] to evaluate the specified QoS metrics of given models.

Due to space limitations, in Fig. 5 are presented only the evolution of the *task expected completion time*  $\bar{\tau}_R$  curves under different numbers of VMs and attack rates.

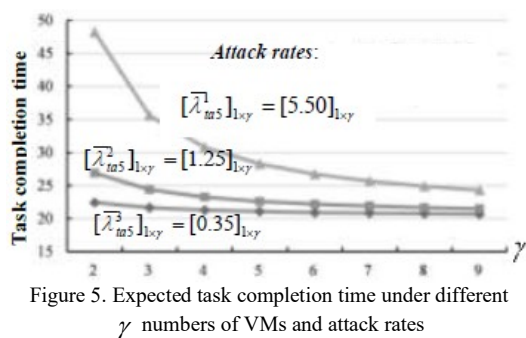


Figure 5. Expected task completion time under different  $\gamma$  numbers of VMs and attack rates

As we can see from the curve with triangular signs,  $[\bar{\lambda}_{ta5}^1]_{1 \times \gamma} = [5.50]_{1 \times \gamma}$ , when the number of VMs increases from 2 to 9, the task completion time decreases from 49.6 days to 23.5 days. The main reason is that as the number of VMs increases, the task execution process is less likely to be destroyed by the attacker.

Also, it should be noted that the use of a MTD technique introduces additional costs of calculation, the total processing time of a task will be affected and the performance of the defended system will be reduced. Therefore, users choose a cloud service provider and pay for the VMs for the task execution. According to the service level agreement (SLA), there is a slowest time threshold  $\tau_{SLA}$ , and the defender must complete the task execution before  $\tau_{SLA}$ . Thus, the sooner the task is completed, the more benefits the defender will get. Let  $c_B$  indicate the benefits the defender earns each day before the threshold. Also, the user needs to pay for the cost of the VM. Let  $c_{VM}$  dollars/hour to indicate the cost of one VM.

Given these parameters, the defender's profit  $P_{profit}$  will be calculated as follows:  $P_{profit} = c_B \cdot \tau_{SLA} - (c_B - \gamma \cdot c_{VM}) \cdot \bar{\tau}_R$ .

We mention that our modeling approach is flexible and can be used on other types of MTD.

In a future work, we will focus on developing a dynamic reconfigurable FMSRN models to evaluate the trade-offs between security and performability of MTD environments based on different VMs policies placement and task migration scheduling algorithms.

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# Information Security in Microservices Architectures

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**Abstract** — In this paper we investigate how can be provided security of an information system, which uses a microservice architecture. So, using of microservice architecture means that information system can be easily developed, deployed, and tested, but, on the other hand it means that it should be protected differently than the information system using monolith architecture. Firstly, a software architect should decide if each service should be protected separately or should be better to protect the system on the whole. Choosing the right way of protecting is very important, because, in some cases, protection of each service separately is not the best idea, as this could lead to code duplication. This means that, in case of necessity of changes a piece of code or fixing a bug it should be done everywhere this code appears. To avoid this, there are developed some services - so called gateways, which, also, very often have implemented the function of user/client authentication and authorization using protocol OAuth 2.0. Anyway, at each stage of development and implementation of a software product, it is necessary to solve many security related problems, and if it will not be done properly, then the company may incur enormous material losses or even may be closed.

**Keywords** — *microservice; OAuth 2.0 protocol; cloud infrastructure; information system security; gateway; software architecture*

## I. INTRODUCTION

Information is a product that can be bought, sold, or exchanged, and very often the cost of the data that is stored in the system exceeds the cost of the information system itself. In addition, information systems can store information with personal data of people, the leakage of which can negatively affect not only the company's image and its economic performance, but also ordinary people, data about which were obtained by unauthorized client. It is difficult to predict how such data might be used. In the best case, the data will not be used at all or will be used, for example, for targeted advertising. In the worst case, a person may be subject to blackmail or lose money from

their accounts. Anyway, the data must be carefully protected.

Protecting information systems using a microservice architecture differs from protecting a monolithic architecture. A feature of the microservice architecture is that such systems are divided into tens or hundreds of small services, each of which must perform its function and, respectively, must be protected [1]. In addition, each of these services can be used by different clients: a browser application, mobile applications (with different operating systems), as well as applications written by third-party developers, etc. Often different clients need different data. Mobile app can reflect less data than desktop user application, and some functions may be hidden altogether.

Firstly, will be identified which issues exist on direct access to the service. After it will be described the characteristics of API gateways, its advantages and disadvantages, and an example of how to implement such edge functions as authentication and authorization using the OAuth 2.0 protocol.

## II. ISSUES OF DIRECTLY ACCESSING SERVICES

As it was mentioned, each of the services can be used by different clients. One of the options for designing an information system is that clients access services directly through the Internet (or, less commonly, through a local area network), as is shown in the Figure 1.

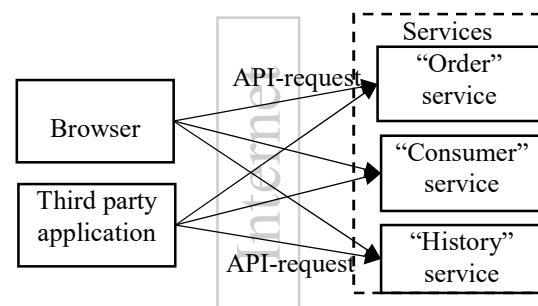


Figure 1. An example of a scheme of requests to services directly from different clients.

At first glance, this sounds pretty straightforward - after all, this is how clients call services in monolithic applications. However, this approach is rarely used in a microservice architecture because it has the following disadvantages:

1. To retrieve the desired data using finely divided services, clients will need to make several requests, which is not efficient and convenient. Too much communication between the application and services can adversely affect the responsiveness of the application, especially if it passes over the Internet. Perhaps, in some cases, requests can be executed in parallel and, in this case, the total time of all requests will not be more than in the case of one request. But sometimes the requests have to be executed sequentially, which reduces the usability of the client. Also, developers of client applications have to write rather complex code to combine services, which, moreover, may not work well on weak devices, but also distracts the developer from their main task - from creating convenient user interfaces. If the user uses it from a mobile device, then for each of his network requests is consumed electricity, which drains the battery faster.

2. Large applications with many users can be deployed on several servers in order to reduce the waiting time for a service response. In this case, there will be several threads of execution that the client should know about, and moreover, the client should know which thread to send the request to.

3. Each non-public service must have a security filter that will check whether the user has the right to make a request and what information the user can receive in response to the request. Consequently, the need for any change in one of these filters often leads to the fact that such a change must be made in each service the number of which, for one information system, can reach tens or hundreds.

4. As the information system evolves, service developers sometimes change the API and their endpoints, disrupting the work of existing clients. This is due to what is known as insufficient encapsulation. Developers can add new services or split/merge existing ones, and if information about services or endpoints is embedded in the client application, changing them can be difficult. Unlike updating services, deploying a new version of a client application can take hours or even days. For example, an update for a mobile app must first be approved by a corporation such as Apple or Google, depending on the app store, and made available for download. At the same time, no one guarantees that users will download it immediately (or even ever).

5. A separate problem is the fact that many organizations provide their services to third-party developers to integrate third-party information systems or applications with the organization's information system. Based on this, third-party developers need a stable interface. When a new version of a service comes out, it is necessary to get third-party developers to use it, but

very few organizations succeed. If an app's API becomes unstable, third-party customers may stop supporting it and move on to competitors. This means that the development of APIs that are used by other organizations must be carefully considered. This usually requires maintaining old versions for a long time, or even keeping them forever, which is a huge burden on the organization.

Instead of giving customers direct access to services, organizations often have a separate public API that a separate team develops. Further will be described the public architectural API component, better known as the API-gateway.

### III. API GATEWAY

#### A. API Gateway Characteristic

An API gateway is a service that serves as an entry point to an application from the outside world. This means that the integration of all APIs over the Internet is no longer at the client level, but at the service or back-end level. It is responsible for routing requests and for some third-party functionality such as authentication. Thanks to the API gateway, the client does not need to make many requests to services, but only needs to make one request to the service, which serves as a single-entry point for API requests in the application. An example of a scheme of requests through the API gateway is shown in the Figure 2.

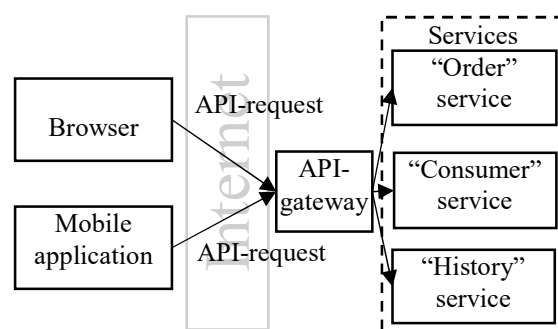


Figure 2. An example of a scheme of requests to services through an API gateway from different clients.

So, all requests made by external clients first go to the API gateway, which routes them to the appropriate services. The API gateway uses API aggregation to process other requests, accessing different services and aggregating the results.

Perhaps a few words should be said about another key function of the API gateway - request routing. Some API calls are implemented by directing requests to appropriate services. When the API gateway receives a request, it checks the routing map to determine which service to route the request to.

Of course, the main responsibilities of an API gateway are routing and API bundling, but it can also take over the implementation of edge functions. An edge function, as

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the name implies, is a request processing operation at the application boundary. Examples include:

- authorization - checking that the client is allowed to perform a certain operation;
- authentication - checking the authenticity of the client making the request;
- limiting the frequency of requests - control over how many requests per second a certain client and/or all clients together can execute;
- caching - responses to reduce the number of requests to services;
- query logging - writing queries to the log;
- metrics collection - collection of API usage metrics for analysis.

#### B. Advantages and Disadvantages of API Gateways

The API gateway pattern has many positive aspects, but it is clear that there are no perfect technologies, and therefore the disadvantages of a gateway should also be known.

The big advantage of using an API gateway is that it encapsulates the internal structure of an application. Instead of calling certain services, clients only need to communicate with the gateway. Each client receives a separate API, which in turn communicates with the services, which reduces the number of requests between the front-end and back-end. It also greatly simplifies the client code.

On the downside, the API gateway will be another component that needs to be developed, deployed, and administered. In addition, there is a risk that the API gateway will slow down the development of the information system. It should be updated with every new service deployed.

### IV. OAUTH 2.0 PROTOCOL

#### A. OAuth 2.0 Characteristic

As discussed above, an API gateway can implement edge functionalities. Two of these functionalities - authentication and authorization - are directly related to information system data security and to user data security also. To implement them, we can use, for example, the OAuth 2.0 protocol.

So, the OAuth 2.0 protocol is an open authorization protocol (scheme) that allows a third party to provide limited access to a user's protected resources without the need to transfer to it (a third party) a login and password [3]. It works by delegating user authentication to the platform on which the user's account resides, allowing a third-party application to access the user's account.

For example, there is a certain information system that specializes in trading on the Internet and the management of which, in order to increase sales, decided to resort to the implementation of the OAuth 2.0 protocol. For the end user, as a result, this decision will mean:

- there is no longer necessity to register in this information system, and instead, you can use other services, such as, for example, Facebook, Twitter or Gmail, which may have a better protection degree;
- access to any data will be provided only after the user's consent, otherwise the information system will not be able to use the user's personal data.

This solution will bring impressive advantages for the information system itself, because:

- there is no longer necessity to save passwords or other personal data in the information system database if the user prefers authentication on a third-party service (Facebook, Twitter, Gmail, etc.);
- with the consent of the user, the information system will be able to access some of the user's personal data (name, surname, date of birth, etc.), on the basis of which it will be able to make recommendations for goods.

So, Protocol OAuth 2.0 defines four main roles:

- *Owner of the resource.* The owner of the resource is the user who authorizes the application to access his account. The application's access to the user account is limited to the "scope" of the authorization rights granted (for example, read or write access).
- *Resource server.* The resource server directly stores the protected data of user accounts and often also acts as an authorization server.
- *Authorization server.* The authorization server verifies the authenticity of the information provided by the user, and then creates authorization tokens for the application, through which the application will access the user data.
- *Client.* The client is the application that wants to access the user's account. Before being accessed, the application must be authorized by the user, and it must be approved by the API.

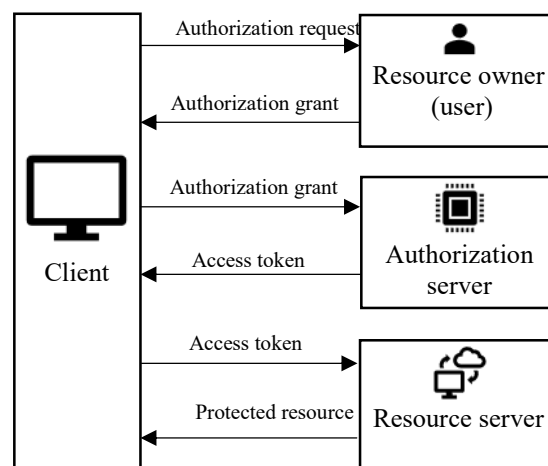


Figure 3. Client request scheme for granting access to a user to his protected resources.

Below it is described step-by-step the process presented in the Figure 3:



1. The application asks the user for authorization to access the resource server.
2. If the user authorizes the request, the application receives an authorization grant.
3. The application requests an authorization token from the authorization server by providing information about itself and authorization from the user.
4. If the application is authenticated and the authorization permission is valid, the authorization server generates an access token for the application. The authorization process is complete.
5. The application requests a resource from the resource server, while providing an access token for authentication.
6. If the token is valid or, for example, it has not expired yet, the resource server provides the requested resource to the application.

The actual order of the steps in the described process may differ depending on the type of authorization you are using, but the overall process will look like this. We will discuss in more detail about the different types of authorization permissions in section *B*.

So, the whole process described above means that every request sent to the API gateway must be accompanied by an access token. An example of an access token string is presented below:

*"eyJpc3MiOiJodHRwOi8vZ2FsYXhpcXZXMUy29tliwiZXhwIjoxMzAwODE1MzgwLjEzY29wZXMiOlsiZXhwG9yZXIiLCJzb2xhci0iYXJ2ZXN0ZXIiXSwic3ViIjoic3Rhbm9leUBhbmRyb21lZGEuY29tIn0"*.

It would be difficult to counterfeit such a token. In addition to all these, the token is often subjected to symmetric encryption, and when it enters the API gateway, it is decrypted and checked to see if it is valid. If the token is valid, then the request is redirected to services.

### B. Authorization Permissions

In the previous section, the first four steps in the process of granting user access to his protected resources deal with the issue of creating an authorization permission and an access token. The type of authorization permission depends on the method used by the application to request authorization, as well as what types of permission are supported on the server side. There are four different types, each of which is useful in specific situations:

- **Authorization Code:** is one of the most common type of authorization permission, because it perfectly fits for multilayered architecture applications, that is, where the application source code and client secret are not available to outsiders. This type is divided into two main parts, that is, user requests for authorization will be made to the authorization endpoint, and, after successful authorization, requests for the token endpoint will be made on the server side of the application. Thus, for information systems using a microservice architecture, this type is likely to be ideal.

- *Implicit:* used by applications where client secret confidentiality cannot be guaranteed. This type is most often used when the application does not have a backend. Due to the lack of a backend, all authorization requests will be made only to the authorization endpoint;
- *Resource Owner Password Credentials:* with this type of authorization permission, user provides the application with his authentication data in the service (login and password). The application, in turn, uses the received user credentials to obtain an access token from the service. This type of permission should only be used when the user has trust in the application or, for example, by applications that are part of the service itself.
- *Client Credentials:* are used when the application accesses the server, that is, user authentication data is not used at all. Unlike the previous types of authorization permission, in this type, the token that will be created will not contain any user data at all. It should be said that this type differs from others also in that it does not have an authorization endpoint, but only the token endpoint is used. This type is very convenient to use when we need to perform operations in which the user is not directly involved. An example of such an operation can be a listener in the information system of an organization, which checks daily if an employee was hired or fired (in other words, for example, if an account was created / deleted on the Outlook service). This type can be used in conjunction with other types of authorization permission.

## CONCLUSIONS

Nowadays, when the world is closely associated with information technology and, information is a key resource, data security is becoming one of the key aspects in the activity of each enterprise.

Today, microservices architecture is one of the most popular architecture on developing an informational system, and more and more often big organizations uses this type of architecture. However, as mentioned earlier, there are no ideal technologies, so information systems using a microservice architecture must also be protected, that can be done by implementing an API component such as an API gateway.

In turn, an excellent decision when implementing an API gateway will be the implementation of such an edge function as authentication and authorization, which is directly related to the security of the information system. It is also necessary to assess the necessity to store some sensitive data in the information system database, or it is better to resort to implementing the OAuth 2.0 protocol.

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# Interest based adaptive billboard content management

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**Abstract**—The street advertising has undergone some significant changes last years: the traditional advertising billboards are progressively replaced by electronic display devices (LED screens) that are able to change the content in real-time and enable the dynamic content management. This paper aims to develop an adaptive advertising strategy based on the preference of the audience in front of the screen. Each person own on his smartphone special software in order to set up his interests in advertising broadcast. In this way the people define their profiles hat are collected by the billboard which selects the most appropriate type of advertising to be broadcasted at that time. The proposed method aims to transform a simple display equipment into intelligent one able to adapt the broadcasted content to the requirements of the nearness people. It aims to maximize the efficiency of billboard operation and, at the same time, to bring satisfaction to the audience.

**Keywords**— street advertising, out-of-home advertising, billboards, digital advertising screens, content management

## I. INTRODUCTION

Street or outdoor advertising, or, called more recently out of home advertising (abbreviated OOH) is one of the oldest and simplest methods of promoting products and services. Street advertising is usually represented by billboards designed to display information about products, manufacturers, sellers, services, locations, etc. They are managed by specialized companies that display that information for a certain period of time and are interested in implementing new display strategies in order to reach as wide audience as possible and increase in this way their profits.

In the Republic of Moldova, OOH accounts for approximately 20% of the advertising market volume. The street advertising market in Moldova offers more than 10 formats (billboard, big-board, city-light, LED screens, cubes, clocks, panels, banners, light-boxes at public transport stations, etc.). Also, the street advertising market in the Republic of Moldova has more than 10 operators with a total of over 6000 different advertising billboards [1].

Advantages of the street advertising:

- More than 70% of people spend most of their time outside their homes.
- Street advertising is the best cost-effective advertising method.
- It has a high visual impact on the people compared to other advertising sources: print media, online press, shops, telephone.
- Continuous display of the message 24/24 hours for all nearby pedestrians and all cars in traffic in the area. Which makes it possible to reach busy, active and moving people. Statistics show that we spend an average of 1.3 hours per day on the street.
- It is free and doesn't require specific technical means to access it.
- It reaches a lot of nearness people without requiring significant investments.

A more detailed analysis of this topic can be found in [2].

The main disadvantages of street advertising are the inability to select the target audience and the extremely low volume of disseminated information (laconic text of up to 2-3 sentences, images, etc.) without the possibility to provide details [3].

Among the factors influencing the efficiency of the billboard are its location, the quality of the content presentation, and, last but not least, the coherence between the broadcasted content and the existing at that time audience near the billboard. As the everyday audience is very heterogeneous, it is practically impossible for traditional billboards to adapt the broadcasted content to present people. More recently, one of the most important factors for increasing efficiency is the use of digital display equipment, their impact on the audience being about 2.5 times higher compared to traditional display. These equipments have marked a new era in the development of street advertising known as Digital Out Of Home advertising (DOOH) and which offers great possibilities compared to the classic methods and which was stormy developed in recent years [4].

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This article proposes an innovative method of organizing street advertising which, based on modern technological displaying equipment and smart technologies, is able to collect the information about the composition of the people in front of the billboard and adapts in real time the broadcasted content to interest as many as possible people.

## II. DESCRIPTION OF THE PROPOSED METHOD

In this article we will analyze the operation of a billboard with digital display (LED screen, plasma screen, projector, etc.) on which are displayed advertising information that is perceived by pedestrians passing in front of the billboard (Fig. 1).

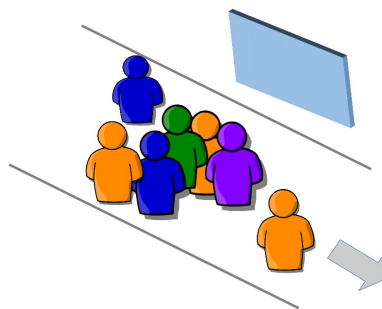


Figure 1. Traditional billboard

If we used the classic strategy for traditional screens with static display, this panel could be rented to a company for a certain duration to display the information about the products and services of that company. The efficiency of this approach is relatively low for the simple reason that the same information is disseminated for a long time (weeks or even months) and the public passing on the street tends to be largely the same (people leaving and returning home from service, those walking through the street near the house, etc.). The proportion of these people can be considerable, reaching in some cases 80-90%. Which means that the informative value of the display decreases day after day, hence the low efficiency of this approach. It depends largely on the location of the billboard and can be quite high in places where the public varies a lot every day (near stations, markets, shopping malls, etc.).

Equipping the billboard with a digital display screen greatly reduces these problems because the information displayed can be changed more often, thus maintaining pedestrians' interest in it. The advertising company can run advertising for several products for the same duration, which leads to a considerable increase in revenue.

The method proposed in this article aims to increase the efficiency of the billboard by adapting in real time the strategy of dissemination of content to the surrounding public. Assuming that the majority of pedestrians have a smartphone capable of connecting to WiFi (IEEE 802.11) wireless network, this equipment can be used, in addition

to all, as a source of information about the preferences of its owner. In order to define his preferences, the user will be asked to install on his phone a mobile application available in the store (Google Play for Android operating system and iTunes for Apple products). That proposal should be attractive in order to interest the user to accept it (a smart marketing solution is required here). It could also include other useful services (eg weather forecast display, exchange rate, etc.). When installing the application, a questionnaire will be launched. By answering the asked questions (checking the answers in a proposed list) the user will create a profile that will specify his preferences and interests. This mobile profile that doesn't contain any personal information (name, phone number, address, email, etc.) may be broadcasted on-demand if requested by another application on the network or may be continuously broadcasted by the application in order to discover certain services in the proximity network (for example, to search in the network people with similar preferences). It is very important to establish the structure of the questionnaire, which should be neither too voluminous with the risk of boring the user when completing it, nor too short to avoid an incomplete and uninformative profile. In order to simplify the structure of the questionnaire, users' preferences will have to be divided into categories (eg sports products, mobile phones, women's clothing, footwear, household appliances, etc.). The user profile will be specified through a list of selected categories in the questionnaire. It will start with the most favorite categories followed by others arranged in descending order according to the degree of preference. It may also be proposed to set the weights for each category in the list. The definition of the content and of the optimal structure of the questionnaire requires a more rigorous analysis and will not be discussed further in this article.

The simplest strategy for running advertising is to use a circular algorithm (Round Robin type) displaying the advertising one by one for a certain duration for each of the categories on the server. The same policy can be applied to products that fall into the same category. This method is a traditional one and ensures an equal display time for each product in the long run. It is not adaptive and does not take into account the audience composition next to the billboard. Its only advantage is the simplicity and fairness of the sharing of display resources between the promoted products.

One way to improve the efficiency of this system would be to adapt the broadcasted content to the preferences of the audience near the billboard. For this purpose, it is proposed to equip the panel with a WiFi access point that will have an open (unsecured) configuration that supports the connection without security key of any equipment in the radio sensitivity area with a radius that can reach up to 100 meters. Given the omnidirectional nature of radio coverage for traditional

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access points, the billboard should be installed at the side of the road so that pedestrians pass only in front of it and not have the rear access. Another solution would be to use a directed broadcast access point (which transmits and receives radio waves only in a certain direction or which uses shielding elements to limit emissions / receptions in / from unwanted directions). The panel will also be equipped with a server containing some installed applications needed to ensure the logic of the system work, including a video streaming server and the information to be broadcasted and eventually be modified in real time through the network. The information about the promoted products is classified in the same categories that were specified in the questionnaire. When it is decided to launch the display of a certain category, a product in this category will be selected according to a predefined algorithm and that information will be displayed on the screen.

When the pedestrian enters the radio sensitivity area near the panel he will automatically connect to the access point and the server will receive his profile. The appearance of the pedestrian will be counted by entering his profile in a list and by increment a variable that corresponds to the number of present users in front of the billboard. From this moment the server will start monitoring the presence of the respective equipment in the sensitivity area, this being possible because its IP address is known being assigned to it by DHCP by the access point. Presence monitoring is done by transmitting through the network at regular intervals of short messages (pings) to which the mobile equipment will respond thus confirming its presence. From the moment when no confirmations are received from the respective mobile phone, it is removed from the list and the presence variable is decremented.

The proposed system is shown in Fig. 2. Pedestrians move in the billboard direction, reach the sensitivity area and then leave it continuing their way.

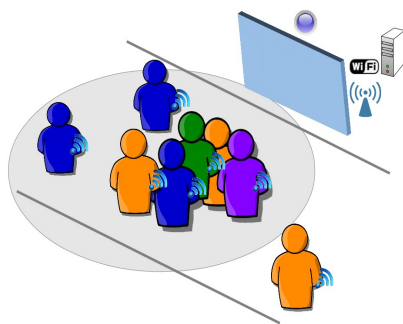


Figure 2. Billboard with adaptive content management

Given that we have a number of  $N$  categories of advertising, we can expect to have around the panel up to  $N$  groups of pedestrians, each of which will correspond to one of the categories defined above. The groups are

monitored separately to know in real time the number of pedestrians in each of them.

The application that manages the advertising display performs the following functions: receives user profiles with their preferences and interests, continuously monitors their presence, counts the audience in the area of radio sensitivity, make decisions about real-time content be displayed on the advertising screen, etc. For simplicity, we'll assume that the ad delivery time for all products in all categories is the same or roughly the same (for example, 30 seconds). In other words, the information displayed on the screen must change every 30 seconds regardless of the evolution of other factors.

The decision on the content been broadcasted in the next time interval is based on the data collected in the previous interval. Advertising will be broadcasted for the category that has the largest presence in front of the panel and at the same time information will be collected about the composition of the audience that will be used in the next time slot.

### III. ESTIMATING THE EFFECTIVENESS OF THE PROPOSED METHOD

The methods of estimating the effectiveness of advertising can be very different: from conducting a survey on its quality [5] to assessing its impact on the sales volume of the advertised products [6]. In this article we will use a specific evaluation method based on results obtained by simulation that would show us the efficiency of the proposed method in relation to other methods.

We aimed to use an agent-oriented approach for simulation and to use a specialized software (GAMA platform [7]) to implement our model. This approach makes possible to describe each agent and its spatial movement through its attributes and behavior. In this case, each pedestrian and the screen are represented by specific agents that interact with each other, thus realizing the logic of the system operation.

We have to define some technical parameters of the analyzed system before the simulation. We will simplify the initial model described in the previous chapter by reducing the number of advised product categories to 4 assuming that a user can request only one category (the simplest case). Therefore we will have only 4 groups of pedestrians who will move in both directions in front of the billboard. The sensitivity area will have a length of 50 meters, the speed of pedestrians will be from 0.5 m / s (slow pedestrians) to 1.5 m / s (fast pedestrians) and will be chosen randomly. Pedestrian arrivals are independent, there are 4 types of pedestrians (one for each category). Pedestrians can move in any direction and are counted at the entrance and at the exit of the sensitivity area.

In Fig. 2. the product categories are coded by color: we have pedestrians belonging to each of the 4 categories (so 4 different colors) and the screen can also broadcast 4 categories of advertising that correspond to those colors



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(the color of the light on the screen in Fig. 2 corresponds to the color of the broadcast category at a certain time). We will set the duration of a time slot equal to 30 seconds (it corresponds to the duration of the advertisement for a product belonging to one of the categories), and the simulation time in the example analyzed below is 10 minutes.

The simulation environment and the respective process are shown in Fig. 3: pedestrians cross the sensitivity area of the billboard moving in arbitrary directions. The system monitors and counts these movements and establishes the category of advertising currently broadcasted taking into account the largest group (the color of the square that corresponds to the screen in Fig. 3)

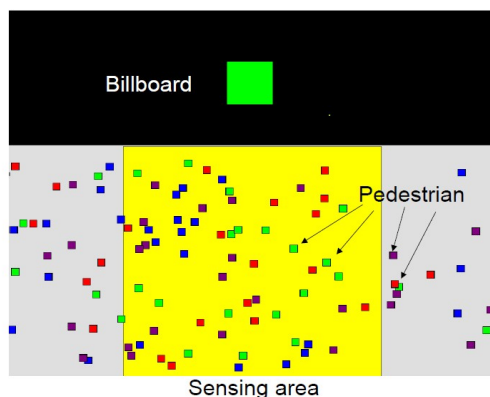


Figure 3. Simulation environment and system simulation (pedestrian movement, dynamic content modification) in GAMA platform

In Fig. 4 are shown the evolution of the groups and the state of the screen: at the top is the number of pedestrians in the 4 groups (4 different colors), and at the bottom are presented the timers for each time slot, their color indicates the category advertising displayed on the screen in that time slot.

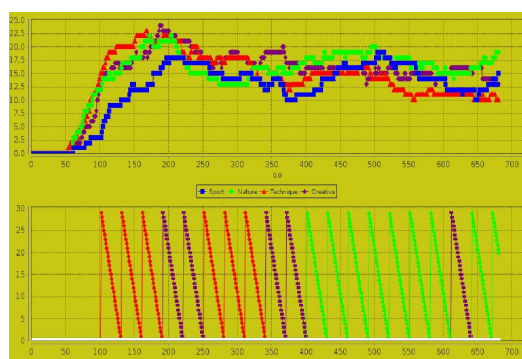


Figure 4. The evolution of groups and screen status over time

We notice the correspondence between the color of the slit and the color of the largest group of pedestrians at that time.

During the simulation for each pedestrian we will calculate the satisfaction index defined by the ratio between the display time of his favorite advertisement and the total duration of his presence in the sensitivity area in front of the screen. The range of variation of this index: [0,1]. The average of these values will be used to estimate the overall system performance index: the overall average satisfaction. The index allows us to compare different system configurations: the larger it is, the more efficient is the system.

Following the long-term similar simulation of the system described above and the one with circular screen allocation, it turned out that the first one is on average 15-20 percent more efficient than the Round Robin system.

## CONCLUSIONS

The main purpose of the article is to propose a solution that would allow an adaptive management of the content broadcast through billboards based on digital display equipment (LED screens in particular) using information collected in real time about the preferences and the interests of the people in front of the screen. The obtained results are encouraging, they demonstrate the feasibility of the proposed method and its adaptability in real time and the proposed performance index allows the comparison of results for different configurations of the analyzed system.

In the future, a more detailed and realistic simulation of the proposed method is foreseen: several product categories and profiles with multiple weighted preferences, more complex pedestrian flows with grouped arrivals, studying the possibility of integrating the method at the level of billboard network.

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# Benefits of Mobile Applications in the Healthcare Industry

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**Abstract.** The scope of this paper is to evaluate the benefits of applications designed for mobile devices in the healthcare industry. This study includes research on adoption of applications running on end users devices within the healthcare and investigates the benefits for the patients and medical organisations after initiating the process of implementation. Besides the mentioned, the article contains a overview regaiind most common use cases of mobile applications in healthcare, modern mobile frameworks used for development and a list of suggestions while developing such mobile application.

**Keywords:** *Mobile application, Healthcare, Patient Care, Patient Experience, Clinic Care, Digital Health, Doctor Supervising, Clinical Data Privacy*

## I. INTRODUCTION

Mobile applications play a significant role in modern society and are being adopted across all industries, health care industry is not considered as an exception. People tend to consume more and more internet traffic using a portable device like a smartphone or tablet, rather than a desktop or laptop [1], in order to navigate over the Internet and find the requested information. A mobile application, usually defined as a mobile app, is a software designed & developed to run on protable devices such smartphones, tablet or even a smart watch. In present a mobile device does not represent anymore handhelp computer with limited capabilities [2], it can be considered as an compact and mobile device that can solve complex problems using the hardware capabilities and installed mobile application on it. Healthcare is in the midst of a mobile oriented revolution, and it will only be a matter of time before mobile healthcare applications change how we deliver information, use services, measure the clinical requests, and pay for healthcare offered services.

In the past year COVID-19 has increased the speed of technology innovations across the National Health Service (NHS) [3] on a global level, because of the need to support the health care industry and population that

uses it on a daily basis. When we analyse the mobile application as primary tool within the healthcare industry, we can classify it as a communication channel that can provide the required patient information to the organization that takes care of him and with the patient consent. The main actors of this channel are the hospitals/clinics, doctors and patients using the mobile applications to deliver the medial information on upper level. The entire health care industry has three main common difficulties:

- finding different type of patients
- gathering medial data from the patients
- communication with patients.

Mobile applications has the possibility to close the last two major difficulties or at least the gaps that blocks from getting them.

## II. MOBILE APPS USE CASES IN HEALTHCARE

There are a lot of mobile applications available in the healthcare industry. They can be categorized into major areas:

### A. Clinical and diagnostic

Clinical and diagnostic applications that allow clinical entities (for ex. doctors) to gather and analyse medical data about their patients or clients. They might include the following list of features like:

- Fetch electronic health records (EHR)
- View lab analisys results in a visual form (like chart, digital imaging etc.) or in standard form
- Printed medical references (like Johns Hopkins Antibiotic Guide (JHABx), Dynamed, UpToDate, 5-Minute Clinical Consult (5MCC), 5-Minute Infectious Diseases Consult (5MIDC), Sanford Guide to Antimicrobial Therapy (SG), ePocrates ID, Infectious Disease Notes (ID Notes), Pocket Medicine Infectious Diseases (PMID), and Iddx [4])
- Other health records related to the patient.

These evidence-based apps serve as medical decision-making information providers for the doctors

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[5]. These type of application usually consists from at least two system roles: the doctor and the patient.

#### B. Remote monitoring

With the current improved mobile devices, not every health condition needs to be monitored within a clinical environment. Remote monitoring apps permit patients to stay at home while they under the virtual care of the providers. Now with internet accesibility, clinical devices designed for patients, using special designed mobile applications, can update their vitals like heart rate, oxygen level, blood glucose readings, blood pressure and other important healthcare information without the need to visit the clinical providers. This offers providers to manage and take care of patients remotly. Remote patient monitoring systems are designed to obtain a number of physiological data from patients. Most common data are Electrocardiogram (ECG), Electroencephalogram (EEG), heart beats and respiration rate, oxygen volume in blood or pulse oximetry, signals from the nervous system, blood pressure, body/skin temperature and blood glucose level. In addition to these, sometimes, weight of the patient, activity history of the patient and sleep data are collected. A number of researches have been done for wound management and sleep monitoring [6].

Heart related monitoring software are the most common type of monitoring systems met in the industry. They are usually integrate in wearable devices that support this hardware capability. The wearable devices might contain the possibility to gather information like ECG, heart rate, respiration rate and blood pressure [7].

#### C. Healthy life style

Modern mobile applications most of the time try to keep their user conversion high as much as possible, so they do deeper engagement with the users. This kind of application towards focus on healthy living tracking health metrics such as obesity, exercises, heart rate, sleep etc. Patients with chronic conditions such as diabetes may benefit from apps that offer diet plan, daily routine, lifestyle changes etc. Pregnant women can even use similar mobile applications about fetal development. Patients with diabetes or heart disease may benefit applications that offer a diet plan tailored to their specific circumstances. There is need for innovative ways to stimulate physical activity and a healthy lifestyle. One promising development is the use of smartphones during exercise. Use of mobile applications may be a powerful tool to encourage physical activity and health [8,9]. Mobile applications are accessible, have a large reach, and have multiple functionalities, such as interactive possibilities and feedback opportunities [10,11]. Although more than 17.000 health and fitness mobile applications have been developed, deployed on mobile stores and are available for the public use [10].

#### D. Productivity

With devices enhanced with more and more capabilities features, developers have started creating more lifestyle, health focused apps. It ranges from apps getting calories intake, heart beat, pulse, oxigen level, to eveng ECG features.

Latest mobile applications advances include IoT enabled functionality where physicians can view the trend and pattern of the patient remotly. Most of the productivity software will offer functions while maintaining Health Insurance Portability and Accountability Act (HIPAA) [12], that is used within United States and General Data Protection Regulation (GDPR) [13], that is used within Europe. Most users download a mobile application to meet a specific goal and feel that the desired application help them to achieve it. Two distinct groups emerged, those who used them to adopt a new behaviour. The majority of participants reported that acceptable apps were free, easy to use, provided visual/auditory cues, and had in-app gamification. Most participants strogly opposed linking their social media with apps and did not use those features [14].

### III. BENEFITS OF MOBILE APPLICATIONS

The impact of mobile applications in healthcare industry differs from country to country, mostly it relies on the adoption rate of the population from



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specific country. A statistic of adoption rate per country regarding mobile apps in healthcare we can observe in the following Figure 1.

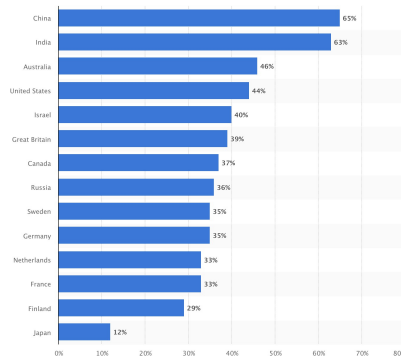


Figure 1. Adoption rate of mobile applications in healthcare per country [15]

Mobile applications offer mutual benefits for all parties in healthcare industry, its more like a bridge that connects two towns. The greatest measurable benefit from the mobile apps is the time spent. From the logistic point of view a patient in order to visit a doctor has to do the following steps:

- Book a window in the doctors calendar
- Travel by car or public transport until destination and return back
- Wait his/her line.

A modern mobile application allows the patient to avoid those expenses, time consumed and provide a contactless (clinics during Covid-19 are considered as well a source for contamination) communication channel with the doctor. Patient in the end gets in touch with the doctor and in the same time the doctor gets the needed information for patients current treatment or simply updating his medial information.

Migrating from classical healthcare in clinic environment and allowing patient to treat remotely from home, under medical surveillance, can be considered as well a optimization of a doctors load that can allow to check out more patients.

The last, but not the least, the entire digital communication and trasnfered data are stored remotely, that allows more flexibility to all parties to access and manage it.

#### IV. MOBILE DEVELOPMENT FRAMEWORKS

Choosing a mobile development framework is an important point for designing an health care mobile application. It is influenced by many factors like development time, cost, maintenance and time to implement new features. Such frameworks can be classified in two basic categories, native mobile development and hybrid mobile development.

Common native mobile development frameworks are:

- Google Android Framework based on Java/Kotlin [16]
- Apple iOS Framework based on Objective-C/Swift [17].

The main aim of hybrid mobile development frameworks is to use a single code base and achieve same results for both platforms Android and iOS. The dominant hybrid frameworks at the moment are:

- React Native [18]
- Flutter [19]
- Xamarin [20]
- Ionic [21].

As shown in Table 1, each development platform has its advantages and disadvantages.

TABLE I. TABLE COMPARISON BETWEEN NATIVE AND HYBRID

<i>Criteria</i>	<i>Native Development</i>	<i>Hybrid Development</i>
Final Cost	High	Medium - High
Required number of developers	One for each platform	At least one developer
Spent development time	Fast	Medium
Native mobile features	Complete adoption	Partially adoption
Performance	High	Medium
Maintenance	High	Medium
Product Complexity Support	High	Medium
Dependency on third-parties	None	Depends
Access to hardware capabilities	Available	Depends on third-party integrations

Selecting the type of mobile development framework represents an important decision that has to be done at the beginning of any development. On later stages when the product passed several cycles of development, it can be modified or changed completely.

#### V. RECOMMENDATIONS

Developing a mobile application for any type of industry is not a cheap and easy task. In order to avoid many confusions on what a mobile application in health care needs to have, the product owner [22] or stakeholders [23] must decide and define the following points:

##### A. Product Stage

Defining at what stage the current product is represents an important step, before diving into deep development or planning stage. Here needs to be defined at what stage the product is, whenever its on proof-of-concept, most viable product or simple idea.

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### B. Feature list

Defining feature list on short-term, mid-term and long term is important for making the development plan and primordial in choosing the mobile development framework. For example if in the roadmap its planned to establish communication with custom medical devices or exploit the mobile device hardware capabilities, then would be more reasonable to go for native mobile development.

### C. Time to market

Time to market represents an important aspect for every product. This is important moment that depends what feature needs to be developed and kicked-off first.

### D. Security

Patient medical information represents a sensitive data. In the digital health world this data must be stored and distributed according to HIPAA and GDPR. These rules apply as well for the mobile applications, from the moment they share same information. The mobile applications as well represent a target for the attackers [24].

## VI. CONCLUSION

Every day we use at least one mobile app to make an action, for example a simple phone call. Mobile applications have become an inevitable part of our life style. With the growth of the performance of the mobile devices and integrations with the IoT segment, the mobile applications markets grow at an incredible speed. This article describes the main categories of the healthcare mobile apps, where each can contain multiple branches of subcategories that target specific use cases. Mobile applications are part of a global ecosystem that can facilitate many aspect of human life. We must consider the mobile apps as an option that could help solve a problem in the lifecare industry or at least offer additional benefits to the patients in order to improve their lifestyle and make their treatment seamless.

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# Sustainable development of the Republic of Moldova on reducing water pollution through the prism of software tools

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**Abstract** — The paper addresses the issue of sustainable development in the field of water resources. A description of two Goals of the Moldova 2030 Strategy is provided: SDG6 and SDG14, both of which prioritize the reduction of water pollution. It shows how these goals complement one another. In order to successfully achieve these Goals, certain international practices for the elaboration and development of software tools must be implemented. The practices mentioned above allow the creation of models for predicting the water quality of aquatic ecosystems. The study of the most frequently used methods and software tools for controlling water pollution currently used is presented. Hence, it is proposed to use software tools to improve the situation of water pollution in the context of sustainable development.

**Keywords** — *aquatic ecosystem; pollutants; prediction scenarios; software tools; sustainable development*

## I. INTRODUCTION

The rapid industrialization of countries has contributed to economic development, but it has also caused ecosystem imbalances by accumulating pollutants, which has a negative impact on the future of all humanity. All environmental factors are being impacted, but the effect on water is particularly concerning. As a result, an increasing number of countries are working to develop pollution-control strategies and techniques [1].

National and international institutions of analysis and research have developed studies and scenarios for long-term development across the time horizon of the 21st century (eg UN: Agenda-21 and Agenda -30; EU: Development Strategies 2020, 2030) [2].

Rio de Janeiro hosted the World Conference on Environment and Sustainable Development (Earth Summit) in 1992. This global gathering defined concrete programs that were brought together in an initiative known as Agenda 21. These programs also address the protection of water resources [2].

One of the central promises of the 2030 Agenda for Sustainable Development is that access to safe drinking water sources must increase as sustainable development progresses.

Water pollution does not contribute to sustainable development, but rather contrary has a negative impact on it.

Access to water is the basis of public health, and therefore is a critical point for long-term development. Society cannot evolve and strive to sustainable development while so many people live without safe drinking water.

To control water pollution worldwide, a number of software tools have been successfully applied, which can predict the degree of pollution, as well as identify the main pollutants. Some of these tools are WASP, Ansys CFX, GWLF, SMS, AQUATOX, CE-QUAL-W2, QUAL2K, WMS, HEC-RAS, etc.

## II. PROBLEM FORMULATION

Currently in the Republic of Moldova there is a major degradation of water quality. The water of the main rivers in the country has a different quality index than national and international standards. In order to improve water quality, all national legislation in the field of water resources is constantly linked to the basic directives of the Council of Europe's [3].

Two interdependent aspects are investigated as a part of assessing the impact of contaminants on aquatic ecosystems [4]:

1. Quantitative characteristics of human activity's impact (amounts of pollutants).
2. The ability of the environment to "resist" this impact - the ability of the environment to neutralize the effects of the impact of planned activities without changing the structure and functioning of the ecosystem, as well as the ability to reproduce resources, etc.

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The water quality in the Dniester and Prut rivers during 2020 recorded high concentrations of the following pollutants: total phosphorus, nitrate nitrogen, ammonium nitrogen, nitrite nitrogen, mineral phosphorus, petroleum products.

As a result, based on the registered indicators, quality classes III, IV and V (moderately polluted - polluted - highly polluted) were established according to GD 890/2013 for the waters of the Dniester and Prut rivers [5].

Obviously, all the pollutants mentioned above have a direct impact on human health, simply because surface water is a source of drinking water for approximately 35% of the country's total population. Consumption of water with a high nitrite content can lead to methemoglobinemia, especially which affects children aged 0-1 years, particularly those fed artificially; causes cancer of the esophagus, stomach, liver, intestines, colon, bladder, and other organs [6].

It should be noted that not all methods and software tools can be applied in all conditions. Thus, different tools may handle spatial and temporal dimensions differently. The number of water quality parameters simulated in the same way can make a difference. Also, the way transport processes are modeled differs between software packages.

Based on the foregoing, the problem of the paper has been formulated, which consists in the analysis of two Goals of the Moldova 2030 Strategy on reducing water pollution, as well as the analysis of the main methods and software tools that ensure water pollution control.

### III. SOLVING THE PROBLEM

Following the familiarization with all the Goals of the Moldova 2030 Strategy [3], it was concluded that the reduction of water pollution is related to the achievement of SDG6 and SDG14 objectives.

Among the targets of the SDG6 we can mention the minimization of water pollution from industrial processes, increasing the protection of water-related ecosystems. The objectives also include issues related to the sustainable management of water resources, including appropriate international cooperation and the involvement of local and regional communities in water management [7].

Even though the Republic of Moldova is not a maritime country, and SDG14 focuses globally on oceanic and maritime ecosystems, the conservation and sustainable use of the country's internal water resources and river ecosystems must be a key pillar of sustainable development. River pollution caused by urban and industrial activity presents problems for farmers who use water for irrigation, tourism entrepreneurs and others [8].

Thus, in the case of the Republic of Moldova, SDG14 largely corresponds to SDG6 targets.

Target 14.1 - Water pollution reduction, including through land-based activities, is a relatively important target. It is directly related to targets 1.5 (resilience of the poor to climate risks), 2.4 (resilient agricultural practices), 3.9 (reduction of mortality and morbidity caused by hazardous chemicals) and 6.6 (protection of water-related ecosystems).

Based on the description of the two objectives, Table 1 shows the comparative analysis between SDG6 and SDG14.

TABLE I. COMPARATIVE ANALYSIS BETWEEN SDG6 AND SDG14 OBJECTIVES

Nr.	Priority policy areas	
1	SDG6	Natural resources and Environmental Protection Waste management Regional development Disaster Management and Civil Protection Clean Water and Sanitation
2		Natural resources and Environmental Protection Waste management Agriculture and Rural Development
Relevant national policy documents		
1	SDG6	Moldova 2020 National Development Strategy Strategy on biological diversity of the Republic of Moldova for the years 2015-2020 and the related Action Plan Water Supply and Sanitation Strategy for 2014-2028 The program for the development of water management and hydro-improvement in the Republic of Moldova for the years 2011-2020 National Regional Development Strategy 2016-2020
2		Moldova 2020 National Development Strategy Moldova 2020 National Development Strategy The strategy on biological diversity of the Republic of Moldova for the years 2015-2020 and the related action plan The environmental strategy for 2014-2023 and the related action plan

The Republic of Moldova should significantly monitor, prevent and reduce the pollution of its surface waters, including rivers. The Dniester River flows



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directly into the Black Sea, while the Prut River has a confluence with the Danube.

According to the latest data of observations and measurements, since 2017, the quality of drinking water in Moldova has been consistently low. At least, this is what the results of the laboratory investigations of the 850 water samples, carried out by S.A. "Apa-Canal Chisinau" specialists, show. The test results show that rural areas have the worst situation. The quality of drinking water from underground sources does not correspond even according to bacteriological indications. Most groundwater sources are affected by livestock farms, landfills, fertilizer and waste dumps [10].

The main purpose of environmental risk assessment is to alert people to the danger of human activities to aquatic ecosystems. It is based on comparing the effects of the impacts of the planned activities and the response of ecosystems to them in order to assess the effectiveness of mitigation measures.

Pollution can be prevented or reduced, for example, by using software tools, that generate certain prediction scenarios based on mathematical models. These scenarios can predict the presence of both pollutants obtained from diffuse pollution sources and those from point pollution sources [9].

For rational consumption and management of water resources it is necessary to have a surface water monitoring system [10].

An essential tool in calculating the water quality class, as well as determining the spatial-temporal evolution of pollutants in order to prevent exceptional situations, is the mathematical and numerical modeling of river systems.

As with the whole of nature, not all situations for aquatic ecosystems are known, because the rate of change is much higher than it was 5-10 years ago.

It is critical that our practices are in line with the laws of nature, the implementation of software tools must be sustainable. In order for the system to be adaptive, vulnerability indicators and progress indicators must be monitored. Adaptation is local, which means that what is good here may not be useful elsewhere, or that some good practice must be replicated in similar situations in other regions.

Adaption methods include:

- a) implementation of technologies that ensure the survival of all living things;
- b) implementation of strategies that contribute to improving the quality of life by ensuring quality water.

At the moment, a number of software tools, such as AQUATOX, SMS, CE-QUAL-W2, Ansys CFX, WASP, etc., are widely used globally to control water pollution the application of which is an efficient method in determining the spatial-temporal evolution of pollutants.

Some of these tools are only developed at the national or regional level, with the goal of solving a certain problem related to the water resources of those areas, and others can be used internationally.

Table 2 presents the main features of the analyzed dynamic simulation software tools.

TABLE II. CHARACTERISTICS OF DYNAMIC SIMULATION SOFTWARE INSTRUMENTS

Nr.	Name of software tool		Description
1	AQUATOX		determines the behavior of various pollutants, such as nutrients and organic chemicals
2	WASP		allows the user to investigate 1, 2 and 3 dimensional systems and a variety of types of pollutants
3	CE-QUAL-W2		two-dimensional, longitudinal / vertical, hydrodynamic and water quality model
4	Ansys CFX		industry-leading fluid dynamics calculation software for turbomachine applications
5	QUAL2K		one-dimensional model of water quality for rivers and streams
6	GWLF		model that provides the ability to simulate leakage, sediment and nutrient loads (N and P) from a river basin
7	MONERIS		model that calculates nitrogen and phosphorus emissions into surface water in different ways
8	WMS		graphic system for simulating hydrographic and hydraulic basins in two-dimensional space. It can be used to model both the quantity and quality of water
9	SMS		software package for surface water modeling. The modeling process includes river hydrodynamics, rural and urban floods, wave modeling, following the dynamics and physical properties of water particles, determination and analysis of pollutants
10	WQRRS		simulates DO, total dissolved solids, P, NH <sub>3</sub> , NO <sub>2</sub> <sup>-</sup> , NO <sub>3</sub> <sup>-</sup> , alkalinity, total carbon, organic components and a number of aquatic biota, including plankton, algae, coliform bacteria, and several species of fish. It shapes the hydrodynamic shape, determines depths and speeds
11	MIKE 11		one-dimensional, easy-to-use, fully dynamic modeling tool for detailed analysis, design, management and operation of both simple and complex river and canal systems
12	InfoWorks ICM		the first software platform on the market for complete and truly integrated 1D / 2D hydrodynamic modeling of both rivers and sewerage systems
13	HEC-RAS		software that allows the user to perform a constant one-dimensional flow, non-uniform flow calculations in one and two dimensions, sediment transport / mobile bed calculations and water

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	temperature / water quality modeling
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To understand the differences between different tools for water pollution control, Figure 1 shows a comparative analysis of the main software tools used for the dynamic simulation of water quality parameters.

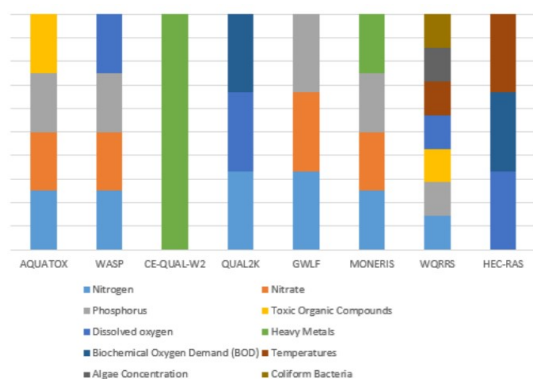


Figure 1. Comparative analysis of software tools for dynamic simulation of water quality parameters. [12]

The figure shows that nitrates can be modeled using the following software tools: AQUATOX, WASP, GWLF, MONERIS. Nitrogen can be modeled using: AQUATOX, WASP, QUAL2K, GWLF, MONERIS, WQRRS. Phosphorus compounds can be identified using: AQUATOX, WASP, GWLF, MONERIS, WQRRS. Heavy metals are modeled with only two software tools: CE-QUAL-W2 and MONERIS. It can also be seen that different software tools can model a different number of pollutants, so CE-QUAL-W2 models only heavy metals, whereas WQRRS can model coliform bacteria, algae concentration, temperature, dissolved oxygen, toxic organic compounds, phosphorus and nitrogen.

In order to achieve the Goals of the Moldova 2030 Strategy analyzed in the paper, the software tools described can be used.

Based on the large number of software tools available, a study is required to identify the most appropriate.

## CONCLUSIONS

Two Goals of the Moldova 2030 Strategy for reducing water pollution were analyzed. Thus, it was discovered that the Republic of Moldova's Strategy Goals are partially correlated with the 2030 Agenda for Sustainable Development.

A study on the water quality of the Dniester and Prut rivers was conducted, revealing a high level of pollution from various contaminants. An important aspect for reducing the degree of water pollution is the use of software tools, which would allow to determine the spatio-temporal evolution of pollutants in aquatic ecosystems.

It was discovered that software tools are not only an important method for determining water quality, but also allow the development of scenarios for predicting water pollution, which will significantly contribute to the Republic of Moldova's sustainable development.

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## **For Notes**





# Networks and Communication Session

# Research Opportunity To Estimate The Energy Gain Of The Received Signal Of The Cluster DVB-T2 SFN SISO

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**Abstract**— In this article, we explore the practical opportunity to estimate the energy gain of the signal, induced at the terminals of the receiving antenna, located in the service area of a cluster DVB-T2 SFN SISO. In order to achieve the research goal, it was assumed that two plane waves reach the input of the receiving antenna, but the reception of the signal is performed through the reference antennas with circular and directional diagrams.

**Keywords**—DVB-T2; SFN; SISO; MISO; reference antenna R&S HL 040; reference antenna RSH 4786; field strength; fading; intersymbol interferences; antenna factor; voltage induced

## I. INTRODUCTION

A digital terrestrial television network with a single frequency SFN (Single Frequency Network), is made up of a group of transmitters that simultaneously transmit the same informational signal, on the same carrier frequencies, without essentially interfering with each other and at the same time forming the same area of service [1].

The network of single-frequency DVB-T2 transmitters can transmit the data flow either in SISO (Single Input, Single Output) operating mode or in MISO (Multiple Inputs, Single Output) operating mode.

In the MISO regime; the cluster transmitters do not emit exactly the same signal. An additional processing step with Alamouti modified coding, divides the DVB-T2 signal between two groups of transmitters on the same frequency, so that the two groups do not interfere with each other. Due to this, the fading of the induced signal at the receiving antenna terminals from several transmitters is insignificant. The application of the Alamouti algorithm reduces the speed of network traffic.

In SISO mode, it is assumed that each receiver will demodulate and decode a signal from TV transmitter,

ignoring other signals. In reality, the receiver starts demodulating the first signal at its input (provided that its level exceeds the receiver's sensitivity threshold), but all the following network signals are evaluated by the receiver as interference. Under these conditions, may occur significant fading of the summary signal at the receiving antenna terminals.

Earlier, in the article [2],[3] it was shown that the interferences will be maximum when the levels of the received signals at the receiver input will be equal (comparable). To reduce interference it is necessary to use the directional receiving antenna oriented to the falling wave with the highest intensity.

This article investigates the practical opportunity to evaluate the summary level of the induced signal at the receiving antenna terminals, located in the service area of a DVB-T2 SFN SISO cluster.

## II. PROBLEM FORMULATION FOR RESEARCH

In order to achieve the proposed objective, was formulated the research problem:

1. There are 2 transmitters in the cluster - Station 1 and Station 2;
2. At the input of the receiving antenna reach the plane falling waves E1 and E2, where  $E1 \geq E2$ ;
3. The reception of falling waves is ensured via directional reference antenna R&S HL 040, or via the circular reference antenna RSH 4786;
4. Both reference antennas are connected to the consecutive receiver by the same feeder and their suspension height remaining constant;
5. Received signal frequency:  $F = 500$  MHz;
6. Following some simulations of the reception mode, which are expressed mathematically, it is necessary to check - what correlation exists between the increase of the signal level, induced at receiving antenna terminals in

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the service area of the DVB-T2 SFN SISO cluster, in relation to the case when a single falling wave of the network is received, with the highest intensity, with the condition that the receiving antenna is oriented strictly in the direction of this maximum radiation.

### III. THE METHOD OF MEASURING THE FIELD STRENGTH AT THE INPUT OF THE RECEIVING ANTENNA

The intensity of the E field characterizes the energetics of the radio frequency signal that reaches the reception point in the form of a plane electromagnetic wave [4]. The value of the field strength is an important energy parameter, on which it depends the quality of the received signal, after its demodulating and decoding.

To find out the field strength at the input of the reference antenna, it is necessary to measure the voltage at the antenna terminals connected to a load of 50 Om. The value of the field strength E [dμV/m] can be calculated by formula (1) [5]:

$$E = U_{50\Omega} + F_a + A_f \quad (1),$$

where  $F_a$  [dBm-1] is the antenna factor in the direction of maximum radiation;  $U_{50\Omega}$  [dμV] is the voltage induced at load 50 Om connected to the antenna terminals,  $A_f$  [dB] are losses in the feeder.

The directivity diagrams of the reference antennas are shown in Figure 2 and Figure 3. From Figure 3 we notice that the directivity diagram of the RSH 4786 antenna in the horizontal plane has an almost ideal circular shape. Table I also shows the R&S HL 040 antenna factor. Table II shows the antenna factor RSH 4786.

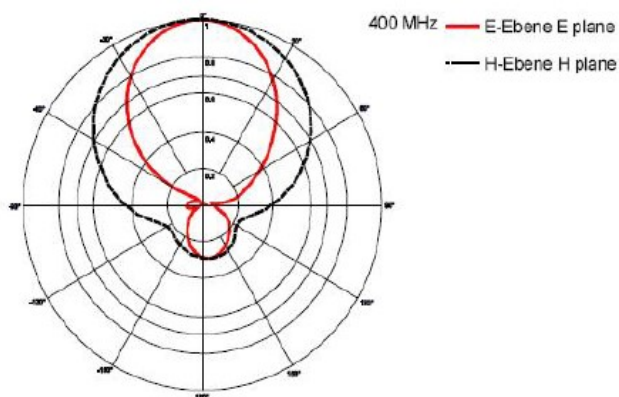


Figure 1. Directivity diagram of the R&S HL 040 reference antenna.

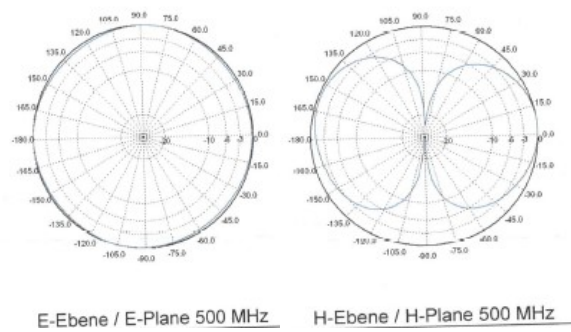


Figure 2. Directivity diagram of the RSH 4786 reference antenna.

TABLE I. THE R&S HL 040 ANTENNA FACTOR

Frequency, MHz	Antenna factor, dBm-1
500	16.37

TABLE II. THE RSH 4786 ANTENNA FACTOR

Frequency, MHz	Antenna factor, dBm-1
500	23.49

As a first step of the research, we will compare the voltage level induced at the receiving circular and directional antenna terminals. Reception conditions: works only Station 1, the directional reception antenna is strictly oriented in the direction of the falling wave  $E_1$ .

$$E_1 [\text{dB}\mu\text{V/m}] = U_{c1} [\text{dB}\mu\text{V}] + 23.49 [\text{dBm}^{-1}] + A_f [\text{dB}],$$

$$E_1 [\text{dB}\mu\text{V/m}] = U_{d1} [\text{dB}\mu\text{V}] + 16.37 [\text{dBm}^{-1}] + A_f [\text{dB}]$$

$$U_{c1} [\text{dB}\mu\text{V}] + 23.49 [\text{dBm}^{-1}] + A_f [\text{dB}] = U_{d1} [\text{dB}\mu\text{V}] + 16.37 [\text{dBm}^{-1}] + A_f [\text{dB}] \Rightarrow$$

$$U_{d1} [\text{dB}\mu\text{V}] = U_{c1} [\text{dB}\mu\text{V}] + 7.12 \text{ dB}.$$

Therefore, at the terminals of the directional antenna R&S HL 040 oriented in the direction of the maximum radiation of the falling wave  $E_1$  is induced the voltage level by 7.12 dB, higher compared to the circular antenna RSH 4786. Already, considering only this aspect, we can talk about the opportunity to use directional antennas in the service area of a DVB-T2 SFN SISO network.

### IV. SIGNAL RECEPTION VIA ANTENNA WITH CIRCULAR DIAGRAM

The following mathematical reports were prepared for the simultaneous reception of waves  $E_1$  and  $E_2$  by means of the antenna with the ideal circular directivity diagram. In this case, the plane waves  $E_1$  and  $E_2$ , will induce at the receiving antenna terminals, connected to the load 50 Om, the voltages  $U_{c1}$  and  $U_{c2}$ . Therefore, at the antenna terminals we will obtain a summary level of the signal:

$$U_c [\mu\text{V}] = (U_{c1} + U_{c2}), \text{ or}$$

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$$U_c [\text{dB}\mu\text{V}] = 20\lg (U_{c1} + U_{c2}).$$

1. We will examine the case when  $E_1 > E_2 \Rightarrow$

$$U_{c1} > U_{c2} \Rightarrow U [\mu\text{V}] = (U_{c1} + U_{c2}) < 2 U_{c1} \Rightarrow$$

$$U_c [\text{dB}\mu\text{V}] = U_{c1} [\text{dB}\mu\text{V}] + \Delta U_c [\text{dB}],$$

where  $0 \text{ dB} < \Delta U_c < 6 \text{ dB}$ .

$$U_{c1} [\text{dB}\mu\text{V}] = 20\lg U_{c1} \Rightarrow$$

$$20\lg U_{c1} + \Delta U_c [\text{dB}] = 20\lg (U_{c1} + U_{c2}), \text{ or}$$

$$\Delta U_c [\text{dB}] = 20\lg (U_{c1} + U_{c2}) - 20\lg U_{c1} \quad (2)$$

Therefore, when the intensities of waves  $E_1$  and  $E_2$  are comparable, the voltages  $U_{c1} \approx U_{c2}$  will be induced at the receiving antenna terminals, and increasing the level of the summary signal of  $\Delta U_c$  in relation to the signal  $U_{c1}$ , induced by the wave with greater intensity, will be comparable to the value of 6 dB. Consequently, at the receiving antenna terminals will appear the significant fading of the summary signal and respectively quite significant intersymbol interventions.

To demonstrate this case, were measured the levels  $U_{c1}$  and  $U_{c2}$  induced at the RSH 4786 antenna feeder output of two falling waves that are transmitted in 31 TV channel. The results of the measurements are shown in Figure 3 and Table III.

We notice that the values  $U_{c1}$  and  $U_{c2}$  are comparable. At the antenna terminals there is a significant fading of frequencies (see the frequency band of the 8 MHz channel), which speaks of the presence of quite significant intersymbol interferences. The quality parameter MER (Modulation Error Ratio) of the received signal has a rather low value  $\text{MER} = 20.6 \text{ dB}$ . The value  $\Delta U_c = 51.6 \text{ dB}\mu\text{V} - 48.2 \text{ dB}\mu\text{V} = 3.4 \text{ dB}$ .

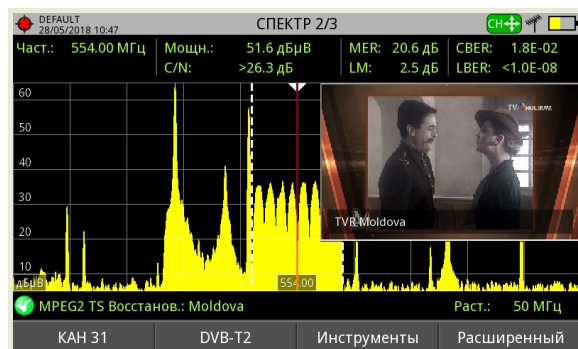


Figure 3. RSH 4786 antenna feeder output signal (Station 1 - On, Station 2 - On)

TABLE III. RESULTS OF DVB-T2 SIGNAL MEASUREMENTS VIA RSH 4786 CIRCULAR ANTENNA

Technical parameters	Station 1 On Station 2 Off	Station 1 Off Station 2 On	Station 1 On Station 2 On
$U, \text{dB}\mu\text{V}$	45.8	48.2	51.6
MER, dB	-	-	20.6

2. We will examine the case when  $E_1 = E_2 \Rightarrow$

$$U_{c1} = U_{c2} \Rightarrow U_c [\mu\text{V}] = (U_{c1} + U_{c2}) = 2U_{c1} \Rightarrow$$

$$U_c [\text{dB}\mu\text{V}] = U_{c1} [\text{dB}\mu\text{V}] + \Delta U_c [\text{dB}],$$

where  $\Delta U_c = 6 \text{ dB}$ .

In this case, the interference at the receiving antenna terminals will be maximum, but signal reception will be impossible.

## V. SIGNAL RECEPTION VIA ANTENNA WITH DIRECTIONAL DIAGRAM

As a first step we will appreciate the voltage level induced at the terminals of the R&S HL 040 antenna, in case when only Station 2 is working. For this we orient the R&S HL 040 antenna strictly in the direction of the falling wave  $E_2$ . Therefore, the voltage will be induced at the receiving antenna terminals:

$$U_{d2} [\text{dB}\mu\text{V}] = E_2 [\text{dB}\mu\text{V/m}] - 16.37 [\text{dBm}^{-1}] - A_f [\text{dB}].$$

For the simultaneous reception of the signals  $E_1$  and  $E_2$ , we will direct the receiving antenna strictly in the direction of the arrival wave  $E_1$ . In this case, the plane waves  $E_1$  and  $E_2$ , will induce at the receiving antenna terminals, connected to the load 50 Ohm, the voltages  $U_{d1}$  and  $U'_{d2}$ , where  $U'_{d2} \ll U_{d2}$  due to the directional properties of this, see Figure 1.

Therefore, at the antenna terminals we will get a summary level of the signal:

$$U_d [\mu\text{V}] = U_{d1} + U'_{d2}.$$

To evaluate the value of  $\Delta U_d$ , were developed the following mathematical expressions:

$$E_1 \geq E_2 \Rightarrow U_{d1} > U_{d2} > U'_{d2} \Rightarrow$$

$$U_d [\mu\text{V}] = (U_{d1} + U'_{d2}) < 2 U_{d1} \Rightarrow$$

$$U_d [\text{dB}\mu\text{V}] = 20\lg (U_{d1} + U'_{d2}), \text{ or}$$

$$U_d [\text{dB}\mu\text{V}] = U_{d1} [\text{dB}\mu\text{V}] + \Delta U_d [\text{dB}],$$

where  $0 \text{ dB} < \Delta U_d < 6 \text{ dB}$ , but

$$\Delta U_d [\text{dB}] = 20\lg (U_{d1} + U'_{d2}) - 20\lg U_{d1} \quad (3)$$

From the expressions (2) and (3) we observe that, when the values  $U_{c1} \approx U_{c2}$  but  $U'_{d2} \ll U_{d2} < U_{d1}$ , we obtain inequality,  $\Delta U_d < \Delta U_c$ . In conclusion, we can make a more detailed precision of the value  $\Delta U_d$ , namely

$$0 \text{ dB} < \Delta U_d < \Delta U_c < 6 \text{ dB}.$$

Therefore, this signal reception option is the most favorable for the DVB-T2 SFN SISO system, because  $U_{d1} = U^{\max}$ , but  $\Delta U_d = \Delta U^{\min}$ . In this case, the fading of the signal at the receiving antenna terminals will be non-essential, but the interference between the symbols will be minimal. To demonstrate this case, were measured the quality parameters of the signal induced at the output of the R&S HL 040 antenna feeder by the same two falling waves, as in the case presented in Fig. 3. The measurement results are shown in Figure 4,5,6 and Table IV.

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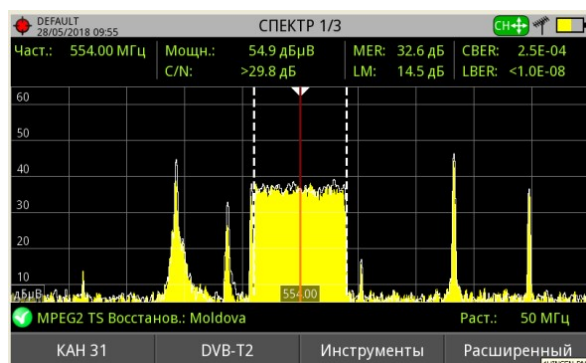


Figure 4. R&S HL 040 antenna feeder output signal, oriented towards Station 1, (Station 1 - On, Station 2 - On)



Figure 5. R&S HL 040 antenna feeder output signal, oriented towards Station 1, (Station 1 - On, Station 2 - Off)

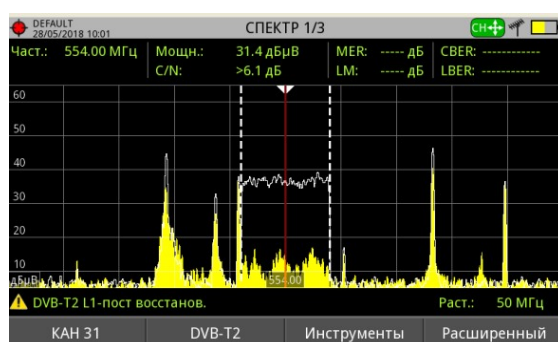


Figure 6. R&S HL 040 antenna feeder output signal, oriented towards Station 1, (Station 1 - Off, Station 2 - On)

TABLE IV. RESULTS OF DVB-T2 SIGNAL MEASUREMENTS VIA RSH 4786 CIRCULAR ANTENNA

Technical parameters	Station 1 On Station 2 Off	Station 1 Off Station 2 On	Station 1 On Station 2 On
U, dBμV	54.5	54.9	31.4
MER, dB	34.2	32.6	-

We notice that  $U'_{d2} = 31.4 \text{ dB}\mu\text{V} \ll U_{d1} = 54.5 \text{ dB}\mu\text{V}$  but  $\Delta U_d = (54.9 \text{ dB}\mu\text{V} - 54.5 \text{ dB}\mu\text{V}) = 0.4 \text{ dB}$ . So the fading of the summary signal is insignificant, but the interferences are minimal. Compared to the case of the circular antenna, the MER quality parameter increased by 12 dB (32.6 dB - 20.6 dB).

## VI. CONCLUSIONS

Following the research opportunity to estimate the energy gain of the induced signal at the receiving antenna terminals in the service area of DVB-T2 SFN SISO cluster, were reached the next conclusions:

1. It is inappropriate to increase the summary level of the  $\Delta U$  signal, induced at the receiving antenna terminals in the SFN SISO mode, in relation to the case when is received a single fall wave with the highest intensity;
2. Estimation of the value  $\Delta U$  may be appropriate only in the case of indirect estimation, at reception, of intersymbol interference. When  $\Delta U \approx 0 \text{ dB}$  – the interferences will be minimal. If  $\Delta U \approx 6 \text{ dB}$  (relative to U [dBμV]) or  $\Delta U \approx 3 \text{ dB}$  (relative to U [dBm]) - the interferences will be maximum. As an example, when the value of  $\Delta U$  becomes comparable to 6 dB (3 dB) we can talk about the fact that the signal reception is organized incorrectly.

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# Implementing Design Science Research Method to Develop a Cyber Security Framework for HEIs in Moldova

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**Abstract**— This scientific paper presents how a problem in the field of cybersecurity can be solved by using the scientific method Design Science Research (DSR). The research problem is the lack of a comprehensive cyber security framework that meets international security standards for HEIs (Higher Education Institutions) in Moldova. Although the need for a centralized approach to cybersecurity in university networks, which are decentralized and open by design, is increasingly emerging with the digitalization of HEI. Thus, actions were identified for each stage of the DSR method, which as a result will produce a cyber security conceptual framework (CSCF) for increasing cyber security in HEIs.

**Keywords**— DSR method; framework; cyber security; HEIs; ISO27001.

## I. INTRODUCTION

Universities currently provide several services based on communication networks. Thus, HEIs (Higher Education Institutions) have become dependent on Information and Communication Technologies (ICTs), in order to provide digital educational and research services, indispensable in the 21st century.

Unfortunately, recent researches have highlighted an impressive increase in cyber-attacks within HEIs in 2020 [1]–[4], which makes the situation alarming and requires prompt reactions. Insufficient knowledge of the risks associated with information assets can significantly damage the activity of HEIs [5]. It is necessary to consider support assets such as: network devices, applications, human resources, infrastructure; that are used to protect the primary assets of HEIs such as:

- business processes: online courses, exams, IT infrastructure for students or dedicated applications;
- information: research data and personal data, intellectual property or dissertation materials, financial records.

Thus, cyber security will play an increasingly important role in the activity of HEIs, in the next period. Cyber security has been defined by the International

Communications Union (ITU) to mean "a collection of tools, policies, security concepts, security safeguards, guidelines, risk management approaches, actions, training, best practices, assurance and technologies that can be used to protect the cyber environment, and organization and user's assets" [3]. Researchers recommend the implementation of cybersecurity frameworks, to achieve proper protection in the campus network [6], [7].

The framework can be defined as a network or a plan of interconnected concepts, which provides a comprehensive understanding of a phenomenon [7]. Approaching cybersecurity in HEIs by implementing a conceptual framework will allow the combination of several existing concepts so that the framework created is one focused on the activity of HEIs and effectively protects cyber security.

In this scientific article, the method of Design Science Research (DSR) proposed by the author to develop a cyber security conceptual framework (CSCF) for HEIs in Moldova was analyzed. Without a strong component that produces explicitly applicable research solutions, research in the cyber security field, faces the potential of losing influence over research streams for which such applicability is an important value [9]. The actions and what were achieved for each stage of the DSR method were established, in order to understand how the CSCF was developed and the result of the scientific study to be reproducible.

Thus, the second section of this work will describe the research problem, in the third section the reasons for selecting the DSR method were established, the fourth section will describe the process by which DSR contributed to the development of CSCF for HEIs in the Republic of Moldova. The last section is reserved for conclusions.

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## II. BACKGROUND

The need for comprehensive research, to create the CSCF for Higher Education Institutions in the Republic of Moldova, was based on:

- the survey in which the stakeholders of the Information Technology departments from the 9 largest state institutions in the Republic of Moldova participated. The results of the survey show that HEIs are not certified with any standards for information security and do not have an authorized cybersecurity framework;
- the literature review of research articles about how to ensure cyber security in HEIs, which elucidated the problem of insufficient research regarding the cyber security frameworks implemented in the HEI.

Researchers have differing views on the cybersecurity framework that would be appropriate for HEIs, however the following standards prevail: ISO27001, COBIT and ITIL. The problem is that standards are oriented of commercial organizations, that why is difficult to implement them in universities [10]–[12].

The research problem can therefore be defined as: "the lack of a cyber security framework for HEIs in the Republic of Moldova". The development of CSCF would solve this problem.

In the field of cyber security, in Moldova, exists the Government Decision 201 (GD.201), of 28-03-2017, on the approval of the Mandatory Minimum Cyber Security Requirements [13], that refers to all public organizations, without a special emphasis on the specifics of HEIs, moreover, in a paper previously published by the author [14], multiple gaps were identified between DG201 and ISO27001.

## III. DESIGN SCIENCE RESEARCH METHOD

The challenge was to select a method that would allow the creation of a product, a security framework that would solve cybersecurity issues in HEIs. This premise was the basis for identifying the scientific method Design Science, intensely used internationally, the finality is an artifact that can be a model, concept or framework [15]–[17].

DSR is defined as "a problem-solving paradigm that seeks to improve knowledge by creating innovative artifacts" [15]. Another approach to DSR is "research in design science (DSR), also known as constructive research, is a methodological approach concerned with the design of artifacts that serve human purposes" [18].

The result of this type of research, as already mentioned, is an artifact that solves a problem in the field, also known as the concept of solution, which must be evaluated by criteria of value or utility [18]. The DSR method has been appreciated as one of the main research methods for engineering [18].

DSR projects must offer both intellectual merit in creative design and extended impact in the application field through original solutions to the research problem [16], [17]. This is seen as an opportunity to demonstrate

the rigor and relevance of Information Systems as an academic field [19], [20], and Information Systems research should help address real-world challenges [21].

Research is linked to the need for solutions to be investigated empirically with specialists from organizations using specific technology [15]. Often, the analysis of the business environment and the derivation of the specific needs to be addressed build the starting point of a DSR project. However, there are also situations where the needs have already been studied and can be taken from existing research [15].

DSR aims to create an innovative solution to the problem, which in most cases builds on the existing components of a solution and combines, revises and expands existing design knowledge [15]. Simon [22] stated that "solving a problem means presenting it so that the solution becomes transparent".

The literature identifies 6 typical stages of the DSR project: problem identification and motivation, definition of objectives for solution, design and development / design of the artifact, demonstration, evaluation, followed by communication of results [9], [15], [23]. In the next section will be assigned the specific actions for each stage of DSR, to develop CSCF artifact.

## IV. COMMUNICATION OF RESULTS

In order to solve the research problem, the DSR method was used, which allowed the creation, development and evaluation of CSCF artifact, which can be later implemented to increase cyber security in HEIs, as long as this scientific method focuses on solving a specific problem in the field [15], [16]. Figure 1 shows the actions performed according to the DSR stages.

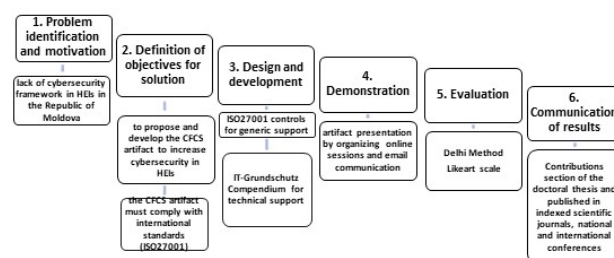


Figure 1. DSR stages

### A. Problem identification and motivation

Due to decentralized networks, consisting of several small networks, opening to the Internet [18], to provide extensive educational services to students, HEIs are vulnerable to various cyber-attacks. Due to the impressive amount of personal data or research data with which it operates, it is of great interest to cyber attackers. However, HEIs in the Republic of Moldova are not certified with any security standard and have not implemented a comprehensive cyber security framework such an Information Security Management System that is



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recommended by ISO27001, or another cyber security framework.

### B. Definition of objectives for solution

The objective was to develop a cybersecurity conceptual framework for HEIs, based on the security standard ISO27001, to comply with the Bologna process, which defines the importance of implementing frameworks internationally recognized as an extremely important process. The challenge was to identify the value criteria for the CSCF artifact. The proposed criteria and arguments can be seen in Table 1.

**Table 1. Criteria of value**

Nr	Criterion	Arguments
1	Target group oriented	Contain controls corresponding business processes in academia
2	Implementation phases	The artifact must determine the main steps after which the cybersecurity framework will be implemented within the HEI
3	Predefined roles	The roles of staff involved in the implementation of cybersecurity in HEIs must be clearly defined, in order to know the responsibilities of the post and to designate the owners of critical assets.
4	Risk management	In order to increase the effectiveness of the security framework, it is necessary to identify the real risks, related to the critical assets and the threats that may affect them. To assess the impact of risks.
5	Efficient	The efficiency of the artifact depends directly on how well it is understood by HEI specialists, who are going to implement it. How clearly the objectives, purpose and implementation phases were defined.
6	Scalable	It can be implemented in any institution, regardless of its size and the complexity of the services it provides
7	International importance	The security framework for HEIs must comply with international standards in this field, and subsequent certification of institutions is an appreciable objective.

The Delphi method was used to evaluate the CSCF artifact, as it is suitable for obtaining expert recommendations when designing a new information system [24], that solves a problem in the real environment. The generic characteristics of the Delphi method are: selection of experts, creation of a panel (repetitive investigation method to follow the evolution of a phenomenon through requests for information, at pre-established intervals, from the same groups of people), anonymity of participants, iterations and feedback [24].

### C. Design and development

The development of the CSCF artifact was based at the initial stage on the review of the literature to identify

the security frameworks for HEIs, recommended by researchers, the security standards analyzed through their implementation in academic institutions and the current state of research in this field. Thus, it was established that the development of the CSCF artifact is based on ISO27001. But the big challenge has been to determine how ISO27001 controls can be implemented, being generic. Thus, it was established that the development of the CSCF artifact should be achieved through the synergy of ISO27001 and IT - Grundschrift Kompendium which is a technical guide containing the necessary tools for the implementation of security controls. And finally, interdependencies were created between university business processes and support assets.

### D. Demonstration

After the CSCF artifact was created, it was presented to the selected experts and stakeholders. The Likert scale, often used in many scientific articles [25], [26] was subsequently proposed to evaluate the artifact in the light of the value criteria set out in point B. Thus, in order to demonstrate the effectiveness of the criterion, it was necessary to place it between 4 “Highly efficient” and 5 “Most efficient”, the criterion was assessed as suitable for the validation of the artefact.

### E. Evaluation

This activity should determine how much the CSCF artifact supports solving the research problem [1], this is possible in view of the objectives set out in point B, compared to the result of point D.

The qualitative method of evaluating the artifact was used, through several Delphi rounds, which allowed obtaining the evaluation through empirical evidence (feedback from experts and specialists in the field) and evidence proven by applying the international standard ISO27001. The qualitative approach facilitates a better understanding of the perceptions, beliefs and attitudes of the participants in the philosophical interpretive study of information systems [27]. The qualitative method allows to understand the context of a solution, including based on the comments made by HEIs specialists.

Thus, for the initial evaluation, the CSCF artifact was presented to the experts for evaluation, a great value representing the recommendations given by the experts. Subsequently, for empirical evaluation, the CSCF artifact was presented to HEIs stakeholders. The post-implementation feedback will be presented after the CSCF artifact will be implemented for a certain period of time in the HEIs of the Republic of Moldova.

### F. Communication of results

The communication of the results took place through the publication of scientific articles and participation with communiqués at national and international conferences.

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Thus, the criteria according to which the CSCF artifact was developed, the novelty of the product and how it will have an impact on the increase of cyber security in the HEI will be exposed. The CSCF artifact was presented to both the technology-oriented and the management-oriented public. This will allow practitioners to reap the benefits of the CSCF artifact, and researchers to build a cumulative knowledge base for further extension and evaluation of the artifact [2].

## V. CONCLUSIONS

The DSR method was the research method selected to develop the conceptual framework for increasing cyber security in HEIs in Moldova.

This research method is qualitative, in order to obtain qualitative results, the Delphi method was selected, and the Likert scale to evaluate the value criteria of the proposed conceptual framework.

The chosen scientific method made it possible to identify the steps needed to solve the identified research problem, so it can be concluded that it is effective in the field of cyber security.

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# AAA protocol in IoT

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**Abstract**—This document is representing not only the description of AAA protocol. It is representing real production problems which I encountered in many years of work with it.

Each from this problem was taken separately. It was analyzed and the best solution was applied to it.

Article is containing not only analyzing of the problem. In this document the solution described was developed and tested in time on different networks starting with few hundred devices and finishing with tens of thousands of them. On production, solution applied worked for years. Based on this point, I can conclude that problems which were on the production, where solved by applying of those solutions.

In order to understand those problems, is needed to understand how this protocol is working and where are the bottleneck points of it.

**Keywords**—AAA; Authorization; Authentication; Accounting

## I. INTRODUCTION TO AAA

AAA protocol stands for *Authorization*, *Authentication*, and *Accounting*. The description of those three words are:

**Authorization:** is the process of verifying the privileges or permissions of the authenticated IoT device to access system resources. Some companies, when producing the device, include a security certificate for authentication, and others authenticate them based on the MAC addresses of the device. In this order the IoT device can get authenticated into the system.

**Authentication:** is the process of verifying the details of an IoT device to identify it and grant access to the system. An IoT device must be network authenticated so that applications can control that device. Authentications are of several kinds.

**Accounting:** is the process in which the list of options supported by the device is checked. Including transmission and operating speeds according to the licenses set.

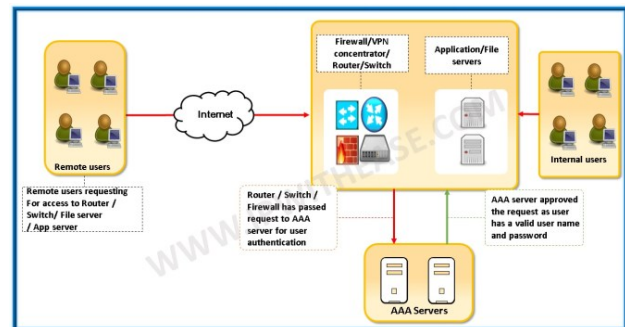


Figure 1. Graphical schema/description of AAA request-reply message

## II. WHAT ARE THE MOST IMPORTANT TYPES OF AUTHENTICATION AND AUTHORIZATION THROUGH THE AAA MESSAGE?

### A. Authorization of good format of the AAA message

Requires client authentication. Initial step in the authorization process. It means the users or device controlled by user which is sending good structured AAA request to an authorization server. [1]

### B. Authorization with specific permissions

Grants the customer access request and can provide specific configuration information needed to start delivering the specific service to the end user. AAA server is interacting with specific module of an application. In a service provider, this module would manage resources and access, and configure the service equipment to provide only the part of authorized service granted to user. It can also take the decisions itself at the authorization level because it has the application specific knowledge needed for that.

### C. Authorization log files

For controlling and checking purposes, the AAA server should have some database where can be stored events which will occur in the AAA server. They will have the time of the event, action proposed, and some additional data. Like MAC address or IP of source which

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sent the message itself. The main point here can be the time of the connection and the traffic or other important data which can be accounted. With help of certificates, this module could support non-repudiation.

#### D. Database of rules and services

A database which contains all available services in the system and all its resources based on which authorization decisions can be taken and the policy rules to take those decision is also needed. Naming convention for services and resources is important as it will be asked from other AAA servers in order to be able to generate complex authorization requests.

#### E. Forwarding of the AAA messages

As it can be a root domain with multiple subdomains in it, which can create the AAA problem parsing issues, a mechanism to forward AAA messages between authentication servers is required. Finally, communication will be done by peer-to-peer protocol and by having all intermediate resources (AAA subdomains servers) transparently.[2]

### III. MULTIPLE DOMAINS IN MULTIPLE TYPE OF SERVICE ARCHITECTURE

Can be distinguished six different models of communication:

#### A. AAA server can work in 3 different authorization models.

Same AAA server can support all 3 authorization models. They are: agent (or client/subscriber), pull (asking for some specific value on time interval), and push. Idea with this model is, that it can be an intermediate server, that can transfer AAA message from origin to next authentication hop, or to final authenticated server. Due to this, is crucial to have the server working in all 3 authorization models.

#### B. Main rule of AAA server

The main rule of AAA server knows exactly how to evaluate the structure of AAA message and how to parse the AAA requests.

#### C. No sophisticated logic is present in its implementation

AAA server has no knowledge what exactly data are containing the AAA message. Due to that, it is just parsing and sending or forwarding data to final device.

#### D. Forwarding of an AAA messages

There are 3 type of domains. A, B, and C. Each of them has their own naming space problems. In order to solve them is needed to use the forwarding of an AAA messages by locating the right server where message should be forwarded based on rules predefined in the system configuration.

#### E. Peer-2-peer protocol

Communication of type A should be a standart peer-2-peer protocol without distinguish between client and server like a separate roles. It means that all routing till the moment when message will be delivered, will be transparent like a peer-2-peer communication.

#### F. Services, applications and domains mixed together

AAA protocol can allow information equipment interconnected for accessing multiple services that's belong to multiple applications that can be located in multiple administrative domains. All of those can be combined in a single AAA message. Next picture will put a cleaner view on how it is combined and working:

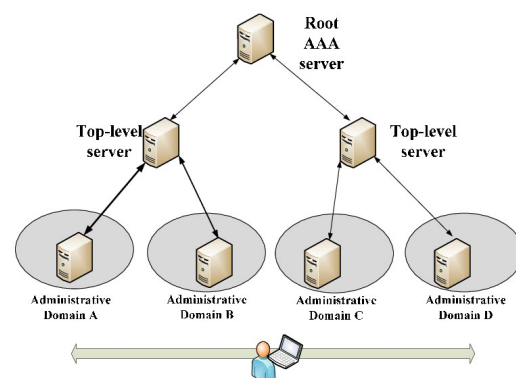


Figure 2. Example of a Multiple Domains and Multiple Type of Requests. (figure caption)

Top-level servers in Figure 2 are representing model A of communication. If the AAA request belong directly to Root AAA server, the communication for AAA message will be transparent and communication model used will correspond to point E.

### IV. WHAT ARE THE MOST COMMON SECURITY RISKS OF THIS PROTOCOL?

Can be distinguished 3 types of most common security risks of this protocol [3]-[7]. They will be described below with 2 sub items for each security risk.

That's assume that there is a number of devices that are interconnected to our application. For some reason, another device is being purchased and trying to authenticate to the network. Given the fact that the number of devices is higher than the number allowed by the application, the last one will not be authenticated in the network. The most common problems are:

#### A. AAA flood request

The device will send Access-Request (AAA-Request) messages at a configured interval of X seconds, or calculated according to a certain algorithm, which does not exceed 2 minutes. This means for the system a fairly



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large flood of data. Because the application party is required to reply to or ignore this message, this means that this message will be read, processed, analyzed and processed anyway.

#### *B. Wrong capacity processing by server*

If there are 2 times more devices than the number supported by the initial application, then they can be a real challenge for the server application that needs to authenticate the devices on the network. This large number of messages, the authentication application, may stop responding and shut down shortly. Usually, it can happen at the moment when initial AAA message is containing a certain amount of fields, and, in the time, number of fields are dramatically increased. At this moment of time, new calculations were not performed as all previous calculations were based on old counting, writing rules and limitation done at design processing of the application.

Depending on the construction of the authentication level of the application, and of the final devices, the decommissioning of the authentication and authorization module may lead to the decommissioning of all IoT devices connected to the network. This moment is important because it must be taken into account when creating and designing the network. In general, there are 2 types of problem solving.

#### *C. IoT devices with RAM memory only*

The device when connected to the network, receives authorization and authentication. This information is stored in its RAM. It will work connected to the network, even if on a regular request it will not receive a positive authentication response, until the device restarts. Then the RAM will be erased, and authentication will be required again.

#### *D. IoT devices with RAM and ROM memory*

The device when connected to the network, receives authorization and authentication. This information is stored in its ROM memory. It will work connected to the network, even if on a regular request it will not receive a positive authentication response, including after restarting the device. Then the RAM will be erased, but the ROM will keep the data of the last successful authentication. In this case, the removal of the device from the network can only be by sending a direct message to the device, deleting the last authentication data, and blocking it to the subsequent massive transmission of data on the network.

Massive request for authentication of all network elements simultaneously. It is assumed that we have a network that operates according to principle 2 point a) listed above. At some point, there is a power outage, and all devices are disconnected. When connecting power, all

devices will require authentication simultaneously from the central device. It may shut down at a high demand for messages. The solutions to avoid the last problem are:

#### *E. Random generation time*

To configure a random time on the IoT device. The authentication request must be from 5 seconds plus a certain factor that can be calculated according to a certain formula, but not more than 2 or 5 minutes. This factor can still be specified later, if the device can keep this information in the ROM memory.

#### *F. AAA time to live configured on the queue*

Limiting the request for queue authentication messages. By using a stack, or a queue, and by limiting the number of messages on that queue, as well as their lifetime. For example, the incoming message may have a lifespan of 5 minutes. If the message was not processed, it was automatically removed from the queue and the next authentication request can be processed. If it is not exceeded 5 minutes waiting time for the message in the queue, or the message limit per queue is not exceeded.

### V. AUTHORIZATION INFORMATION

Authorization decisions needed and services involved in authorization process will be described in this section. [3]-[7]

1. Authorization message at parsing time should be able to take the next information: information about the requestor which can be MAC or IP based, the service/method asked request, and the operating environment (sometime it can be VxWorks or some configured Ubuntu/Debian distribution, etc). AAA message will be transported via TCP/UDP protocols and specific listener based on destination port will receive the message and will parse it.

2. Final result will be the representation of AAA message information as a sets of attributes. This information can also be grouped in objects.

3. Due to needs of keeping all the data into a single message, appeared the need of packaging authorization information. In such manner sending it to different services or applications which can process is done more easily as it will be a single AAA message which will be sent.

4. Attributes are divided in 2 sides. From 1 side, they should be the standard one. (e.g. identity information, group information, sender information, destination information, ...) and for another side, they can be a specific application or service protocol implementation. In this way, this attribute can be read only by application of a single company or set of products.

5. Authorization decisions can be divided in 2 sides. From one hand it can be based on identity information,

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and for another hand the decision can be based on role access control authorization.

6. Authorization information should specify the number of attributes and the additional AAA message size which will come with the message.

7. Other, non AAA protocols, should be able to add their own attributes and encapsulate it to AAA message. In this way, other protocol information can also reach needed server where their attributes will be parsed. Response of those attributes will come with AAA reply.

8. In some organization system administrators should be able to define their own attribute types. Later on, those attributes will be encapsulated into AAA message. For organizations those attributes can be very important in order to make right authorization decisions.

9. New attribute in the AAA message should be possible to be defined without including a central administration authority. Like a subdomain in entire domain may use its proper AAA plus new attributes.

10. For newest created attributes in the AAA message should be possible to define their own types. Based on this, and instance of an attribute can lead to different values. Like an enumerated value.

11. It can be possible to get different instances on the same AAA attribute based on its enumerated type or value. Each domain, sub-domain or authorization authority can have a different instance of same attribute.

12. Authorization decisions are taken based on some rules. AAA protocols should come together with a mechanism for updating the rules in order to be able to control authorization decisions.

13. In authorization decision can be a chain of AAA entities. It can happen when a subdomain architecture is build. In this case, first subdomain server can forward this request to root domain.

14. Intermediate AAA entities should be able to add their own local authorization attributes information to a AAA request or response. In this way will be possible to track the source of AAA message and to know where the response should be sent back.

15. Sometime can be required to have a separate deploy of AAA message entity. Or the deploy can be integrated with application entities. AAA endpoints can build their own AAA message. It can happen in MESH network configuration. In this case, 2 endpoint which exchange information directly.

16. Creation and encoding of rules that should be active and processed by the AAA server accordingly to the attributes given by another AAA server should be supported in AAA protocol. Depending on level of authorization of AAA attributes, the requesting AAA Server should be able to view those attributes or not. It can be done in the process of Marshalling the AAA message in different way. Since the data can be sent in a raw format, it is very important that it can be read and well parsed in other language. Due to that, a specific parser can

be used in correspondent way by taking into account version number or flag indicated in AAA message.

17. Can be distinguished 2 type attributes: critical and non-critical. IE: There are critical information without it the AAA message cannot be recognized, and additional information which can come as part of additional functional, feature implementation, etc.

18. Authorization rules can be interpreted based of combinations of other authorization rules which were already evaluated. Important thing is member of one AAA group cannot access the resources of another member.

19. Authorization decisions can be based on the geographic location of a requestor or AAA entity. In this way a new development logic is required to be implemented. From one hand is needed to add a specific geo location for this device, and from other hand, is needed to add an additional field for AAA message for subdomain forwarding.

20. Authorization decisions should be based on the identity (which can include a TLS/SSL certificate) or the equipment itself which is used by the requestor (can be identified based on MAC address), service (authentication one which can work in mode described in point III. A) or an AAA entity.

21. In case of having multiple instances of a specific attribute, there should be an unambiguous mechanism where a receiving peer can determine the value of specified instance. In this manner, marshalling parsing and versioning (sometime including gateway information) should be implemented. It has a correspondent order per version, so in that case mapping can be done accordingly.

## VI. SECURITY OF AUTHORIZATION INFORMATION

Authorization information should go in secure way to its destination. It is very important aspect as it should assure that no repudiation attack or spoofing attack can take place. [3]-[7]

1. Authorization information should be securely communicated in AAA and application protocols. Algorithm which is responding for authenticity, integrity and privacy for this information should be specified.

2. Authorization information can be sent using AAA protocols in different security levels. From less secure mechanisms for data integrity/confidentiality to highly secure.

3. The security requirements can differ between different parts of a package of authorization information. This point can be interpreted as getting access to the network or to some resources. In case of network access, data can be sent in open format without any encryption. However, using access to some specific resources, is requiring to send the data only in encrypted format. As open format is not recognized by the resource which should grant access to some specific services or resources.

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4. In AAA protocols should be implemented mechanisms and algorithms that will prevent intermediate administrators breaching security. Man-in-the-middle attacks, where an intermediate administrator can change AAA messages on the fly should be prevented.

5. AAA protocols should have implemented on receiving and answering to a host for not more than a few retries per minute. This parameter can be configurable on algorithm based. It has the meaning of not allowing flooding attacks where the attacker can send a lot of AAA messages till the moment when it will be detected and blocked by the system. This kind of attack is causing waste of CPU and RAM memory resources.

6. AAA protocols should be capable of communicating secure less in the network where the security was already implemented. Like VPN tunneling or IPSec. In that case, securing again over secured connection can be resource waiting.

7. Trusting peer-2-peer confidentiality, integrity, authentication, and non-repudiation can be required for packages of authorization information. It can be used by sending AAA information for root domain, and the subdomain at processing time, can remove from this message some data. At this point root domain will get an "easy" message which can be parsed quickly. Such type of messages is using less CPU or memory resources.

8. AAA protocols can be used in networks where no peer entity authentication is required (e.g. a network address which is inside a secure LAN can be enough). It will ask anyway for secure AAA message. This point is

the opposite of point 6. However, it is saying that we are already in a secure environment, so no reason to secure again those data.

9. All AAA messages should be encrypted by default for all protocol options. Implementations of AAA entities (agent, pull and push) should use the secure defaults unless otherwise configured/administrated by the administrator of the resource. This idea can change in different organizations, but the principles will remain the same. Interpretation of "secure" can change based on organization rules and privacy levels.

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# Mission Monitor and Control Platform for TUMnanoSAT Ground Segment

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**Abstract**—This document will cover the overview, development and implementation of mission control platform for TUMnanoSAT, a CubeSat developed at Technical University of Moldova. A mission control platform is essential for a space mission in order to command and control different subsystems, monitor their health, process telemetry and useful data, receive and control requests but also in presented scenario it should be strongly linked to radio software defined architecture from ground station.

**Keywords**—satellite; mission control; ground segment; TUMnanoSAT; communication; Software Defined Radio

## I. INTRODUCTION

Global space activities in general and CubeSats in particular are experiencing unprecedented growth. Just in 2020 the world registered 1260 new satellites and other space objects with the United Nations Office for Outer Space (UNOOSA). It means that just in one year were registered 10% of all space objects ever registered since 1957 [1]. Also, as for 2021, over 1500 Cubesats were launched [2].

Center for Space Technologies from Technical University of Moldova aligned with those standard and developed a Cubesat which will be launched from International Space Station after winning KiboCube round 4, organized by UNOOSA and Japan Aerospace Exploration Agency (JAXA). TUMnanoSAT was developed based on international Cubesat Standard [3].

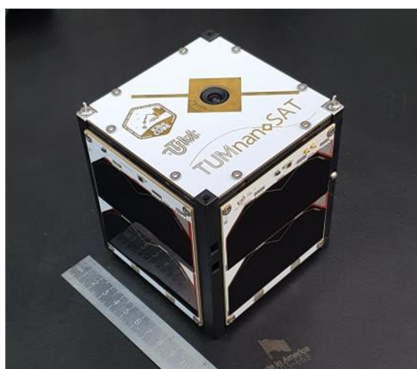


Figure 1. TUMnanoSAT – a 1U CubeSat

The basic mission of this satellite is an educational one, in the light of offering students, masters and PhD students the possibility of direct involvement in the design, development, integration, launch and post operation of a nanosatellite. Apart from educational purpose, TUMnanoSAT has other missions, including scientific objectives:

- Research of sensors based on nanostructures under space conditions;
- Establishing an efficient satellite - ground station communication mechanism;
- Research of the total irradiation dose (TID) level using RadFET. [3]

Besides satellite, in every spacecraft system, there is always ground segment which basically consist of ground station and a monitor and control center. In order to assure a successful mission, at Center of Space Technologies was set up a whole infrastructure with two ground stations and a mission control center with the possibility of processing, command and control.



Figure 2. Mission Monitor and Control Room at Center of Space Technologies

## II. GROUND STATION OF TUMNANOSAT

The reception of the satellite telemetry data and payload data is achieved through a radio architecture. The functionality of a traditional radio architecture, within a satellite communication, is primarily based on hardware components, with minimal software configurability [4].

Conventionally, they consist of: modulators, coders, amplifiers, filters, mixers, etc., dedicated to a certain mode of transmission. The software part is dedicated to the control of the interfaces with the communication network.

Given that the hardware predominates in this model, a possible upgrade of the system would mean a total change of the model and a redesign of the system. Taken into account that ground station should be able to communicate with different satellites that have different communication parameters this traditional hardware radio architecture is outdated. SDR or Software Defined Radio solves this problem. The IEEE have defined SDR as a „radio in which some or all of the physical layer functions are software defined” [5].

SDR provides a new approach in designing a ground station, an approach that brings primarily significant reduction in design complexity, cost and offers a flexible environment, versatile radio architecture development.

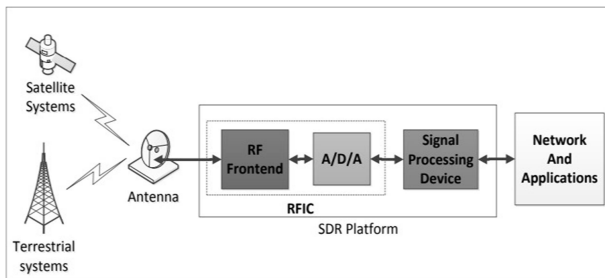


Figure 3. Generic SDR-based radio system [6]

As was mentioned in a SDR platform radio specifications can be implemented entirely by software, making also less complex integration of this platform in mission control platform. At this time, there are a lot of frameworks for implementing radio functions and digital processing units. The most popular being GNU Radio The USRP is usually controlled by GNU Radio software, an open software with a lot of digital processing blocks for signal acquisition, error correction, message handling, etc. Also, this open software allow to create digital blocks from scratch for specific requirements. It can be used with external RF hardware to create software-defined radios, or without hardware in a simulation-like environment [6].

The continuous developing of SDR technology made possible to have Commercial-off-the-shelf (COTS) SDR frontends. One of the most popular is USRP B series from Ettus Research with a coverage from 70 MHz to 6 GHz [7].

This frontend along with GNU Radio and other components of ground station (antenna, feeder, rotor, relays, etc.) is used in TUMnanoSAT ground station.

Those components should be implemented in mission control and communication platform.

### III. CONTROL AND COMMUNICATION PLATFORM

The main problem of existing open source or commercial platforms for mission control is that there is almost no possibility to integrate SDR component in their framework. Therefore, was

decided to develop and implement a custom solution for mission monitor and control.

The mission control and communication platform for TUMnanoSAT is divided in 3 general blocks. The first block represents the USRP E310 which is the frontend device in this SDR architecture. The second big block is the signal processing algorithm, created using GNU Radio Companion and the third component represents the application itself that makes the interaction with the user. The tool that chains all the mentioned blocks into a complex system is the ZMQ protocol. Here are used push/pull types of ZMQ sockets to make the main blocks communicate between them.

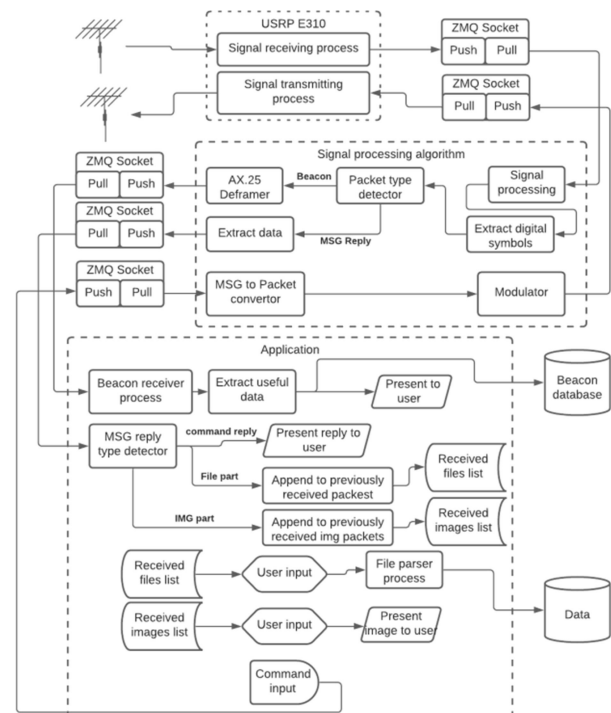


Figure 4. Architecture of mission monitor and control platform

The USRP E310 device doesn't have much responsibility in this architecture when it comes to processing. The main tasks for this device here are digitalizing the signal that it receives from the satellite and sending the digital data to the signal processing algorithm via LAN or, if speaking of transmitting signals than the task consists of receiving the digital samples via LAN from the processing algorithm and sending them through air to the satellite.

The signal processing block is basically a very complex python script created with the help of GNU Radio Companion software. The main functionality of this block consists of receiving the digitalized data from the USRP E310, demodulation of the signals, extracting digital symbols, detecting whether there is a beacon packet or a command reply type of packet and sending the data to the corresponding ZMQ Socket. On the other hand, when there is the need to transmit data, this block receives the message of the command through ZMQ from

the upper layer application, packs the message into a corresponding packet, modulates the message and sends the samples to the USRP E310 where the signal is emitted through the air.

The application closes the loop in the architecture. Besides interaction with the user using its graphical interface, there are some more tasks that this block has to complete. One of the tasks is running a beacon receiver which receives the beacon packets from the signal processing algorithm, extracts the useful data from the packet and presents the data in a user-friendly way. The extracted data is also sent to the beacon database to be stored for later processing if needed.

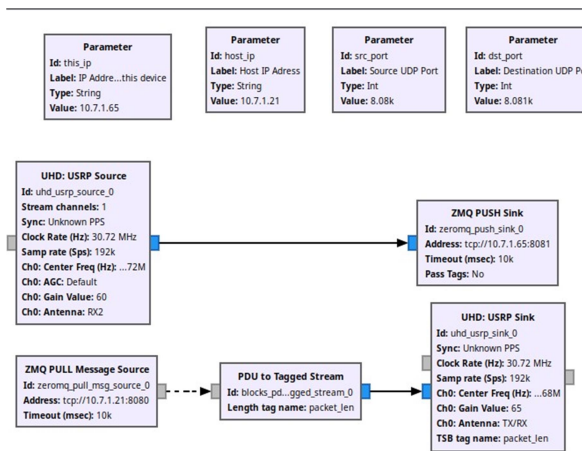


Figure 5. Flowchart of Frontend USRP

Another task that has to be done at this level is running the message reply receiver. This is the process that receives the data related to answers for the sent commands. The answer to the commands can be one the next three types: command reply text; file part; image part. If the receiver detects the command reply type of message the message is simply presented to the user in the log window. Otherwise, if the received message is a file part or a image part, it is appended to the corresponding packets that were received earlier and represent the same file or image. When the process of receiving a file/image is finished, the file/image is appended to the list of the received files/images. The user can select any image from the list and it will be presented or it can select the files from the received files list and extract the useful information from the file. When the information is extracted from a received file it is automatically sent to the database, if the database is connected, where it is stored for later.

The last but not the least important task that is done by the application block is giving the user the opportunity to send the commands to the satellite. The command for the satellite can be typed in manually or selected from the dropdown menu. When the command is selected, or typed

and checked, it is then sent, via ZMQ, to the signal processing algorithm where it is further processed and sent to the satellite.

The mentioned application has an extended functionality. First of all, the application allows the transmission of commands to the TUMnanoSAT educational nanosatellite and the reception of the answers from it. The commands can be configuration (commands that allow setting the parameters of the nanosatellite subsystems), resetting (commands that allow resetting the parameters to the default values or resetting the subsystems in part), data request (commands that allow the nanosatellite to request the data recorded by the subsystems image request (commands that allow you to request images taken in a specified orbit).

In addition to the service communication with the nanosatellite, mentioned above, the application allows the reception of the beacon that it emits with a determined interval depending on the energy budget available to the nanosatellite. The beacon involves a series of parameters that describe the operation of the nanosatellite. Parameters such as the number of pictures taken, the voltage on the battery, the voltage on the solar panels, the error codes if any, the operating time of the nanosatellite, the number of its resets and much more. The beacon is packaged using the AX.25 amateur radio protocol on the 436.68 MHz frequency. This information is public and anyone who has a resonant antenna in the UHF band with sufficient sensitivity, as well as a device or algorithm capable of extracting information from AX-25 packets can receive and decode the beacon emitted by the nanosatellite.

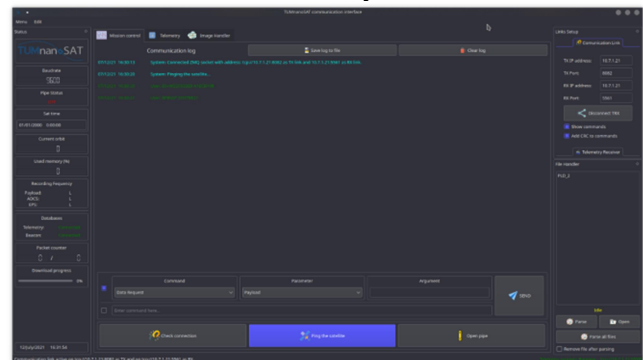


Figure 6. Application interface of Mission Monitor and Control Platform

#### IV. THE MISSION MONITOR ANT CONTROL PLATFORM VALIDATION

The validation part of the monitoring and control platform with the integration of the functionalities of the SDR component within the architecture was performed in a typical scenario of ground station – satellite communication through the application presented in the previous chapters.



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There were validated 4 basic functionalities of the mission monitor and control platform with the scenario described above:

- Checking the command-response grid between the satellite and the earth station
- Decoding the telemetry from the satellite with the presentation of the states on each subsystem
- Download, decode and present the images captured by TUMnanoSAT
- Downloading, decoding useful data and entering them in the database for further processing

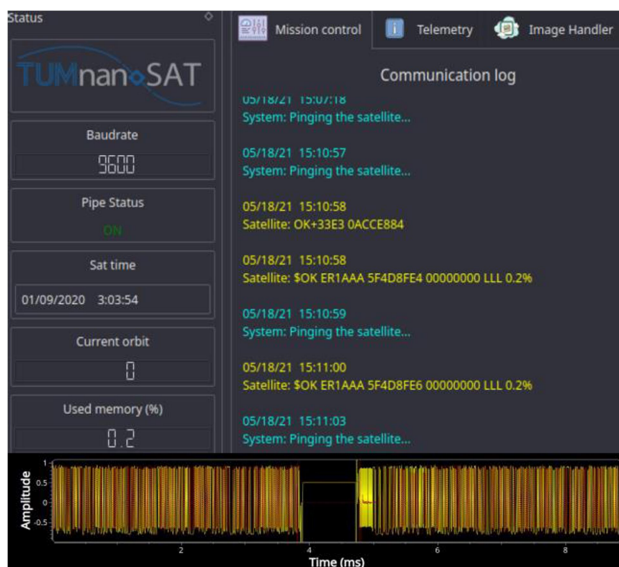


Figure 7. Application interface of Mission Control Platform

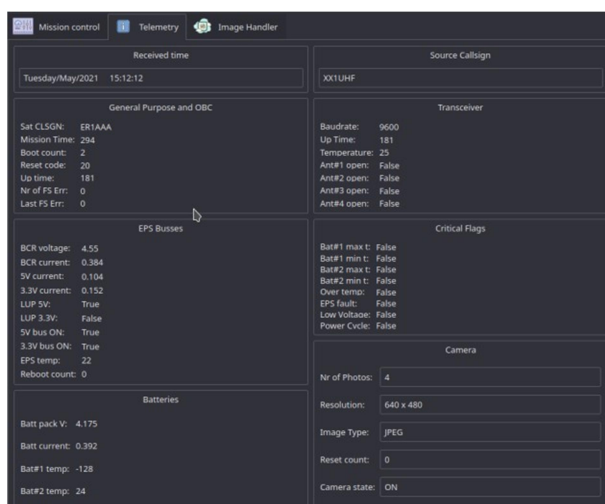


Figure 8. Decoded telemetry of TUMnanoSAT

For the first validation was tested the command-response grid of satellite. There were checked all possible commands from ground station to satellite. Each time the satellite responded with corresponding messages. An example is presented above.

Telemetry was sent from satellite at 30 seconds interval (depends of battery state). The platform successfully decoded all AX.25 and the state off all subsystems off satellite was monitored.

The image and useful data acquisition, decode and storage also passed the verification within the mission monitor and control platform. Also, it was decided to apply automatic request for missing packets on important data acquisition.

## V. CONCLUSIONS

In this paper was presented the architecture, development and implementation of the mission monitor and control platform for TUMnanoSAT ground segment.

It was described the possibility of integrating the Software Defined Radio communication component in the general architecture of the monitoring and control, predominantly using the ZMQ sockets as an abstraction of an asynchronous message queue.

Analyzing the validation of mission control platform, it was observed that proposed architecture with 3 general blocks: SDR frontend, signal processing block and application could be a solution for a ground segment in a typical Cubesat mission.

## ACKNOWLEDGMENT

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# Empirical Study of Cyber Security Threats in Moldovan Higher Education Institutions

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**Abstract**— Higher Education Institutions (HEIs) have always been the target of cyber attacks due to the information assets they hold. The move to online study as a result of restrictions imposed in the spring of 2020 has led to increased cyber security threats to academia due to the vulnerabilities of online learning platforms and video conferencing applications. The hypothesis of this paper was that Moldovan Higher Education Institutions had to face cyber security challenges similar to international higher education institutions, through the empirical study, the use of the questionnaire-based survey to collect quantitative data from stakeholders of the institutions.

The results of the survey conducted between September and November 2020, showed that HEIs in Moldova are targeted by cyber attacks as well as international ones and the nature of threats is mostly the same, namely: malware, phishing and DoS attacks.

**Keywords**— threat; attack; HEIs; malware; phishing; DoS/DDos; third-party software.

## I. INTRODUCTION

The use of Information and Communication Technology in academia has transformed the way we approach learning and educational activities in general. The Covid 19 pandemic, that began in the spring of 2020 and continues to this day, has been an impetus for the transition from traditional classes to online education. IT departments have had to cope with the growing requirements to ensure the continuity of the educational process, such as high volume of data storage, centralized configuration of video conferencing applications and emails, online learning platforms; they represented only some of the challenges of the new reality.

HEIs from the Republic of Moldova, as well as the international academic environment, had to face new challenges. And the resulting digital progress is impressive. In addition to the online learning platforms used for real-time access to educational resources and online exams, the range of digital services has grown significantly. Here we can mention the electronic libraries, the implementation of university management systems, online admission, etc.

Thus, in the near future, Moldovan HEIs could implement new services to increase their profits, by attracting more potential students who, due to the fact that they are abroad, do not opt for universities in the Republic of Moldova. Many international researchers believe that as distance education becomes more prevalent, countries and Higher Education Institutions, that do not provide distance education courses will need to look at this option to retain and expand their student population [1], [2]. According to the latest research conducted by 2023, the online education market will grow by an average of 16.4% annually [3]. A recent global survey by Pearson Education, an academic publishing organization, showed that 90% of 7,000 respondents believe that online education will continue to play a very important role in the field, even after the end of the Covid-19 pandemic [4].

The digitization of HEI and academic distance learning are undeniably beneficial, but new problems arise with regard to the protection of communication networks. Problems related to threats, vulnerabilities and cyber-attacks targeting the communication networks used to carry out online activities. The ISO27000 information security standard defines the cyber threat as: "the potential cause of an unwanted incident, which can lead to damage to a system or organization"; vulnerability as: "weakness of an asset or control that can be exploited by one or more threats", and cyber-attack as: "attempt to destroy, expose, alter, disable, steal or gain unauthorized access to or make unauthorized use of an asset"[5].

The data in the security reports reflect a significant increase in cyber security attacks in higher education institutions as a result of distance learning in 2020 [4], [6].

The purpose of this article is to reflect the results of the survey conducted by the authors in September-November 2020, which was attended by eight stakeholders from the largest higher education institutions in the Republic of Moldova. A stakeholder can be "any group or individual who can be affected or is affected by the achievement of the firm's objectives" [7].

<https://doi.org/10.52326/ic-ecco.2021/NWC.05>



The survey focused on identifying real cyber threats and attacks in the Moldovan academic environment in 2020, in order to identify the cyber security challenges faced HEIs and whether they are similar to those of international HEIs, analysed by the authors in published scientific articles [4], [6] and international cyber security reports [8]–[10].

The hypothesis to be demonstrated in this scientific article is that Moldovan Higher Education Institutions face the same cyber security challenges as international HEIs, through empirical study.

The paper is organized as follows: the second section will reflect the analysis of cyber threats in 2020 that have affected HEIs internationally, the third section will describe the method used to demonstrate the hypothesis, the fourth section is for results and limitations, and the last will reflect the authors' conclusions.

## II. BACKGROUND

In 2020 the education domain had a loss of \$ 3.90 million for data breach, according to IBM & Ponemon Institute [8], which conducts cybersecurity research. Referring to another study realized by CheckPoint [9], a leading provider of cyber security solutions to governments and corporations globally and in Europe too, the average number of weekly cyber-attacks per academic organization in July-August 2020, increased by 24%. In contrast, the overall increase in the number of attacks in all sectors in Europe was only 9% [6].

The new challenges of 2020 are due to the vulnerabilities of video conferencing applications and online learning platforms [6].

The use of online learning platforms has increased in 2020. The data provided by Google Trend (figure 1), for the period 2019-2020, showed a massive increase of interest in various learning platforms, both in Europe and globally. Complex courses were created, which had several types of activities, such as seminars, lessons, glossaries, practical tasks, assessment tests. It is also attested that Moodle is the most popular learning platform [4].

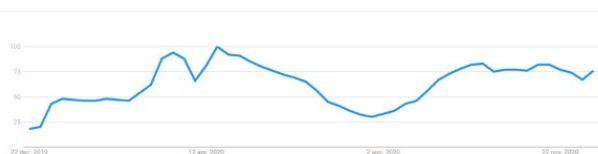


Figure 1. Global interest level for Moodle 2019-2020 [4]

A really impressive increase in use, during the pandemic with Covid-19, had the applications for teleconferencing, because the vast majority of activities and events planned offline, migrated, due to the new conditions of activity, in the online environment [4]. According to the report submitted by the company Datanyze, the world leader in technography, top three

teleconferencing applications used in 2020, globally were: Zoom, GoToWebinar and Cisco Webex [4], [10]. Thus, if in December 2019, the ZOOM application registered 10M daily users, in March 2020, ZOOM registered about 200M daily users [11].

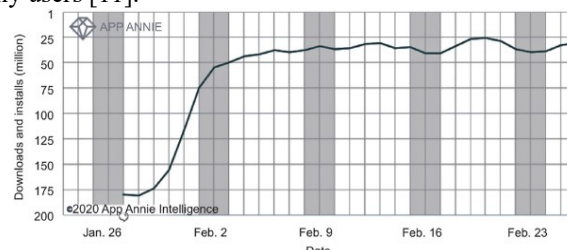


Figure 2. Zoom application usage [12]

The number of users who encountered various threats, in 2020, related to online learning platforms and video conferencing applications increased by 20455% [6], [13].

In June 2020, Microsoft Security Intelligence reported that 61% of the 7.7M malware attacks recorded in the last 30 days, were related to the education domain, more than any other sector of the industry [13]. The malware that has targeted educational domain the most in 2020 is ransomware [6]. Ransomware is malicious software that allows a hacker to restrict access to authorized users, such as students or university staff, by encrypting disks and then requesting a form of payment to lift the restriction [14], [15].

The same report [13], shows that DOS/DDoS attacks have increased, in educational domain, by 350-500% in 2020 compared to the same period in 2019 [6]. Denial of Service (DoS) attack is executed to determine a specific category of information warfare where a malicious user blocks legitimate user from accessing network services by exhausting the resources of the victim system [16]. The substantial increase in DoS / DDoS attacks in HEIs is primarily due to distance learning, as the vast majority of university services, such as: access to the university library, study hours, access to course resources, exams and intermediate assessments, admission to studies; this year have been in the online environment, and disruption of these services shall interrupt academic activity [6].

The leader of cyber threats in HEIs was phishing. It is a social engineering attack wherein a phisher attempts to lure the users to obtain their sensitive information by illegally utilizing a public or trustworthy organization in an automated pattern so that the internet user trusts the message, and reveals the victim's sensitive information to the attacker [17]. According to new research conducted by Barracuda Networks [18], HEIs were targeted in June-September 2020 by more than 3.5M phishing attacks, more than 25% of phishing attacks occur in the educational sector. In the UK, according to a Jisc survey, phishing is the biggest threat to corporate network security in HEIs [19].

According to the data presented in this section, it can be concluded that cyber-attacks in the international

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academic environment have increased as a result of distance learning.

### III. METHODOLOGY

The method used by the authors to identify the challenges and approach of cyber security in HEIs in Moldova was the survey based on the questionnaire.

To conduct this survey, 8 stakeholders from 8 largest HEIs in Moldova were contacted. A special invitation email was sent to the selected sample (university stakeholders) so as to ensure that data collection was limited to the specific target group. The survey was based on online platform, namely Google forms. To ensure data confidentiality, anonymous participation was enabled, and the results were stored in a local database for further analysis.

Before finalizing the survey tool, we conducted a small pilot study to evaluate the reliability and validity of the tool. The main purpose of the pilot study was to verify whether respondents are able to understand and answer all the questions [20]. Two methods were selected for the study. The first method was to present the survey tool to IT experts, with several years of experience working on cybersecurity issues. And the second method was the analysis of international practices in this area, useful resources were identified in the UK, which at the government level [21] has implemented annual surveys that identify the state of cybersecurity in national HEIs. Based on the feedback received from IT experts, several minor changes were made to the questionnaire. The research design is reflected in figure 3.

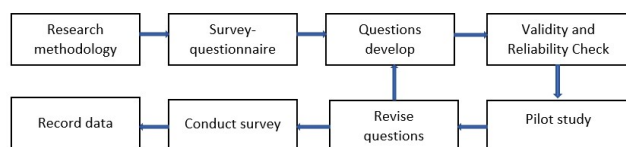


Figure 3. Questionnaire Research Design Procedure

The survey was created to demonstrate the hypothesis of this study. Response choices to the multiple-choice questions were based on issues and concerns related to Cyber Security Threats in HEIs. The survey took approximately 10 min to complete.

Survey results were recorded in Google Forms and an Excel spreadsheet was used to collect eight stakeholders' responses. Descriptive statistics of the responses to the survey are presented in graphs. The descriptive statistics provide summaries about the sample's answers to each of the questions as well as measures of variability (or spread) and central tendency [22].

### IV. RESULTS AND LIMITATIONS

In this section, we present the results obtained. The survey was conducted in the month of September to November in 2020, deals with the status of cyber security threats that have hit respondent's organization. It was found that 80% of higher education institutions in Moldova were attacked in 2020 (institutions that participated in the survey). Based on these responses, further explanations are provided. The distribution of cyber threats that HEIs have had to deal with, is reflected in Figure 4.

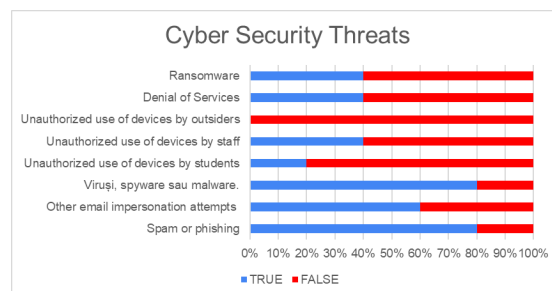


Figure 4. Cyber threats facing HEIs in 2020

Thus, it can be seen that the biggest challenges for stakeholders in 2020 were spam or phishing attacks (80%) and attacks with malicious programs: viruses, worms or Trojan Horse (80%). Ransomware or DoS attacks were recorded by 40% of respondents. And threats targeting unauthorized use of university devices by staff, such as computers, servers or network devices, were recorded by 40% of organizations. Unauthorized use of the devices by students or outsiders was not a threat, probably the main reason being that the educational process took place mostly online, so visits by students or outsiders were not frequent and were recorded.

When asked what are the 3 most common threats to your institution, stakeholders selected from a list of 10 options: DoS or DDoS attacks (40%), Phishing and Social Engineering (20%), Ransomware (20%) and MITM attacks (20%), the results are graphically shown in figure 5.

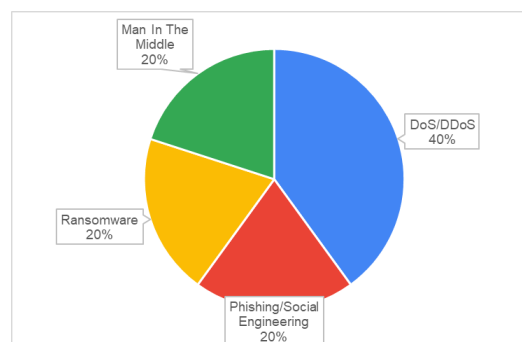


Figure 5. Frequent cyber threats

Although the findings presented in this paper provide important points for assessing cyber security threats,



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several limitations need to be highlighted, which we plan to improve in the future. The questions covered in the survey should be checked by several cybersecurity experts. The preliminary data produced valuable results; however, further research needs be carried out on universities. The sample size must be increased, which may improve the findings.

## V. CONCLUSIONS

Ensuring cyber security in HEIs is a current priority, especially in the context of the Covid 19 pandemic. Empirical studies can elucidate the real challenges in this area. Thus, based on the results of various security studies and reports conducted in 2020, a hypothesis was developed targeting HEIs in Moldova regarding the security threats faced by stakeholders during the pandemic. The hypothesis was to determine through quantitative data analysis, questionnaires-based surveys, which network threats targeted university networks in 2020, and which, in the opinion of stakeholders, are the most common security threats in HEIs in the Republic Moldova.

The results of the survey reflected a high rate of cyber-attacks taking place in HEIs in Moldova, so that 80% of respondents said that in 2020, the institution they represent was targeted by cyber-attacks. This means that, although Moldovan academic institutions are not as well known in the international arena, ensuring cyber security must be a priority. Cyber security threats remain the same as in international HEIs. It is advisable for HEIs to create cybersecurity frameworks that will target the completeness of the security measures that need to be implemented to secure the academic environment. Also, annual government surveys, similar to those in the UK, which aim to identify the level of cyber security in education, given the dynamic digital development in this field, will allow the adjustment of recommended protection measures to real threats.

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# Knowledge-based Society Session

# From human knowledge to information technologies: some epistemological remarks

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**Abstract**— The knowledge based society developed the new technologies of information and communication in order to use better all the data at different levels and to manage them efficiently. Computers have the capacity to store information, to select it, or to provide it. Human mind, memory and other capacities, are replaced by the upgraded capacities of the computers. Computers are able to store just semantic information, but they do it better than any human epistemic subject. Computers incorporate tacit knowledge and use it also as information or rules to manage the data. Therefore, in KBS the human transition from information to knowledge is accompanied by a reverse computational transition from knowledge to information.

**Keywords**— *information, knowledge, knowledge based society, tacit knowledge*

## I. SOME PRELIMINARY REMARKS<sup>1</sup>

The classical distinction proposed by Weaver between three level is still a good starting point. The first is the technical level which refers to “the accuracy of transference of information from sender to receiver”, the second is the semantical level, related with “the interpretation of meaning by the receiver, as compared with the intended meaning of the sender”, and the third is the so-called “influential” level, which concern “the success with which the meaning conveyed to the receiver leads to the desired conduct on his part.” [2, p. 11]

If the first level implies only technical problems which are solved increasingly better in an engineering mode by developing technology, the other two levels contain in themselves premises for a philosophical approach. I will follow here an epistemological path which is focused on the dynamics of knowledge and information in a knowledge based society. Some preliminary remarks are necessary in order to clarify some concepts.

I agree without any doubt, at least for argument’s sake, and I will use in the following considerations the so-

called general definitions of data, information and knowledge based on an erotetic approach. [3, pp. 106-107]

An item is a piece of information if it has a semantic content. This means that it is a piece of information if and only if:

1. It consists of one or more data;
2. These data are well-formed;
3. These well-formed data are meaningful.

From sentence 1 results that without any data we don’t have any information. So, what are the data? I think that the most elementary definition is also philosophical acceptable. If the world would be characterized by absolute uniformity we don’t have any data. Therefore, a datum is the effect of a difference in the world. A homogenous world, with identical parts, isn’t able to produce some data or it is able to produce a single datum about it, that about the fact that it is. From sentence 2 results that the data have to be ordered according to some rules which are structured in a syntax.

From sentence 3 results that the data are related with meanings and they become semantical items which should be understood and interpreted correctly and even in terms of truth.

For example, 12 is a sign that makes a difference, but isn’t yet informative because we have to attach to it a meaning to transform it from an empty sign into an informative one. 12 can become an astrological sign, a number of chairs or a bus route. Therefore, a datum becomes information if and only if it becomes meaningful.

In conclusion, according to the general theory of information, information is described as data plus meaning. I will use this idea of semantic informational content in an epistemological context as an acceptable definiens for the concept of knowledge.

Following the causal analysis of information, beliefs and knowledge proposed by Dretske in [4, part III], I will define beliefs as semantic structures with an executive function, namely, they have the role to shape the system’s output. If this condition is fulfilled, then the semantic structures work as cognitive structures in that system. This means that a belief will be stored in memory,

<sup>1</sup> For a development of the ideas from this paper see [1].

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which is a part of the cognitive system, in an accessible way and it will be used when it will be necessary for a cognitive process. Therefore, the semantic structure is a cause of the output in the system. This means that a semantic structure is qualified as a cognitive structure and as a belief if and only if its semantic content determine in causal mode the output in the system in which it appear. As a result of these assumptions, we have to make a difference between semantic structures and cognitive structures. The concept of information helps us to understand the difference.

Dretske's definition for information as a causal process is this:

"Information (in signal or structure S) causes E insofar as the properties of S that carry this information are those the possession of which (by S) makes it the cause of E." [4, p. 198]

Let's take into account a perceptual belief. All the information about angles, lines and gradients will be used causally as ingredients but all of them won't be structured immediately in a cognitive content even if they will be related with a semantic content. The cognitive status as belief is given but the capacity to exercise a control over the final output.

Therefore, following Dretske, "information is commodity capable of yielding knowledge, and what information a signal carries is what we can learn from it... Knowledge is identified with information-produced (or sustained) belief." [4, p. 44] These being said, if we preserve the definition of knowledge as justified truth belief, we could claim that knowledge as a "dynamic human process of justifying personal beliefs toward the truth" is similar to and different from information: "First, knowledge, unlike information, is about beliefs and commitment. Knowledge is a function of a particular stance, perspective, or intention. Second, knowledge, unlike information, is about action. It is always knowledge 'to some end'. And third, knowledge, like information, is about meaning. It is context-specific and relational." [5, p. 142].

## II. THE TACIT DIMENSION OF KNOWLEDGE AND ORGANIZATIONAL KNOWLEDGE

My thesis is that in the knowledge based society the development of new technologies changes also the communication practices and the way in which knowledge is transferred and conveyed. As a result of these practical changes the concept of knowledge itself is reconsidered especially in terms of its objectivity. The idea of an objective knowledge which is free of context and values is revised. Michael Polanyi in [6] criticized the idea of an objective knowledge which is free from any subjective influences and tried to argue that at least in the context of discovery the subjective dimension of knowledge is very important. It is obvious that the scientific discoveries are related with some feelings and beliefs. In Polanyi's view there is a tension between reason and explicit critical

interrogation, on the one hand, and the tacit dimension of knowledge, on the other hand. Polanyi argues that personal choices and imagination are inherent parts of research process which are motivated, always significantly, by passions. Therefore, the discovery of truth isn't independent from any personal elements. Moreover, the scientific research needs some abilities which depend from the individual characteristics of the researcher.

In order to grasp this difference and to conceptualize it, Polanyi proposed the distinction between personal knowledge and propositional knowledge which is understood in terms of the differences between tacit knowledge and explicit knowledge. This means that we are able to know more than we can say with the help of our language. We can convert tacit knowledge in propositional knowledge, for example, we can transform some tacit procedures associated with a practice in explicit rules but something will remain always at the implicit level. Anyway, this dynamic of the two knowledge forms is based on the possibility of reciprocal transformations between tacit and explicit knowledge, but if we take into account the historical process of knowledge development then we have to accept in principle, following Polanyi, that all knowledge is somehow and ultimately either tacit knowledge or rooted in tacit knowledge.

Another crucial feature of knowledge based society which is also related with the tacit dimension of knowledge consists in the new role of different organizations in the production of knowledge. If we think in the light of the traditional Cartesian distinction between subject and object or between the knower subject and the object which is known and try to rethink it, then we'll understand an organization as a mechanism which has not only the capacity to process the information received from outside in order to be able to adapt to the environment, but also the capacity to create knowledge and new information with the help of its own inner mechanisms, to send them from the inside out to the environment and to modify this environment.

Nonaka and Takeuchi in [5] proposed a theory of organizational knowledge or of knowledge creating organization which is based alike on the distinction between explicit and tacit knowledge and on supposition that knowledge is socially created and transformed through the interactions between the individuals which work in an organization. Their paradigm could be better understood with the help of a case study. The two Japanese philosophers discuss the case of a bread making machine. They describe the way in which the tacit knowledge which is owned by the bread maker can be extracted and worded in such a manner that become possible to incorporate it in a bread making machine<sup>2</sup>.

<sup>2</sup> In terms of Collins's distinctions between kinds of tacit knowledge it is obvious that this approach starts from one case of relational tacit knowledge, but the case should be redefined if we want and Collins himself did this. See [7], Appendix 1..

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Nonaka and Takeuchi have made in [5] a distinction between the four modes in which knowledge is transformed in an organization:

- from tacit knowledge to tacit knowledge, a conversion which is called socialization,
- from tacit knowledge to explicit knowledge, a conversion which is called externalization,
- from explicit knowledge to explicit knowledge, a conversion which is called combination, and
- from explicit knowledge to tacit knowledge, a conversion which is called internalization.

Socialization is an interactive process in which an individual learn and acquire knowledge, mental models and skills from others without using language, but only by observation, imitation, and practice, all of these understood as forms of sharing experience. The information is extracted from a mixture composed sensations, feelings and thought contents embedded in a context.

Externalization is a process of converting tacit knowledge into explicit concept and judgments with the help of language. Tacit knowledge may become explicit not only if the informational content is constrained to take the shape of an assertion, a theory or a hypothesis but also if it take the shape of a metaphor, an analogy or a model. By externalization the new explicit concepts are created from tacit knowledge.

Combination is a process of fitting and incorporating the concepts into systems. In this process the epistemic subject uses different technical equipments, facilities and networks. The previous information and knowledge is reconfigured, sorted, and combined with new information which was added. In the knowledge based society were developed new technical means which have the capacity to store in databases and to process the information according with the cognitive aims which were previously established.

Internalization is a learning by doing process of transforming explicit knowledge into tacit knowledge in the form of mental models and the so-called know how. The explicit knowledge is expressed linguistically in theories, documents, books, manuals, databases, and also it is spread in universities, or by the help of mass/media and other interactive means. Therefore, knowledge is re-experienced and interiorized by the epistemic subjects, individuals and organizations.

Nonaka and Takeuchi theory, following Polanyi, gave a definition of tacit knowledge which is based on the presupposition that it could be made explicit in some conditions. Therefore, in their view tacit knowledge is equally with implicit knowledge and it is opposed to

explicit knowledge. This means that tacit knowledge is reduced to a relational property. Harry Collins developed in [7] this analysis of tacit knowledge and he has made a distinction between three types of tacit knowledge:

- somatic tacit knowledge which is embodied in the human body and brain;
- relational tacit knowledge which is able or not to become explicit in some circumstances;
- collective tacit knowledge which is embodied in society.

The approach proposed by Collins enlarged the traditional meaning of tacit knowledge and assured a new perspective on the role of it in knowledge based society.

I think that in the light of previous distinction proposed by Collins we can identify other two components of organizational knowledge which have a tacit dimension:

1. Knowledge embedded in organizational technologies, rules and procedures. Any organization tends to regulate itself with the aim to use efficiently its own knowledge. A person won't have any knowledge of these rules outside the organization and he or she is able to have some performances only within the organization.

2. Knowledge culturally embedded as aggregate of perceptions, values, beliefs, faiths and visions. This kind of knowledge contains a diversity of elements, from the neural software which have a cognitive interface to the so-called anonymous collective thinking in which an individual is kept. Some philosophers mentioned the importance of a biological or a historical a priori that grounds the knowledge and establish the conditions of its possibility.

last name only). Use the Dr. or Prof. title with each name separately; do not use plural Drs. or Profs. with lists of names.

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# The European Education Area and the Covid-19 Pandemic

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*Abstract - Over the last decades, across the European Union (EU), the concern for improvement of vocational education and training within the member states grew in importance. The COVID-19 pandemic affected this area of a strategic importance. Therefore, the European Union is considering the adoption of the certain measures aimed at reforming it. According to the EU vision, vocational education and training are essential to the restoring of Europe after the COVID-19 pandemic. Each member state of the European Union manages its national education and training systems and establishes the content of the curricula. According to 165 of the Treaty on the Functioning of the European Union, (TFEU), the EU takes on the role of contributing to a quality education, encouraging the cooperation between member states. The fast outspread and the virulence of the COVID-19 pandemic led to the instauration of a panic feeling at global level. The global dynamics was turned upside down, causing survival, production and consume issues. Governments decided to introduce restricting measures across the economical and social plans. World economy was greatly affected: the markets collapsed, both in Europe and the United States, Latin America and Africa. The states adopted measures at national level, closing the borders and enforcing protectionist decisions. In their turn, citizens were ready to accept isolation measures in order to protect their health and lives. At the same time, free circulation and commerce, as well as the financial system, suffered as well. Therefore, autocratic and populist manifestations were greatly fuelled. Recession was in place and hundreds of millions of people became unemployed across the globe. State aids are the only financial resource for millions of people and numerous companies. A complex vicious circle came into being: the reduction of trust led to less crediting, unemployment and bankruptcy.*

**Keywords -** *lifelong learning; digitalisation; inclusion; mobility; innovation; social cohesion.*

## INTRODUCTION

Due to the high geographical extent, to the number of victims and the recession of more than 170 states, the COVID-19 pandemic surpassed the financial crisis of 2007 in terms of extension, which also affected all the continents. European states urgently took measures to combat financial insecurity. Some of these measures were criticized, others were said not to have been adopted fast enough or not properly implemented. The European Union sought to perpetuate the citizens' confidence in its ability to manage the crisis. It was involved in ensuring the medical services but also in post-pandemic recovery. The measures envisaged in the field of vocational education and training are also part of this context [1].

The European Council met in Barcelona in March 2002, in the context of the Lisbon Strategy and approved the work programme entitled "Education and Training 2010". It established, for the first time, pathways of European cooperation in the field of education and training, by identifying certain common objectives [2].

If the situation requires it, the EU supports and completes the actions taken by national states. The Europe 2020 strategy stresses the importance of education and training in achieving these goals. Therefore, the EU supports the actions of the states aimed at modernizing education and training systems [3].

## I. VOCATIONAL EDUCATION AND TRAINING ACROSS THE EUROPEAN UNION

In the Council of May 12<sup>th</sup>, 2009, it was agreed on the establishment of the Strategic Framework for Vocational Education and Training (ET 2020). Four strategic objectives were set, which were going to be implemented by 2020.

These concerned the following:

- Lifelong learning and mobility*, by reforming the education systems.
- Encouraging *the quality and efficiency of vocational training*, by increasing the level of the basic competences.
- Promoting *equity, social cohesion and active citizenship*, so that all citizens could improve the competences characteristic to their profession throughout their whole life.
- Supporting *creativity and innovation* in the educational process, through the importance given to the acquisition of competences, entrepreneurship and knowledge in the cultural area.

The cooperation accomplished through ET 2020 was based on the *exchange of information and experience* between the vocational education and training systems of EU member states. Parameters and indicators were established, whereby progress made in meeting the objectives should be assessed. The progress was monitored by the European Commission, which, in this regard, collaborated with the national states.

The Erasmus+ programme, which supports students, trainees and employees for further training abroad, hence increasing their employment opportunities, contributed to improving cooperation in the field of education and training. Also, this programme encourages cross-border collaboration between higher education institutions, in order to innovate and increase the quality in education [4].

European cooperation in the area of vocational education and training led to notable results, although there are many other things to be accomplished. Progress was made in ensuring the necessary capacities for teachers, improving general education, adapting to digital transformation and developing new principles for improving vocational education and training (VET).

At the same time, through the Strategic Framework for Vocational Education and Training 2020 (ET 2020), some common benchmarks were introduced across the EU.

Until 2020, a series of obvious results were achieved. At EU level, almost 95% of children attend pre-school education from the age of 4. Over the last

decade, the level of young adults graduating from tertiary education significantly increased, exceeding the 40% target set in 2009 [5].

A decrease in the rate of young people abandoning the education system without obtaining a higher secondary education diploma and not pursuing vocational training courses was registered (from 14% in 2009 to 10.2% in 2019, the EU target being 10 %). As concerns failures, the EU failed to meet its target of reducing, by 2020, the number of 15-year-olds who achieve unsatisfactory results in reading, maths and science, to less than 15%. Also, the financial crisis affected the involvement of adults in learning activities; hence the target of 15% was not reached (however, it increased to 10.8% in 2019).

The Erasmus+ programme played a key part in the intensification of cooperation and in accomplishing national reforms, providing the necessary financial support. Structural and investment funds across the EU also provided resources for national reforms.

## II. ESTABLISHING A EUROPEAN EDUCATION AREA BY 2025

During the communication of September 30<sup>th</sup>, 2020, addressed by the European Commission to the European Parliament, to the Council and to the Economic and Social Committee, as well as the Committee of the Regions, Commission President Ursula von der Leyen, undertook to create a European Education Area by 2025.

In motivation of this initiative, the European official showed that the COVID-19 pandemic affected significantly the European education and training systems. Over 100 million Europeans belonging to the education and training community were forced to tackle new means of learning and teaching. The health crisis does not have to be an obstacle in the way of learning and developing competences, or in the way of employment possibilities. That is why member states need to cooperate across the EU to create “future-oriented” education systems, by implementing a European Education Area.

The necessary measures proposed after the COVID-19 pandemic target early years education, vocational education and training, higher education, research, adult education and non-formal learning. Creating the European Education Area is possible due to decades of cooperation between the EU member states in the educational field [6].

The strategic framework for European cooperation in vocational education and training (ET 2020), had a fundamental role in supporting the first initiatives referring to the European Education Area and in implementing national reforms. At the same time, it



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also contributed to the reaction of the education and training community to the COVID-19 pandemic.

A quality education is able to transfer to young people the knowledge, skills and attitudes they need to succeed in life. At community level, the vision regarding quality envisages youth acquiring certain basic competences, including digital competences, which should allow them to find a satisfactory job [7].

However, according to the survey conducted in 2018 as part of the Programme for International Student Assessment (PISA) of the Organization for Economic Co-operation and Development (OECD) conducted at EU level, a high percentage of students is not able to solve basic exercises at mathematics, science and reading (22.5% for reading, 22.9% for mathematics and 22.3% for science) [5].

In 2019, one fifth of the youth living in EU member states did not have basic digital competences. The lack of these competences affects the lives of the citizens and requires the adoption of subsequent remediation measures for adult learning.

An important element for improving the quality of education is to promote the freedom of movement of students and teachers and to encourage the association of educational institutions in Europe and not only. However, many teachers and students face difficulties related to lack of information on learning mobility, insufficient training in foreign languages, financial barriers or full recognition of the learning outcomes and qualifications acquired during their mobility.

Quality education involves supporting language learning and multilingualism, as well as promoting cultural and linguistic diversity in schools.

The introduction of a “European perspective in education” can provide students with information on the significance of Europe and the European Union. This cultural approach is complementary to the national and regional vision.

Last but not least, we should mention the fight against discrimination in schools and against “aggressive behaviours” (*bullying*).

Unfortunately, the inequalities that are based on the social and economic status could not be reduced by means of education. Students with disadvantaged backgrounds have poor school results. Also, across the EU, the unsatisfactory results in reading and early school abandonment are higher when it comes to boys, as compared to girls.

Also, poor school results are obtained by pupils coming from rural areas or from migrant families. The COVID-19 pandemic stressed the importance of geographical localisation of the pupils and their families.

Across the EU, women have higher levels of education than men but lower rates of school

performance. And yet, men have better paid jobs. At the same time, women have fewer leadership positions in higher education.

Europe's prosperity depends on the implementation of policies and investments in education and training, which should encourage green transition and digital transition.

In the context of the COVID-19 pandemic, young people are going to be the most affected, as they have problems finding a job. The labour market will generally be profoundly affected. Under these circumstances, digital competences become compulsory, especially in a post-Covid-19 world. The implementing of digital competences in all the activity sectors will be a must. Still, two out of five Europeans aged 16 to 74 do not have such competences.

Transition towards a sustainable economy, with consideration for environment protection, plays an important part when it comes to employment. Overcoming the economic and social consequences of the COVID-19 pandemic and promoting a transition to “a greener and more digitalized world” can be accomplished only if people have the adequate competences and education.

To do this, we need to transform the behaviour and competences of European citizens, and we must use the education systems as main catalysts.

At the same time, green transition requires investments in education and training, in order to increase the number of specialists involved in creating a “climate-neutral” economy that uses resources efficiently.

The document prepared by the European Commission stresses the fact that “teachers, trainers and educational staff are in the centre of education”. In the context of the COVID-19 pandemic, millions of teachers in the European Union were forced to adapt to schools closing but they ensured the continuity of the learning process by adopting remote learning.

No doubt that innovation in education is not possible in the absence of teacher and trainers. In the European Education Area, the vision on the educational profession must include very competent and motivated teachers. Teaching and professional training should be appreciated. Currently, the majority of the EU member states is facing a deficit of teachers.

Over the next decade, approximately one third of the teachers will retire. Therefore, attracting competent people into the system is a necessity. The teaching profession needs revalorisation from the social point of view, and in some EU member states also from the financial point of view. Only one teacher out of five working in the lower secondary education believes that his/her profession receives the right valorisation in society. Furthermore, about half of the teachers consider

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that the numerous administrative tasks represent a stress factor within their profession.

The mobility of students and teachers was stimulated by the Bologna Process. Statistical data reveal the fact that the experience of studying abroad contributes fundamentally to improving career perspectives. A significant percentage of Erasmus+ graduates, respectively 80%, are employed in less than 3 months after completing their studies. However, unfortunately, only 5% of the students benefit from the Erasmus+ programme. The main obstacles are financial problems and non-recognition of learning.

Due to the 41 pilot universities, more than 280 higher education institutions in the EU have been implementing deeper models of cooperation. The higher education sector showed that it can cope with change in the context of the COVID-19 pandemic.

Still, the crisis amplified the challenges of “digitalisation, innovative pedagogy, inclusion and well-being”. Consequently, European higher education systems should intensify cooperation between educational institutions.

This could lead to implementing some common learning programmes and courses which would contribute to boosting the students’ mobility between educational systems in various states. Cross-border cooperation leads to valorisation of the “strengths” of various higher education institutions, with public sharing of material and online resources, courses and infrastructure for various disciplines.

Higher education institutions may have an important role in the recovery post COVID-19, as they are main players in the “knowledge square”: *education, research, innovation and service to society*.

There is a need for automatic recognition of qualifications for the studies abroad, which would allow EU Member States to intensify their cooperation beyond the current possibilities, due to the Bologna Process. The European Education Area can play a “catalyst” role for the Bologna Process [8].

Greater importance must be given to educational programmes based on advanced digital competences, namely cutting-edge technologies: “artificial intelligence, cybersecurity and high-performance computing”, where the deficiency is high.

Cooperation in the educational field is currently an essential instrument in implementing the EU external policy. This represents a soft “instrument of power”. Educational cooperation is vital to the EU geopolitical desiderata and the objectives referring to sustainable development until 2030.

The modification of the world order (through the rise of China), points to the need to strengthen the cooperation across the EU, including the educational field. Annually, hundreds of thousands of students or more, coming from third countries, attend the courses of

tertiary education within the EU. The transparent legal framework for conducting these activities is provided by the EU legislation.

Expanding the partnership between the European Education Area and non-EU countries, especially those in the Western Balkans, is an important element in the vision to be implemented by 2025.

Over the last twenty years, the Erasmus+ programme helped to strengthen the connections between EU member states and other countries. Every year, European universities undertake exchanges with other universities and nearly 50,000 students and professors are involved.

International partnerships led to the creation of innovative curricula and the introduction of joint degrees. Furthermore, joint projects were developed in research areas and new jobs were created [5].

In order to establish a European Education Area, the Commission submitted a series of proposals which should be implemented together with the member states, with the six mentioned dimensions being followed. In order to increase the quality in education, the Commission will support the member states in the process of implementing certain *efficient policy reforms*, which should support *basic competences*. These initiatives will mostly aim at the curriculum and the evaluation. The Commission intends to improve the consolidated Erasmus programme, in order to boost *mobility for the purpose of learning*. For promotion of *multilingualism*, the Erasmus programme will support linguistic competences “from a life-long learning perspective”, in order to create opportunities that are favourable to teaching and learning abroad.

In view of supporting *inclusion* in the educational field, the initiative “Pathways to Success in School” will support students in acquiring their basic competences. The Commission will create a group of experts which are going to elaborate strategies for creating learning environments that should support the groups at risk of getting unsatisfactory results.

At national level, the EU member states can use a series of financing instruments such as the European Social Fund or the Recovery and Resilience Facility.

In order to encourage inclusion and a better quality in the vocational education and training systems, the Commission will support the establishment of 50 centres of professional excellence which will be financed through the Erasmus programme. These centres of professional excellence will aim both at the basic training for youth, as well as at the further training and professional retraining dedicated to adults.

The Commission is going to take steps for preparing a joint European approach with regards to introducing *micro-certificates/micro-credentials*, which should increase the learning opportunities. These can

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complete the curricula designed for students. Also, an increasing number of adults will be forced to retrain. In order to validate and recognize these micro-certificates across the EU, the Commission will present, in 2021, a *Proposal for a Council Recommendation*.

The European Commission promotes gender equality in education and training. A new agenda for transforming higher education will take into account promoting “gender equality”, with regards to options for studies and promotion of women in decision-making positions in higher education.

In order to promote green transition and digital transition through education and training, financing programmes that support this double transition may be used, such as the Recovery and Resilience Facility and the Just Transition Fund. For promoting the ecological transition within the EU, the Commission launched the “Education for Climate” Coalition.

For the purpose of promoting digital education across the EU, the Commission promoted the Digital Education Action Plan, which seeks to solve the disparities regarding digital competences. A future programme entitled “Digital Europe” will include financing for developing advanced digital competences.

To improve the teachers’ competences and increase their motivation, the Commission will launch the Erasmus Teacher Academies, through the new 2021 Erasmus. The Academies will be focused on continuous professional development. The Commission intends to create 25 Erasmus Academies by 2025.

In 2021, the Commission will launch a *European Award for Innovation in Teaching*, in recognition of the outstanding contributions of teachers. As far as European higher education institutions are concerned, the Commission aims to provide incentives for at least 5,000 higher education institutions in Europe, to adapt to post-COVID-19 conditions. These incentives will aim at accelerating the transformation of European higher education institutions. The transformation implies *connectivity* between various higher education institutions, *inclusion*, which should enable access to education of a mixed group of students, *digital and green training and resilience*, as well as *innovation*, which also involves research and innovation in learning and teaching. The Commission intends to pursue an *agenda for the transformation of higher education* throughout 2021. Its objective is to fully implement the *European Universities Initiative*, included in the Erasmus programme. The Commission will discuss, together with EU Member States, the introduction of a *European Degree*, which will allow students to choose where to study. In order to increase student mobility within the EU, a *European student card* will also be created. At the same time, the Commission will support member states in automatic

mutual recognition of higher education qualifications at EU level by 2025 [5].

### III. EDUCATION IN THE CONTEXT OF THE COVID-19 PANDEMIC

The outbreak of the COVID-19 pandemic put a strong pressure on the health systems, on the social, political and economic life and on the education system. The crisis caused by the SARS-CoV-2 virus revealed the fact that the education system was not prepared for the national implementation of technology in the teaching process.

This led many of us to become aware that an acceleration of the digital transition is imperious. As the SARS-CoV-2 virus spread extremely fast, the executives of European countries adopted radical decisions based on preventive approaches, which were not based on certain data. Many of these decisions were perceived by the population as measures to limit individual rights and freedoms and not to combat the spread of the virus.

Due to this crisis situation, many European states decided to close schools – and so was the case in Romania. As a consequence, the most profound transformation of education and training in the recent history of Europe happened. Pupils, students and teachers adopted digital education, in order for the school year could continue. Unfortunately, for many of them, this was the first contact with digital technology. In Romania, the big challenge was represented by the transition to online education, for which the state system was totally unprepared. It was impossible to adopt the contents of the curricula overnight, which meant that the adaptation to the new online teaching method varied according to each person.

Actually, the COVID-19 pandemic only aggravated the existing problems in Romanian education, namely poor financial resources, school dropout, striking differences between rural and urban areas, insufficient teaching staff or inadequately trained staff. It is a reality that, in 2021 Romania, there are areas without internet access, rural regions that do not have a signal for mobile means of communication or where children know very little of what a computer or tablet is. In this dramatic context, “inclusive and high-quality education” is being mentioned. Undoubtedly, the educational area has some critical shortcomings, but, on the other hand, in society as a whole, progress is also slow.

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There are many people who need help and that need to be supported. The COVID-19 pandemic led to the dropping out of school for many children. In fact, a trend was accelerated and aggravated, the dropout rate being particularly high in Romania. On the other hand, the pandemic led us to look for remedial solutions. Several solutions for the continuation of the school year were identified (the green, yellow and red scenarios). However, even so far there is no plan or strategy that works without raising the suspicion of the actors involved. Of course, the reaction of society to the measures and decisions taken in the context of the pandemic was one of hostility. This is due to the characteristics of this society, which refuses rapid and forced changes.

The feeling of suspicion manifested within the population was amplified by the lack of transparency and the avoidance of taking responsibility for adoption of firm and clear measures. Also, the communication between the authorities and the population was inefficient. The COVID-19 pandemic led to closure of the schools around the world, severely affecting the educational process and worsening social inequities. As a consequence, improving the education system must be a priority across the whole Europe. In times of crisis, online education may represent a viable solution. However, a number of measures need to be taken to improve the whole process: providing digital infrastructure, reorganizing the curricula, training teachers and students. Only by making a series of crucial decisions can the online educational process become a viable alternative.

A successful country is a country prepared for the digital era. Education reform involves the digitalization of the national education and training systems. To improve this process, the European Union Member States must work together in order to achieve future-oriented educational systems. In order to progress, the only solution is to develop a spirit of unity and solidarity. The experience of the present shows us the need to strengthen the educational system, both at national and at European level.

Investing in the development of education is the primary condition for a quality education. Educational policies are essential for the professionalization of teachers and educational management. These policies are the result of analyzes performed by specialists in the field. Subsequently, the results were submitted to public debate, where representatives of the civil society have the opportunity to present their views. Therefore, the process is an extensive one, involving all the stakeholders in the

development, improvement and modernization of the education system. The process of integration into the European learning area involves the adaptation of European education and training programs [9].

The European Commission funds projects to support the beneficiaries of the educational process: students, teachers, parents, in order to increase the level of involvement and improve the level of training and qualification. The success of a modernization strategy involves both the allocation of means and resources, as well as the active involvement of those interested. Therefore, European policies and programmes need to be implemented according to well-defined strategies.

The main goal of the Bologna Process was to establish a European Higher Education Area. It was focused on international cooperation and academic exchange, in order to promote the mobility of students, professors and researchers. At the same time, the aim was to improve the youth's preparation for future careers and to become active citizens in European democratic societies [10].

Currently, the Bologna Process comprises 47 states, thus representing a great success in terms of educational cooperation at European level. By creating the European Higher Education Area, member countries have agreed to implement a three-cycle higher education system: bachelor's, master's and doctorate; recognition of completed periods of study at foreign universities; implementation of a quality assurance system.

The Bologna Process represented major reforms in the higher education system for participating countries. The legislation has been amended and the most important principles of the educational process have been revised in order to create a knowledge-based society. In 1999, Romania signed the Bologna Declaration, as a member, assuming the fulfilment of the objectives of reforming higher education.

In 2000, the most ambitious European development project was launched, namely the Lisbon Strategy. The project was to have a 10 year-duration (2000 – 2010), initially aiming at the development of the European Union states in economic, social and environmental terms. In 2005, the text was revised, with interest shifting to technological growth and employment. Therefore, the new Lisbon Strategy focuses on technology-driven growth and innovation, so that Europe should become an attractive space for investment and jobs.

In the long-term achievement of the Lisbon Strategy objectives (respectively the economic growth and employment), education and training had a major



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contribution. Research and development are an essential component of the Lisbon Strategy, strongly boosting economic growth in the European Union member states.

Research and innovation were supported through major European projects. The implementation of these projects involves collaboration: lifelong learning; the transformation of higher education (the Bologna Process) and the use of common European instruments in research and innovation processes [11]. All these initiatives led to substantial changes in terms of quality, transparency and mobility.

Europe faced many problems and challenges throughout its history. These led to the identification of new strategies adapted to new situations, especially within the education system. The economic and financial crisis, triggered in 2008, was a moment of reflection, which led to the adoption of a new economic vision, in order to get the European Union out of crisis. The solution identified for economic recovery was to create an economy that was smart (based on knowledge and innovation), sustainable (resource-efficient, competitive and greener) and inclusive (ensuring economic and social cohesion).

In 2010, the European Council adopted the Europe 2020 Strategy, which included the European Union's initiatives to combat the economic and financial crisis. To achieve the strategic objectives, the emphasis was placed on making investments in areas such as education, research and innovation. In order to achieve the objectives of the Europe 2020 Strategy, seven initiatives were been settled: *the Innovation Union, the Digital Agenda for Europe, a Resource-Efficient Europe, an Industrial Policy for the Globalization Era, the Agenda for New Skills and Jobs* and the *European Platform Poverty*.

These initiatives aimed at supporting *smart growth*, namely improving the quality of the education systems, at national and European level. Economic growth and the creation of quality jobs are generated by performance in research, the use of technological resources, the support of innovation and the exchange of knowledge across the European Union.

The European programs are strategies and means of modernization and are supported by major investments in the field of knowledge.

## THE IMPORTANCE OF THE EUROPEAN EDUCATION AREA (2025)

As part of the meeting that took place in Brussels on 30 September 2020, European leaders committed to turn the idea of a European Education Area into reality by 2025. Together with the Digital Education Action Plan, the European Education Area is an initiative that gives the citizens of the European Union the opportunity to learn and work anywhere in the world. The main principle of the European Pillar of Social Rights is the right to education, training and lifelong learning.

The strategy of the European Union is based on sustainability, quality and digitalisation while education is "at the core of the European way of life". Achieving the European Education Area by 2025 is a means by which education can support the European community and economy.

Another central objective assumed by 2025 is to improve competence and motivation in the profession, in order to support the development of teaching skills. The European Education Area also covers higher education institutions. The European Commission supports Member States in improving cooperation between higher education institutions. Achieving this goal will focus on the experience gained by European universities, selected under the Erasmus+ and Horizon 2020 programs. Therefore, education is an important area of a stronger Europe at global level.

Through the 2025 European Education Area, the European Union is committed to providing all the tools to support the education systems of the member countries. However, the success of this approach is closely related to the collaboration capacity of European states. The European Education Area is the "hope" that education and training need in the European Union.

The European Education Area is also a commitment made by the European Commission, together with the other European institutions and partner countries, to give education a central role in the European Union. Education is "a new center of power" in the process of rebuilding Europe. The future of the European Union depends on the ability of European leaders to achieve the goals for which the European Union was created. In this context, improving education systems is a priority.

Therefore, the European Education Area aims to create higher quality and better paid jobs within the European Union. At the same time, it creates favourable conditions for the green and digital transition, which European cities should implement. Also, it aims to strengthen the European identity in order to increase the tolerance of European citizens and to build a united Europe. In fact, at continental level, national identity

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remains much stronger than a diffuse and more difficult to define European identity. However, the national identity was, in its turn, built, an important role in this process being played by the creation of the nation state. In this context, the creation of a common national history and the identification of its own fundamental values was a role played by the national education.

As a consequence, the role of current education is also to contribute to strengthening the European identity, by promoting common symbols, values and interests.

The 2025 Strategy is a call to action for the European Union member states, which requires a sustained effort and everyone's involvement. It is a way by which quality education can become accessible to all children and young people. The future of the education system depends, to a very large extent, on the capacity of European states to learn from the lessons of 2020. At the same time, it depends on the capacity to capitalize on the experiences gained.

The European Union considers that education and training will play a decisive role in the post-COVID-19 recovery. The proposal to set up a European Education Area came in the context of the challenges

brought by the COVID-19 pandemic. Cooperation between member states in the field of vocational education and training has been going on for several decades. Starting from this reality, the European Commission proposed the intensification of this collaboration, identifying means and objectives of implementation for six essential directions/axes. The main interest is focused on creating competences for European citizens, competences that should prepare them for the green transition and the digital transition. There is no doubt that the success of the European Education Area, which is an ambitious project, will depend on the continued cooperation between EU member states. Taking into account that the field of vocational education and training is the responsibility of each state, the ability of EU member states to reach common goals will play a significant role in turning this project into a reality. A number of pathways have been identified at European level, in line with the principle of subsidiarity, respecting the competences of the Member States in the matters of education and training at national, regional and local level.

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# Knowledge-based Society and the School

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**Abstract**— In a knowledge-based society, the school is the most important institution, being responsible for the society of the future. Dewey and Lipman showed that the traditional school failed, focusing on the transfer of knowledge from those who know to those who do not know, from teacher to student. Such a school is concerned with ensuring success, performance, but it offers answers to questions that students don't ask and ignores questions that they raise. On the whole, the school needs to adapt its practices so that students can learn how to ask questions and how to think for themselves.

**Keywords** — *child; education; question; school; teacher.*

## I. INTRODUCTION

The goal of education, at least in a knowledge-based Society, should be the development of reasonable individuals, according to the founder of philosophy for children, Matthews Lipman [1]. At the beginning of his university career, in the early 1950's, Lipman had no particular interest in education. His concerns in this area, as well as the idea of bringing together education and philosophy, emerged in the late 1960s, when he realized that there was no discipline in the school curriculum to help students think more reasonably, more reflectively, more critically, and a college course of introductory logic – as just his course at Columbia University – came too late to might offer benefits in reasoning. Once aware of the importance of acquiring thinking skills by young people to help them approach the world as early as possible, right from primary school, Lipman had nothing to do but find an appropriate way of instruction in reasoning for children. So, in the early 1970's, he started the educational project of philosophy for children as a quest for thinking in education [2].

But on the road to implementing the Lipmanian project of philosophy for children there was a serious obstacle from the start – the school. The reputation of traditional school has been ensured by the fact that it has succeeded in making children effectively believe they cannot think without the help of teachers and can only answer questions that their teachers ask. The school, more than any other social institution, produces the society of

the future; young people learn to be reasonable so that they can later live as members of an inquiry society [3]. For these reasons, I argue that the main business of the school must be to teach children to think for themselves, because, as Harry Stottlemeier says, “is that kids need to be free to think for themselves just as much as grownups do, maybe more so” [4]. I will also point out that John Dewey's view on school and education remains an always useful introduction to this discussion, both for beginners and experts<sup>1</sup>.

## II. THE CHILD WHO ASKS QUESTIONS

Almost all of the teachers who work in education today have been trained in a school system based on a from up to down learning model; all students listen to learn, but the student who asks to learn appears to be a disruptive factor. Against this excessively curious student, the school system reacted for a long time through punishments, including corporal ones.

At present, those educators unable to reform themselves – even if they no longer resort to corporal punishment – continue to perceive negatively the students asking questions: “He's a nice boy, but he asks questions.”, said the teacher to the parents about their child who had just started school. It does not matter that the child's questions are not off topic of the lesson or that they do not divert the attention of classmates – this child is not as nice as the others, because he asks questions [5]. How do children feel in a school that finds asking questions to be a problem? Are they fulfilled? Are they happy?

The second sentence, introduced by the adversative conjunction “but” (“but he asks questions”) forces us to distinguish between two models of learning. One is downward and is focused mainly on the transmission of knowledge from up to down, that is to say from the

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teacher, as an authority, to students. The other learning model does not involve domination, teachers knowingly giving up the greatness and authority that gives them a chair still fixed on a pedestal; these teachers choose to become facilitators and co-inquirers alongside their students, as in philosophy for children session. In the first model, the question constitutes the teachers' privilege, and students listen to learn, but in the second, there is a reversal, and students ask questions to learn.

Not only in school, but in society as a whole, our standards of learning are changing and becoming more and more complex. According to Latin etymology, the child up to seven years old (*infans*) is the child who does not have the ability to speak. But children learn from the beginning of life, building and reconstructing images of the world, with almost every word learned, and developing their vocabulary through an ostensible learning of words, and being constantly in need of parental corrections. The child's questions are provoked by his curiosity, that "interest in finding something" or that "reason that can cause a person to do all kinds of research, but in an accepted setting" [6].

Most of the child's questions are answered in an accepted and unquestionable knowledge framework. Let's imagine that a child accompanied by an adult takes a walk in the park. The adult would have no difficulty answering the questions the child wants to know if there is still a long way to go to the park, how long they will stay in the park, or what time they will leave for home. The child receives answers immediately, because such questions require only the adult's authority. Not so quickly come the answers if the child will continue with other questions involving the idea of time: What is an hour? What is a clock? How does a clock measure time? In a similar way, if the child's questions concern different species of trees, flowers, birds encountered in the park. Such questions put the adult in difficulty, because they require a certain level of knowledge according to scientific disciplines.

It is possible for the adult to ignore such questions or even to admonish the child for this reason. In such cases, the child will no longer show curiosity and will become a silent child. The silent child has another chance to become curious and questioning again: school.

### III. TEACHERS AND THEIR QUESTIONS

Teachers, whether primary school, middle school or high school, spend much of the class asking questions, according to some researchers, about half the time [7] (Graesser, Person 1994; Cotton 1988). In a single day, a teacher would ask between three hundred and four hundred questions [8] (Levin, Long 1981), reaching about thirty thousand a year [9], and in a career, about two million questions [10] (Kerry 2002).

Contrariwise, the number of questions asked by students during a class is very low – on the average, one student asks one question per week, and over 90% of the

total questions asked in an hour belong to the teacher [11]. Furthermore, few students' questions are related to their understanding of the topics taught [12] – many questions are procedural, for example: "Do we also write the date?", "How much time do we have to solve the problems?", or they appear only seemingly as questions – for example: "Can you repeat?". And in the case of questions asked by the teacher, over 50% are related to the conduct of the lesson (for example: "Who finished solving all the problems?"); 35% are questions that involve recalling information (for example: "How many feet does an insect have?"); and only 8% of the questions require analysis, generalizations, or deductions (for example: "Why is a bird not an insect?") [13].

Similar data can be found in a pioneering study on the use of the questions during class (1912), which showed that teachers had control over classroom interaction by averaging about four hundred questions in a single day, the teacher's questions and the students' answers occupying 80% of the class time; more than that, teachers used the question "as a means to bridge gaps and kill time during a class hour, thus perverting its legitimate and valuable function as an educational agent" [14].

The effect of teacher questions on students, including attitudes toward learning and participation in class discussions, began to be a major concern in the 1950s, for pedagogues, psychologists and philosophers. But John Dewey's view remains an always useful introduction to this discussion, both for beginners and experts.

### IV. THE CHILD AND THE SCHOOL

Dewey already states that both university and school are places of inquiry. A central aim of education is to prepare students to be able to make reasonable judgments about some controversial situations they face. This means that the school is not limited to providing impartial knowledge, but must also ensure improving reflective thinking skills. children must learn what makes sense, what enlarges their horizon, instead of mere trivialities, to become acquainted with truths instead of things that were regarded as such fifty years [15].

The child is an active being, like the adult, and likewise, he learns by facing the problems encountered in the activities that interest him. But the traditional school is not the place for such an active human being; on the contrary, it was designed for listening, not for working, as it can be seen from the arrangement of the benches in the classroom. There is very little place in the traditional schoolroom for the child to work. The workshop, the laboratory, the materials, the tools with which the child may construct, create, and actively inquire, and even the requisite space, have been for the most part lacking. The things that have to do with these processes have not even a definitely recognized place in education. The child is required to listen, in order to retain or memorize as much as possible of what the school authorities provide. Or, the

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child does not come to school as “a purely latent being”, but on the contrary, as an “already intensely active” being, bringing at least fourfold interests: “in conversation, or communication; in inquiry, or finding out things; in making things, or construction; in artistic expression”. Therefore, the teacher, instead of trying “gradually to draw out some hidden germ of activity” should manage these natural resources of the child, “giving them direction” [16]; thus, the child will learn best not by listening, but by experimenting.

Dewey founded, in 1896, an experimental school, The University Elementary School, also known as The Laboratory School, which he managed until 1904 [17]. His venture came from the belief that school should be an experimental opportunity for pedagogy, as the laboratories do for biology, physics or chemistry. In order to accomplish the educational process, Dewey introduced scientific experiments, outdoor lessons, and changed the furniture in the classrooms [18]. He hoped that, in such a school, children would be actively involved in the educational process. The lessons should have been based on the child's interests, which, in turn, are related to the child's real needs, which, lastly, the teacher will know through the child's questions. Dewey distinguishes the child's actual needs from the needs that teachers believe would make learning more attractive. Therefore, each lesson should have been conceived as an answer to the child's questions - thus, for each child, knowledge would become a process that is built dynamically and individually. But teachers selected for The Laboratory School were accustomed to traditional teaching methods, and were unable to promote the appropriate type of thinking for such lessons based on the students' questions.

Students are aware that the teacher knows the answers to the questions asked in class and, therefore, they seek to provide, each time, the expected answer. Such teachers present themselves to the students as the possessors and distributors of knowledge – they decide the questions, the respondents, the rules of the conversation. They intend to instruct, while the desire to learn belongs to the students. Do the teachers' intention and the students' desire overlap or do they never meet? Develay summed up the rupture as follows: “the school answers questions that students do not ask and does not answer questions that students ask” [19].

## V. THE SCHOOL AND LEARNING HOW TO THINK FOR THEMSELVES

According to Lipman, there are three fundamental models of public and private institutions in our society: the family, as an institution of private values; the state that represents institutionalized public values; and the school that embodies the fusion of family and state. Out of these three institutions, the school is the most important, because “through it past and present generations deliberately and consciously attempt to stamp a design

upon the future”. In addition, the school is the only institution that “can legitimately claim to be worldwide,” because regardless of the cultures in which it is encountered, schools share the same “presupposition that children go to school to learn”; they learn basic skills (reading, writing and arithmetic proficiencies) and content (geography, history, literature). But the chief business of the school should be to strengthen the child's thinking and moral judgment, Lipman believes. It is precisely in this respect that the traditional school failed, focusing on the transfer of knowledge from those who know to those who do not know, from teacher to student. Knowing by absorption and storage in memory has become the basic rule of learning. Thus, children who started school full of curiosity gradually become passive, careless, uncritical, thinking only of what they have been taught to think. Of course, they expect the school to function differently, to continue the stimulation of the child's thinking and speech, close to that already begun in the family. But at school they discover a „completely structured environment” with a schedule and a classroom language; they find that “schooling is enervating and dispiriting rather than animating or intellectually provocative” [20].

In Lipman's first philosophical novel, Harry Stottlemeier's Discovery, imaginative children criticize the school and the grownups who do not know how to run the schools. There is no question that kids should run the schools; Mark emphasizes that his dissatisfaction is related to the fact that those who run the schools do not seek to understand the children and, especially, why children are at school.

The discussion starts by specifying the role of school as an institution in any society: “We're in school to learn.” Then, the children examine some aspects of a traditional school's activity: students learn “answers” and “how to solve problems”, of course, problems given by teachers. The image of a different school emerges when Mark expresses his reluctance to “learn how to solve problems”; he thinks that instead of “learning how to solve problems”, it would be more interesting to learn “how to ask questions”. Thus, a transition takes place from the standard school where children come to learn only basic skills and content to the school where children should learn more than anything else thinking skills: “We should be learning how to think”, Harry said. It is true that in the traditional school students learn also to think, but they do not learn how to think for themselves: “we never learn to think for ourselves”, said Mark who is outraged that teachers do not admit that the student has “a mind of my own”, and that they fill his mind with “all sorts of junk”, as if his mind were “the town junkyard” [21].

The discussion about school is a learning model promoted in philosophy for children – community of inquiry. It is non-authoritarian and anti-indoctrinating; it respects the value of inquiry and reasoning, encourages the development of alternative modes of thought and

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imagination, and shows how children are able to learn from one another.

## CONCLUSIONS

The traditional school offers answers to classical problems, but this knowledge is already possessed by machines. Therefore, students should learn differently, to be able to invent new professions on their own, when needed. And teachers should adopt the position of the researcher and encourage students to think for themselves.

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# Knowledge-based Civilizations: the Search of Development (Socio-Philosophical Trends)

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**Abstract** — Knowledge-based civilizations are considered as new socio-philosophical phenomena, the complexity of conceptualizing their initial attitudes is shown. The article substantiates the need to develop a theory of civilizational coding as a mechanism for the formation of new knowledge that affects the socio-economic and spiritual and moral development of civilizations, the acceleration of economic growth of states, the increase in the level of spirituality of a person and society in the conditions of challenges, risks and bifurcations. An attempt has been made to create a civilizational paradigm of concrete actions based on the acquisition and use of new knowledge, allowing to determine the meanings and guidelines for the development of various events, to identify the causes that determine certain negative phenomena

**Keywords** — civilizations; sociology; civilizational code; new knowledge; philosophy; cascade of bifurcations.

## I. INTRODUCTION (HEADING 1)

“The Long Twentieth Century”, the components of which were the destruction of “old” regimes and the simultaneous creation of “new hopes and illusions”, in Arrigo Giovanni’s figurative expression; a famous Italian scientist and professor of sociology at Johns Hopkins University, was a time of fear and suffering, world wars and weapons of mass defeat, terrorism and climate shocks, new deadly diseases and concentration camps, genocides and the GULAG [1].

In none of the past historical eras has there been so much violence, killed and wounded, deprived of freedom and dignity of people. After the Second World War, due to the wildest world conflict, an interesting international project arose - the United Nations Organization, which also did not meet the hopes of millions of people. Humanity waited for the XXI century as a time capable of solving many problems, such as ending wars and poverty, disease and hunger, illiteracy and inequality,

violence and ugliness. After the turbulent end of the last century, it seemed that the time of storms had passed, and now the ship called the Earth is waiting for a happy voyage [2].

According to many modern researchers, the current century will be even more ambivalent and unpredictable, unusual and to some extent surprising, which is characterized by cultural and spiritual uncertainty, disruption of the unity of civilizational streams and a conflict of symbiosis and synthesis of cultural foundations. In a state of bifurcation, in a situation of choosing the future, it is rapidly moving towards a model called “chaos”. On the one hand, it is at the forefront of an intellectual revolution that will fundamentally change the way people live, work and communicate with each other. In recent years, the society has made huge strides forward in the development of science and technology: from laboratory experiments with fruit flies to “reproductive” cloning of living things and the creation of genetically modified organisms; from heat lamp computers the size of a house to a much more efficient miniature device that fits in the palm of your hand; from Yuri Gagarin’s flights to the landing of spacecraft on the Moon and Mars and from an electric engine to a nuclear reactor and a hydrogen bomb. Artificial intelligence and neural networks, robotics and genetics, management and control over large amounts of data, massive introduction of new digital technologies that form the basis of “Industry 4.0” and wireless communication enhance the efficiency of intellectual resources in people’s lives, contribute to their transformation into the most important subjects of modern civilization. Today, the level of knowledge has already reached such a level that almost any information can be found on social networks in ten seconds. The development of technologies, primarily computer and telecommunications, has led to the fact that the number of high-tech research turns into quality [2, 3].

On the other hand, the world is terrible for its unpredictability. The habitual models of life are destroyed, the boundaries of the permissible change can



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collapse in a few minutes, like the 110-storey twin towers. Man is gradually becoming one of the most dangerous and unpredictable creatures on the Earth. Everything that surrounds him is fraught with obscurity and uncertainty, risk and turbulence, entropy and unpredictability, chaos and death. The cascade of bifurcations (the Feigenbaum sequence, or the period doubling scenario) is one of the typical scenarios for the humanity's transition from order to chaos, from a simple periodic regime to a complex one. The analysis of the mechanisms of this transition in real systems and various models of order showed the universality of these scenarios. The model of the development of a complex system through a sequence of bifurcations and the idea of chaos as an extremely complex and developed structure is applicable to phenomena of a very different nature: physical, biological, social, economic, i.e. to any civilizational systems where there is a sequence of period doubling bifurcations. A cascade of bifurcations leads sequentially to a choice between two solutions, then four, and so on; the system begins to oscillate in a chaotic, turbulent mode of successive doubling of possible values, which can lead civilization to death [2, 3, 4].

"We no longer dream of the future," says Ivan Krastev, the chairman of the Center for Liberal Strategies (Sofia), a leading researcher at the Institute of Human Sciences (Vienna), and Svetlana Babaeva, a member of the Russian Council on Foreign and Defense Policy, who said that: "We are afraid of the future. Even in the Soviet Union, there was not such a situation. They were afraid of the present, but hoped that in the future there would be a different life, the legitimacy of the Soviet system was built on the fact that children would live better. And now a person is afraid that his children will not live better, even if they live longer. Moreover, we can no longer imagine how they, in principle, will live ..." [5].

Thus, scientific and technological progress turned out to be not only triumphant victories for mankind, but also numerous social, political, economic and spiritual problems. Paradoxical as it may seem, the more technically equipped a society is, the less adapted its members are to life. Environmental pollution with production and consumption waste, predatory attitude to natural resources, irrational use of natural resources gave rise to an ecological situation that has become one of the most acute global problems of civilization. The number of man-made disasters is growing in the world, which lead to numerous human casualties, serious damage to human health, destruction of various kinds of objects and material values, large-scale degradation of the environment and other tragic accidents.

After such events, information appears in many publications around the world that modern civilization is dying. For example, Australian experts from Melbourne conducted a study and found that human civilization in its modern form is doomed to extinction in thirty years [6].

But it is not so. Civilization is alive, but it is in a systemic crisis that exists in all spheres of social life, both material and spiritual. The current state of world politics and economics, culture and ecology, spirituality and morality is a crisis of the modern model of the

development of civilization. This is a crisis of "the flesh and spirit of the society", a lack of intelligence and knowledge.

As numerous studies show, the crisis of civilization is, first of all, the terrible use of modern knowledge, its institutional foundations, which give local civilizations a fundamentally new quality in the conditions of the formation of a new social reality. The lack of knowledge for solving modern problems is accompanied by entropy and instability, social, economic and political chaos, spiritual trauma of people, a sharp polarization of society, loss of moral priorities, destruction of social institutions, loss of trust in power, loss of identity and spiritual traditions.

This means that the modern world is working at the limit and requires the search for new possible ways and forms, sources and mechanisms for dealing with the existing problems. It is important to realize that the disastrous risks are taking on global proportions. In this regard, it is important to create new mechanisms for the interaction of civilizations at all levels, both globally and locally. The knowledge paradigm of understanding and managing the development of mankind can become an imperative for the survival and development of states. A new worldview level of understanding of current events is needed, capable of adequately and correctly formulating the existing problems and outlining ways to adequately resolve them, to ensure the transition to a new intellectual level in the study of social reality. At the same time, according to the Belarusian scientist, Doctor of Economics, Professor Kirill Rudy, it is important to take into account everything that affects life - economic laws, personal experience, habits, phobias, intuition, mood, understanding of the present and vision of tomorrow. This is all that is "encoded" in the form of information, emotions, events, and then reproduced in new knowledge [7].

We need a fundamentally new model of human development based on new knowledge. The theory of civilizational coding can become such a model, which makes it possible to go beyond the framework of scientific reflection, to comprehend the problem of "how to develop, where and how to go?" and become an urgent need of the society. But first, it is necessary to answer a number of very complex and important theoretical questions and, first of all, what is civilization in the modern sense, what is its structure and methodology of cognition.

In the current century, the attention of domestic and foreign scientists to the problems of civilization has increased. At the same time, the idea of society as a set of fields with different structures, actors and strategies (a key theme in the extremely influential works of Pierre Bourdieu) is clearly more attractive to many researchers than the idea of civilization [8]. It is necessary to study the civilization more deeply and thoroughly as a sociological phenomenon that affects all aspects of human life. The famous Icelandic sociologist Johan Arnason proposed an ideal type (analytical model) of civilizational formations, in which he distinguished two sides: interpretive-institutional and spatial-temporal [8].



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In his works, J. Arnason develops the so-called relational approach to the study of civilizations. One of its key features is the emphasis on the ability of civilizations to mutual enrichment and borrowing certain civilizational features. At the same time, the development of civilization, according to the author, is not always limited to a predictable scenario - its direction can change under the influence of the creativity of social action and random events. Characterizing the relationship between different civilizations, the researcher highlights the interaction of history and traditions, various ways of modernization and alternative forms of modernity. [8, 9].

The famous Israeli sociologist, specialist in the field of comparative studies of civilizations Shmuel Eisenstadt proposed a definition of the "civilizational dimension of human societies", which he understood as "a combination of ontological or cosmological visions ... with the definition, construction and regulation of the main arenas of social life and interaction" [10, p. 2]. In S. Eisenstadt's understanding, we are talking about civilizations not as some self-sufficient structures of the greatest space-time coverage in the spirit of the "metahistorical" tradition of civilizational analysis [10]. His version emphasizes not homogeneity and internal consistency, but heterogeneity, ambivalence and antinomy of the cultural premises of civilizational formations. Cultural orientations of civilizations do not program the institutional structure of societies, but rather form common cultural problematics, suggesting a plurality of different and often contradictory articulations and interpretations, some of which can crystallize into relatively stable cultural models [8, 9].

Based on the analysis of numerous domestic and foreign studies, I propose the author's structural and temporal definition of civilizations - these are social organizations of people located on a rather vast territory, united by a geographical environment and living space, a system of economic management and historical memory, ethnic characteristics and mentality, politics and religion, fundamental values and spiritual and moral traditions, a system of knowledge and technologies for their storage and transmission and constantly developing on their basis.

Thus, at present, civilization is understood as a certain integrity, a set of material and spiritual, mental and moral, aesthetic and other values. The living space and length in time, historical memory and stability in comparison with other social formations, heterogeneity and ambivalence of modernity and constant development in time are its most important characteristics. This approach allows us to formulate the idea of the discreteness of history and the possibility of dividing the civilization process into specific types of civilizations.

The theory of civilization coding is based on a fundamentally new knowledge and aimed at studying and creating concepts that reflect the essential properties of the current and future state of civilizations, outlining landmarks and trajectories of forward movement, allowing to go beyond scientific reflection and comprehend the problem of "how to develop, where and how go?". The essence of civilizational coding is in the

scientific study of social reality, a radical rethinking of ideas about it, the development of specific proposals for its improvement and the purposeful movement of societies towards a better future. The development of competencies and capabilities of civilizational coding, the use of its basic principles as methods of searching and forming a fundamentally new knowledge about the future states of societies allow subjects of management activities of various levels of complexity to more effectively use the potential of civilizational technologies in conditions of intense novelty and reach a new level of understanding of modern civilization.

The possibility of code activity aimed at the formation of new models of civilizations is primarily due to the presence of general patterns inherent in civilizations, the existence in social systems of cause-and-effect relationships, stable elements and relationships and an interval of uncertainty in their development, allowing the necessary recombination of biological (genetic) components, cultural and social characters, through which a certain set of values and traditions is formed, transmitted and reproduced in future generations [11].

The core concept of civilizational coding is the civilizational code as an informative system of civilizational signs, symbols, artifacts, which has a specific meaning in a specific and chronotropic context. Without it, it is difficult, almost impossible, to trace the development of human relations. Only the code is able to answer the question: can Belarusians ever become Americans, Russians - French, and Chinese - Japanese. A civilization code is a strictly fixed set of genetic, social and cultural values and meanings, symbols and spiritual experience, a stable set of formal and informal principles and rules for storing historical memory, behavioral formats and knowledge, which has been established in the consciousness and behavior of people, thanks to which culture and social experience, skills and abilities are passed from generation to generation and regulate the interaction of people in everyday activities, form a complex of roles and statuses that can become the basis for the development of civilizational relations. This is the definition of a civilization code in a broad sense. In a narrow sense, the civilization code represents the elements that are naturally related to each other (views, knowledge, values, traditions, etc.) that determine the activity of social subjects aimed at preserving customs and traditions, cultural and historical memory, searching for new ways and opportunities for purposeful influence on the development of civilizations [1-2].

The civilization code determines the stable functioning of civilizational structures, offers a clearly delineated semantic model of social actions and helps to find a way to the future, taking into account the experience of the past and the modern development paradigm. The code is able to offer a clearly outlined civilizational paradigm as a semantic model of actions, to draw an ideal model of the future state of humanity.

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find a way to the future, taking into account the experience of the past and the modern development paradigm. The code is able to offer a clearly outlined civilizational paradigm as a semantic model of actions, to draw an ideal model of the future state of humanity.

The essence of the civilization code is embodied in its multidimensional structure. The main component of the civilization code is the traditional national values, traditions and spiritual ideals of the people, which for thousands of years have been the spiritual, moral, and ideological basis of the Belarusian society. The worldview, in turn, determines the purpose and meaning of life, determines the development of society and the state, shows what a person is guided by in his daily activities. The main components of the civilization code include: traditional values, social experience, social expectations, generally significant values and meanings, culture, knowledge and mentality, historical memory of the people, etc.

With the help of socio-philosophical analysis of the civilizational coding, to solve numerous problems, collective reflection is constantly carried out as a structured dialogue between various stakeholders in the formation of future civilizations (scientists, designers, specialists), which makes it possible to determine both the narrow sides and prospects of civilizational construction, strategy and success tactics in creating a scenario for an effective future. In the course of civilizational code activity, a clearly delineated semantic model of actions is formed, capable of solving existing problems with the help of new knowledge and theoretical tools provided by philosophy and sociology.

It must be fixed in a certain coordinate system and analyzed using modern socio-philosophical mechanisms in order to understand the integrative civilizational knowledge as a system of attributes and artifacts of being acting in society, carrying information about the past, present and future of civilizations. The theory of civilizational coding is able to conduct a scientific analysis of the knowledge system and offer a fairly accurate scenario for the development of phenomena and events in the future. It is important to understand the importance and necessity of coding as a specific transit of knowledge, search for optimal ways of transforming information and presenting it in the communication space of civilizational processes [2-3, 11].

Civilizational coding as a model for obtaining a fundamentally new integrated knowledge in its activity uses values and symbols, historical traditions and peculiarities of mentality, mental schemes and collective ideas, confessional and political, social and cultural, aesthetic and moral, ethnic and other factors. The main objects of civilizational coding are multilevel and structural-functional, actually existing and objectively operating social systems with specific organizational, civilizational, subjective-identification technical, technological and organizational parameters. At all levels of the spiritual order, it is important to see and perceive,

understand and feel how much they mean in the life of each person, how much they are able to give new knowledge, what meanings and values, aspirations and attitudes, desires and interests, ideals and motives that affect thoughts and actions, consciousness and worldview of people [2-3, 11-12].

Human history is the history of civilizations. It is impossible to imagine the improvement of societies in isolation from the development of civilizations based on knowledge. It is knowledge that is an integral part of any civilization, its locomotive and helped humanity to move from savagery through barbarism to civilizational (in the modern sense of the definition) development. Knowledge as the ability for purposeful actions directs the subjects of civilization to the solution of the most complex problems. Further accumulation of knowledge, their constellation, use to increase the vital activity of peoples led to the emergence of local civilizations. The modern era has set new challenges for humanity. Its transition to a higher level of civilizational development is real only when using new knowledge, creating new development models, and, above all, the theory of civilizational coding, using the achievements of science and technology in all spheres of human relations.

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# The Nonhuman Character Of Technology And Nature Revealed Through Photography

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**Abstract** — Tools, like photography, are helping the man fighting nature. However, inside the essential structures of photography there is no signification function. Therefore, the objects represented in the photograph appear as they are in nature, meaningless and without human presence. The photograph, like other technical devices, does not retain the meaning of things. And so, photography is equivalent to nature, which equivocally has nothing to do with human meanings and values.

Only in the field of subjectivity and human intersubjectivity the meanings given to world objects are able to survive. In addition, free of sense objects from photography or film, under the guidance of consciousness can combine in unexpected ways and, as a result, produce alternative meanings. Hereafter, the photograph circumscribes an element that corresponds to the basic function of art in general, namely the opportunity to readjust the daily life in which we live in by giving possible meanings and opening up alternative perspectives. In this context, the man is no longer formalized by abstract rationality, but returns to the rethinking of the living environment in which he cohabitates with others.

**Keywords** — *technique, nature, history, photography, capitalism, mass, meaning, signifying function, everydayness, subjectivity, intersubjectivity, ration, abstraction, dehumanization.*

The nature seen by Kracauer, is deprived of human meaning sediment from which are built the value priorities of reality. The pure nature is unwrapping from the system of cultural meanings, meaning human meanings, leaving behind just a sequence of things separated from the meanings which were given by a dominating and emancipated conscience. The one thing that brings closer the photography to nature is the common way of how the things appear to be. In both cases a kind of indifferent touch is sensed, plane and homogeneous, that places itself outside the human meanings. In other words, in the bare nature any object with a conferred meaning is suspended.

On the other hand, the non-involvement of the man in the same way purifies the nature from meaning. Here, in the picture we can see the bareness of nature, because

even if this was a product of the human technical development and on a daily basis it is taken by someone specific, the access to nature's essence is restricted, which is why on the ontological level the man is no longer capable to make any changes. We find ourselves standing before a raw relationship, where a lot of things are exposed in front of us like an old-fashioned clothing, to which we don't know how to refer because of incapacity of finding a meaning that would allow us to connect to the origin of the époque's content. The object from old pictures are meaningless, therefore deprived of any effective human presence.

Given this, the stuff from an old photography are presenting themselves from a natural perspective the way they are, wiped off any meaning of human history. Through the effective human absence, we can root for missing the direct contact with those very objects which once were given so much sense, which was a result of someone's direct experience with the object.

So what should we understand out of all this? Surely, it doesn't mean that once we don't have the direct access to objects from the past we can't talk about them or we can't know them. Actually, we are very much capable to do so but only through the indirect experiences, which supposes the mediation idea. The great absence, suggested by Kracauer, refers to the actual, mundane presence, which is the most concrete and in which every one of us is in this singular moment that we intertwine with objects we encounter, building meanings where not only objects become known but also the people in a specific story. One thing that gets a photography closer to nature is the univocal way of how all objects are treated. Being displayed in a photo, there is nothing extra is attributed to them, only the ways they are seen remain. In both cases, a particular approach is exhibited, as mentioned before, an indifferent one, plane and homogeneous placed beyond the human-meanings zone. The bare nature, as we've seen, lacks the cultural component. The fact that the photography, original from opposite side of the nature, the technical side, which in its turn has evolved in a human

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meaning framework, is approaching the closest to the nature's essence and is fortifying along its qualification a general inventory of nature according to its irreducible elements.

Therefore, for Kracauer the photography is a environment where a succession of objects in space is shown. The photo places the elements in a line, ignoring their meaning. Even if it apparently looks like a monogram, it isn't. In a monogram one can see something invisible, like a name and surname of a person. Neither one nor the other are installed at the line's surface that tangle in irregular ways. Only behind this decoration we can explicitly capture the person. If we would leave aside the monogram that is caught by a phenomena of a specific human experience, we could discover „ a general inventory of nature” made out of raw elements whose essential propriety is the spatial appearance.

The unquestionable value from Kracauer's actuality that photography celebrates is confirmed by the abundant presence of the illustrated magazines. Here, the world is being shown in the way that it is accessible to the camera. Kracauer suggests that not a single other époque has known more about itself than ours, if we understand first of all that: the fact of having an image of things that look like themselves that's done via a photo [6, p. 95].

In most of the cases, the object of the photo is given and it is accessible in its original form. The way a photograph exists is one of reproducing, whose purpose is to connect us to its object. This blending function of photography reflects its sign structure that refers to something more specific. That is, being able to recognize a friend from a Facebook picture whom I met in flesh a day before. Regardless of all this, we just can't deny admitting the fact that there are people, objects and phenomena that we've only seen in pictures, and this should lead us to the idea of inversion where a person's recognition is being done based on his presence on the photo.

Even if in a photo there are all the necessary conditions for a sign to be connected to the original, the photography cannot possibly be a pillar for remembrance. Therefore, another way of approaching the photography through which it's proven that it does not aim to reproduce an original through pictures, is recognized in the background of selective mode of memory manifestation. According to Kracauer, selectioning is a memory property. The overwhelming presence of photos in the world triggers a suppression of memories. The photographs display the object with all his spatial details captured in one moment, while memories focus on some properties and relevant manifestations of and from a person, a specific person's life.

We remember an object due to some particular situations and concrete perspectives of where we've met and how have we been positively or negatively marked by it. The *great fight* is held between the way one remembers

that the object is and the way it appears on a photo. The avalanche of photography, according to Kracauer, must provoke some doubts referring to the memory's validity and in this way to deprive of vigor the cornerstones on which a memory is built. So, we have a separate vision on decisive traits of an object, which however risk to be erased by the multitude of photographs that reproduce it.

The masterpieces lose from their original value exactly because of this reproducing reason. Instead of being distinguished from its replicated background, the original is simply fading. In order to illustrate this uniformity, Kracauer refer to an old German saying *mi(t)gefangen, mitgehangen* (caught together, hanged together). Another example from the same series would be the parable of how Charlie Chaplin who has participated at the impersonation competition of himself got the second place.

In the illustrated magazines appears a world which the public see it but can't perceive. In the illustrated magazines the public sees a worlds that the illustrated magazines is blocking to be perceive [6, p. 95]. Deleting the barriers between catching the object in a spatial continuum in a photography and its spatial emergence in its highly similar level determines its „history” evaporation. This idea brings Kracauer to an affirmation that related to other époques, ours knows the least about itself. The illustrated magazines represent a declared stake to cognition. In these circumstances the photography kills the recollection. The illustrated magazines interpret the world as a totality of photos. The world itself has a photographic look.

Being available to be photographed starts off this look, trough which the world is reduced to a spatial continuum. A celebrity keeps the cameras focused on her, worthy of being photographed and reaching the front-pages of the illustrated magazines. In this greedy overload of illustrated papers with photos, Kraucauer sees a fear of death where the world is getting stuck. The death recollecting is implicitly composed in any other memory, and photographs can remove it. Photographing the world means and supposes its perpetuation or immortality.

Hereafter, there are two acceptances of photography in the modern world that knock out each other. The first one resonates with what a photo must do as a sign that it is. So that photo's *must-do* coincides with bringing an object as close as possible to that very moment when it is missed the most, which means that a photo sends us back to the original object that it's represented on it.

The second acceptance aims the rapport between the conscience and the world, which in fact it mediates. Through photos, the world gets closer and in the same time farther. The photographs obstructs the world, being a kind of indirect presence of it. The fact of reducing the world to the sum of all the pictures it appears on, takes on a development on Kracauer's comparison between memory and photography.



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In this very acceptance the photo destroys the memory. A rather unexpected conclusion appeared from the faith background that the pictures help us memorizing, help us to remember. Taking all this into consideration, photographs function in another way than memories, but even so, it's like photo's recollecting help shouldn't be cancelled.

Kracauer's position justifies starting from the memory's correlation with history, where history is performed through a given meaning, a given idea and it's found in a personalized vision of he who builds a vision around what happened with him. Given the fact, depending on the valuing intensity, of wishes and believes, the conscience operates selectively the happenings that occur.

Normally, we wouldn't remember something that for us had no important value and vice versa, we would rather remember the things that affected us in a very specific way, positively or negatively. The photos cut out from a spatial continuum a scene where things appear in all its' details [1]. A reason which the spatial appearance of an object is covered by spatial continuum given from a camera's perspective.

In another of Kracauer's analysis aspect, he refers to the historical evolution of representations trough image, which starts with the *symbol*, where its roots emerge from natural type of society. The photography is a modern manifestation of this evolution. The reference to this natural society, Kracauer is overtaking from the XIX century Swiss anthropologist Johann Jakob Bachofen, who was noticed through his studies about the primitive family and matriarchy. In Bachofen's conception, the society's evolution has known at its beginnings the unity between conscience and nature, the reason for which in the symbol's content the physical world was represented in the first place. This direct reflection of the nature doesn't margin to symbols only, alike words which were referring to a sensorial-material reality only, eventually ran deeper and revealing concepts more and more abstract.

The whole register of evolution from *palpable* references to nebulae concepts, religion comes to its positioning. The rapture debut from nature's den takes place when the conscience becomes self-referential, what will have as an effect the loss of the identity between the nature and human. An idea that is infused in the entire XIX century way of thinking, starting with representatives of the classic German philosophy which reaches its climax in the in the Marx's conception about society.

However, the representations via picture didn't detach from their symbolistic structure. These natural reports satisfy the man's need of symbols in which the *visible bodily intentions of the conscience* are conditioned [2]. Even if the conscience separates from nature, it continues to think in concepts, that are still used with a mythological function. Anyway, the symbolic function is gradually removed from the images, so that the symbolical

representation becomes an allegory. Repositioned this way, the image makes a general idea that differs from it-intelligible .

Let's focus a bit on this change of accent of the way a picture functions. So, in a human society conditions, marked by a unity of conscience and nature, the pictures were just symbols that were sending us to a sensitive where nature was encountered directly. Than later, throughout the history the conscience development of oneself tears this unity, a reason why the conscience starts operating with general concepts, though the way it happens remains of a symbolistic structure [4].

As a consequence, the symbolic representations are taken as tools for an idea's meaning as it happens with the allegories, and the symbols themselves become a sensitive embodiment of this idea. Thus, if from the start through the symbols the man was getting closer to nature, than in the conscience's evolution on oneself, the man by the means of symbols narrows down his general ideas to his conscience. The difference between approaching an idea from an allegory and from a symbol, is followed by Kracauer from the German philologist Georg Friedrich Creuzer, who supports that the object of thinking is comprised in the symbol, while in an allegory „the thinking is preserving the image only” [6, p. 97].

Once photography enters the daily life of social life, there is a division of reality into human reality, we can also call it cultural, technical and natural reality.

The existence of these three components of division should not lead us to the idea of a triad. Consequently, it is a matter of contrasting the reality of human meanings with the realities of nature and technology. The fusion made between technique and nature is valid because of the same way of treating things, which implies a indifference to the meanings attributed by man. Which is why Kracauer identifies photography by resemblance to an inventory of things illustrated from a natural perspective. The established partnership between photography and nature is strengthened by the eradication of man from their content. But it is not so much man who is removed, but especially the sum of the meanings that come from being in the world. Meanings prove to be an ideational envelope that sits over things as they are displayed in nature and that are given in a subjective experience.

Human life cannot be imagined in the absence of these degrees of significance. It would be wrong to interpret man as a mark of photography. No, photography still serves human purposes and manifests itself in a community of people, in fact, in this place is the meaning of photography which consists in showing something that is absent. Consequently, the photography is produced by man and is intended for man. Using a metaphor, with the hope that her choice will make things clearer, we could say that the photo won the trophy in a competition to recover the past according to the most meticulous level possible. Certainly cases of photo editing must be

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excluded. Their purpose is to distort reality. Traveling through photography to an object from the past, captured in a fragment of time, we discover the object exactly as it was the moment the shutter was operated. This accuracy belongs to the photographic image, because these images represent the object beyond preferences and meanings, which would result from a cultural selection. The photographic image homogenizes all the elements that appear in the content of the represented object.

It is natural for a cultural individual to select a favorite element from a photographic surface, because it is affected by his own social context. In photography, however, everything is flat and equal from a natural perspective. This natural homogeneity is uneven and tangled in the flow of perceptions of a concrete person. That's why photography is not a monogram. It has nothing to hide, everything it has to show appears in an indifferent spatial succession where all the elements are equal. There is no meaning behind it. The way something is shown in a photo is similar to a grid in which a grouping of things recorded by their property to appear in space is inserted. In parallel with photography, historicism assumes the inventory of all phenomena that show up over time. But just as we cannot find any meaning from the spatial alignment of the elements in a photograph, so also from the temporal sequence of events, which defines historicism, we will not find any meaning of them.

Normally, according to Kracauer, consciousness penetrates the chain of temporal successions and discovers a meaningful history that it preserves. From the simple successive order of events we can extract only a simple order of them. The review of the time sequence of events as such does not bring to light any transparent meaning. From its technical position, photography detaches the natural element from the world of human meanings. The data strings from the photo are dried up by any human manifestation. Man is expelled from the all-encompassing narrative of the photographic image, and the possible intrusions of meaning are struck by an invincible negligence of the natural perspective through which an

object is represented in the photography. The expulsion of man from the natural and photographic circuit reveals death in this context. The dimension of death is characterized by the total absence of man, and technique and nature are also independent of man.

It turns out that in photography and in nature there is a world of death - a world cleared by man.

Man in his history, in his life, in his feelings is able to hold together a lot of scattered elements, because all these represent a value and a meaning for him.

In nature we will not find any meaning, but in a person's life we will find it. The elements stored in a photograph do not have a cohesion from which a meaning would be produced, they are as they are from a natural perspective and independent of man. The effects of technological progress lead to a categorical demarcation between human and natural. From this delimitation the objects abandon their human values and through the technique expose their natural foundation.

Thus, photography facilitates the opposition between consciousness and nature. In the photo, things are shown in their pure, manless way [2], [3]. In essence, nature is not human and is beyond any meaning. The technique produced as a result of the evolution of enlightened reason is in the same closed position towards man as nature. In both cases, man is the one who humanizes nature and technique.

Predominant in this tendency to dehumanize the technique is not the self-management capacity of an AI, but the structure in which no human presence is involved.

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# Civilizational Code as a Definition, a New Scientific Discipline and an Innovative Paradigm (Socio-Political Trends)

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**Abstract** — The work explores the concept of a civilizational code, its features, structure, functions and analysis of the main subjects. The author's definition of the concepts of civilization code and code relations is proposed. The study of the civilizational code allows us to consider it not only as a scientific concept, but also as a teaching discipline and a scientific paradigm that would not only reveal the essence and content of the meanings and guidelines for the development of local societies, but also analyze the causes that determine the processes and phenomena taking place in society.

**Keywords** — *theory of civilizational coding; civilizational code; historical memory; identity; traditional values; national idea; mentality; code relations*

## I. INTRODUCTION

In modern society, traditional values are lost, the mentality of citizens is deformed, and the value norms of culture and morality are eroded. The magnitude and impact of political crises are increasingly being felt throughout the world.

In addition, society regularly faces many other unsolvable problems: the global economic crisis, the fight against disease and hunger, environmental disasters and catastrophes. The worst blow was dealt by coronavirus, which aggravated the economic crisis, affected the future health of the entire population of the planet, claimed many human lives, and forced to rethink the concept of life.

The state to which modern society came was foreshadowed by many doctrines and scientists, but many problems remain unresolved.

## II. GENERAL DESCRIPTION OF THE WORK

### A. Purpose and object of the study

The purpose of the work is to study the concept of "civilizational code" and nominate it for the role of a new educational discipline and scientific paradigm, which will be able to reveal the essence and content of the meanings and guidelines for the development of local societies, as well as analyze the causes that

determine the processes and phenomena taking place in society. The object of the study is the civilization code of Belarusian society.

### B. Relevance of the topic

Social and political crises and upheavals in society require the development of a new paradigm that reveals the interrelationship of events, phenomena and processes of the past and the present, and also allows social design and forecasting taking into account the socio-cultural, political, economic specifics of society (code), which is located in the depths of the consciousness of societies, transmitted from generation to generation and able to consolidate the nation.

## III. THEORETICAL BASIS FOR THE STUDY OF THE CONCEPT OF "CIVILIZATIONAL CODE"

### A. The concept and essence of a civilizational code

The main problem in the study of the civilizational code is that the definition of "civilizational code" has a terminological ambiguity. In addition, the essence of this concept is not understood. Each domestic and foreign scientist gives his own understanding of what he implies under the civilizational code ("tradition," "mentality," "archetype," "core" or "iconic scheme of activity") and based on this, builds its semantic construction of the interpretation of the concept.

In this regard, in this context of the study, we will use the author's concept of "civilizational code." The civilizational code is a set of fundamental patterns (models) of human existence and life activity, in which enshrines basic human life meanings and values, ideas and images, traditions and innovations, norms and rules characterizing the mentality of both individuals, social groups and the population of the country as a whole [1].

The civilizational code has the following features:

1) length in time (historicity). The civilization code has a long centuries-old stage of formation and development;

2) a certain spatial position and stability compared to other socio-historical entities. Political regimes and leaders, political ideology may change, the borders of states may change during national liberation and

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conquest wars, but the code will remain in the memory of the people forever;

3) the presence of specific social institutions as carriers of fundamental values and ideals;

4) a significant influence on the development of culture. The civilizational code and culture are directly dependent and mutually interrelated. For a long time, the terms "civilization" and "culture" were considered completely synonymous;

5) universality (inclusiveness). The scope of the civilizational code is the whole society.

6) sociality - orientation towards inclusion, joining the community. The main purpose of the civilizational code is to unite society into a single whole, to help the people identify themselves civilizationaly;

7) mentality - a civilizational code is fixed on a subconscious level in human consciousness, in the emotional and intellectual component in which values and meanings are accumulated that connect people into groups and are transmitted to new generations;

8) high social significance;

9) ideology expressed in the totality of values, meanings reflected in various spheres of human life;

10) heredity and memory, which reproduces the continuity of social being [1].

The civilizational code also assumes the presence of certain grounds - these are the sources, the supporting parts on which it is formed, developed and maintained. These include: mentality, knowledge of the world, social experience, social expectations, skills, abilities, social structures, traditions, valid values and meanings, culture, standards of behavior, spiritual ideals of the people, identity, historical memory of the people, national ideas, etc. [1].

Mentality is a set of attitudes and perceptions, value orientations, views and assessments, norms of behavior, morality and ethics, and many other factors that characterize a particular group of people. Mentality makes it possible to understand the mindsets of the broad masses, the behavior of various social groups and stratum, nations and ethnic groups.

Historical memory is a constantly developing socio-cultural phenomenon that contains a set of knowledge and beliefs, ideas and opinions, assessments of events and processes of the past. It is very important to maintain the continuity and succession of social being, transferring to future generations the past experience, the accumulated values, behaviors and elements of the national-cultural heritage, all that our ancestors have accumulated and preserved in memory.

The individual's social experience refers to the experience of a person's participation in various types of activities and interpersonal interaction in the performance of a set of social roles that imprint the understanding of life.

Social expectations mean subjective orientations in the form of a combination of social attitudes,

stereotypes of behavior, assessments that are shared by members of a social group or the whole society about events. Social expectations ensure the cognitive, emotional and behavioral readiness of individuals for certain events.

The world of meanings legitimizes the life of a person in society, gives it meaning and order, allows you to more clearly perceive and evaluate the history of the people, connects the past and the present in their collective memory. The meanings of each people include their own values that are not reduced to the values of other peoples. On the basis of common meanings, common values are developed and a common culture is created.

The main component of the civilizational code is the traditional national values, the spiritual ideals of the people, which for thousands of years formed the spiritual, moral, worldview basis of any society.

Functions of the civilization code:

1. theoretical function - promotes the knowledge of sociocultural, political and other phenomena and processes in society, reflects social reality and reveals its inherent objective connections and patterns;

2. the function of socialization means that the civilizational code helps both citizens and the whole society to understand and assimilate existing values, norms and ideals, traditions and innovations, to join them, to absorb experience, to preserve all this and to transfer it to descendants;

3. integrative function consists in the fact that the civilizational code unites socio-cultural communities, forms a single socio-cultural space, contributes to the emergence of a sense of collective "we";

4. the ideological function is that the civilizational code is always a system of socially significant ideas, traditions and norms, which are preserved and transmitted by individuals, social classes, stratum, groups and communities. The most striking expression of this function of the civilizational code is expressed in ideology;

5. constructive function - a system of signs, symbols, means of anthropological and sociocultural nature, human life meanings and values, ideas and traditions, norms and rules that can motivate the action of both individual individuals and social groups, inspire them to actively participate in various socially-public and cultural processes;

6. normative function - contains certain guidelines and norms that guide and develop society, form a general system of values;

7. educational function - the civilizational code will always carry the element of enlightenment, education of citizens, thereby building society and the state on the foundation of the most important national and human values, traditions, innovations, ideas and images;

8. orientation function - helps to navigate society and social space, to adopt the socially positive

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experience of previous generations and to transfer these values, norms and guidelines to other generations, and, therefore, stimulates and guides human behavior, transforms and develops society [2].

#### *B. Identity is the basis for the formation of a civilizational code*

Identity is the basis of group self-consciousness in society, integrates the population of the country and is the key to the stability of the state.

For example, the vector of development of all subjects of social relations determines a collective identity, which is a complex of ideas that form a coordinated, solidarity motivation of individual and group behavior. In turn, social identity is a combination of a person's ideas about his place in society, about values and patterns of behaviors that are approved on the basis of correlating himself with socially significant cultural guidelines and social roles, with social institutions and relationships. Social groups, confessions, ethnos, the state, civilization are the carriers of social identity.

The origins of the study of the identity problem were laid in ancient Greece. It was there that the linguistic-cultural principle of self-identification was formulated: everyone who speaks Greek is Ellin, and someone who speaks a different language and adheres to other customs is a barbarian. Then many centuries later, the French sociologist G. Lebon proposed a slightly different concept of identity. To such features of the self-identification of the nation as the commonality of language, folklore and blood kinship, the scientist added "an unconscious connection of the person with an ethnic group" [3]. Another scholar, M. Barres developed the ideas of G. Lebon about innate ideas inherent in all members of an ethnic group and defined self-identification as a relatively coherent system of ideas and feelings, and a person - the heir to the physical and spiritual qualities of ancestors, which are transmitted from generation to generation in an unchanged form and their reflection can be found in the way of life, customs and traditions.

The scientific study of identity theory began with the work of the famous American psychologist E. Erickson, who defined identity as a sense of the individual's organic belonging to his historical era and the type of interpersonal interaction characteristic of this era. Identity is also a factor in creating material goods and strengthening the cultural heritage of the country, uniting society, ensuring its stability and security, maintaining the values of social justice in society, preserving and genesis of tradition. It is identity that is the ground on which the civilizational code grows, increases and feeds on, is preserved and transmitted to future generations.

Identity is formed on the basis of history and memory, language and culture, uniting all the

accumulated collective experience. This experience can then be embodied in specific social practices, professional activities and civic engagement.

#### *C. Institutionalization of subject-object relations*

The subjects of the civilization code will be individuals, groups, nations, peoples - carriers and transmitters of certain code information. A specific subject will be the state as the main exponent of national interests, the spiritual, intellectual and innovative potential of the country, an instrument for preserving the historical heritage and educating citizenship and patriotism. The state forms the interaction of all agents within the framework of a single stream of socialization, focused on the assimilation of the required values of culture and ideology, and supports proper standards of behavior in society.

Important subjects of the civilizational code are social and ethnic communities, classes and social strata, the family, the army, educational institutions. A particularly important place is occupied by the institution of the family, as a bearer of a generic and family nature. The family conveys from generation to generation spiritual and religious traditions, national values and culture.

The sphere of the civilizational code is all spheres of society, the totality of ideas and images, values and traditions, certain norms that have accumulated in society over a long historical period. Accordingly, the object of the civilizational code will be all clusters constituting the civilizational code, with a combination of all the processes and phenomena that occur within them, values and traditions, experience and behaviors.

Thus, in a narrow understanding, the whole set of relationships and mutually agreed relations arising from the interaction of subjects and objects of the civilizational code can be called code relations.

In a broader sense, code relations are relations between the carriers of civilizational code (state, social communities, groups, classes, family institution, army, education, religion, individuals, etc.), as actors who have historically long-term, in a given territory, fulfilling certain social roles and functions, form ideas, values, customs and traditions, rituals and behaviors in various spheres of their life and objects, which are aimed at a certain mechanism of influence, the main goal of which is the transfer of the civilizational code to future generations [4].

#### *D. Trends and prospects for the development of a civilizational code*

Any scientific cognition is aimed at obtaining new knowledge and is a system of cognitive actions aimed at producing and theoretically systematizing of knowing about a particular existing reality. In the scientific knowledge of any object, it is customary to distinguish its essence and principles, subject-object study of the

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problem, its regularity, a new conceptual and categorical apparatus, as well as certain methods of cognition. According to the analysis of all these requirements, we can argue that the civilizational code can claim a theoretically formalized branch of knowledge.

The material studied in this field, accumulated experience and knowledge can be systematized into a separate discipline "Theory of Civilizational Coding." In the system of categories of civilizational code, the concept of "code" is the source as a kind of cumulative meaning, which contains the basic values, norms, meanings, traditions of the people. The subject of study of this theory are phenomena, processes, relationships, mechanisms, patterns of formation and development of the civilizational code, its main elements and institutions.

A significant contribution to the study of the concept, content, essence and structure of the civilization code was made by the Belarusian scientist Doctor of Sociological Sciences, Professor I.V. Kotlyarov. The author not only explores this problem in his works, but also laid the foundations of the theory of civilizational coding. According to the scientist, the basis of this theory is "the idea of identifying and studying the influence of subjective factors and objective reasons on the formation of the future condition of states and societies, creating a paradigm of their civilizational development, expressing it in the form of a civilizational code, creating images of the future of sociums" [5].

#### ACKNOWLEDGMENT

1. The definition of "civilizational code" formed on the basis of two concepts "civilization" and "code," taken from different fields of scientific knowledge, nevertheless represents one holistic phenomenon.

2. The civilizational code has its own sphere of distribution, it is inclusive and covers the whole society, the totality of processes and phenomena that occur in society.

3. The formation of the theory of civilizational coding implies a deep study of such complex structural components of the civilizational code and its foundations as historical memory, national idea, mentality, historical and national values, stereotypes, ideology, etc.;

4. The civilizational code as a new scientific paradigm includes the presence of a variety of social institutions that are the bearers of fundamental values and ideals in each society. Together, subjects and objects of the civilization code form code relations.

5. In view of the fact that identity is one of the main grounds on which a nation can be consolidated, in the study of the civilizational code it should be given a special place, formed as a separate block for research.

6. When studying the civilization code, it became necessary to introduce a new categorical apparatus and interpret such new definitions as "code socialization process," "code culture," "code relations," "code identity," "code modernization."

7. Further work on the development of the theory of civilizational coding will include a more detailed and itemized study of the methodology of the subject using methods such as: sociological, historical, normative-value, comparative, structural-functional.

8. Scientific knowledge of the concept of the civilizational code gives us every reason to talk about it as a future scientific theory and knowledge paradigm.

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# Hybrid lesson - a reality between two extremes

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**Abstract**— This article aims to analyse the essence, the specifics and the importance of the technical means that are used and applied in a hybrid lesson. Also, the arguments of the implementation of the hybrid model for full and part-time studies. In addition, the briefly analysis of the basic components of hybrid lesson such as, students, the teacher, teaching methods and technical means that are used for.

**Keywords**— *Hybrid lesson, Technical means, Teaching-learning model, Study method*

## I. INTRODUCTION

After nearly two years, we can say that the COVID-19 pandemic has significantly affected many aspects of socio-economic life. It defined the new perception of the reality. We witness the change of social norms in both negatively and positively way, the awareness of the importance of natural human values.

The education system has not remained intangible, it has also undergone transformation. Some levels have been negatively affected, others have been reconfigured and updated.

The pandemic situation forced unconditionally all educational institutions and the teaching staff to test and implement the delivery of educational content in online format. Talking about our community, the teaching-learning online practice has been unexplored. The pandemic has pushed the entire academic community to think about new ways to deliver distance learning and drastically transformed the way we teach, learn and interact with each other. For now, as a result, we can affirm that in a short space of time, the educational reform was forced to take place. Due to the pandemic period, students and teachers had not only to master software, acquire new teaching-learning platforms, but also to get access to computers. All three components, educational institutions, teachers and students have adapted efficiently to the new existing conditions. In this way, different

models, techniques and methodologies of online learning were tested, evaluated and implemented. [1]

Among a large variety of models for organizing online educational process, there is a specific one model, called hybrid, which essentially combines the online with the traditional way of teaching.

## II. HYBRID LESSON. ARGUMENTS

The term hybridity has its roots in Latin and essentially refers to the field of biology, cross-fertilization or the fusion of separate parts or species into a new one. The hybrid is a result of the offspring of two varieties, different species of plant, animal and it is composed of the fusion of existing parts.

In pedagogy, the hybrid model is a teaching method that uses technology to create a variety of learning environments for students. The hybrid model is a combination of traditional personal training with digital distance learning; is a type of blended learning that refers to the implementation of synchronous lessons that are taught simultaneously on site and online.

The hybrid method consists of a complex interaction of four components: technology, pedagogy focused on new methods and techniques, interactive teaching-learning and between teacher and student. These components describe the following interactions: teacher-student, student-student, student-context, the space that is online and offline and finally the technological component that links their interaction.

Hybrid pedagogy not only describes an easy mix of on-site and online learning, but refers to bringing the types of learning that happen in a physical place and the types of learning that happen in a virtual place into a more engaging conversation and dynamics. [2]

It is clear that in a hybrid class, face-to-face activities are often combined with technology-mediated activities. Teachers and educational institutions that use intentionally



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the hybrid method try to incorporate technological means and tools in order to improve and expand making it more interactive and accessible delivery of the teaching content but also, to improve students learning, respond to their interests and learning preferences. In previous work on hybrid education and hybrid learning highlighted a change in the structure of education just as in teaching and learning towards connectivity, networks and collaborations. [3-6]

Hybrid learning environments are similar to traditional classrooms in that they both include the presence of teachers and students, and some research on distance education has found that technology-supported distance learning is at least as effective as traditional distance learning in classrooms and has led to more effective instruction.

In order to ensure the delivery of the content, the achievement of the proposed objectives, the assurance of the interactivity of the teaching-learning activity, the tasks and assessments in the classroom and outside the classroom, it is necessary to plan in details the whole course before its launch. It is clear that a hybrid lesson requires changes in institutional practices, the arrangement of educational spaces and the assessment of new ways of learning and teaching methods.

Arguments. The straightforward benefits that a hybrid lesson can provide for students and teachers are the release from the constraints of place and time. Within the Faculty of Computers, Informatics and Microelectronics, a survey was conducted among the part time students. To one of the questions: "Which of the following options do you think is the best regarding the student-university interaction during a pandemic?" their answer is the following, out of the whole University, 67% preferred the online form and 25% offline one. The students of this faculty not always can be physically present when teaching activities are carried out, some of them are at work, others abroad, some have chronic illnesses and are not allowed to social exposure, or in situations of natural disasters, etc. Following the discussions with the full-time students of this faculty, some of them, year I or II were determined to continue distance learning, i.e. some students for various reasons, predispositions were not happy and are not willing to give up the traditional way learning while third and fourth year students on the contrary, were prone to conduct online studies.

In both cases, it appears that some students may be potentially excluded from the traditional teaching process. For this reason, we can consider that a solution would be to adopt the hybrid learning method.

Being constrained by the created pandemic situation, but also by the wish to try the new type of lesson with the launch of the program - UTeach 2021, within Tekwill Ambassador we take the challenge to achieve the study, teaching activities (lecture, seminars, laboratory ) and the curricular analysis in order to carry out hybrid lessons and

to integrate the Year I full time and part students, also, to include students with disabilities and at last but not least to test the teaching methods and techniques for a possible application to FCIM on distance learning. In addition, to analyse the effectiveness of teaching methods and techniques applied during the lesson, from "Digital Approach project of mixed teaching activities" which provides two components: planning and testing on the specific subject "Communication and Academic Writing" and for "Discrete Mathematics". These are two distinct areas both in terms of content and methods used.

Of course, the transition to an audience during hybrid lesson requires a shift from teacher-oriented methods and techniques to students-centered (online) where they are given autonomy and independence in learning. Again, the situation with COVID 19 leaves its stamp on the strategy of the ongoing lesson, although the purpose of this project is to take advantage of the situation to ensure and achieve the synchronous integration of students who for various reasons, cannot be present physically in classrooms.

### III. TECHNICAL MEANS

Technology must be seen in a hybrid lesson as a way to improve teaching-learning for all types of lessons. Technology has the potential to create dynamic learning environments that connect students to the real world, making learning more interactive and more effective. During these lessons, technologies play an important role, for those online they ensure connection and inclusion, for those offline it highlights the presence and perception. We can consider that many traditional teaching methods are effective for hybrid learning if there is the right technology. Online students can use the wireless microphone and the teacher will connect the computer to the speaker, so that the dialogue takes place between them. Thanks to a teleconferencing system, students can see the teacher and colleagues online, students offline, they can see colleagues through a TV placed on the wall or mobile stand. The new audio systems allow discussions with a clear sound, the teacher acquires unconditional mobility, he can move freely. Sure, a 360-degree room would fit in, covering the entire classroom; are sensitive microphones and speakers that would exclude echoes and other disturbances, noises, there would be a mobile TV, an interactive whiteboard and projector, each student would have a laptop connected to the wi-fi network.

Any additional equipment (microphones, cameras, secondary devices, etc.) are simply extensions of this basic model described above and serve to make audio and video better for online students. To use the equipment effectively, teachers should learn how to program the equipment and operate it during lessons.

Online lessons are expressed through the teaching-learning experiences that teachers design. We keep in mind that technology does not involve students only, they have an additional impact, however teachers are who do it.



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The technical means are essential, but we find that they are not sufficient. We bear in mind, that each component such as students, teachers and the used teaching methods should not be excluded from the process of carrying out such a type of lesson.

Obviously, the target of achieving the teaching objectives is the student. We can see that in essence the student's person is doubled (online and in the classroom). We must always keep in mind that the online student must not feel isolated, we can easily lose him or he can exclude himself. It follows that he must whenever possible to be included in direct contact, communicate and interact interpersonally with his colleagues and the teacher. To accomplish this, the teacher must use specific teaching methods and techniques. An active student will depend on the following components that can contribute in organizing a successful development of a hybrid lesson - the number of students engaged in the audience, social and psycho-physiological characteristics, student moral maturity and responsibility, level of training, knowledge and culture gained, skills and abilities possessed and of course motivation. We need to train our perception of responsibility. It serves as an orientation compass through which the student assumes the observance of the duties, of some internal norms and after the fulfillment, the observation of which is effectively included during the study process.

The student must be trained to use the real cases of use of the achieved knowledge. He must learn immediately and consistently.

Students must be involved in solving real cases in social-professional life, they should be introduced into social interaction, creating a space and an atmosphere in which their new knowledge are discussed, evaluated and applied into practice. For some students, the hybrid method makes studies less expensive. International students can be exempted from paying tuition fees, visas and tickets, rent and consumption, etc.

The teachers must move from the role of instructor and sole provider of teaching materials to that of co-participant with students, to adapt their techniques, methods, professional skills in the teaching process in order to help students to develop their skills, abilities, knowledge and the mentality to achieve a social and professional success. Teachers seriously need to prepare the lectures or seminars. They must provide students with individual tasks and projects. They do not have to be quantitative, but qualitative. The lesson must unfold like a movie script, everyone is in action, the sequences are changing. Methods used in a hybrid lesson. Taking into account the above, the methodological arsenal of the teacher must be diversified, to include tasks and involve both the student and the group, to be in line with the topic objectives, to facilitate interactions, to ensure student evaluation, etc.

The case study method allows a discussion between students on the topic suggested topic by the teacher or student. The teacher is perceived as the leader of the discussion developing critical thinking in students. Game-based learning develops social thinking, competitiveness, cooperation and critical thinking during the game. Role model teaching involves demonstrating the solution of a task by dividing it into small sequences. The 7-minute presentation involves students making a speech on a topic prepared in advance or a topic proposed during the lesson. The student has 7 minutes to demonstrate oratorical skills, persuasiveness, arguments, demonstration of a mental and emotional state, etc. Online students can easily make presentations on a chosen topic. Fishbowl as a method involves dividing the audience into two corresponding groups online and offline, where one group is granted participant status to the other observer status with limited rights of intervention. A topic is proposed that is lively discussed by a subgroup. The other listens carefully, after the analysis and group discussions take place. Project-based learning is an excellent technique for a hybrid lesson. Students are given the opportunity to participate in a TV news show. We can use two subgroups, one online and one offline. In time, each student in a subgroup prepares a topic for news, another presents the sports section, and respectively the other political news, weather, economic news, one being a presenter, etc. In the end, each subgroup presents its news, the others are spectators. Brainstorming, Detective, me against myself and many other techniques can be used skillfully in a hybrid class.

#### IV. THE HYBRID TEACHING-LEARNING MODEL HAS ITS ADVANTAGES AND DISADVANTAGES

One of the most beneficial components of the hybrid lesson is their alignment with differentiated instructional models that offer personalized learning activities for various groups of students - with disabilities, abroad, mobile difficulty or attending classes, etc. Each student can choose the environment and comfortable place, they can participate in synchronous and asynchronous learning activities. While planning teaching activities, the teacher take into account students' learning preferences. Another positive factor is that students could record lectures online, they can review some of the course content as often as necessary for a better understanding. The classroom of a hybrid lesson through technological arrangement, offer a transition step for testing new teaching tools, methods and pedagogical techniques. Subsequently, their impact on student learning can be estimated. Taking into account the university autonomy that is represented as an economic entity, the costs are reduced by the increased maintenance of infrastructure, staff, services, etc. can be found as a benefit. The teacher can use the asynchronous assessment method as a virtual environment in a live environment. Strengthening

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integration, cohesion, co-participation and the competitive spirit in the audience. The hybrid learning method offers more freedom for recreation, independence, through which online are creating for students the feeling of distance or estrangement. For online students, the hybrid lesson saves time, money, etc. The hybrid teaching model could serve as an effective strategy for the partial reopening of educational institutions.

The disadvantages of a hybrid lesson could be the lack of skills among teachers regarding the use of modern technologies, the other way, the same, the lack of skills within students regarding the use of modern technologies. Physical overwork is another disadvantage that occurs from the time spent in front of the computer. Investments in hybrid learning are essential for institutions, arranging hybrid learning spaces is expensive. Teaching methods and strategies for a classical lesson may not always be effective for online teaching - learning. During the online lesson, there may be a tendency not to comply with educational standards.

In order to avoid the potential disadvantages of the hybrid model, the following recommendations must be taken into account: in order to follow where students have deficiencies in the assimilation of the material, we must use technology; we design the lesson plan, they must be structured and include interactive teaching methods, provide as needed the course material and the seminar material; the teacher must take the position of mentor and come in to help students; give students a clear vision of what to do and what is expected of them, do not come directive, rather be a support in the assimilation of knowledge; design asynchronous activities with the academic group or a subgroup of it; test the technical means before the start of the lessons, in case of technical problems, or temporary lack of electricity, transfer the subgroup online in solving tasks asynchronously; collect information through questionnaires from students about the teaching process and in particular about the methods and techniques used; ask students to have the room lit, it gives a sense of direct presence; the hybrid method of the lesson, as well as the others caused by the pandemic is a new one for our teachers so we cannot exclude various types of challenges or mistakes, test the technique and capitalize on its potential, apply for new teaching methods, software and educational platforms; engage students in their learning, they must be autocratic, they are not visionaries, they must be involved in the choice of content, interaction; build a strong culture and a strong and cooperative academic community by avoiding the

syntagma “we- they” and replacing it by the new one “we”.

## V. CONCLUSIONS

In the traditional situation, the hybrid lesson is an efficient way to carry out teaching activities during the pandemic period. The hybrid lesson gives the opportunity to adapt and combine elements of different models (online and mixed) to find something that works best for your own unique set of circumstances - technology support, the specific of the subject, etc. For part-time education this method is a necessity, it gives the sense of individual maturity and the possibility of flexibility and also, of the assumed freedoms.

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# The specific of IT Recruitment and what is the biggest challenge for an IT Recruiter

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**ABSTRACT** - Recruitment includes the process of sourcing, attracting, interviewing, selecting, hiring and onboarding employees. In other words, it involves everything from the identification of a staffing need to filling it. Finding good, loyal employees is hard. IT Recruitment puts emphasize more on sourcing. It assumes that IT companies need to find their candidates, not just waiting for applicants. Because in IT industry the jobs are looking for candidates, not viceversa. So, the purpose of this topic is to explain why IT Recruitment is so different from other industries and what is the biggest challenge for an IT Recruiter, nowadays.

**Keywords** – Recruitment, IT industry, human resources, HR departments

## I. INTRODUCTION

The performance of a company is influenced, directly, by the quality of the work force involved in its activity. With the rapid expansion of field with a major importance, such as mobile application development, online marketing and programming, finding the best specialists has become increasingly difficult.

Recruitment is an important part of an organization's human resource planning and their competitive strength. Competent human resources at the right positions in the organization are a vital resource and can be a core competency or a strategic advantage for it. The objective of the recruitment process is to obtain the number and quality of employees that can be selected in order to help the organization to achieve its goals and objectives. With the same objective, recruitment helps to

create a pool of prospective employees for the organization so that the management can select the right candidate for the right job from this pool. Recruitment acts as a link between the employers and the job seekers and ensures the placement of right candidate at the right place at the right time. Using and following the right recruitment processes can facilitate the selection of the best candidates for the organization. Thus, according to Edwin B. Flippo, recruitment is the process of searching the candidates for employment and stimulating them to apply for jobs in the organization”

Its very important for a company to have enough specialists, in order to ensure the quality and continuity of work. Recruiting process is the one allow the creation of a database with potential candidates from which the ones that best meet the requirements of the vacancies will be selected. If not now, then after a year, or two.

Today, technology is becoming very important in business. It affects the individuals, communities, and businesses. Information technology or IT refer to an entire industry. No matter small or big business, IT has helped the organization, manager, and workers in a more efficient management for improving their productivity and output.

With hundreds of companies in information technology receiving massive investments every year, investments are piling up; hence, there is supposed to be a higher number of IT workers joining the IT industry workforce.

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To maintain such a process, IT companies need IT Recruiters. Who they are and what they are doing different from other industries?

Recruiters are the driving force behind the process of recruitment through technical skills assessment. A process that can be deemed successful only if it is able to provide '*qualified candidates*' as per the requirement. Incidentally, it is also one of the key metrics of recruiters to measure their performance.

IT Recruiters are responsible for the process of identifying, attracting, interviewing, selecting, hiring and onboarding employees. In other words, it involves everything from the identification of a staffing need to filling it.

At first view seems that is nothing different. But there are some challenges. Under this circumstance, the HR department faces some of the biggest challenges in IT recruitment to nurture, recruit and retain talents.

The major problem in finding qualified talents is the technical and professional knowledge over the field, and the minor ones are requisite soft skills, experience and formal education.

Successful recruitment validates every business. By adopting a hiring process that is time and cost-effective, companies can find qualified and suitable candidates by letting away the recruitment challenges. While these challenges are only a snapshot of a few barriers to mitigate in 2021, finding a creative strategy to tackle these obstacles may be a secret sauce in reaching the recruiters' goals.

## II. THE MAJOR PROBLEMS FACED IN IT RECRUITMENT PROCESS

Ramping back up after an economic recession affects every aspect of work, and filling post-recession gaps in employment comes with its own set of recruiting challenges. The current pandemic-driven economic downturn has produced unique new recruitment challenges — and magnified existing ones.

Technology continues to play a critical role in recruiting, and that role is rapidly expanding as more companies move recruiting processes online. Even recruiters who have never used technology now rely on it for their daily functioning. Candidate-facing technology, such as video interviewing software, expands your candidate pool to include remote or out-of-state candidates, while technology use on the back end helps recruiters optimize their function.

IT crises are not necessarily caused from the outside, but from within the industry, more precisely from the unbalanced mechanisms of supply and demand. Too much demand for specialists, too low supply.

From this imbalance are born new needs, competition, wage inflation. Also from this imbalance arises the need for IT companies to differentiate themselves in the race to

find and attract talent, thus developing an effective staff insurance policy.

Today, the selection of the resource is an activity based on the management of human resources, it is more resilient than a basic, intuitive. The recruitment process of an IT company depends on external and internal factors, which must be taken into account when calculating the need to fill certain positions. [1]

The recruitment of competent persons is a rather important task of human resources management, and the recruitment process itself must be constantly adjusted to the changes that occur in society.

The problem of hiring is present in each and every industry, but when it comes to the IT market, this has shown a whole new level of difficulty, with the most recognizable one is to find qualified candidates.

The IT industry is booming with its implementation in many aspects of our daily lives, leading to the unprecedented requirement for IT job openings to be filled.

IT recruiters, believe that the IT specialist on the Moldovan market rarely applies for a job, there could be 2 candidates in a month. In this case, recruiters must make a supply. This process involves identifying and attracting potential candidates. A source creates interest and pursues passive candidates.

Before an IT recruiter can master the offer, he or she must first master the basics. In fact, Boolean searches allow you to combine words and phrases using the words AND, OR, NOT (known as Boolean operators) to limit, broaden, or define your search. A good researcher should know how to do a Boolean Search, and we could use it for LinkedIn sourcing, as well.

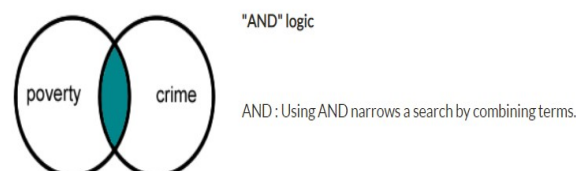


Figure 1. Operator AND.

For example, if we are looking for a designer who has experience with Blender and is from Chisinau, the basic string could look like this: Example: Designer AND Blender AND Chisinau. Therefore, an AND operator tells the database/search that ALL search terms must be present in the resulting records. (Google will look for all conditions to be met before returning any results.)

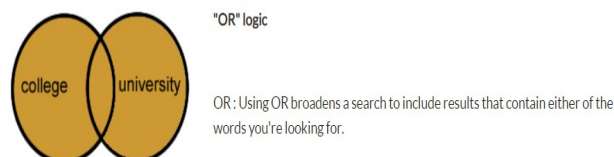


Figure 2. Operator OR.



<https://doi.org/10.52326/ic-ecco.2021/KS.08>



Using OR will help us broaden a search to include results that contain either of the words we type. It is also a good idea to use OR when there are several common spellings or synonyms of a word. [4]

Example: Designer OR Artist

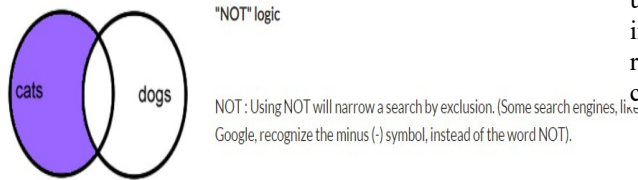


Figure 3. Operator NOT.

Using NOT will narrow a search by excluding certain search items. Example: UX/UI AND Designer NOT Artist [3]

Instead of LinkedIn, we could find good IT potential candidates on GitLab and StackOverflow.

GitLab is a web-based DevOps life-cycle tool that features a Git-repository manager that provides Wiki, issue-tracking, and more. Creating an X-Ray search string is easy. We can just use the **site:** operator, add the keyword, and end it by removing the nonvalid site. In case if we are looking for a Java Developer, we can use next example:

`gitlab.com Java -inurl: (docs|forum)`

However, this will give us all pages where those keyword are mentioned. Targeting the profile page is quite easy in this case because all profile pages have a "Member since" mention of them.

Stack Overflow. Is a Q&A site, and based on their statistics a developer asks a question on this site every eight second or so. Stack Overflow is an interesting place for sourcers because many developers visit this site daily, unlike LinkedIn.

An IT Recruiter can easily check the programmer's Stack Overflow reputation and learn more about their knowledge. Every profile on Stack Overflow includes information as: technologies that the developer is currently working, interesters, projects & references, etc.

The biggest challenge for IT Recruiters is that they can no longer search by the classical method. They need to explore special forums and platforms. Where upon, they must maintain a technical discussion and attract candidates with the possibility to test new technologies. [2]

### III. THE MOST COMMON INTERVIEWS FOR AN IT COMPANY

The classic method of interviewing, as a query, no longer works. You can be sure that candidates may refuse to come to the interview or, in general, refuse to participate in the next stages of the whole process.

The candidates prefer a personalized and individual approach. This means a very friendly discussion about the company opportunities such as benefits, career and salary growth. After that the candidate, for sure, will be open to share his experience. It means project experience, complexity of tasks, stack of technologies that he has used previously. Usually, HR department has to adapt interview questions to this precise industry. We recommend using the following types of interviews that currently work with developers and IT.

#### A. Case interview

During a case interview, the interviewer asks you to analyze and solve a challenging business situation. Many of the cases they present are based on real-life situations, often having occurred at the company. Technology industry may use a case interview to see how you problem solve in situations that you may experience at work. During a case study, thoroughly read all the instructions they give you to ensure you can correctly solve the case.

#### B. Unstructured interview

An unstructured interview is when the questions an interviewer asks you change based on your responses. They may have a few questions prepared ahead of time but then think of more questions during the interview. This kind of interview tends to be more fluid and casual. Though this may seem less intimidating than a traditional interview, still treat it seriously and remain professional.

Since there are no guidelines for these interviews, a researcher is expected to keep their approach in check so that the respondents do not sway away from the main research motive. For a researcher to obtain the desired outcome, he/she must keep the following factors in mind:

- Intent of the interview.
- The interview should primarily take into consideration the participant's interest and skills.
- All the conversations should be conducted within permissible limits of research and the researcher should try and stick by these limits.
- The skills and knowledge of the researcher should match the purpose of the interview.
- Researchers should understand the do's and don'ts of unstructured interviews.

Advantages of Unstructured Interviews:

- Due to the informal nature of unstructured interviews – it becomes extremely easy for researchers to try and develop a friendly rapport with the participants. This leads to gaining insights in extreme detail without much conscious effort.
- The participants can clarify all their doubts about the questions and the researcher can take each opportunity to explain his/her intention for better answers.

<https://doi.org/10.52326/ic-ecco.2021/KS.08>



- There are no questions which the researcher has to abide by and this usually increases the flexibility of the entire research process.

Disadvantages of Unstructured Interviews:

- As there is no structure to the interview process, researchers take time to execute these interviews.
- The absence of a standardized set of questions and guidelines indicates that the reliability of unstructured interviews is questionable.
- In many cases, the ethics involved in these interviews are considered borderline upsetting.

### C. Behavioral-Based Interview.

Known as Critical Behavioral Interviewing (CBI), the theory is that past performance in a similar situation is the best predictor of future performance. This method of interview probes much deeper than the usual interviewing techniques. Have specific examples ready that highlight your attributes in core areas such as teamwork, problem-solving, communication, creativity, flexibility and organisational skills. However, be structured in your answers and explain your examples in terms of the situation, the task, the action you took, and the outcome achieved. [5]

After the interviews, it is important for all participants to receive a feedback or follow-up, even if the final answer is no. This helps both, the candidate and the organization, and opens the door to further collaboration, as I mentioned about consulting their own databases.

## IV. CONCLUSION:

In the case of the IT industry, the role of human resources department, especially the talent recruitment division, has gradually gained its credit, under the circumstance of talent shortage in recent years.

As far as we are concerned, recruitment is an important process for which it is necessary to pay close attention to details. To put it another way, underestimating one of the factors, will influence the quality of the recruitment process. But in this case, the company may incur additional costs over the time.

No matter what type of interview we will do, or how we will organize it. The most important factor is to adapt the interview to the company processes and requirements. The tools of the interviewer are his questions. They should be used with dispatch and yet with the utmost care. Sarcasm or obscure humor should be avoided unless the interviewer is positive that the interviewee perceives them as such. Usually, the latter's interpretation of such activity is entirely serious; he or she may respond at the time with a semblance of perceived humor, but the real reaction is often deep concern and suspicion. In the same time we need to do this very delicate manner, friendly, and not as an interrogatorium as I mentioned previously.

Through the judicious use of questions, the skilled interviewer not only obtains information but also guides the talk along productive lines. Leading questions or questions designed with built-in responses are usually not very effective. Similarly, the double negative type of interrogation is to be shunned as it tends to evoke anxiety. To avoid slipping into such traps, even the best interviewer should review his questioning techniques from time to time.

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