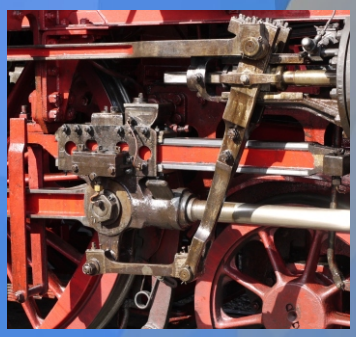
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C O N T E N T S

TECHNOLOGICAL BASIS OF "INDUSTRY 4.0"

Basic use of OpenWeatherMap for an IoT system with Sigfox
Takeshi Tanaka, Satoru Tada, Masayuki Yamauchi, Koji Kakugawa, and Katia Vutova 1

Application of biologically inspired engineering as industry 5.0 tool to create a good organisational structure
Ismar Alagić 5

DOMINANT TECHNOLOGIES IN "INDUSTRY 4.0"

Binary logistic regression for defect-free electron beam welding
Elena Koleva, Asya Asenova-Robinzonova 9

Application of the mathematical model of Johnson-Kendall-Roberts in the study of the Young's modulus of erythrocytes in patients with type 2 diabetes mellitus
Anika Alexandrova, *Maria Kyulavska*, Nadia Antonova, Irena Velcheva, Elissaveta Zvetkova 12

Self-cleaning coatings of oxides transition elements (including - TiO2) on a photovoltaic covering glass
Stancho Yordanov, Mihaela Aleksandrova, Vladimir Petkov, Marieta Gacheva, Bojidar Jivov, Lyuben Lakov 19

Determining normalized friction torque of an industrial robotic manipulator using the symbolic regression method
Baressi Šegota Sandi, Mrzljak Vedran, Prpić-Oršić Jasna, Zlatan Car 21

SOCIETY & "INDUSTRY 4.0"

Perspectives of digitization of primary health care services
Turkan Ahmadova 25

Public Procurement as a Demand-Side Policy Instrument
Miglena Pavlova, Kristina Vasileva 28

Analysis of Public Sentiments and Emotions in the Government Domain
Gloria Hristova, Nikolay Netov 32

Basic use of OpenWeatherMap for an IoT system with Sigfox

Takeshi Tanaka[1], Satoru Tada[1], Masayuki Yamauchi[1], Koji Kakugawa[1], and Katia Vutova[2]

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Abstract: *Using the Sigfox network, one of LPWA (Low Power Wide Area), and the Internet, we developed a temperature, humidity, pressure, and Internet of Things devices with different sensors to measure various physical data. It is much simpler to work with weather data when using OpenWeatherMap's widely recognizable weather products. In this study, OpenWeatherMap's meteorological data were captured every 15 minutes using are Sigfox communication, which is one of LPWA. These data were transferred to ThingSpeak using MATLAB analysis and time control of ThingSpeak.*

Keywords: *OPENWEATHERMAP, INTERNET OF THINGS, SIGFOX, MATLAB/SIMULINK, THINGSPEAK, LPWA (LOW POWER WIDE AREA)*

1. Introduction

Knowledge and information have not yet been exchanged in the information society (Society 4.0), and issues resulting from a lack of inter-disciplinary cooperation have arisen.

Society realized that Society 5.0 would involve all people and things being connected by the Internet of Things (IoT), allowing the sharing of various knowledge and information.

Against this background, using the Sigfox network and the Internet, we developed Internet-of-Things devices equipped with temperature, humidity, barometric pressure, and different sensors to measure different physical data [1-5].

OpenWeatherMap is providing highly recognizable weather products that make working with weather data easier. OpenWeatherMap works with millions of developers around a clock and believes that these benefits might be suitable for most applications, up to the complex enterprise systems. 1) A spectrum of ready-to-use weather products 2)Short-term and long-term forecasts, history, and observation 3) Any location on the globe 4) Transparent pricing and licensing.

In this study, OpenWeatherMap's meteorological data were captured every 15 minutes using Sigfox communication, which is one of LPWA. The MATLAB analysis and time control of ThingSpeak were used to transport these data to the platform.

2. OpenWeatherMap [6]

2.1. Weather data in a fast and easy-to-use way

We offer widely recognized weather solutions that significantly simplify working with weather data. We collaborate with millions of developers around a clock and believe that these benefits might be appropriate for most applications, up to the complex enterprise systems.

- A spectrum of ready-to-use weather products
- Short-term and long-term forecasts, history, and observation
- Any location on the globe
- Transparent pricing and licensing

2.2. Weather API

Please, sign up to use our fast and easy-to-work weather APIs. We advise using our One Call API 3.0 as a starting point for using OpenWeather products. Please have a look at our items, which are part of professional collections, for greater functionality.

2.3. Case of Hatsukaichi, JP

We accessed the home page of OpenWeatherMap and obtained the weather data of Hatsukaichi City, and the results are depicted in Fig.1-3.

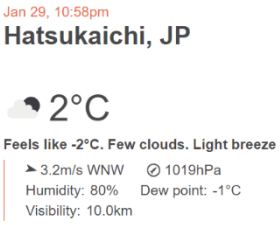


Fig. 1 *Hatsukaichi city weather data (temperature, humidity, air pressure, wind speed, etc.).*

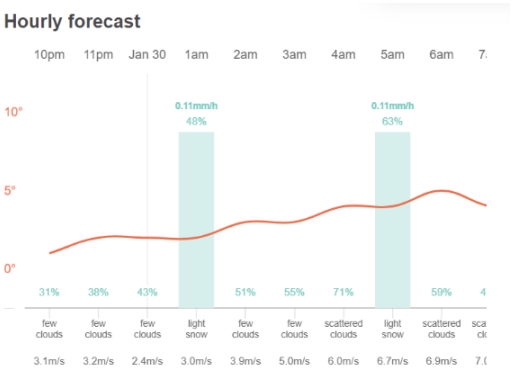


Fig. 2 *Hourly weather forecast for Hatsukaichi (temperature, humidity, cloud conditions, etc.).*

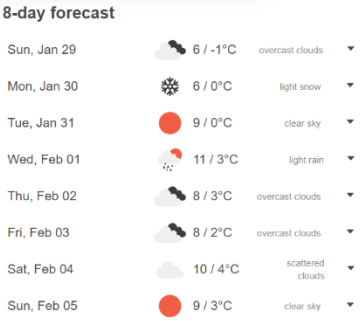


Fig. 3 *Eight-day weather forecast for Hatsukaichi City (temperature, humidity, cloud conditions, etc.).*

Next, the weather data obtained in json type using the weather API (reference 2.B Weather API) is shown below.

{"coord":{"lon":132.3333,"lat":34.35},"weather":[{"id":801,"main":"Clouds","description":"few clouds","icon":"02n"}],"base":"stations","main":{"temp":275.12,"feels_like":271.87,"temp_min":275.12,"temp_max":275.12,"pressure":1019,"humidity":80,"sea_level":1019,"grnd_level":1019},"visibility":10000,"wind":{"speed":3.18,"deg":284,"gust":7.09},"clouds":{"all":21},"dt":1675001453,"sys":{"type":1,"id":8029,"country":"JP","sunrise":1674943852,"sunset":1674981373},"timezone":32400,"id":1863018,"name":"Hatsukaichi","cod":200}

3. MATLAB/Simulink and ThingSpeak

ThingSpeak (see Fig. 4) is an IoT analytics platform service that allows you to aggregate, visualize and analyze live data streams in the cloud. Data sent by your devices to ThingSpeak is instantly visualized by ThingSpeak. With the ability to execute MATLAB code in ThingSpeak, you can perform online analysis and processing of the data as it comes in. IoT systems that need analytics are frequently prototyped as proof of concept using ThingSpeak[7].

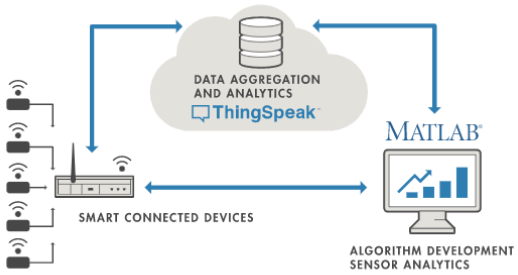


Fig. 4 *Overview of IoT devices, ThingSpeak, and MATLAB [7].*

The channel setting of ThingSpeak at the time of data transfer is shown in Fig. 5.

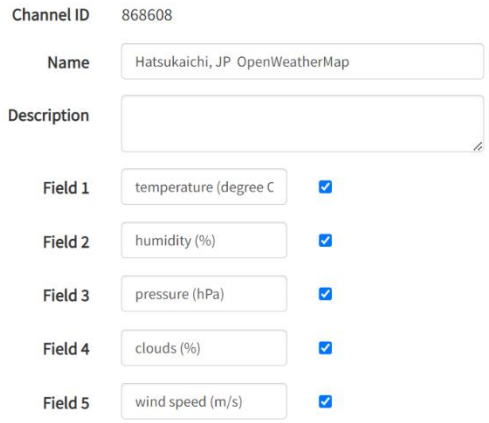


Fig. 5 *Channel setting of ThingSpeak.*

3.1. MATLAB Analysis App [8]

Explore data collected in a channel or scraped from a website

- Find and remove bad data
- Convert data to different units
- Calculate new data
- Build data models

You can incorporate features from any of the licensed MATLAB Toolboxes offered by ThingSpeak in your analysis code (see Fig. 6). You can publish data after analysis to share your findings with others.

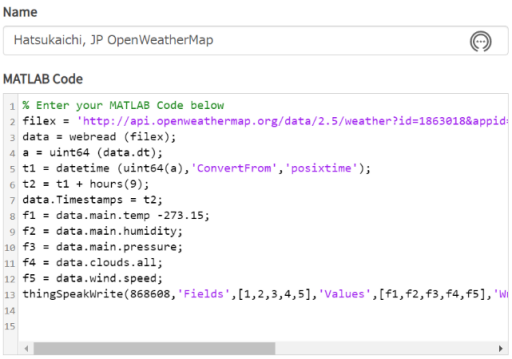


Fig. 6 *MATLAB Analysis of ThingSpeak.*

3.2. Time Control[9]

TimeControl works with other ThingSpeak apps to act at a specific time or on a regular schedule. You can use TimeControl with:

- ThingHTTP to communicate with devices, websites, or web services
- ThingTweet to send alerts via Twitter®
- TalkBack to queue up commands for a device

For instance, you can make a ThingHTTP request that calls someone through Twilio®, controls a device, or connects to a thermostat that accepts HTTP requests.

Next, the time to operate MATLAB analysis was controlled using TimeControl (see Fig. 7). Since the Sigfox data transfer interval is 15 minutes, 15 minutes is chosen as the repetition time for doing MATLAB analysis using TimeControl.

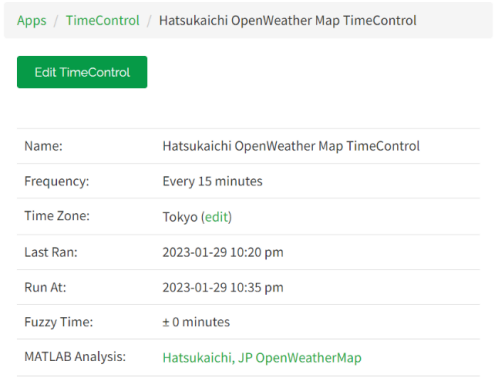


Fig. 7 An *example of setting the Time Control of ThingSpeak.*

4. Graph OpenWeatherMap data using MATLAB/Simulink and ThingSpeak

The data in json format collected from the OpenWeatherMap homepage using the API was used to graph the weather data using Thingspeak's MATLAB analysis and time control.

As examples of meteorological data, temperature data is illustrated in Fig. 8, humidity data in Fig. 9, atmospheric pressure data in Fig. 10, cloud ratio in Fig. 11, and wind speed in Fig.12.

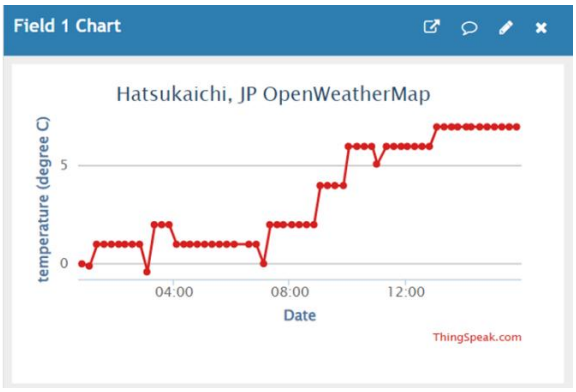


Fig. 8 *Temperature in Hatsukaichi.*

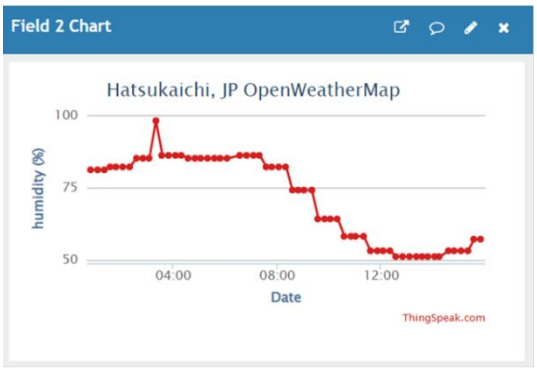


Fig. 9 *Humidity in Hatsukaichi.*

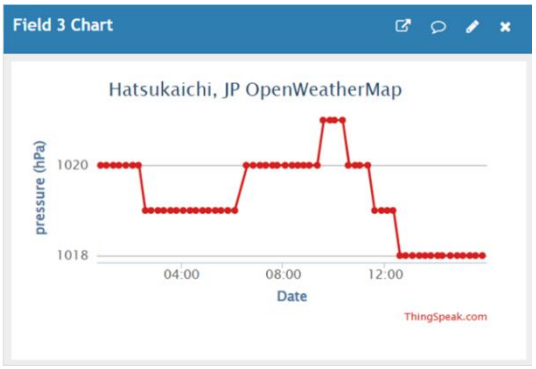


Fig. 10 *Pressure in Hatsukaichi.*

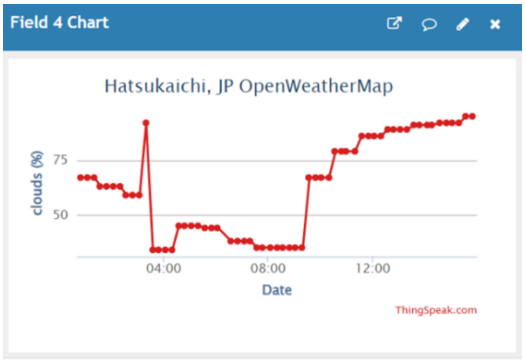


Fig. 11 *Clouds (%) in Hatsukaichi.*

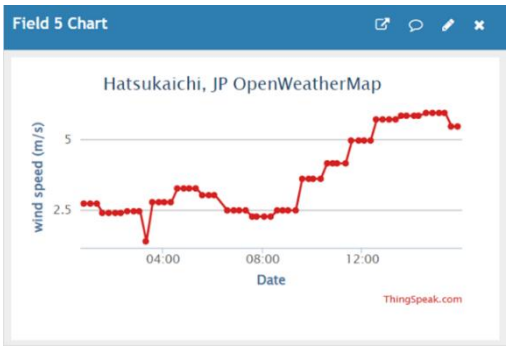


Fig. 12 *Wind speed (m/s) in Hatsukaichi.*

5. Summary

Using the Sigfox network, one of low power wide area, and the Internet, we developed temperature, humidity, pressure, and IoT devices with various sensors to measure different physical data. Highly identifiable weather products from OpenWeatherMap make it much simpler to work with weather data.

OpenWeatherMap's meteorological data in json format obtained from the OpenWeatherMap homepage using the API was used to graph the weather data utilizing Thingspeak's MATLAB analysis and time control.

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We would like to thank Enago (www.enago.jp) for the English language review, and Altner Co., Ltd., who provided us with some of the IoT devices used in this research.

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8) https://thingspeak.com/apps/matlab_analyses (accessed Jan. 29, 2023)

9) https://thingspeak.com/apps/timecontrols (accessed Jan. 29, 2023)

Application of biologically inspired engineering as industry 5.0 tool to create a good organisational structure

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Abstract: *In this article, it will present you how a bionics technique as technical solutions of Industry 5.0 from nature leads managers to creation a good organisational structure. Industry 5.0 penetrates into the very essence of human existence and the relationship to machines and automated processes. It is not possible to consider the new industrial revolution without mentioning the more recent scientific discipline called "bionics". What is bionics? "Bionics would be a return to nature with the aim of finding solutions to technical problems. The development of bionics is the key concepts of Industry 5.0 [1].*

Bionics is a tool for solving problems in the conceptual and applied phases of design. The goal of bionics is to use biological inspiration in designing organisational structure that mimic the behaviour of living organisms. There are many characteristics that can identify a bionic mechanism. One of the abilities is to work independently in complex environments, can adapt to unplanned and unpredictable changes and perform multi-functional tasks. In every organization, it is most important to know who has the highest authority. Nature offers examples of organizations of other living beings that are effective and work without control, without leaders, without instructions, yet everyone in this organization knows what to do. In this article, the efficiency and working efficiency of insects such as ants in order to create a good organisational structure has been studied.

KEYWORDS: BIONICS, INDUSTRY 5.0, LEADERSHIP, ORGANISATION, COMMUNICATION, COLLECTIVE INTELIGENCE.

1. Introduction

The concept of industry 4.0 is intended for a "smart factory" in which all processes are automated, from communications to production processes, with the aim of achieving maximum effects expressed in money. Industry 5.0, on the other hand, is focused on the interaction between people and machines. This joint work of humans and robots combines human creativity and skill with the speed, productivity and precision of robots in order to create new commercial and social values. Industry 5.0 is more humane, returning the "human touch" or people to production. This work concept is suitable primarily for small and medium-sized enterprises where full automation is not possible or not profitable, and market demand is increasingly looking for products tailored to the needs of customers [1].

Many people will agree with the fact that human civilization has reached a kind of technical-technological peak in its development. There is little left that has not yet been invented. However, every day we are faced with some eternal questions and dilemmas that can be answered by scientific materialism or a holistic approach. We often return to the question "how was the universe created"? On the one hand, we have the dogmatic religious teaching that this is the result of divine power, and on the other hand, we come across scientific interpretations that seek their source in the determinants of quantum physics, Newton's law of gravity and Einstein's theory of relativity. In the context of quantum physics, we can assert that the very basis of life at the level of the deepest reality is governed by the laws of subjectivity, omnipresence and non-causality. Newton's law of gravitation and Einstein's theory of relativity are the result of intuition and only after that follows Cartesian science, which puts materialism, objectivity and causality in the foreground. A complete answer to the question requires a comprehensive micro and macro observation of the cosmos, with the note that the most important human trait is intuition. How did it all begin and how was our planet formed?

Let's look at the following mathematical interpretations [1]:

$E=m \times c^2$ ...(1)

$m=E/c^2$ ...(2)

$1kg=(300.000.000\ J)^2/(300.00.000\ m/s)^2 =1$ ...(3)

The following mathematical-physical interpretation follows from the above-mentioned equations [1,2]:

- For 1 kg of mass it is necessary 9×10^{16} J;
- The production of all forms of energy in 2021 in the world amounted to 20.848,34 kWh;
- For the creation of our planet it was necessary: $2,5 \times 10^9$ kWh x $5,9 \times 10^{24}$ kg;
-The mass of the universe amounts to 10^{54} kg;
-Only 4% of the entire universe was needed to create mass;
-The speed of light is not the highest speed in the universe;
-The laws of Newtonian physics do not apply in the quantum world;
-Only 4% of DNA are already known, etc.

After all the above, the question arises: "is it possible that this is how it all started"?

The INDUSTRY 4.0 is based on digitization, which has turned the world into a data mine of increasing value. The companies that started digging and looking for this type of coal mine in the 21st century today know best what consumers want, maybe even better than the consumers themselves. The zenith should be achieved with smart factories whose main goal is to achieve higher productivity. Robots and machines that, in some cases, will already be in a state of continuous communication with each other, will do their work more efficiently every day, while people will practically be excluded from work processes, where tasks are repeated. Only highly qualified people will be able to occupy the positions. The answer to everything said is contained in "bionics". It is impossible to consider the new industrial revolution without mentioning the more recent scientific discipline called "bionics".

What is bionics?

"Bionics would be a return to nature with the aim of finding solutions to technical problems". In popular jargon, this would be "imitation of nature" and the application of natural processes in technical systems and processes.

2. Bionics

Bionics connects "nature" starting from the developmental doctrine and ecological postulates with "technical systems" that incorporate elements of imitation of nature into constructions and "energy systems" that rest on alternative sources and ecological awareness. Bionics is an interdisciplinary field that involves the study of nature and the transfer of "discoveries from nature" through application in technical processes and systems. We must once again return to the already mentioned concept of

"balanced development", which takes into account the requirements of economic, social, ecological and ethical development by finding the lowest common denominator among the listed four factors. This is far beyond the concepts popularly called "sustainable development" which did not take into consideration the ethical context of development. What we all learn from nature is best shown by the illustration given in Figure 1 [1].

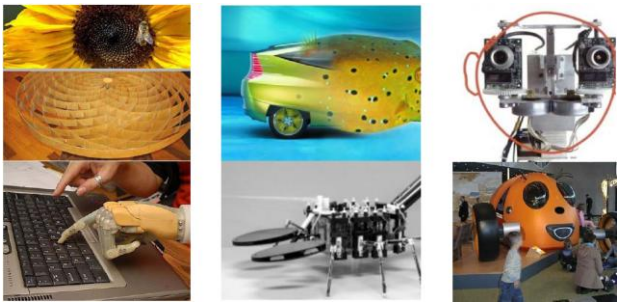


Fig. 1. *Examples of learning from nature.*

The word bionics is a combination of following two terms biology and electronics. This scientific field, which is also called biomimetics, biomimicry, bionics or biogenesis, has reached impressive levels that include the imitation of some of the human thinking processes in computers by copying some human traits, such as decision-making and self-management. By adapting mechanisms and capabilities from nature, scientific approaches have helped people understand related phenomena in order to design new devices and improve their capabilities. Researchers in the field of bionics today recognize the definition defined by Neumann in 1993: "Bionics as a scientific discipline systematically deals with technical adaptations and the use of constructions, procedures and development principles of biological systems."

Bionics certainly does not mean a complete imitation of nature, even if something like this is possible in individual cases. On the other hand, there are many principles from nature also cannot be further technically developed. The most successful architect and constructor is nature. Finally, it made a human being, the most complex known system. Therefore, imitating nature is an opportunity to take advantage of what the lab from nature has perfected long time before. Generally, all innovations from nature are led towards to circular economy. This solution designed to save materials, energy and can be decomposed and reused through application of 3R principle (e.g. reduce, re-use, and recycle).

3. Applications of Bionics in everydays life and business

Have you ever looked for examples in nature for solutions to the following phenomena, technical processes and systems, such as: air conditioners, breathing underwater, compasses, antifreeze, airplanes, clocks, lighting, electricity, artificial blowers, desalination, jet propulsion, submarines, rotary engine, thermometers, sonar, etc. Bionics is a kind of "shortcut" to world's discoveries, for which we would otherwise wait a long time. Who among you has watched the birds when they fly to southern destinations? Have you noticed that the entire flock flies in a formation that looks like the letter "V"? Are there any advantages to such a thing? There are advantages, as the wing sweep of the first bird in the flock creates lift that helps the bird immediately behind it. When birds fly in a flock, the duration of the flight is reduced by at least 71%, depending on weather conditions, compared to the time required when the bird would fly "alone" (see figure 2) [1] .





Fig. 2. *Formation of birds.* ***Fig. 3.*** *Ants at their work - cooperation..*

How ants share their work, you can see from figure 3. This phenomena has been researching by international experts. Ants have created a highly orderly career scale. This career scale focuses them on their current task rather than what awaits them in advance. They perform three different functions and usually move from one workgroup to another with age. The youngest are supposed to serve as servers to the queen, the next by age as cleaners, and the oldest go out and look for resource needed for survival. The third role, which takes place over relatively unknown territory and is away from the home base, is mostly reserved for the senior ants [7].

Among animals, as well as the entire world of flora and fauna, we find many more examples that are a quality basis for bionic technical solutions, such as:
-Spider's web (silky thread made by spiders, which have the hardness of high-tech materials such as "Kevlar" used to make protective vests, see figure 4);
- Pearl shell (unbreakable ceramic);
- Chameleons (hide without moving);
-Bees, turtles and birds (navigation without a map) and others.

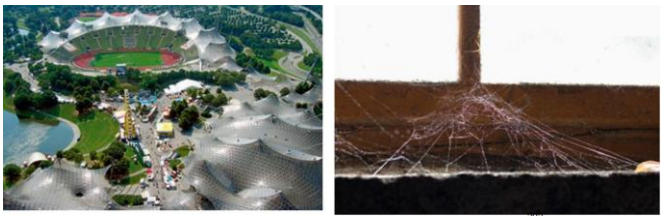


Fig. 4. *The Olympic Stadium in Munich is made in the shape of a "spider web".*

The development of medical devices has long been finding ideas for technical solutions in nature (see figure 5).



Fig. 5. *An example of the application of bionics in medicine in the application of implants.*

Energy can be produced by looking for solutions in bionics, and the example given in figure 6 shows that energy producers are devices installed at the bottom of the ocean that move like sea plants [1].

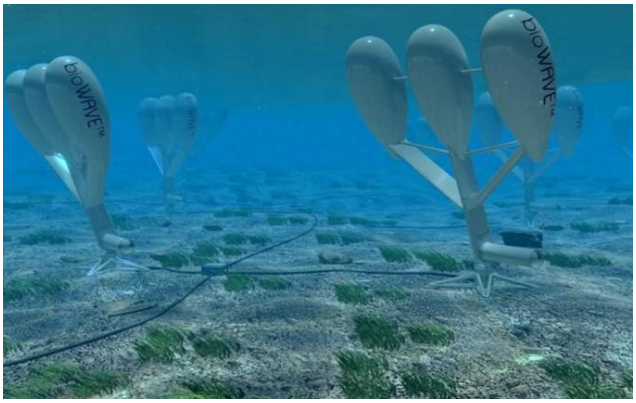


Fig. 6. *An example of energy production at the bottom of the ocean.*

Another example of the application of bionics is special sports clothing that adapts to weather conditions given in Figure 7 [1].



Fig. 7. *The application of bionics is special sports clothing that adapts to weather conditions.*

Recently, special swimming costumes, which are modeled after the skin of a shark, contribute significantly to the achievement of top results in swimming, which is shown in Figure 8 [1].

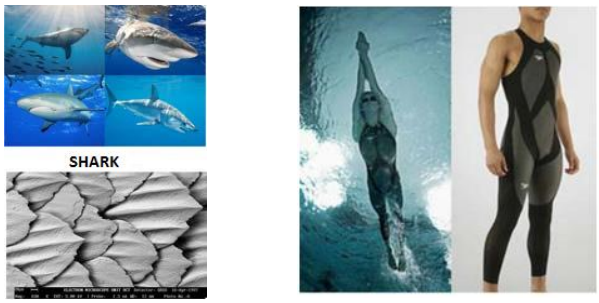


Fig. 8. *Examples of special swimming costumes created by bionics knowlewdge.*

Many people have heard of the "Lotus Effect" (see figure 9.). This is the effect of the droplet washing of dirt from the waterproof material or surface. The name comes from the water-repellent properties of the lotus leaf, which allows it to quickly remain dry and clean when in contact with water. This served as an ideal solution in the application of bionics to describe the efficiency of facade coatings, the latest technology in the development of water-repellent materials, as a clean face [1].



Fig. 9. *The Lotus effect.*

The humpback whale (lat. Megaptera novaeangliae) is a species of baleen whale characterized by distinctive body shape, with long pectoral fins and tubercles on its head. The tubercles allow the humpback whale to move under its prey and release the bladder ring. These bubbles form a cage that makes it easier to catch food. Bumps on humpback whale fins, known as tubercles, have been shown to change the distribution of pressure on the fin, causing some parts to slow down before others. Prototypes of wind turbine blades have shown that delayed deceleration doubles turbine efficiency at wind speeds of 17 kilometer per hour and allows turbines to capture more energy from lower wind speeds. The tubercles effectively direct the air flow over the blades and create vortices that increase lift. This example in figure 9 is shown [1].

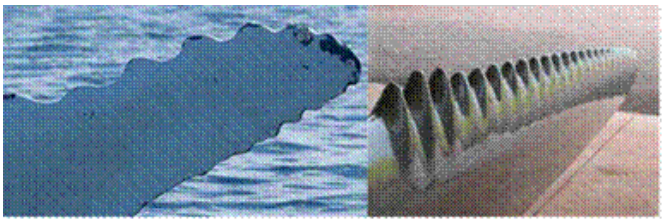


Fig. 10. *Humpback whale with tubercles vs.a prototype wind turbine blade.*

4. The applications of Bionics in terms of good organizational structure

After evolution of civilization, the nature has developed inventions that work, are fit for purpose and last. By using minimal resources to achieve maximum efficiency, it came up with numerous permanent solutions. Humans have always sought to imitate nature by recognizing that this ability is still well ahead of many of present technologies. One of the abilities of bionic system is to work independently in complex environments, can adapt to unplanned and unpredictable changes and perform multi-functional tasks.

Every business system, whatever it was a production or any other, is intended to create functional organizational structure. Does it dependence of company's management ability to develop new products and market them, to optimize organizational structures, to make decisions in situation of crisis, or to accelerate communication processes within organization? The methods used by living beings to conquer a new living environment by developing new abilities can be a model and might be key for building modern innovation model in the company. Innovation based on the human central nervous system model the main driver of organization to sustainability within an ever changing business environment by adapting organization and finding capabilities from nature to improve their control and supervisory structures [2]. How can animals like ants survive in the world of natural selection at all? Ants are phenomena in terms of being highly organized within their decisions. Dislike other animals, only ants, bees and birds represent

large but systematic colony of their own organization. Ants follow the model of a sophisticated system with high level of decentralization. All their working tasks are based on an interaction of many individual ants, instead of having one leader transferring tasks into a hierarchy. They follow simple rules to make this system more efficient. One of these rules is the need for interaction at the low level. When ants build, they communicate with other ants directly at low level. Dirt-collecting ants cooperate; those that create a pile of dirt work together, and those that form a structure also stick together. Ants do work and create structure without central coordination. Their organizational skills are example of the best practice. No ant sees the broad context. No ant advises another what have to do. Actually, there is no leadership is needed. Even complex behavior can be reconciled with relatively simple interactions among ants. Researchers didn't yet understand how ants organize themselves the way they do. It's still not sure why ants are so focused on job without any supervisory by leaders. Companies are also analyzing their business models to see how the coordination behavior of ants as well as bees and birds can be applied to workers and production processes [3].

Despite more processing power of human brain than ant brain, humans do not seem to be so organized when they do our own work. The reason for this must be accepting rules that are too complex. Even when humans apply the simple rules, they end up distorting them by introducing additional rules as side effects of own complex personalities [6]. People spend a lot of time forming leaders, yet leadership is not lesson learned. Human does his best only when they do something without pressing. Ants can teach human colony a lot about leadership. They live in colonies made up of several millions of individuals. Ants don't have leaders, but they work on right way, as we can see in figure 11.



Fig. 11. *Ants at work - building infrastructure.*

Firstly, what humans can do is to stress on a simply approach. Humans are born with certain natural tendencies, but most of the inclinations are learnt. These lesson learned tendencies create differences for a number of reasons, which include the knowledge database, the procedure it is implemented, experience, expectations, and the motivation of the learning one. As a result, the lesson learned tendencies are on very low level of perfection. One of such tendencies is also leadership [8]. Removing the concept of leadership is the first step to a potentially more optimized organization [7].

Have you ever looked closely at a termite anthill? If you take a closer look, you will surely notice a technical system with regulated ventilation and recuperation, i.e. fresh air heating, which is visible in Figure 12.



Fig. 12. *An example of an "anthill" as an idea for a bionic solution.*

The philosophy of ants is that each ant is in the right workplace. Each of them counts and they do not distinguish between good and bad performers. They simply put the right ants in the right jobs. Strong ants become warriors; medium-sized ones become workers. When ants from other colonies approach them, they immediately recognize them as "wrong ones at the wrong positions" and remove them. People can do the same. If a person sufficient at work, he could be put to the right place instead of being criticized. If the right job for this person can`t be found, only then he should be dismissed. However, if we do decide to keep such person, we need to make sure of what they really do and that this is acknowledged by everyone in the organization [3,4,5].

5. Conclusions

In general, bionics can be defined by the following mathematical equation:

Bionics = Nature + Man + Technology + Economy …(4)

The fusion of biology and technology through bionics will enable future innovations in the world. All companies and their management should strive to behavior of ants in order to create more efficient their organizational structure. The business environment where employees are respected, important and a feeling of being trusted at job should be created. This would create a self-organization where the workers themselves, like ants, would eliminate those who do not take care about the prosperity of the firm.

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Binary logistic regression for defect-free electron beam welding

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Abstract: *Using the method of binary logistic regression, the dependence of dichotomous variables on one or more, quantitative or qualitative independent variables is studied. In order to solve problems with binary dependent variables, binary choice model estimation methodologies, such as logistic regression (logit) and probit regression (probit), can be implemented. The logistic model is based on the logistic distribution, while the probit model is based on the normal distribution. In this paper the binary logistic regression methodology is applied for obtaining defect-free welds by electron beam welding process, based on experimental data.*
Keywords*: BINARY LOGISTIC REGRESSION, MODEL ESTOMATION, ELECTRON BEAM WELDING, PREDICTION.*

1. Introduction

Usually, the values of dichotomous variables are related to the probability of an event, which occurs depending on the independent variables under study. Using the method of binary logistic regression, the dependence of the dichotomous variables (binary, when they can be classified into two categories) on one or more independent variables can be studied. These independent variables can be both quantitative and qualitative [1, 2]. An alternative method of statistical research for binary dependent variables is the discriminant analysis [3], which also allows to assess the belonging of the variables to selected groups. The application of discriminant analysis assumes that the distribution of the independent variables is normal. For the application of logistic regression, this condition is not necessary, while at the same time the results are comparable to those of the discriminant analysis [1, 4].

Electron beam welding (EBW) is an advanced method of production of high-quality joints by local melting and solidification of the material, applied for a wide range of industrial applications: aerospace, automotive, defence, semiconductor, medical, nuclear, oil & gas, power generation and a variety of other industries. EBW is the most common method among special welding methods [5, 6].

The aim of the present work is to implement a model-based approach for the prediction of the presence of defects, depending on the variation of the electron beam process parameters – electron beam power, welding velocity, the distances from the magnetic lens to the surface of the treated stainless-steel samples and to the focus of the electron beam. It is assumed that the appearance of defects is more probable under some regime conditions [7], which can be defined as unfavourable. For the definition of these process parameter areas a logistic model is estimated and applied for the prediction of the optimal regime conditions of electron beam welding.

2. Binary logistic regression

Logistic model estimation is a methodology for modelling dichotomous variables (binary choice) and is based on the logistic distribution, while the *probit* model is based on the normal distribution. These models are similar and often the obtained results are also similar. The cumulative logistic distribution function is:

$$F(x) = \frac{1}{1 + exp\left(-\frac{x-\mu}{s}\right)}. \quad (1)$$

It is assumed that the dichotomous variable y is transformed into a continuous variable $\hat{y}_n$, which is estimated to represent the probability of the occurrence of one of the two events y = 1 or y = 0. For the event y = 1 the transformed $\hat{y}_n$ is:

$$\hat{y}_n = P(y = 1/x). \quad (2)$$

The variable $\hat{y}_n$ is unobservable (latent), continuous in the range (0, 1), and the decision corresponding to the value y_i = 1 is made when $\hat{y}_n$ exceeds a certain threshold value δ (usually a threshold value of δ = 0.5 is accepted).

The general representation of the logit model is the following:

$$logit(x) = \Lambda(x) = ln\left(\frac{P(y=1/x)}{1-P(y=1/x)}\right) = b_0 + b_1x_1 + b_2x_2 + \cdots + b_nx_n. \quad (3)$$

In the obtained model, the coefficients b_i are estimated using the maximum likelihood method [3]. The estimated model, besides the first order terms, can be augmented with interaction terms or higher order terms.

An inverse transformation to a binary predicted value is performed by the link function, which is the cumulative function of the logistic distribution. A solution for $\hat{y}_n$ is obtained:

$$\hat{y}_n(x) = P(y = 1/x) = \frac{1}{1+e^{-X\beta}} = \frac{e^{X\beta}}{1+e^{X\beta}}. \quad (4)$$

where $X\beta = b_0 + b_1x_1 + b_2x_2 + \cdots + b_nx_n$. The solution, corresponding to the value y_i = 1 is received, when $\hat{y}_n$ exceeds the accepted threshold value δ from 0 to 1 (typically δ = 0.5). Then for the predicted value of the output characteristic is obtained:

$$\hat{y}(x) = \begin{cases} 1, & \text{if } \hat{y}_n(x) \geq \delta \\ 0, & \text{if } \hat{y}_n(x) < \delta \end{cases}, \quad (5)$$

where δ is the defined e threshold value (δ = 0.5).

3. Case study

An experiment (81 trials [7]) of electron beam welding of stainless-steel samples of type 1H18NT was conducted. The accelerating voltage was 70 kV. The experiments were performed with beam power values of P = 4.2, 6.3 and 8.4 kW and welding velocity of v = 80 cm/min, 20 cm/min and 40 cm/min, with three values of the parameter z_0 (the distance from the main surface of the magnetic lenses of the electron gun to the focus of the electron beam): 176 mm, 226 mm and 276 mm and the distance between the magnetic lenses and the surface of the sample (z_p) for different values between 126 mm and 326 mm.

The measured weld quality characteristics were: the area of the weld cross-section, the depth and the width of the weld the presence of one or two defects is detected. The requirements for the geometry parameters of the welds differ, depending on the technological requirements. Nevertheless, there is a constant requirement for the absence of defects in the welded joints. The presence or absence of defects can be predicted, assuming that this depends on the considered process parameter values.

Based on the logistic regression, several models are compared (with only first order terms, with interaction terms and higher order terms) by the deviance R^2, adjusted deviance R^2 and Akaike Information Criterion (AIC), indicating how well different models fit the experimental data.

The following best model for the presence of defects in the weld (absence y = 0, presence y = 1), depending on the electron beam process parameters – electron beam power (P), welding velocity (v), the distances from the magnetic lens to the surface of the treated stainless-steel samples (z_p) and to the focus of the electron beam (z_0), was obtained:

$$\Lambda(x) = 165.3 - 27.0P - 1.297v - 0.561z_0 - 0.781z_p - 0.412P^2 - 0.000381z_p^2 + 0.2281Pv + 0.0883Pz_0 + 0.1557Pz_p + 0.000797vz_0 + 0.00579vz_p + 0.00267z_0z_p - 0.001196Pvz_p - 0.000429Pz_0z_p$$

The estimated model, besides the first order terms, was augmented with interaction terms and higher order terms, for which likelihood ratio test was performed. The current model has a deviance R^2 value of 46.02%, an adjusted R^2 value of 30.15%, and an AIC of 77.64. Higher values of deviance R^2 and adjusted deviance R^2 indicate a better fit. Smaller values of Akaike Information Criterion (AIC) indicate a better fit. Another link function or another modelling approach might have better fit statistics.

The Pearson, deviance, and Hosmer-Lemeshow goodness-of-fit tests [2] indicate that the null hypothesis of an adequate fit is accepted (p-values are larger than the accepted α significance level of 0.05) – consequently there is insufficient evidence to claim that the model does not fit the data adequately. The results from the goodness-of-fit tests are presented in Table 1.

Table 1: *Goodness-of-fit tests.*

Test	***Degrees of freedom***	χ^2	***p-value***
Deviance	66	47.64	0.957
Pearson	66	43.99	0.983
Hosmer-Lemeshow	8	1.90	0.984

4. Results and discussion

Table 2 presents the classification table, which reflects the number of correctly classified positive observations - TP (True Positives), correctly classified negative observations - TN (True Negatives), positive observations, classified as negative (error type I) - FN (False Negatives), negative observations, classified as positive (type II error) - FP (False Positives).

Table 2: *Classification table.*

Observations	***Predicted values***		***Quantity***
	Positives $\hat{y} = 1$	Negatives $\hat{y} = 0$	
Positives $y_i = 1$	TP = 12	FN = 7	19
Negatives $y_i = 0$	FP = 5	TN = 57	62
Total	17	64	81

From the table, it can be seen that the number of correctly predicted positive results ($\hat{y} = 1$) is 12 out of a total of 19 observations $y_i = 1$, and the number of correctly predicted negative results ($\hat{y} = 0$) is 57 out of a total of 62 observations.

With the obtained classification data, relative characteristics and indicators for the accuracy of the estimated logistic regression model were determined. They are presented in Table 3.

The relative number of correctly predicted positive cases is 63.16%, and the relative number of correctly predicted negative cases is 91.94%, or the average value of observations correctly predicted by the model is 77.55%.

The accuracy ACC = 85.19% of the binary regression logistic model is relatively high and it can be said that the estimated logistic regression model can be used for prediction purposes.

Table 3: *Indicators for the accuracy of the logistic model.*

Indicator	***Value***	***%***
True positives rate	TPR = TP/(TP + FN) = 0.631579	63.16
True negatives rate	TNR = TN/(TN + FP) = 0.919355	91.94
False positives rate	FPR = FP/(TN + FP) = 0.080645	8.06
False negatives rate	FNR = FN/(TP + FN) = 0.368421	36.84
Sensitivity	Se = TPR = 1 – FNR = 0.631579	63.16
Specificity	Sp = TNR = 1 – FPR = 0.919355	91.93
Positive predictive value	PPV = TP/(TP + FP) = 0.705882	70.59
Negative predictive value	NPV = TN/(TN + FN) = 0.890625	89.06
Accuracy	$ACC = \frac{TP + TN}{TP + TN + FP + FN} =$ 0.851852	*85.19*

The estimated logistic model is implemented for the investigation of the dependence of the predicted value of the transformed continuous output for the defect appearance $\hat{y}_n(x)$ on process parameter variation of the electron beam welding of stainless-steel samples of type 1H18NT. Fig. 1 presents a contour plot $\hat{y}_n(x)$ depending on the electron beam power P and the welding velocity v for constant values of the other two process parameters – the distance from the main surface of the magnetic lenses of the electron gun to the focus of the electron beam - z_0 = 226 mm and the distance between the magnetic lenses and the surface of the sample - z_p = 226 mm. These constant distances define a position of the focus of the beam exactly on the surface of the treated sample.

If the accepted threshold value is δ = 0.5), it can be seen that the defects will appear ($\hat{y}_n(x) = 1$) for values of the electron beam power between 5.6 kW and 7.5 kW and for welding velocities in the region from 20 cm/min to 25 cm/min.

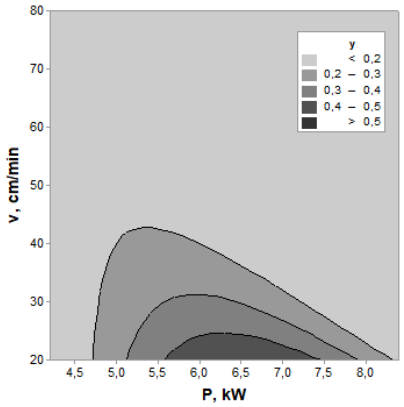


Fig. 1 *Contour plot of $\hat{y}_n(x)$ depending on the electron beam power P and the welding velocity v for $z_0 = 226\ mm$ and $z_p = 226\ mm$.*

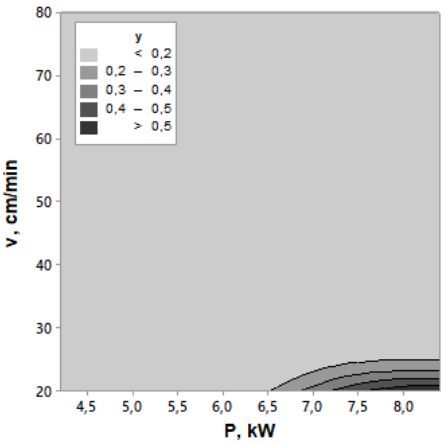


Fig. 2 *Contour plot of $\hat{y}_n(x)$ depending on the electron beam power P and the welding velocity v for $z_0 = 226\ mm$ and $z_p = 276\ mm$.*

Fig. 2 presents a contour plot of the continuous output for the defect appearance $\hat{y}_n(x)$ as a function of the electron beam power P and the welding velocity v for constant values of the distances z_0 = 226 mm and z_p = 276 mm. These constant distances define a position of the focus of the beam above the surface of the treated sample. It can be seen that the defects will appear ($\hat{y}_n(x)$ = 1) for values of the electron beam power between 7.7 kW and 8.4 kW and for very small welding velocities in the region from 20 cm/min to 21 cm/min.

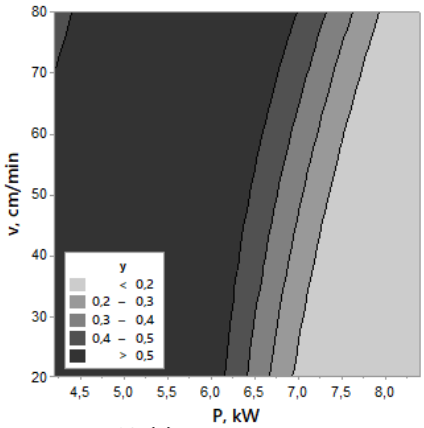


Fig. 3 *Contour plot of $\hat{y}_n(x)$ depending on the electron beam power P and the welding velocity v for $z_0 = 226\ mm$ and $z_p = 176\ mm$.*

In Fig. 3 a contour plot of the continuous output for the defect appearance $\hat{y}_n(x)$ as a function of the electron beam power P and the welding velocity v for constant values of the distances z_0 = 226 mm and z_p = 176 mm is presented. These constant distances define a position of the focus of the beam below the surface of the treated sample. It can be seen that the defects will appear ($\hat{y}_n(x)$ = 1) for a wide range of process parameter values - for electron beam powers from 4.2 kW to 6.2-7 kW and for welding velocities in the whole region from 20 cm/min to 80 cm/min.

5. Conclusions

In this paper the binary logistic regression methodology is applied for obtaining defect-free welds by electron beam welding process, based on experimental data, and depending on the following process parameters: electron beam power, welding velocity, the distances from the magnetic lens to the surface of the treated stainless steel samples and to the focus of the electron beam.

The estimated binary logistic model is used for the investigation of the influence of these parameters and the definition od the areas, where the defect appearance is expected. The obtained results show that at a distance between the magnetic lens and the focus of the electron beam of z_0 = 226 mm the defect appearance is most probable for a focus position below the surface of the stainless steel samples. On the other hand, a position of the electron beam on the sample surface or above the sample surface will result in defect appearance for small welding velocities - below 24 cm/min or 21 cm/min correspondingly.

Further optimization of the process electron beam welding can be done by integration of different technological requirements for the geometry of the welded joints with the additional constraint for the absence of defects. Multicriterial parameter optimization methods can be applied for the simultaneous fulfillment of all requirements for all quality characteristics.

Acknowledgements

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Application of the mathematical model of Johnson-Kendall-Roberts in the study of the Young's modulus of erythrocytes in patients with type 2 diabetes mellitus

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Abstract: *The goal of the present study is to evaluate the elastic properties (Young's modulus) of erythrocytes from healthy donors and patients with type 2 diabetes mellitus (T2DM), by using an atomic force microscope (AFM). Morphological and mechanical characteristics of red blood cells are studied in parallel by PeakForce QNM (Quantitative NanoMechanical Mapping) mode of AFM Dimensional ICON Bruker NanoScope V9 Instrument. Young's modulus is calculated based on the mathematical model of Johnson-Kendall-Roberts by the application of the "two-point method". AFM images of the erythrocytes from the healthy donors show that erythrocytes with a normal biconcave shape predominate. In patients with T2DM, the so-called erythrocyte polymorphism is studied. The Young's modulus of erythrocytes, in patients with T2DM, significantly statistically increases by 27% ($p \leq 0,001$), compared to the data of healthy donors. The studied Young's modulus by AFM can be used in clinical practice as a precise biomarker for the state of the red blood cells in T2DM.*

Keywords: *YOUNG'S MODULUS, JOHNSON-KENDALL-ROBERTS MATHEMATICAL MODEL, ATOMIC FORCE MICROSCOPE, TYPE 2 DIABETES MELLITUS, ERYTHOCYTES (RED BLOOD CELLS, RBCs)*

1. Introduction

An elastic modulus (Young's modulus) is the stress divided by the corresponding strain, with greater values indicating the decreased deformability of a solid body [1, 2]. Young's modulus is a mechanical constant that characterizes the elastic properties of the material from which the solid body is made. It does not depend on the dimensions of the body and is associated with "hardness" – the rigidity of the solid body. The elastic properties of heterogeneous objects, such as cells, can be evaluated by Young's modulus [1, 2]. Larger values of Young's modulus mean an increase in rigidity, correspondingly a decrease in the elasticity (deformability) of the cells [3, 4].

Atomic force microscopy (AFM) can be used to evaluate and visualize the surface structure of cells [3, 4, 5]. One of its applications is to measure changes in the red blood cells (RBCs, erythrocytes), related to their deformability (Young's modulus), in type 2 diabetes mellitus (T2DM) [6, 7]. The incensement of glucose concentration in patients with T2DM results in a decrease of RBC deformability, which can be associated with changes in the shape of the erythrocytes [8]. The changes of morphological characteristics (shape, cell sizes, surface roughness, etc.) and mechanical parameters (Young's modulus, adhesion force, etc.) of erythrocytes can result in microvascular complications (diabetic retino-, nephro-, neuropathies, cardiovascular, neurovascular- and peripheral vascular diseases) in T2DM [6, 7, 8, 9].

The main approach to study the mechanical properties of objects by using AFM is a technique called (nano)indentation, i.e. deformation of the sample (the cell), as a result of the action of force with which the probe (top of the cantilever) of the atomic force microscope presses the cell [10, 11]. The main source of quantitative information about the mechanical characteristics of the sample (cell) is obtained from the so-called force curves, which show the dependence of the interaction force between the probe and the sample, and the distance between them [10, 11]. The analysis of these force curves allows the quantification of mechanical parameters such as deformation, stiffness, Young's modulus, etc. [10, 11, 12].

One of the main problems (tasks) in the accurate determination of Young's modulus of cells using AFM is the choice of a mathematical model for calculating the elastic modulus that will describe well the contact between the soft cell and the hard probe of AFM [10, 11, 12]. The most commonly used mathematical models for calculating the elastic modulus of various materials [14, 15] are the Hertz model, the Sneddon model, the Deryagin-Muller-Toporov model (DMT), and the Johnson-Kendall-Roberts model (JKR).

- In the Hertz and Sneddon models, the interactions between perfectly elastic homogeneous bodies, that are axisymmetric and smooth, are described. The adhesion forces between the probe tip (with the spherical shape in Hertz's model; or the shape of a cylinder, cone, or pyramid in Sneddon's model) and the sample (the cell) are not taken into consideration in these models. The mathematical models of Hertz and Sneddon are unsuitable for calculating Young's modulus of cells, which are soft and delicate objects – with a heterogeneous surface. Additionally, there are significant adhesion forces between the cell and the probe tip [16, 17].

- In the DMT model is accepted that adhesion forces act outside the contact area between the sample and the probe tip. This model is suitable for studies on the contact of solid materials with weak adhesion [10, 18].

- In the JKR model is accepted that adhesion forces act only in the contact area; it gives more accurate results when sticky and soft materials (such as blood cells), come into contact [19]. Therefore, we accepted that the most correct mathematical model for calculating Young's modulus of blood cells is the JKR model.

Determination of Young's modulus by the mathematical model of Johnson-Kendall-Roberts using the "two-points method"

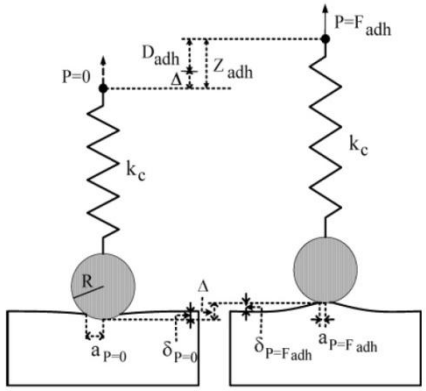
Using the JKR model, it is assumed that the tip of the AFM probe and the sample (cell) are two elastic bodies. The AFM tip is represented as a sphere, and the spring represents the cantilever of the AFM (Fig. 1). When the AFM tip approaches a soft sample (cell), the adhesive interaction can draw the tip into the sample, and when the AFM tip retracts from a soft sample, the tip can pull and deform the sample by adhesive interaction [20].

The deformation of the sample Δ is obtained from the distance between the points where the external load $P = 0$ and where the external load $P=F_{adh}$ (Fig. 1).

- The deformation of the sample Δ defines the amount of deformation of the sample when it is pulled under the adhesive interaction between the tip and the sample.

- Z is the retraction distance of the AFM`s piezoelectric actuator, and D_{adh} is the deflection displacement of the AFM cantilever during this procedure.

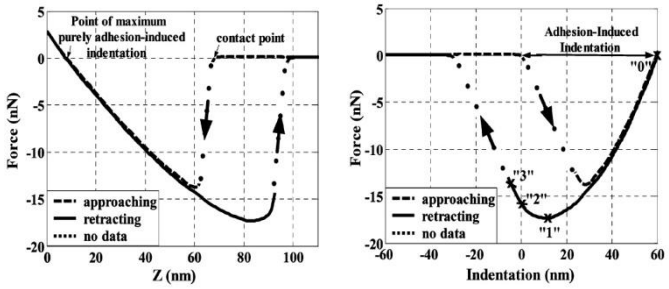
- The total retraction distance Z_{adh} of the AFM piezoelectric actuator consists of the deflection displacement D_{adh} of the AFM cantilever and the deformation of the sample Δ [20].



A) B)

Fig. 1. *The AFM tip and sample are considered two elastic bodies. The AFM tip is represented as a sphere, and the spring represents the AFM cantilever. A) The sample is deformed by adhesion when the external load P=0. (B) The sample is deformed by adhesion when the external load* $P=F_{adh}$ *[20].*

A typical force curve obtained by using AFM is presented in Fig. 2 A. In a "contact point" of the force curve, the interaction becomes attractive when the tip contacts the sample surface. Once the tip touches the surface, the tip is pulled into the sample by the adhesive interaction between the tip and the sample. This is shown as the sharp decrease of the force on the AFM cantilever in the extension part of the force curve in Fig. 2 A [19, 20].



A) B)

Fig. 2. *AFM force plot: (A) A typical AFM force curve for the case of an AFM tip interacting with a soft sample under adhesive interaction; (B) The corresponding force vs. indentation plot. The forces on the AFM tip as it approaches the surface are indicated by the dashed lines while the forces upon retraction are shown by the solid lines. Point "0" is where the AFM tip has zero external force, "1" is where the tip has a maximum external force, "2" is where the tip has zero indentation in the sample, and "3" is where the tip ruptures from the sample [20].*

The force curve is converted to the corresponding force-indentation plot in Fig. 2 B. There are some distinct points on the force-indentation plot that correspond to the moments of interaction between the tip and the sample surface. At point "0" (Fig. 2 B), where the AFM tip is drawn in the sample surface due to adhesive interaction, the stored elastic and surface energy are balanced and zero external force acts on the AFM cantilever. The indentation between the point where the tip begins to contact the sample surface and point "0" is defined as adhesion-induced indentation. Point "1" is the place where a maximum external force acts on the tip; point "2" is the place where the tip has zero indentation in the sample; and point "3" is where the tip ruptures from the sample (Fig. 2 B). Points "0", "1" and "2" can be obtained directly from the force curves, and point "3" can be predicted by the JKR model [19, 20].

From the relationships between indentation (δ) - contact radius (a), and between external force (P) - contact radius (a), Young's modulus of samples can be determined by combining any two of the points in the retraction part of the force curve, and this method is called the "two-points method" [19, 20]. The indentation (δ) and the external force (P) are both functions of the contact radius (a), interfacial energy (γ_{12}), and the sample elasticity (E), i.e.: $\delta = \delta(a, \gamma_{12}, E)$, and $P = P(a, \gamma_{12}, E)$. For every two points on the force curve, there are four equations and four variables a_1, a_2, γ_{12} and E, where a_1 and a_2, are the contact radii at two points on the force curve. The indentation (δ) and the external force (P) at each point can be obtained directly from the force curve in Fig. 2 B [20].

According to the JKR model [16, 21], the contact radius (a) of the contact area is obtained from the following equations:

$$a^3 = \frac{R}{K}\left[P + 3\pi R\gamma_{12} + \sqrt{6\pi RP\gamma_{12} + (3\pi R\gamma_{12})^2}\right] \quad (1)$$

$$a_0^3 = \frac{6\gamma_{12}\pi R^2}{K} \quad (2)$$

$$\delta = \frac{a^2}{R}\left[1 - \frac{2}{3}\left(\frac{a_0}{a}\right)^{3/2}\right] \quad (3)$$

where (P) is the external force, is the interfacial energy, a_0 is the contact radius under zero external force, (δ) is the sample deformation, $R = R_1R_2/(R_1 + R_2)$ is the combined radius of the two spheres with radii of R_1 and R_2, $K = 4/3\pi(k_1 + k_2)$ is the combined elastic coefficient, k_1 and k_2 are the elastic constants of each sphere, as:

$$k_1 = \frac{1 - \nu_1^2}{\pi E_1} \quad (4)$$

$$k_2 = \frac{1 - \nu_2^2}{\pi E_2} \quad (5)$$

where ν_1 is the Poisson's ratio of the sample, ν_2 is the Poisson's ratio of the tip of the probe, E_1 is Young's modulus of the sample (cell), and E_2 is Young's modulus of the material from which the tip is made $(E_2 >> E_1)$ [20, 22].

For negative force, the spherical tip of the probe adheres to the sample. The contact radius a_3 at the rupture point is obtained by:

$$a_3 = \frac{a_0}{\sqrt[3]{4}} = 0{,}63a_0 \quad (6)$$

The point "3" in Fig. 2 B for the JKR model then can be located by using equation (6).

Combining points "0" and "3", it is obtained the following:

$$\delta_0 = \frac{1}{3}\sqrt[3]{\frac{16P_3^2}{K^2R}} \quad (7)$$

And

$$\delta_3 = \frac{1}{3}\sqrt[3]{\frac{P_3^2}{K^2R}} \quad (8)$$

By combining equations (7) and (8), it is written:

$$K = \left(\frac{1 + 16^{\frac{1}{3}}}{3}\right)^{\frac{3}{2}} \frac{P_3}{\sqrt{R(\delta_0 - \delta_3)^3}} \quad (9)$$

For the case when the modulus of elasticity of the tip significantly exceeds that of the sample ($E_2 >> E_1$), the modulus of elasticity E of the sample (cell) is obtained from the equation:

$$E = \frac{3(1-\nu^2)K}{4} \quad (10)$$

where ν is the Poisson's ratio of the sample and *K* is the combined elastic coefficient – equation (9) [20, 22].

By combining points "0" and "2", it can be obtained analogically:

$$E = \frac{3(1-\nu^2)P_2}{8}\left(\frac{3}{\delta_0^3 R}\right)^{\frac{1}{2}} \quad (11)$$

By combining points "0" and "1", *E* can be obtained by solving equations (1-3). First, a_0 and a_1 can be solved from (3), since because a_0 and a_1 are known from the force curves; second, one combines equations (1) and (2) and obtains:

$$a_1^3 = \frac{R}{K}\left[P_1 + \frac{a_0^3 K}{2R} + \left(\frac{P_1 a_0^3 K}{R} + \left(\frac{a_0^3 K}{2R}\right)^2\right)\right]^{\frac{1}{2}} \quad (12)$$

from which *K* can be written [20, 22].

The goal of the present study is to evaluate the elastic properties (Young's modulus) of erythrocytes from healthy donors and patients with type 2 diabetes mellitus, with the mathematical model of the Johnson-Kendall-Roberts by the "two-points method", using an atomic force microscope.

2. Materials and Methods

Preparation of blood samples from healthy controls and T2DM patients. Human blood samples are collected from volunteers following the ethical principles of medical research – Declaration of Helsinki, and all of them gave written informed consent. Healthy donors (control group) are selected if they did not have any chronic diseases, as non-smokers, females, who didn't take any hormone replacements or contraception, etc. Patients with T2DM are diagnosed, according to the guidelines of the American Diabetes Association (ADA) [23].

The *in vitro* experiments are realized with blood samples from 15 healthy individuals (*average age 53 ± 9,3 years*) and 15 T2DM patients (*average age 61,8 ± 7,7 years*). Venous blood samples are drawn by venipuncture and collected in 6 ml tubes with K_2EDTA as an anticoagulant.

Sample preparation for AFM. Erythrocytes are separated from each blood sample from the healthy subjects and the diabetic patients by a centrifugation method. The concentrated erythrocyte suspension is washed twice with saline, as the hematocrit is adjusted to 40%. From the obtained erythrocyte suspension, 3,5 µl are taken and fixed with 700 µl 0,5% glutaraldehyde (GA) for 30 min, at room temperature. Fixed erythrocytes are washed twice with saline and twice with distilled water, then plated on mica. The samples are dried for about 1 day, and after that, they are examined with AFM [24].

AFM imaging and measurements. The fixed erythrocytes are examined by using the AFM Dimensional ICON Bruker NanoScope V9 Instrument (AFM Bruker), which works in a PeakForce QNM (Quantitative Nano-Mechanical Mapping) imaging mode. This is one of the newest AFM modes of work, combining the advantages of static (contact) and dynamic (periodic) modes of operation [15, 25]. This method is similar to the standard tapping mode of scanning probe microscopy, where the probe and the sample are brought together intermittently. It operates by controlling the maximum force applied by the probe to the sample and allows a rapid force–distance curve to be generated at every pixel [26]. The force curves could be analyzed quantitatively to obtain a series of specific characteristics on the map of each sample. High-quality images of the relief (topography) and quantitative (nano)mechanical maps of the studied samples can be obtained in parallel, through high-speed scanning, using the PeakForce QNM mode [27].

The cantilever's deflection sensitivity, spring constant, and tip radius are calibrated in advance. Morphological and mechanical properties of red blood cells are studied simultaneously in PeakForce QNM mode using silicon cantilever RFESP (a tip radius of 8 nm, a resonance frequency of 75 kHz, and a spring constant of 3 N/m), at room temperature. The obtained images are analyzed with the program NanoScope Analysis 1.9 (Bruker).

From every blood sample, three arbitrarily selected erythrocytes are examined. The total number of erythrocytes studied in healthy individuals is *n'=45* cells, and the total number of studied erythrocytes in T2DM patients is *n'=45* cells. For every erythrocyte from healthy individuals and diabetic ones, the following AFM images are found: a 2D topography, a 3D topography, a cross-sectional profile of the cell, and a map of Young's modulus.

Evaluation of the topography of erythrocytes is made by determining the cell *diameter – d* (horizontal distance corresponding to the diameter of the cell is measured), and roughness of the cell (based on three arbitrarily selected cross-sectional profiles from the surface of each erythrocyte), by the specific parameters [24, 28]:

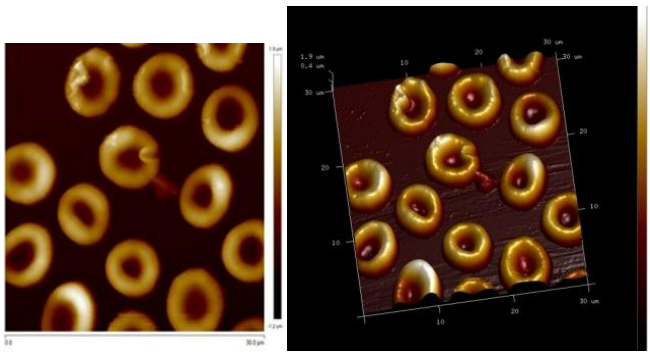
- *maximum height* – R_{max} (difference in height between the highest and lowest points on the cross-sectional profile relative to the center line (not the roughness curve), over the length of the profile);
- *average roughness in ten points* – R_z (average difference in height between the five highest peaks and five lowest valleys relative to the center line over the length of the profile; in cases where five pairs of peaks and valleys don't exist, this is based on fewer points.);
- *average roughness* – R_a (average value of the roughness curve relative to the center line).

The maps of the elastic modulus of red blood cells are compiled according to the values of *Young's modulus* determined in each nanoindentation point by calculation according to the Johnson-Kendall-Roberts mathematical model by the "two-point method". The Young's modulus of erythrocytes is presented as average values obtained from the force curves – up to 2000 for each cell, of all nanoindentation points entering an arbitrarily selected section of the peripheral parts of each cell.

Statistical analysis. Data analysis is performed based on the software packages Sigma Plot 11.0. All data are presented as average ± SD (standard deviation). The significance of differences is evaluated using the t-test and the Mann-Whitney Rank Sum Test. Differences are accepted as significant at $p<0,05$.

3. Results

AFM images of fixed erythrocytes from healthy donors show that the red blood cells with a biconcave shape, so-called *discocytes* or *normocytes*, are predominated in the samples (Fig. 3 A, B).

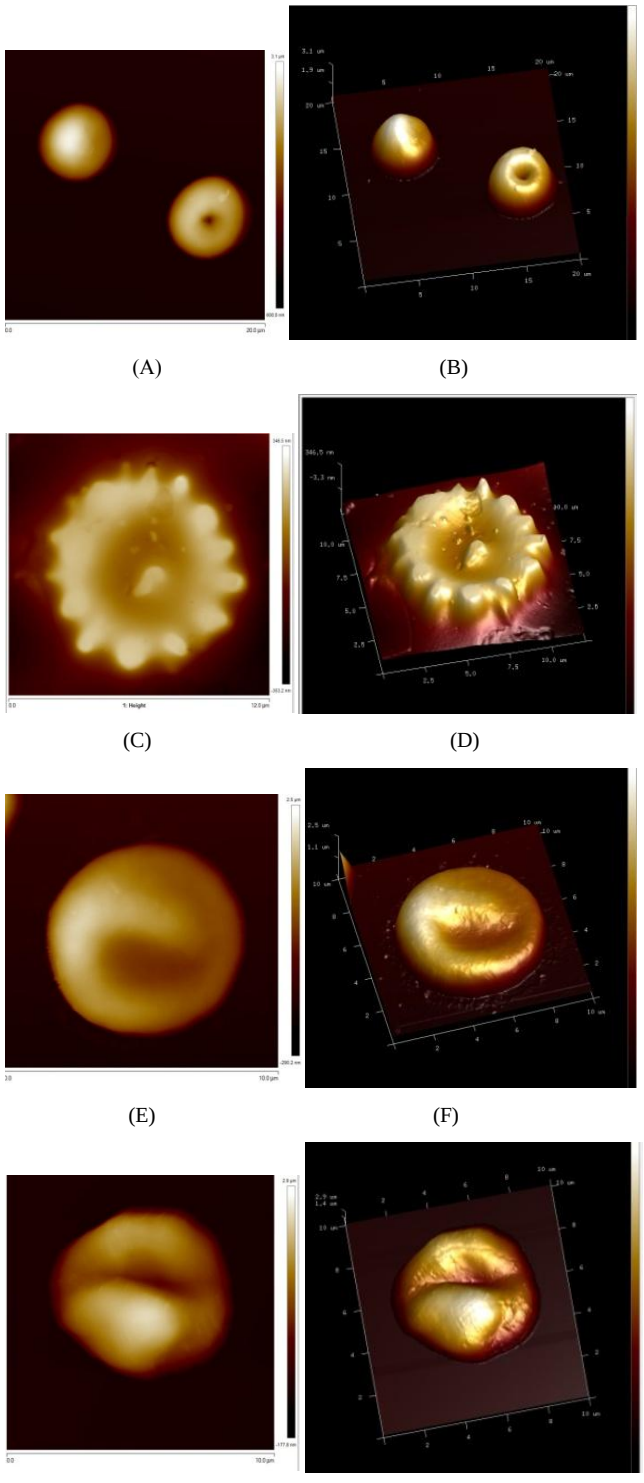


(A) (B)

Fig. 3. *AFM Bruker images of erythrocytes with normal biconcave shape (discocytes or normocytes), from a healthy donor: A) 2D topography; B) 3D topography.*

AFM images of fixed red blood cells from patients with T2DM illustrate a change in the size (*anisocytosis*) and shape (*poikilocytosis*): the so-called erythrocyte polymorphism. Erythrocytes with pathological changes in the shape, so-called *poikilocytes*, are observed as follows:

- *spherocyte* – erythrocyte, which has lost its double concave shape and turned into a spherical cell (Fig. 4 A, B);
- *echinocyte* – erythrocyte with many small, evenly spaced needle-like outgrowths throughout the membrane (Fig. 4 C, D);
- *knizocyte* – an erythrocyte that is a triple concave (Fig. 4 E, F);
- *elliptocyte (ovalocyte)* – erythrocyte, which has acquired an elliptical shape (with varying degrees of expression), etc.



(A) (B)

(C) (D)

(E) (F)

(G) (H)

Fig. 4. *AFM Bruker images of erythrocytes from T2DM patients: A, C, E, G) 2D topography; B, D, F, H) 3D topography. A, B) spherocytes; C, D) echinocyte; E, F) knizocyte; G, H) atypical form of an erythrocyte.*

The diameter (*d, μm*) of fixed erythrocytes from healthy individuals is between *5,6 μm* and *6,7 μm*. In T2DM patients it is elevated and varies between *6,5 μm* and *7,5 μm* (Table 1; Fig. 5 A). In the diabetic patients, the diameter of erythrocytes increases statistically significantly by 14% (*p≤0,001*) in comparison to the data from healthy donors.

Table 1: *Averages values and standard deviations of morphological parameters and mechanical parameters of erythrocytes from control group healthy individuals (n=15) and patients with T2DM (n=15).* *Note: d – diameter; R_{max} – maximum height; R_z – average roughness in ten points; R_a – average roughness; E – Young's modulus; n – total number of examined persons from each group; n` – total number of examined cells from each group; t-test: *** p≤0,005.*

Parameter	Control group n=15, n`=45 cells	Patients with T2DM n=15, n`=45 cells
D, μm	6,16±0,56	7,03±0,51***
R_{max}, μm	1,42±0,21	1,74±0,24***
R_z, μm	1,1±0,19	1,19±0,31
R_a,μm	0,31±0,09	0,36±0,08
E, MPa	98,6±11,67	124,89±9,41***

The evaluation of the roughness (*R, μm*) of each erythrocyte (Fig. 6 A, C), is made by the profiles of three arbitrarily selected cross-sectional lines from the topography image of each RBC. From the cross-sectional profiles of the surface of erythrocytes in healthy individuals, it is found that they have a typical morphology – a double concave shape (Fig. 6 A, B), while in patients with diabetes, the RBC surface has an abnormal shape (Fig. 6 C, D).

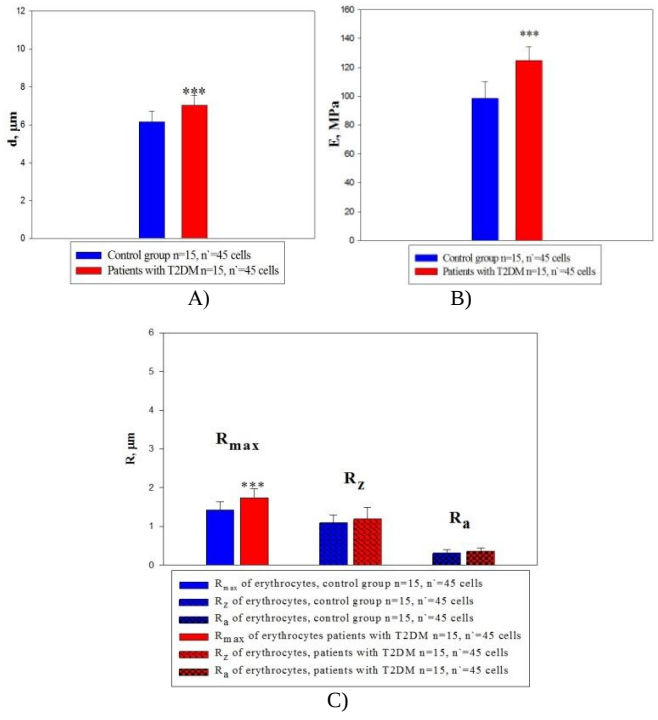
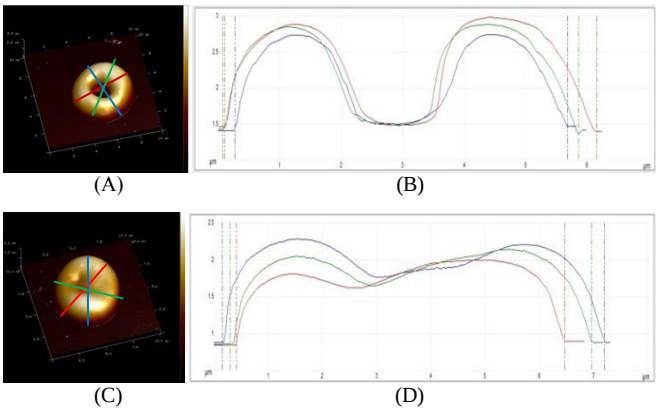


Fig. 5. *Average values and standard deviations of the morphological and mechanical parameters of erythrocytes from control group healthy individuals (n=15), and patients with T2DM (n=15): A) diameter – d; B) Young's modulus – E; C) roughness, evaluated by the parameters: maximum height – R_{max}; average roughness in ten points – R_z; average roughness – R_a.*

In patients with T2DM, the erythrocyte maximum height (R_{max}, *μm*) statistically significantly increases by 23% (*p≤0,001*), the average roughness at ten points (R_z, *μm*) increases by 8%, and the average roughness (R_a, *μm*) increases by 16%, compared to the control group of healthy individuals (Table 1; Fig. 5 C). Therefore, the erythrocytes from diabetic patients are higher and their relief of the surface, evaluated quantitatively by morphological parameters

for roughness (R_{max}, R_z, R_a) is changed, in comparison with the topography of erythrocytes in the control group of healthy objects.

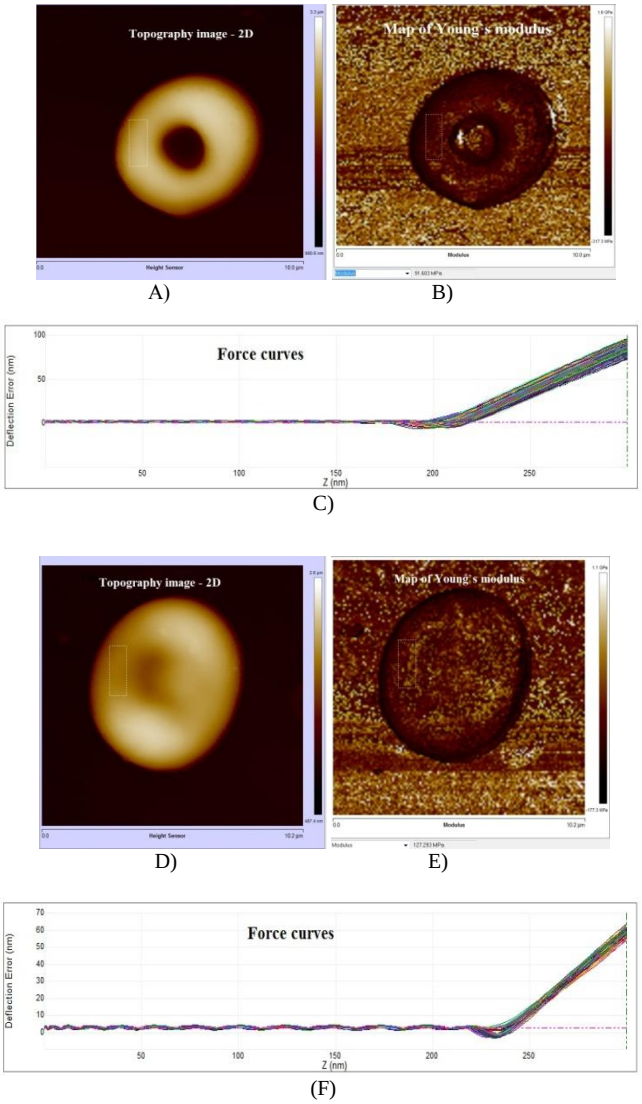


(A) (B)

(C) (D)

Fig. 6. *AFM Bruker images of: A) erythrocyte (discocyte) from a healthy donor; C) erythrocyte (elliptocyte) from a T2DM patient. A, C) 3D topography with three cross-sectional lines from the cell surface; B, D) profiles of three cross-sectional lines from the cell topography.*

For each of the RBCs studied (Fig. 7 A, D), corresponding Young's modulus distribution maps (Fig. 7 B, D), have been evaluated.



A) B)

C)

D) E)

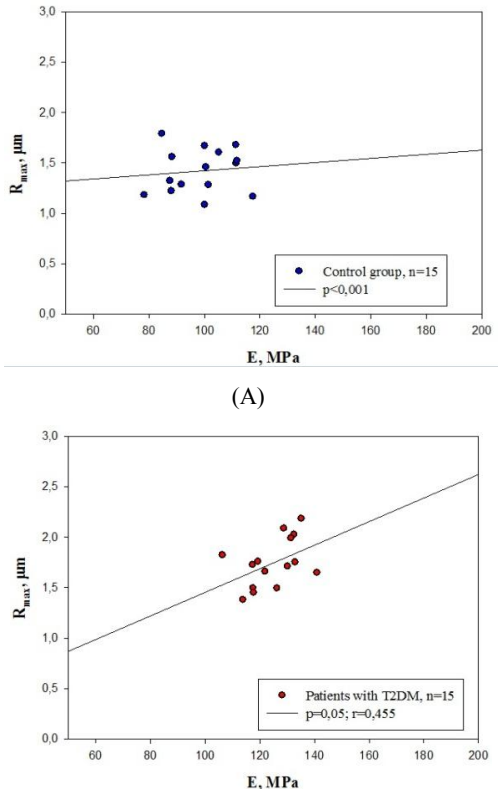
(F)

Fig. 7. *AFM Bruker images of: A, B) erythrocyte (discocyte) from a healthy donor; D, E) erythrocyte (elliptocyte) from a T2DM patient. A, D) 2D topography; B, E) Young's modulus distribution map of erythrocyte; C, F) force curves of all nanoindentation points entering the arbitrarily peripheral section of the erythrocyte membrane, which are used for calculation of the average value of Young's modulus of erythrocyte.*

The values of the elastic modulus for every point of nanoindentation from Young's modulus distribution map are calculated according to the mathematical model of Johnson-Kendall-Roberts, by the "two-point method". The average value of Young's modulus of each RBC is determined for an arbitrary peripheral section (with a rectangular shape), from the membrane of the erythrocyte (Fig. 7 B, E). The force curves (Fig.7 C, F), of all nanoindentation points (up to 2000 for each cell) entering the arbitrary peripheral section of the erythrocyte membrane are used for the calculation of the average values of Young's modulus of the erythrocyte.

In patients with T2DM, the average value of Young's modulus (*E, MPa*) of erythrocytes increases statistically significantly by 27% ($p \leq 0{,}001$), in comparison with healthy individuals (Table 1, Fig. 5 B). These changes indicate the reduced deformability (increased rigidity) of erythrocytes in T2DM patients, compared to RBC deformability in healthy individuals.

The linear correlation analysis between the mechanical parameter – Young's modulus (*E, MPa*), and morphological parameter – maximum height (R_{max}, *μm*) of the erythrocytes in the control group, doesn't prove a correlation between them (Fig. 8 A).



(A)

(B)

Fig. 8*. Linear correlation between Young's modulus (E, MPa), and maximum height (R_{max}, μm) of erythrocytes, from: A) control group of healthy individuals; B) patients with T2DM.*

A positive correlation between *E* and R_{max} of erythrocytes ($p=0{,}05$; $r=0{,}455$) is demonstrated in patients with T2DM (Fig. 8 B). Therefore, in diabetic patients, the modulus of elasticity is increased (the deformability of RBCs is decreased), in parallel with the changes in the relief of the cells (the R_{max} was increased).

4. Discussions

AFM can be considered as an informative technique that is used for structural studies of erythrocytes, and to measure Young's modulus indicating the elasticity (deformability) of cells. By application of the AFM, the morphological and mechanical characteristics of erythrocytes in healthy individuals and patients with T2DM can be studied simultaneously. Significant differences are found in the diameter, height, roughness, and Young's modulus

of erythrocytes in T2DM patients, compared with the results in healthy individuals.

In other studies [7, 24, 29, 30, 31, 32], conducted with atomic force microscopes and simultaneous application of experimental methods and mathematical models, different values of Young's modulus for erythrocytes in healthy donors and diabetic patients also were obtained.

The most commonly applied mathematical model for calculating Young's modulus using AFM is the Hertz model [29, 31, 32, 33, 34]. Through this model in a study [29], the elastic modulus of erythrocytes in diabetic patients (*E=0,0143±0,0014 MPa*) is found to be higher, than E of healthy donors (*E=0,0044±0,0006 MPa*). According to Hertz's mathematical model, Young's modulus of RBCs is calculated also in the study [30], in healthy donors E=74,47±4,97 MPa, and in patients with T2DM *E=102,75±4,78 MPa*, and in research [31] - in healthy donors *E=0,0083±0,0012 MPa*, and in patients with T2DM, E =0,0153±0,0039 MPa. In the publication [32], for the modulus of elasticity of erythrocytes calculated by the Hertz model is found that *E=85,8±11,9 MPa*, for the control group, and *E=122±5,7 MPa* – for diabetic patients. According to Sneddon's mathematical model, in a study [34], it was found that Young's modulus in healthy donors is *E=0,0018±0,0002 MPa*, and in diabetic patients, it is *E=0,0025±0,0006 MPa*.

From the maps of the elastic modulus of erythrocytes from healthy donors and patients with T2DM (Fig. 7 B, E), was established that the surface of the cells is heterogeneous – the peripheral parts of the RBCs have lower Young's modulus, than central parts. As a result of this, if Young's modulus is obtained from Hertz's or Sneddon's mathematical models (which can only be used for perfectly homogeneous bodies), then it will be incorrect.

In a study [7], it is established for the modulus of elasticity, calculated according to the mathematical model of DMT, that for the control group, it is *E=46710±39210 MPa*, and for the patients with T2DM *E=56483±64418 MPa*. Erythrocytes are soft, "delicate" objects, and the adhesion force between them and the tip of the cantilever could be significant and cannot be neglected. Therefore, Young's modulus values, which are obtained by the DMT model [7] can be assumed also that are inaccurate because in this model the adhesion forces act outside the contact area between the tip and solid sample.

Until now, in the scientific literature, cannot be found studies in which Young's modulus of erythrocytes is evaluated according to the mathematical model of JKR. In our study, the results obtained for the elastic modulus of the RBCs in healthy donors *E=98,6±11,67 MPa*, and patients with T2DM *E=124,89±9,41 MPa*, are calculated by the mathematical model of JKR by the "two-point method".

For erythrocytes in healthy individuals or patients with T2DM, the elastic modulus values were calculated by different mathematical models [7, 24, 29, 30, 31, 32, 34] and differ greatly from each other. To be able to compare Young's modulus values evaluated in different studies, this modulus must be calculated by one specific mathematical model, which could reflect most precisely the experimental cell model. The mathematical model of JKR describes more accurately the interaction between the cell and the tip of the cantilever. Thus, it is more appropriate to determine Young's modulus by this model. Therefore, we suppose that the values of the elastic modulus of erythrocytes in healthy donors and patients with T2DM obtained in our study are accurate.

The results obtained in our research (Table 1; Fig. 5 B), show that elastic modulus of RBCs in diabetic patients statistically significantly increases, when it is compared to the control group of healthy individuals. The deformability of erythrocytes plays an important role in their movement in blood vessels, oxygen transfer, etc. A decrease in erythrocyte deformability leads to a reduction in capillary blood flow and subsequent microvascular complications, which are often observed in T2DM patients [9, 35, 36]. Changes in erythrocyte deformability (decreased), increased diameter and their increased ability to aggregate - associated with increased blood viscosity, are closely connected with increased blood coagulation, causing the development of thrombosis in patients with T2DM [8, 24, 37].

Increased glycation of hemoglobin, altered cholesterol levels, and oxidative stress in T2DM patients can lead to changes in RBC morphology, and a formation of echinocytes and spherocytes with impaired deformability [38, 39]. Changes in erythrocyte shape can be used as an early biomarker of diabetic complications, allowing better monitoring and treatment of diabetic patients [24, 40].

The simultaneous study of changes in cell morphology and mechanical characteristics of RBCs is important to elucidate the pathogenesis of vascular complications and especially of thromboses in diabetic patients [24, 40]. The established positive correlation between the elastic modulus and the roughness of erythrocytes, found in this study (Fig. 8), can be used as biomarkers in the clinical management of T2DM [6, 9, 24].

5. Conclusion

The morphological (diameter, height, roughness) and elastic (Young's modulus) characteristics of erythrocytes have been studied in parallel by AFM. The mathematical model of Johnson-Kendall-Roberts was applied, as more suitable for calculating Young's modulus of the cells. The values of the elastic modulus of erythrocytes from healthy objects and patients with T2DM, obtained using a model of JKR by the "two-point method", are the most accurate. Significant differences are found in the diameter, height, roughness, and Young's modulus of erythrocytes in T2DM patients, compared with the results of healthy individuals. The studied AFM morphological and mechanical characteristics of erythrocytes can be considered as precise biomarkers for the state of patients with T2DM. This is important for the diagnosis, prevention and successful monitoring of treatment of the T2DM in the clinical practice.

6. Acknowledgment

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Self-cleaning coatings of oxides transition elements (including - TiO_2) on a photovoltaic covering glass

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Abstract: *The aim of this paper is to review the cleaning of solar photovoltaic (PV) systems and applied coatings that eliminates costly automated cleaning systems by using nano-sized TiO_2 combined with various organic binders.*
Keywords*: PHOTOVOLTAIC SYSTEMS, SOLAR ENERGY, SURFACE CLEANING, TIO_2, HYDROPHOBIC, HYDROPHILIC.*

1. Introduction:

Solar radiation is the sum of the electromagnetic and corpuscular radiation of the Sun, which is the main source of energy and daylight for the Earth. It propagates in the form of electromagnetic waves at the speed of light and reaches the earth's surface through the atmosphere. The sun's rays pass through it to reach the surface, and it partially reflects, scatters and changes their quantity and quality. Less than two billionths of solar radiation reaches the Earth, but it is the main source of energy for all physico-chemical processes occurring on the Earth's surface and in the atmosphere. There are different forms of light - direct sunlight when the sky is clear and diffused light when the sky is cloudy

Photovoltaic power generation is a technology for generating renewable energy from solar radiation. A photovoltaic (PV) solar cell is a device used to convert solar radiation into electrical energy using semiconductor materials. There are many types of photovoltaic (PV) solar cells, such as - polycrystalline silicon, monocrystalline silicon, thin film and amorphous [1].

Solar energy production from photovoltaic (PV), concentrated photovoltaic (CPV), and concentrated solar (CSP) systems has grown steadily in recent years due to the ever-increasing demand for energy, as well as environmental and economic concerns related to fossil fuel consumption.

The average amount of solar energy falling in one year on one square meter of horizontal earth surface, expressed in kWh/m^2, defines the theoretical resource of solar energy. The average annual duration of sunshine for Bulgaria is about 2150 h, and the average annual solar radiation resource is 1,517 kWh/m^2 [2].

Cleaning the surface of photovoltaic systems is a worldwide problem.

A comprehensive review of the dust problem on photovoltaic systems is given. There are expensive automated cleaning systems that have emerged in recent years, such as electrical, mechanical, chemical, and electrostatic. [3].

Self-cleaning materials have unique properties due to their practical applications in the field of energy and the environment /4/. The self-cleaning coatings that are applied to glass (a major part of solar panels) are divided into two categories: hydrophobic and hydrophilic. Both saw coatings are self-cleaning through the action of water. The first (hydrophobic) is cleaned by the rolling droplets, and the second (hydrophilic) by flowing water that washes away the dirt.

The key difference between hydrophobic and hydrophilic molecules is that hydrophobic molecules are non-polar while hydrophilic molecules are polar. Water is a well-known solvent for dissolving most of the compounds. There are compounds in nature that do not mix with water. Substances that can mix with water are called hydrophilic substances; substances that cannot mix with water are known hydrophobic substances. This is mainly due to the polarity of the water molecules. Non-polar compounds cannot be dissolved in a polar solvent. Polar compounds can dissolve in polar solvents. Nonpolar compounds dissolve in nonpolar solvents. Therefore, hydrophilic substances must be polar to dissolve in water

Photocatalytic TiO_2/SiO_2 coatings with excellent superhydrophilic wettability were investigated on lightweight polycarbonate substrates for self-cleaning applications [6].

Regardless of whether the surfaces are hydrophilic or hydrophobic, they characterize the molecular-scale self-cleaning mechanism of TiO_2 coatings.

Self-cleaning glass uses an organic process where dirt is broken down by daylight and then washed away by rain.

Hydrophilic coatings, which are based on titanium dioxide, have an additional property: they react with sunlight and thus help the chemical breakdown of accumulated dirt. This is a process known as photocatalysis.

Research is focused on hydrophobic and hydrophilic coatings. There are also disadvantages that prevent the mass use of these coatings. Hydrophobic material processing is an expensive and time-consuming technique, and the coatings produced are usually unclear, which precludes their applications in coatings on glass substrates. Self-cleaning coatings based on hydrophilic coatings that rely not only on the flow of water to wash away dirt, but also on sunlight, as the coating breaks down organic dirt while reducing the adhesion of inorganic dirt (Fig. 1, 2).

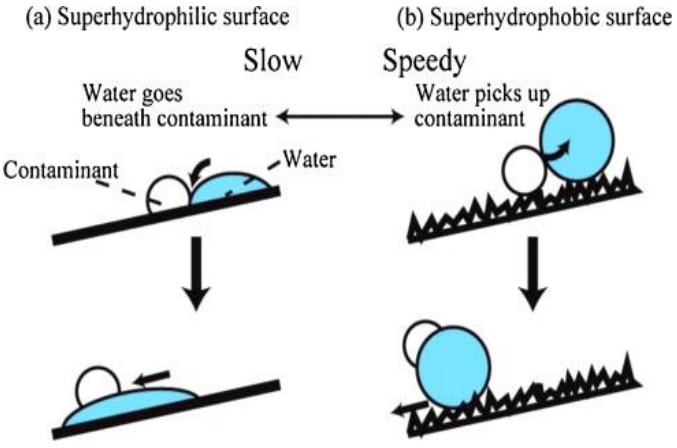


Fig. 1*. Schematic representation of self-cleaning processes on (a) superhydrophilic and (b) superhydrophobic surfaces.*

Table 1. *Contact angle and wettability*

Contact angle:	**Wettability:**
$\theta > 90°$	Hydrophobic
$\theta > 150°$	Superhydrophobic
$0° < \theta < 90°$	Hydrophilic
$\theta < 10°$	Superhydrophilic

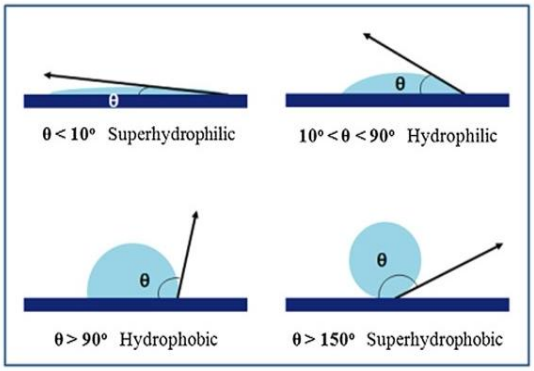


Fig. 2. *Schematic representation of a drop of liquid in equilibrium on a hydrophilic and hydrophobic surface.*

Research is focused on the participation of TiO_2 - as the main component in self-cleaning coatings.

Titanium dioxide TiO_2 is a versatile transition metal oxide that has a large number of applications such as protective coatings, photodetector, optical thin films, microelectronic devices, self-cleaning surfaces, and photocatalyst for the degradation of organic pollutants in wastewater. All these applications are a translation of their attractive properties such as high transmission in the visible region, wide band gap for the anatase phase (3.4 eV) and high photocatalytic activity under ultraviolet light [5].

Adsorption of hydrophobic molecules explains the self-cleaning properties of titanium dioxide. The possibility of aqueous photolysis has been investigated and a useful method developed. Water is transparent to visible light, it cannot decompose directly, but only by radiation with a wavelength shorter than 190 nm.

2. Experiment:

Many variants of coatings involving TiO_2, different types of solvents and silane derivatives have been investigated.

Glass substrates were cleaned in acetone to avoid any organic contamination and then washed with ethanol and water. Double distilled water was used for all experiments. Precursor materials such as $Ti(OCH(CH_3)_2)_4$ and silane derivatives were used for the synthesis of the coating layers. Isopropanol, ethanol and water function as solvents. Acetic acid is used as a chelating agent.

The goal of the research is to obtain self-cleaning glass intended for photovoltaics, construction, automotive and other fields. Applying a few nm thick titanium oxide coating to the outside of the glass creates two mechanisms by which the glass self-cleans. The first is the photocatalytic effect, where ultraviolet rays catalyze the breakdown of organic compounds on the surface. The second is the hydrophilizing effect, in which water forms a thin layer washing away the destroyed organic compounds.

3. Conclusions:

In conclusion, there should be continued research interest in the development of self-cleaning TiO_2-based materials to make the research a reality.

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Determining normalized friction torque of an industrial robotic manipulator using the symbolic regression method

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Abstract: *The goal of the paper is estimating the normalized friction torque of a joint in an industrial robotic manipulator. For this purpose a source data, given as a figure, is digitized using a tool WebPlotDigitizer in order to obtain numeric data. The numeric data is the used within the machine learning algorithm genetic programming (GP), which performs the symbolic regression in order to obtain the equation that regresses the dataset in question. The obtained model shows a coefficient of determination equal to 0.87, which indicates that the model in question may be used for the wide approximation of the normalized friction torque using the torque load, operating temperature and joint velocity as inputs.*

KEYWORDS: *GENETIC PROGRAMMING, FRICTION TORQUE PREDICTION, INDUSTRIAL ROBOTIC MANIPULATOR FRICTION, MACHINE LEARNING, SYMBOLIC REGRESSION*

1. Introduction

Artificial intelligence (AI) is one of the key tools used in robotics [1] and other fields such as medicine [2], epidemiology [3], complex system engineering [4] and others today. AI can be used in many different applications in robotics – path optimization [5], determining kinematics [6] and dynamics [7] of robotic manipulators, predicting grasp strength [8] or fault detection [9].

The goal of the presented research is to apply symbolic regression [10] to the problem of determining the joint torque of a robotic manipulator, when given the temperature, torque load of the joint, and velocity as inputs. As lowering of normalized friction torque can have a positive effect on energy use [11] and equipment durability [12] not just in robotics, but other fields as well, developing friction models is an important task [13]. Symbolic regression was chosen because it generates models shaped like equations, which allows for easier integration and later analysis of models when compared to the so-called black-box models [14].

The goals of this paper are to obtain a dataset from a previously performed research, given as a figure. After a simple formal analysis is performed on the extracted data, the genetic algorithm will be applied in order to perform symbolic regression on the collected data. The final goal of the paper is to demonstrate that symbolic regression can be applied to the dataset of this type, in order to regress an equation describing the relation of joint radial velocity, joint torque load, and working temperature as inputs to the normalized joint friction torque.

This paper will initially present the methodology of obtaining the data, followed by the short description of the symbolic regression process, with the results being finally presented and discussed.

2. Dataset generation

The data used in the presented research is obtained from an article by Garcia et al., dealing with determining the relevant factors for the energy consumption of industrial robots [15], in a form of a graph figure. The graph provides shows the relation of normalized friction torque to the radial velocity of the robotic manipulator joint. Four curves are given for the four different operating points – with combinations of two different variables. First variable is the torque load of the joint at two different values (0.01, and 0.70 Nm). The second variable is the operating temperature, also given at two different values (33 and 80 °C). The separate operating points will be marked separately in the software, and the above variables will be added manually when the final dataset is combined. To convert the graphed figure into the numeric data, a software WebPlotDigitizer [16] has been applied. Fig. 1 shows the interface of the WebPlotDigitizer software, loaded in a browsing window. The left and right side show the markup tools, while the middle shows the source image [15], with the manually marked points given in the middle.

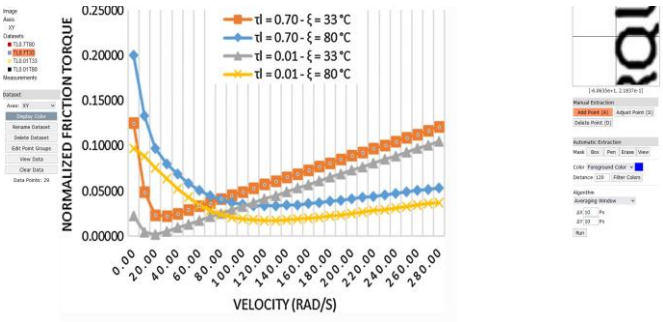


Fig. 1. *WebPlotDigitizer interface with the data points manually marked for extraction*

The process starts by marking two known points on x axis (in this case 60.0 and 240.0 have been used), and y axis (in this case 0.05 and 0.2 have been used). Then, each of the datapoints of the selected series are marked and their values are exported. This process is repeated with all of the separate data series, with the exports later merged in Microsoft Excel with the values of torque load and temperature added, as given in the original figure legend [15]. It should be noted that WebPlotDigitizer allows for automatic detection and extraction of data points, but this has yielded poor results – possibly caused due to data series overlap, so manual marking has been used. One thing to note regarding the manual extraction is the need for extreme precision and consistency in the manual marking of the data points, as mislabeling the datapoints, even by a little amount, will cause wrong values to be extracted. To confirm the proper extraction has been performed the data points are separately plotted and compared to the original data. Extracted data points are given in Fig. 2. The comparison between the original and extracted data shows that the extracted data is accurate.



Fig. 2. *Data points extracted using WebPlotDigitizer*

An example of 10 data points extracted from the figure are given in the Table 1. The data points in question are the first ten values given for the operating point of 0.01 Nm torque load and the operating temperature of 33 °C. As it can be seen the data extracted for the x-

axis shows a high precision, which is another indication of precise value extraction.

Torque Load	Temperature	Velocity	Friction Torque
0.01	33	5	0.021137026
0.01	33	15	0.002332362
0.01	33	25	0.000145773
0.01	33	35	0.004081633
0.01	33	45	0.008892128
0.01	33	55	0.010641399
0.01	33	65	0.015889213
0.01	33	75	0.020262391
0.01	33	85	0.024635569
0.01	33	95	0.028571429

Table 1. *Example of the extracted data points*

Statistical analysis can be performed on the extracted data. For each of the columns (torque load, operating temperature, velocity, and normalized friction torque) statistical descriptors (minimum, maximum, average value, standard error value and correlation to the output) are given in Table 2, along with other relevant information such as unit.

	Torque Load	Temperature	Velocity	Norm. Friction Torque
Minimal value	0.01000	33.00000	4.76190	0.00015
Maximal Value	0.70000	80.00000	285.71429	0.19956
Average	0.35500	56.50000	145.39135	0.05178
Standard deviation	0.34650	23.60195	84.24268	0.03275
Output correlation	0.31778	-0.22761	0.20264	1.00000
Output covariance	0.00361	-0.17596	0.55914	0.00107
Unit	Nm	°C	rad/s	-

Table 2. *Descriptive statistics of the extracted data*

In the extracted data the first three columns (torque load, temperature, joint velocity) are defined as inputs, while the normalized friction torque is defined as the output for the AI methods described in the following section. Torque load and temperature have only two possible values (0.01 and 0.07 for torque load and 33 and 80 for the working temperature). Torque load shows the highest correlation, but the lowest covariance to the output. Temperature shows negative correlation and covariance indicating that a higher work temperature equals a lower friction torque. Finally, the joint velocity ranges between 4.76 and 285.71 rad/s. It shows the weakest correlation amongst the input values, but the highest covariance to the output variable. The output variable itself, normalized friction torque, ranges between 0.00015 and 0.19956. The average value is 0.05178 with a standard deviation of 0.03275.

3. Genetic programming

Symbolic Regression with the use of Genetic programming is a hybrid technique combining elements of both evolutionary computing [17] and machine learning [18]. It works by generating random equations, which are tested against the existing data to determine the quality of each individual equation [19]. Then, three operations are applied to these equations, with those equations that provide a better fit being more likely to be selected [20]. These operations are crossover, mutation, and reproduction. Crossover combines two solutions into one, with the goal of obtaining a better overall solution by combining two good ones [21]. Mutation randomly changes a solution to introduce a random change, which allows stagnation of solutions, and to possibly obtain a higher quality solution through a slight modification to an existing good solution [22]. Finally, reproduction allows for a good existing solution to be copied into the next iteration of the algorithm, in order to preserve good solutions for further use [23].

The equations generated by the genetic programming are given in the tree shape, with each function being given as a root node for the operation with the operands as the child nodes. For example, a simple equation such as $y = \sin(x) + x$, would be written as $add(\sin(x), x)$. For that reason, the equations that are generated can be converted and simplified using automatic software, such as Sympy [24], that will allow us to render the obtain equation in a more commonly understood format.

In the presented paper the genetic programming was implemented using GPLearn Python library [25]. The number of possible solutions in each of the algorithm iterations is set to 5000, while the number of algorithm iterations is set to a maximum of 200, with the possibility of the algorithm stopping in the case of early convergence to a satisfactory solution ($R^2 > 0.99$). Probability of crossover, mutation and reproduction are set to 0.7, 0.2 and 0.1 – respectively. All of the other settings are left at default values. The manual tuning was selected due to the GP not being overly sensitive to the hyperparameter selections [26], and the belief that these parameters, set based on the experience obtained during the previous research in the field could be used to obtain a satisfactory solution [27, 28, 29].

The models are evaluated using coefficient of determination (R^2). R^2 provides the information of how much of the variance in the original data is contained in the predicted data, or in other words – how well does the model predict the data as the output varies [30]. It is a commonly used metric for determining the quality of predictive models [31]. The value of R^2 is a float which ranges from 0 to 1, where 0 indicates no variance of the original dataset is present in the predicted data, while 1 indicates all the variance in the original dataset is present in the predicted data, or in other words – a perfect prediction [32]. This means that higher values of R^2 indicate a better prediction. R^2 is calculated according to:

$$R^2 = 1 - \frac{SS_{RES}}{SS_{TOT}}, \tag{1}$$

where SS_{RES} and SS_{TOT} are calculated as:

$$SS_{RES} = \Sigma(y_i - \hat{y}_i), \tag{2}$$

and

$$SS_{TOT} = \Sigma(y_i - \bar{y}). \tag{3}$$

In the above equations, $\hat{y}_i$ represents the predicted value corresponding to the value y_i in the dataset, while $\bar{y}$ is the mean output value of the dataset.

4. Results and discussion

The results show a coefficient of determination equal to 0.86. This score indicates a model that is good for a general approximation, but it is not precise enough to obtain a high-quality predicted value for the given input parameters. So, while the model may not be used to get the exact value, it can be used for a general approximation of the expected normalized friction torque.

At the end of the execution the model is saved in the shape of the equation, in the previously described tree shape – which may not be

optimal for further implementation as it cannot be directly integrated in most programming languages or tools commonly used. The obtained equation from the model is given as:

$$div(div(add(mul(div(X0,X2),div(add(X1,X2),mul(X2,X1))),sub(mul(add(X0,X2),div(X0,X0)),sub(mul(X1,0.400),add(X2,X1)))),add(sub(div(add(0.129,X2),sub(X2,X2)),mul(add(-0.216,-0.932),div(X0,X0))),sub(mul(div(X0,-0.896),div(X2,X0)),div(sub(X2,0.129),sub(X1,0.987))))),mul(div(sub(sub(add(0.889,0.692),mul(X1,X1)),div(sub(X2,X2),sub(X2,-0.071))),sub(mul(mul(X0,-0.640),div(X1,X0)),sub(add(X1,X2),mul(-0.579,X2)))),div(add(mul(mul(0.645,X0),div(X0,X1)),div(div(X1,0.320),add(X0,X1))),div(div(mul(-0.825,X1),div(X1,X1)),add(add(X0,X0),add(X1,X1))))) \quad (4)$$

where the symbols *X0*, *X1*, and *X2* indicate torque load, temperature and the joint velocity. As the above can be hard to read and interpret we can simplify it and convert it to a more commonly used equation form using Sympy [24]. This allows us to obtain the simpler equation given below:

$$\frac{A}{B}. \quad (5)$$

Due to the length, the equation is expressed with two coefficients *A* and *B*, with the coefficients in question being defined as:

$$A = -0.825\xi \cdot (-1.64\xi - 1.579\omega)(\tau_l + \tau_l\ (\xi + \omega)/(\xi + \omega^2) + 0.6\xi + 2\omega), \quad (6)$$

and

$$B = \left((1.581 - \xi^2)(2\tau_l + 2\xi)\left(0.645\tau_l\frac{2}{\xi} + \frac{3.125\xi}{\tau_l + \xi}\right)\right) \cdot \left(1.15\omega + 1.148 - \frac{\omega - 0.129}{\xi - 0.987}\right). \quad (7)$$

For easier understanding, in equations 6 and 7, the symbols *X0*, *X1*, and *X2* have been replaced using the appropriate physical symbols used in the original paper [15], according to the following:

- Torque load on the joint of the manipulator – τ_l,
- Operating temperature – ξ, and
- Radial velocity – ω.

5. Conclusions

The presented results show that achieving a regressive model with some degree of accuracy is possible using an algorithm that provides an open model that is easy to integrate. Still, the results do show that the precision achieved is not high enough to be used in application where an extremely high precision of the model is necessary. The achieved results could be improved in a couple of different ways. First is the application of different regression methods to the dataset which have shown to perform better on similar datasets, such as multilayer perceptron artificial neural networks, or gradient boosted trees. The second is collection of more data-points, either through direct measurement, collection of data from other papers with similar themes as the one the data for the presented research has been collected, or synthetic data generation. Finally, the precision could additionally be improved by adding additional input variables into the dataset, as this could provide additional information to the model that would allow for a higher precision regression.

In the addition to the above, the article shows that it is possible to prepare datasets for machine learning from previously existing figures that visualize potential input data using the data extraction tool like WebPlotDigitizer. This opens up possibilities of using a significant amount of existing non-digitized data from previous research, allowing for a wider application of data-dependent techniques such as machine learning.

Finally, the results demonstrate that it is possible to achieve a somewhat precise models of normalized friction torque using torque load, operating temperature and the radial speed of the robotic manipulator joint using genetic programming, although future work should focus on significantly improving the regression quality of these models through previously described approaches.

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Perspectives of digitization of primary health care services

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Abstract: *In today's globalized world, digital mechanisms are rapidly working through the inner layers of the economy, influencing and attracting those who shape, regulate, drive and manage the economy. The main approach here is the active application of new technologies - digital mechanisms, in the processes taking place in any sphere of the economy, including health care. Rapid advances in technology have necessitated the creation and implementation of new models for delivering quality primary care services. The COVID-19 pandemic has also highlighted the need for innovative digital solutions in health care. For these reasons, the formation of integrated models based on the application of new technologies in the context of the digital transformation of health systems is a guarantee for the delivery of quality primary health care services. The article examines the content and possibilities of digitalization of primary health care services, health technologies and areas of application, focusing on new technological opportunities, and the effectiveness of digital health services.*
Keywords*: DIGITAL PRIMARY HEALTH CARE SERVICES, HEALTH TECHNOLOGIES, DIGITAL HEALTHCARE*

1. Introduction

The provision of more equitable, comprehensive and integrated health services worldwide is a key objective of health systems. The Astana Declaration also states that primary health care is the cornerstone of universal health care and represents the most comprehensive, effective and efficient approach to improving people's physical and mental health as well as their social well-being [17]. Primary health care is the provision of comprehensive and accessible health services by physicians, based on meeting personal health needs, developing sustained partnerships with patients and providing health care in a family and community context [10]. As the revolutionary impact of the Internet increased, as information and communication technologies became more advanced and pervasive in society, the use of new technologies in health care expanded and new benefits for health care were demonstrated. From technologies that enable better management of human health, to diagnosis and monitoring of diseases, all digital health technologies have a profound impact on health service delivery and health system management. The use of digital technologies not only improves the quality of primary health care, but also acts as an important means of enhancing the capacity, knowledge and skills of health professionals [18].

1.1. Defining high-quality primary health care

Improving the availability, accessibility and quality of health services is at the core of primary health care [16]. This approach suggests some thoughts about primary health care. First, primary health care should be based on an ongoing partnership between health-care providers and patients. As these services span childhood, adolescence, adulthood and old age, the relationship between the two parties is important throughout the life of the patient. Second, primary care services should be provided in the context of the patient's family and the wider community. Thirdly, primary care services should be provided in a more integrated and accessible system. Although these ideas are accepted as standards, there are a number of limitations in their practical implementation [12].

Quality primary health care is the provision of comprehensive, integrated, accessible and equitable care through an ongoing relationship with patients in a variety of settings [16].

Factors that determine the quality of primary care services include:

- Payment models - payment models that support integrated professional teams working in constant contact with patients can ensure the provision and maintenance of high-quality primary care;

- Improving accountability and quality - effective measurement of important primary care functions can improve quality over time;

- Digital health - effective use of technology can make health services more accessible and professional practice more efficient, quality and convenient for individuals and professional groups;

- Inter-professional teams - coordinated work by appropriately qualified doctors and other professional groups can improve public health;

- Research - gathering empirical evidence on the epidemiology, organization and delivery of primary health care can contribute to continuous improvement in this area;

- Leadership - coordinating the work of those responsible for primary health care services can increase accountability and ensure uniform decision-making in this area;

- Laws and regulations - regulations and legal documents containing conditions for the provision of primary health care services can enable stakeholders to make necessary changes [12].

It should be noted that instilling a culture of quality in primary care is the basis for continuous quality improvement. Quality improvement depends on clear and accurate performance measurement data at the patient, provider and, more broadly, population or system level. Health management systems and information systems are considered a necessary component for changing and improving the quality of primary health care services. Consideration should also be given to global geographical disparities in access to technology, taking into account the need for systems of collection, measurement, reporting and feedback in developing ways to improve primary health care [20].

2. Digital health in primary care

In recent years, advances in software, data storage and high-speed Internet bandwidth, as well as the widespread use of smartphones, have stimulated the introduction of new technological products into modern health care and contributed to the growth of the digital health industry [12]. For example, e-health can be used to establish an online doctor-patient relationship, provide training to health professionals through online learning, monitor common diseases and epidemics, and promote and advance individual health care and public health. The digitalization of health thus provides new tools to strengthen the health sector as a whole at local, national, regional and global levels. The use of these tools can reduce costs, speed up the process of care, save time, control the use of medicines, reduce logistical problems, etc. [19]

Increasing demand for primary care has encouraged potential innovative changes in health care ecosystems. Digital technologies have been used to improve the availability and efficiency of services. The use of technologies that collect, process, manage and evaluate health information, as well as the use of technologies that provide appropriate advice to patients. However, differences in technology acquisition and boundaries between traditional health

and modern innovative health are difficulties in the use of digital health technologies. In addition, there is always an increase in mobile applications and new technologies available to patients, but also challenges in terms of evidence, regulation and evaluation. It should also be considered that a sustainable and effective trainer of the workforce and patients providing primary health care services must be provided [13].

Digitalization of primary care services is considered successful when the infrastructure is continually improved, regulations and management guidelines are developed based on principles of equity and accessibility, primary care professionals and patients are involved in digital decision-making, regular training is provided and health data privacy and security are assured [14].

2.1. Digital technologies in primary health care services

There are currently two trends in digital health: 1) patient-centred technologies such as personal health records, patient portals and mobile health apps are developing rapidly; 2) primary health care, including family practice, is being promoted as an important factor in reducing overall health care costs and improving health outcomes. As a result of these trends, all types of digital health technologies, which offer opportunities for patient-centred and personalised services, act as solutions to many primary care problems. Primary care providers face challenges in processing a wide range and volume of clinical data. Of course, the human mind cannot keep up with new types of advances all the time. Ultimately, this leads to the emergence and increasing need for virtual support. As primary health-care services span from childhood through adolescence, into adulthood and old age, health-care providers depend heavily on such technological support to provide all necessary services to the population. International experience suggests that technologies such as Electronic Health Records (EHRs), Big Data and Telehealth, which provide virtual consultations, are being used more in primary care. [5, 14]

Electronic Records are a digital version of paper-based patient records, but are designed to go beyond standard clinical data to include more information about a patient's health. Several concepts are distinguished in this context: - Electronic health record (EHR) - a dataset created and stored in a healthcare facility that provides access to patients' medical records to patients, doctors, employers and other interested parties; - Electronic Medical Record (EMR) - legal patient data created in hospitals and outpatient facilities (regarded as the source for EMR); - Electronic Personal Health Record (EPR) - active management of and access to a patient's own information.

Sharing medical information with patients can improve the level of communication between patient and doctor, the quality of treatment and, ultimately, treatment outcomes. Here, special attention should be paid to ensuring access to electronic records for different population groups and eliminating inequalities in their use. [9, 14]

Big data is the term used to describe the large volumes of data created by digital technologies that collect patient histories and help manage healthcare operations. Beginning in the 1960s, information technology was first used to collect and process large volumes of various statistical data in medicine. The volume of data has only increased significantly in the last 15-20 years due to the digitalisation of healthcare. Although much medical data is still stored on paper, there is a trend towards rapid digitisation. Patient portals, research, electronic medical records, wearable devices, search engines, shared databases, etc. They are components of "big data". [7, 11]

Telemedicine. Conducting consultations with patients via videoconferencing and various portals, remote diagnosis of vital functions, transmission and exchange of medical images, laboratory tests, electronic personal data, including continuing medical education, etc. are considered part of telehealth. According to studies, 90% of the world's health care institutions have begun using telemedicine technology. Using the latest innovations in telemedicine, it is possible to reduce healthcare costs, increase efficiency and profitability, and offer affordable and accessible services to patients. Mobile telemedicine devices have already appeared in countries around the world. [12, 1]

Augmented Reality (AR) and Virtual Reality (VR). AR and VR are some of the most advanced and cutting-edge technologies used in the healthcare system to improve the quality of healthcare services and patient care. Most of the virtual reality technologies currently used in healthcare are used for educational purposes. Creating virtual learning opportunities for healthcare professionals can help improve their skills and training. [4]

2.2. Digital primary health care services during COVID-19

The use of new technologies to develop 'smart' care is growing. As networks of people and technology become increasingly interconnected, healthcare organisations need better tools to address large-scale challenges. The COVID-19 pandemic, demonstrated once again the need for better data and information-sharing systems between health systems, governments and other organizations. During the pandemic, big data from various sources grew rapidly. "Big Data created new opportunities to meet the challenges of storing, processing, sharing and using this data. The conditions have also been created to prevent the spread of the virus by analysing medical data in real time using artificial intelligence technologies to detect the virus. Medical software and application downloads increased by 65% during the pandemic. According to the survey, 46% of 5,000 respondents used telemedicine services during the COVID-19 pandemic. 56% of users reported that telemedicine services were easy to use. Overall, 77% of patients were satisfied with the use of these services, which can be considered a significant victory for health professionals. [2, 3, 15]

3. Conclusions

The digital transformation of the health care ecosystem is changing the expectations of society as a whole, which requires the introduction of new technologies to improve the quality and accessibility of health services. Specific knowledge and skills are needed to understand, implement and regularly evaluate new health care innovations. In this context, primary care providers need to be involved in the development and implementation of digital solutions, and patients and healthcare providers need to be continuously trained. Infrastructure, information sharing and security, regulations and standards also need to be improved. Most importantly, digital health services must prevent existing inequalities from worsening. Collaboration between all stakeholders in the health system can help to achieve this goal.

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Public Procurement as a Demand-Side Policy Instrument

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Abstract: *Public procurement has acquired new dimensions in recent decades, going beyond the elementary satisfaction of certain needs. Public procurement connect to public policies through its horizontal nature. In present study, public procurement is perceived as an important demand-side policy instrument that can effect both the speed and the direction of economic development. A key argument supporting the view of public procurement as an important policy instrument is that they accounts for about 14% of EU GDP. At the same time, governments frequently overlook procurement as a policy instrument (and demand-side tools in general). The study of public procurement as a policy instrument, given their proven market effect, merits further analysis. Hereof, this research is focused on exploring strategic procurement approaches for economic development. Actually, through public procurement, governments can contribute to the development of growth-generating economy sectors in the role as an important lead consumer by setting standards and exacting superior performance.*

Keywords*: PUBLIC PROCUREMENT, STRATEGIC PUBLIC PROCUREMENT, PUBLIC POLICIES, PUBLIC POLICIES INSTRUMENTS, ECONOMIC DEVELOPMENT, HIGH TECHNOLOGY*

1. Introduction

In recent decades, public procurement rules are no longer just about that 'how to buy' - they offer incentives for about 'what to buy'. The concept of Value for Money (VfM) emergence and development lead the understanding that contracting authorities buy strategically, without aiming only the lowest price achievement. Desire expression for better and sustainable public finance management is the focus rising to strategic public procurement in recent years. Public sector expenditure through the public procurement system forms 14% of The European Union (EU) gross domestic product (GDP) [1]. This amounts more than 1.9 trillion euros. This enormous purchasing power refers in particular to sectors such as energy, transport, defence, IT and healthcare services, where the public sector is a key demand source.

Redirecting public sector purchasing strength through strategic procurement can become a powerful demand-side instrument for maximizing policy outcomes in a number of areas.

2. Public Procurement and Public Policy

2.1. Strategic Public Procurement

The notion of public procurement pithily assumes so that procurement is awarded in areas intended to satisfy public needs. Public procurement can be defined as "the acquisition by means of a public contract of works, goods or services by one or more contracting authority from contractors chosen by them, intended for public purposes or for the needs of public authorities, and in the case of utilities - for sectoral activities' implementation [2]. The rationale, purpose, and starting point of public procurement should always be to solve societal problems, to satisfy human needs, or to meet global challenges, such as environmental or health problems [3]. The concept of sustainable development through the public procurement prism, brings procurement into a strategic dimension beyond the elementary certain needs satisfaction. Strategic Public Procurement (SPP) involves the awarding of environmental ("green"), socially responsible and innovative procurement. SPP affects all sustainable principles' sub-dimensions (Fig. 1).

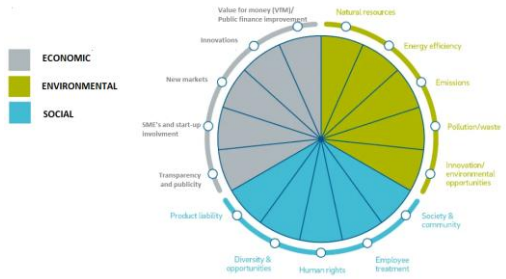


Fig. 1: *Strategic Public Procurement affects all sustainable principles' sub-dimensions*

Strategic or sustainable public procurement is defined as a process by which organizations procure goods, services and work in a way that achieves value for money based on the life cycle costing (LCC) of products and services and generates benefits not only for the organization but also both for society and the economy, while minimizing environmental damages. LCC is a methodology where costs of a given asset are considered throughout its life-cycle. It is a method for directly calculating and comparing the real costs of different alternatives for use in procurement decision making (Fig. 2).

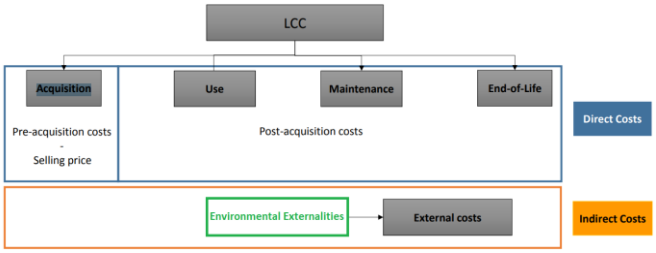


Fig. 2: *Life-cycle costing (LCC) in public procurement*

On the other hand, "green" public procurement can be considered as a process by which public authorities seek to obtain products, services and construction works with a reduced impact on the environment. Socially responsible public procurement takes into account one or more social considerations to achieve social goals, and innovative procurement involves purchasing of innovation process or results. In all cases, the aims of strategic procurement go beyond a specific need satisfaction.

The total value of public procurement contracts in the EU determines their significance. It is not only a key pillar of strategic management and service delivery, but also a key economic activity. If used strategically, public procurement can improve the market economies competitiveness as well as to help important policy outcomes delivery in response to today's societal and economic challenges, especially these relevant to sustainable growth and employment. Smart contracting achieves best value for money (VfM). Public authorities demand can significantly enforce and strengthen markets for innovative, environmentally and socially responsible goods, services and work. Governments need to admit the importance and encourage the use of public procurement as an instrument to address both budgetary bottlenecks, caused by the crises, on the one hand and to achieve the strategic challenges on the other.

2.2. Public Procurement as a Demand-side Policy Instrument

Public procurement links to public policies through its horizontal nature. Public procurement is in general an instrument of all sectorial policies. It is due to the fact that at all policies carried

out in the EU member states is carried out through the expenditure of public funds, in compliance with the common legislation.

On the other hand, the study of public policy refers to what the state does, to its activity in respect to community cohesion and to uphold a certain society orderliness. The public policy approach is a continuation of theories about the modern state, which through its legitimate institutions brings rationality to society. A classic understanding of public policy is that it is whatever governments choose to do or not do [4]. The truth is single definition does not exist - there is a whole concept behind the notion. The concept of public policies refers to the measures government stand behind and which cause a change in the behaviour of individuals and after all - in the community development [5]. One of the public policy science basic assumptions is that it can be defined as a temporary organization for goals achievement. In the same vein public policy could be considered as a governmental supported actions that are taken to change the social environment in the community desired direction [6].

The measures by which legitimate authorities and their institutions achieve the goals formulated at the political level are in fact the public policy instruments [7]. Instruments are part of public policy actual implementation [8], and may serve different purposes and lead to different results and effects. That implies the policy instruments choosing is an important policy formulation point, as it have a direct effect on implementation outcomes. In other words, and this can be taken as a conventional and general definition, the public policy instruments are the set of techniques that government bodies exercise their power by in an attempt to ensure support and effect (or prevent) social change. They represent management techniques that in one way or another involve state power usage or its deliberate limitation. This is no surprise that instruments can be and have been categorized in a variety ways in the scientific literature. Thus for example, according to its nature, they can be mandatory or voluntary, according to the sphere - social or economic, etc. (Table 1).

Public procurement can be considered as a public policy implementation economic instrument. Some authors even consider public procurement as part of a new generation innovation policy instruments. On the other hand, according to its inherent market impact, public procurement participates as a demand-side market mechanism. Supply and demand are major catalysts in the "Smith's invisible hand" motion. It is well known that the demand should be supported not only by a willingness and need for a certain good, but also by sufficient resources for its provision. Hence, a key argument supporting the view of public procurement as an important policy instrument is the exactly significant amount of public expenditures through the public procurement system. Considering the high funding potential, public procurement can be regarded as an important *demand-side policy instrument* [9, 10, 11], that can effect both the speed and the direction of economic development.

It is important to pay due attention to the need of equilibrium when choosing supply' and demand' side instruments in the process of policy design-making. Most policies architecture are focused on the supply side, concentrated on conditions creation and specific technological capacity provision in the economy. Hence, supply side policy instruments are mainly used. This may leads to a distortion of a results and failure in goals achieving, according to some authors. Moreover, these authors consider a demand-side instruments based policy as more effective than that based on supply-side policy instruments [12, 13, 14]. For example, if the market is formed on the supply basis, it is possible that the consumers will not be able to satisfy their needs with offered solutions. On the other hand, if weak consumer activity, the proposed solutions would not be successfully commercialized. This is no-win situation - neither for consumers ("demanders") nor for suppliers.

Recently, this perspective seems to have gained popularity, both in science and in the practice of governments, including at the European level. The focus on the demand side receive more and more attention. Over the years, public procurement has been used to achieve various political goals. The use of public procurement as a political instrument is by no means a new phenomenon. Following McCrudden: [It is not too much of an exaggeration to say that modern procurement systems evolved along-side the development of the Welfare State, and it is hardly surprising that the former was used in part to underpin the goals of the latter] [15]. Development of understanding reflects and responds to the growing EU concerning on how to maintain a competitive advantage in a globally competitive economic environment. The fact that countries such as the USA or Japan, which have adopted more strategically focused public procurement policies, outperform the EU on a number of economic indicators further justifies this point of view. According to The European Commission, public procurement have an important potential for [16]:

- Boosting the economic recovery, the green and digital transition and the resilience of the EU;
- Delivering higher quality public service on an optimal budget;
- Addressing an arising need;
- Modernising public services;
- Helping start-ups and innovative SMEs launch and grow;
- Moving markets towards innovation.

2.3. Strategic Public Procurement - Market Effect

Conceptually, in the public procurement process, at least two types of participants cooperate - the contracting authority and the candidate/participant(s). In the case of SPP, this interaction aims to solve a specific "problem". Even more, it is the satisfaction of an identified need of public interest in the case of public procurement. The solution itself is achieved by using the available knowledge among the participants that implies the mobilization of the existing knowledge and potential of the market. Considered as an act, SPP is a special case of consumer-supplier interaction. [17]. Within this interaction, interactive learning takes place [18] - per se as a social process governed by institutions [19]. In this way, public authorities participate in the market supply formation through the public procurement system.

Except as a demand coordination instrument, the SPP, including innovative public procurement can contribute to a faster introduction of new technologies (solutions). Potentially, another added market value of public procurement is related to technology transfer. Too often there is a gap (a phenomenon known as the "valley of death") between innovative solutions and their final commercialization. Thus, when contracting authorities act as start-up customers or first clients. Public authorities can "create" an innovation directly as a response to a need identified by acting as a *"proxy customer"*. It is also necessary to consider the relationship between strategic public procurement and the economic growth and stability creation, due to the ability of public procurement to "open up" the market for small and medium-sized companies, including start-ups.

Public procurement "greening" is, in turn, a powerful instrument for improving environmental performance in a variety sectors, such as energy, transport, healthcare, where the public sector is a key demand source. "Green" requirements usage inevitably provokes the creation of high technologies that both meet the contracting authorities' specific needs and also are in line with the green transition goals. In addition, strategic public procurement stimulate cooperation between different market participants.

3. Strategic Public Procurement – How to Use the Potential?

SPP approaches and practices research is a matter which relevance is reinforced by the complexity of the tasks to be solved in the modern public administration agenda.

Stimulation of SPP application require a certain amount of mandatoryness of the instrumentarium. Regulation refers to the rules applying by public and government bodies to impact the behaviour of the private actors in the economy. Hereof, it may have an effect on the performance (quality, compatibility) or consequences (health, safety, environment) of the products, services or works (construction) [20]. According to the EU public

procurement legislation in force, the applying nature of this type of procedure awarding is voluntary, left in the field of discretionary power. In some areas, such as the automotive industry, construction or packing and packaging, regulations set minimum, mandatory environmental requirements. So far this regulation approach remains sporadic. On the other hand, a holistic approach is the introduction of the principle of sustainability, as the main one in the public procurement regulation, along with those the Treaty on the Functioning of the European Union resulting from.

On the second place, policies should 'recognise' public procurement as an instrument to achieve the goals formulated. Hence, public procurement issues should be deliberate during the strategic documents development for each specific policy - strategies, action plans, etc. On the next place, public procurement is a significant element of public finance management, sensitive to social and economic environment changing, the political and private interests. As such, it is a complex and often changing matter that requires and implies management capacity building. Only in this way, public sector organizations can be strong participants in the process of unfolding the potential of strategic public procurement and could derivering maximum benefits from.

In a practical point of view, some approaches and practices would contribute to the public procurement application as a demand-side policy instrument strengthening. Such are, for example, functional procurement - based on functional specifications and quality-oriented award criteria.

In general, after needs identifying, procuring authority normally describes the desired goods, services or works characteristics in the tender documentation (more precisely in technical specification). Usually technical specification describes very precisely and in detail the requirements for procurement object (that means describes existing 'off-the-shelf' goods, services or works). This type of procurement is known in the literature as a *public regular procurement*. Such a regular procurement examples are stationery delivery, telecommunication services, repair and maintenance of building stock works, etc. A large number of regular public procurements are perfunctorily conducted, i.e. the procuring authority describes the same product as in previous procurements in a routine manner. This manner poses risks for sustainable market development. Such repetitive product procurement leads to lock-in situations and inertias sooner or later [21].

Increasingly, the application of the so-called *"functional"* over conventional "technical" specifications in the SPP context is considered, as an approach to drive market potential. Functional specifications are oriented towards describing the final result desired. So in case of functional procurement, procuring authorities describes the function to be performed or the problem to be solved (functional specification) instead of describing the product that is to perform the function. Hereof, they specifies *what* to be achieved rather than *how* to be achieved. This description may represent a reformulation of the need or "problem". In this way, an opportunity for the economic operators to use their potential and to "produce", commercialize or adapt the available arsenal of solutions to meet the requirement is provided. In turn contracting authority has the opportunity to choose the best solution. So-called *functional public procurement* can become an important policy instrument. The probability that the "solution" will be provided in the form of new and/or high technology with respect to the principles of sustainability increases. Inviting the market to satisfy a specific need or solve a specific problem can also be seen as an instrument to improve competition and public-private partnership.

In addition to functional specifications, which application is very weak in EU, a way to "strategize" the procurement process is applying of other than "the lowest price" award criteria. Data show that the proportion of procedures awarded based on "the lowest price" in EU is equal to 80% [22].

As mentioned, the main formula for the development of sustainable and modern, high technologies and solutions is their appropriate funding. In this sense, the path to sustainability and resilience implies the application of the VfM concept and the quality criteria preference when choosing the needs satisfaction way. Inclusion of all the costs in the procurement process trought LCC award criteria is another useful practice.

Summed up, it seems that SPP as a process require sustainable principles consideration on all procurement cycle stages but mainly in planning, forecasting and preparation ones. Also cooperation and information exchange with all stakeholders is needed, incl. economic operators, end users, etc. Functional procurement and quality award criteria is also appropriate. To be effectively complete SPP also imply post-contract management - assessment and lessons learned (Fig. 3).

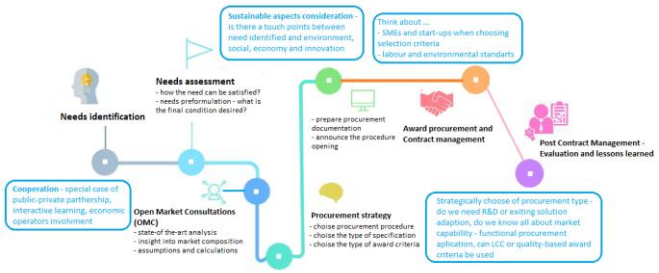


***Fig. 3** SPP Process Example*

As can reasonably be concluded, the implementation of this type of procurement, due to the complex nature of the matters and multi-decision-making, requires a high professional administrative capacity. This issue merits higher attention and deeper analysis.

4. Conclusion

Possible approaches and practices for strategic public procurement consideration of is a matter relevance is reinforced by the complexity of the tasks to be solved on the modern public administration agenda. Strategic public procurement contributes to increasing the added value of public funds spending. It would potentially maximize public policies outcomes in various areas through involvement of the public sector purchasing power. The question is to unfurl and guide this potential. On the way of dealing with nowadays challenges, the SPP opportunities should not be overlooked. It should be considered as an important aspect when designing or redesigning policy instruments. It is necessary that the strategic approaches and practices should be systematically applied for optimal results achievement through the public procurement as a demand-side policy instrument. This can be facilitated through broad political and practical support.

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Analysis of Public Sentiments and Emotions in the Government Domain

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Abstract: *Digitalization of public services is a key component in the development of e-government. Citizens' opinion, needs and overall satisfaction with the provided services are key to the successful implementation of digital transformation across the government sector. Hence, for policy makers it is highly important to develop efficient methods for analyzing public opinion. The main aim of this paper is to use unconventional apparatus to mine public opinion in the Bulgarian government sector. The proposed approach relies on the application of natural language processing and text mining techniques. The study aims at discovering the sentiments and emotions freely expressed by citizens in popular social media websites in Bulgaria. Several topics of public interest are analyzed and insights on public perception of aspects of Bulgarian e-government are derived. Furthermore, benefits and limitations of using sentiment lexicons for mining public opinion are outlined.*

Keywords*: E-GOVERNMENT, PUBLIC SERVICES, DIGITALIZATION, SENTIMENT ANALYSIS, EMOTION MINING, NATURAL LANGUAGE PROCESSING, TEXT MINING*

1. Introduction

Digital transformation is a topic of wide public interest and importance not only for the industry (Industry 4.0), but also for the government sector. Digitalization of various public services is a key component in the development of e-government [1]. The burst of the COVID-19 pandemic emphasized even more the importance of digital transformation. Despite the undeniable negative consequences of the pandemic on people's life and overall well-being, it should be noted that this huge challenge had a positive effect on the path to digital transformation. The business was forced to digitalize many services sooner than planned. Take the tremendous change in the bank industry, for example [2]. Policy makers also had to speed up their plans for the development of electronic public services and the improvement of already existing ones.

There are many complex factors that influence e-government in terms of speed of development and quality of the provided services [1]. Citizens are the main users of mobile applications or other types of electronic services in the government domain. Their opinion, pain points, needs and overall satisfaction with the provided services are key to the successful implementation of digitalization across the government sector. Hence, for policy makers it is highly important to develop efficient methods for studying and analyzing public opinion. Digitalization of public services in Bulgaria has been a controversial topic which gained a lot of attention in the recent years. The analysis of public opinion on this hot topic has been mainly performed with the help of surveys and in-depth interviews.

The main aim of this paper is to use unconventional apparatus to mine public opinion on digital transformation in the Bulgarian government sector. The proposed approach relies on the application of natural language processing and text mining techniques. The study aims at discovering the sentiments and emotions freely expressed by citizens in popular social media websites in Bulgaria. Several topics of public interest are analyzed and insights on public perception of aspects of Bulgarian e-government are derived. Furthermore, benefits and limitations of using sentiment lexicons for mining public opinion are outlined.

2. Related Work

In this section, we provide a brief review of related work in the field of public opinion mining in the government domain as well as a summary of current methodologies for the application of sentiment analysis on textual data. Rongxuan, Bin and Jianing [3] propose an analytical approach for the analysis of public reviews about government apps. The authors utilize deep learning techniques to develop an aspect-based sentiment analysis system. The practical implications of the study are important in the e-government domain since the developed system is capable of capturing users' emotional needs and reactions to features of government apps. In [4] is proposed a business intelligence system aimed at tracking citizens' discussions, opinions and general satisfaction with policies of the Mauritanian government. Authors employ sentiment analysis techniques and develop a dashboard in an attempt to help the government in easier tracking of topics of public interest and sentiment polarity of public comments posted in social networks.

In [5] are analyzed citizens' tweets about the "Digital India" initiative. Citizens' attitudes towards the campaign are first manually labeled into several categories followed by the application of techniques for descriptive analysis and discovery of verified Twitter accounts (for example, the Twitter page of Digital India) which received highest number of supportive/criticizing comments. In [6] is proposed an analytical approach for detection of propaganda against e-government. Deceiving information posted online carries major reputational risks and might have a huge impact on the development of digital public services. The proposed approach in [6] relies on the application of sentiment analysis techniques in order to detect hidden social networks and analyze in detail the negative comments about government services and the connections between users who wrote them. The main aim in [7] is to develop a sentiment analysis system that incorporates a neutrality detector model in the analysis of user opinions of an online payment system used by the government sector in Jordan. Authors create a sample of public comments posted in Facebook and Twitter which are manually annotated as expressing "positive", "negative" or "neutral" sentiment. The proposed approach relies on the application of machine learning techniques for sentiment classification.

Sentiment analysis is a broad research field focused on the extraction and analysis of people sentiments, opinions and attitudes expressed in textual data towards various topics of interest [8]. In [9] the sentiment analysis field is broadly divided into two related but different concepts – namely, opinion mining and emotion mining. Opinion mining mainly concerns the analysis of expressed sentiments in their polarity utilizing three main sentiment categories – positive, negative and neutral. This task is also known as opinion polarity classification [10]. On the other hand, emotion mining concentrates on the emotions reflected in a given text [9]. Emotions can be described utilizing a wider range of categories far beyond classifying them as only positive, negative or neutral. For example, emotions expressed in a given text might be categorized as joy, anger, fear etc.

Despite the difference in sentiment categories, both opinion polarity classification and emotion mining might be accomplished using similar methodologies in the text mining field. One very popular and established approach for sentiment analysis relies on the application of sentiment lexicons. These are dictionaries that contain words and phrases associated to positive or negative

sentiments. Furthermore, the scope of such dictionaries might be broadened to include also emotions [11]. Among the most popular sentiment lexicons are SentiWord [12], VADER [13], NRC [11], AFINN [14] and other. The major advantage of using sentiment lexicons is that they are easy to use, fast and the results can be easily understood and explained. Lexicons are a common choice in completely unsupervised settings when labeled data is not available or expensive to obtain.

Another general approach for sentiment analysis includes the application of machine learning techniques. Such methods are suitable in use cases when training data is available. Some of the most popular algorithms for sentiment text classification include Logistic Regression, the Naïve Bayes algorithm, Support Vector Machines (SVM), as well as different techniques from the deep learning field. In the past few years, another approach for sentiment analysis has emerged. The Transformer architecture [15] proposed by Google in 2017 combined with concepts from transfer learning led to the development of the so-called "pre-trained models". The last are trained on large volumes of data and might be utilized in a wide range of problems in the natural language processing field including sentiment analysis.

3. Methodology

The main aim of this study is to employ natural language processing and text mining techniques in order to discover the sentiments and emotions expressed in citizens' discussions regarding aspects of digital transformation in the public sector of Bulgaria. To accomplish the main goal, public comments and discussions posted in various social networks used in Bulgaria were scraped. As a next step a dictionary of carefully selected keywords was developed – the selected words are related to several topics of interest regarding digitalization in the public sector (in general) and the usage of digital public services. Data were filtered based on the keywords in the dictionary. Public comments in the following ten topics were extracted from the scraped data:

1. E-government/E-governance; 2. Usage of Personal Identification Code (PIC)/National Revenue Agency (NRA)/National social security institute (NSSI); 3. Various administrative services (for example, issue of Criminal Record Certificate, change of permanent address, insurance status check etc.); 4. Electronic prescriptions and medical referrals; 5. e-Health/Electronic health services; 6. Distance learning in schools; 7. Distance learning in universities/Online lectures; 8. Online enrollment in university/schools (paying fees online); 9. Traditional classroom learning (face to face); 10. Usage of online gradebook.

After data filtering according to the chosen ten topics, textual data were processed in order to create a sample suitable for further analysis. Public comments and discussions in social networks are completely unstructured data often characterized by a lot of noise (the opposite of official documents which often follow a particular structure and have few misspellings or unusual observations). For this reason, an important step before the actual data analysis is to apply techniques for text data processing and cleaning. The following natural language processing tasks were performed during this phase of the current empirical study – case normalization; removal of URLs and fragments left from the data scraping process; removal of digits and special characters; removal of some patterns which are typical for textual data in social networks but are not relevant for the current analysis; word tokenization.

In the previous section were mentioned the general methodologies for the application of sentiment analysis. Sentiment lexicons represent a straightforward, fast and simple approach for mining public sentiments. Furthermore, many of the available lexicons are most suitable for application on textual data from social networks/discussion forums on the Internet. For these reasons, the current research employs the lexicon-based approach for discovering sentiment polarity and emotions expressed in citizen discussions. Most of the available sentiment lexicons are developed for textual data in English. To the best of the authors' knowledge there is only one publicly available sentiment lexicon developed for textual data in Bulgarian. It is developed by Kapukaranov and Nakov on movie review data [16]. However, the lexicon's domain is substantially different than the data domain in the current study. For this reason, data were translated to English (original text data is in Bulgarian) in order to broaden the scope of potential sentiment lexicons that might be utilized.

The previous section already mentioned some of the most widely used sentiment lexicons. However, most of these resources perform only sentiment polarity categorization meaning that each text receives a score which tells whether the text implies overall positive/negative/neutral sentiment. Since the current study aims at discovering not only the polarity of expressed sentiments towards digitalization in the government sector, but also the emotions of the general public, the NRC Emotion Lexicon is utilized in the empirical experiments. This dictionary contains approximately 27 000 English words associated to eight basic emotions (anger, fear, anticipation, trust, surprise, sadness, joy, and disgust) and two sentiments (negative and positive). More details regarding the lexicon and its development could be found in [11].

The application of the NRC lexicon on textual data is simple and straightforward. A given word which is part of the lexicon might be associated with several emotions. For example, the word "love" might be associated with both the "positive" sentiment category and the "joy" emotion category. For each textual observation (comment) in the sample, the sentiment lexicon generates a list of associated emotions. This list is based on the words comprising the text. After taking into account all the words part of a given text that are also part of the lexicon, each emotion/sentiment category is associated to its corresponding frequency of appearance in the given text ("Emotion Score" - ES). For example, if for a given text the frequency of appearance of the "joy" emotion is 0.5 while the frequency of other emotions is less than 0.5, then this text will be categorized as expressing mostly "joy" emotions. Here is an example of how the calculation of the "Emotion Score" (ES) will be made for the text document d_i and one of the emotion categories (for example, "joy"):

$$ES_i\ ("joy") = \frac{p_i}{Q_i} \quad (1)$$

p_i – number of words in the document d_i which are associated with the "joy" emotion (count of the "joy" emotion);

Q_i – sum of the count of each emotion/sentiment presented in the document d_i;

$d_i, where\ i \in 1 \ldots N$ – document d_i. The overall number of text documents in the sample is denoted by N.

The Emotion Score is simply the frequency of appearance for a given emotion/sentiment in a text document. After applying the lexicon on data, each public comment in the sample is associated to a list of corresponding ten Emotion Scores (eight emotion categories + two sentiment categories). Then, each document is labeled with the emotion/sentiment category which received the highest Emotion Score (the most prevalent category in the document). It is important to note that one document might be associated with several prevailing emotions/sentiments. A drawback of sentiment lexicons is that they are limited to the number of words they include. When in a given text document cannot be found words from the NRC dictionary which are associated with a given sentiment/emotion category, then the Emotion Score for this category is set to zero. This means that there might be documents that cannot be classified into any of the respective sentiment/emotion categories.

4. Empirical Study

To accomplish the main goal underlying the current study, public comments were scraped from various Bulgarian social networks. Then, keyword filtering was applied on data in order to extract comments on chosen ten topics of public interest as described in the previous section. The final sample (after data filtering) contains 3072 public comments divided into 10 topics (groups). Comments were published in the time period from July 2019 to January 2022. Table 1 reveals the six most common social networks included in the sample. It can be seen from Table 1 that there is one dominant social network - almost 83% of the public comments were published in "bg-mamma.com". Indeed, this is probably one of the most popular discussion forums in Bulgaria where people share their thoughts on various subjects (lifestyle, economics, politics, parenthood etc.).

Table 1: *Most common social networks included in the sample*

Social network	Frequency
bg-mamma.com	82.58%
dnevnik.bg	3.35%
kaminata.net	1.66%
magelanci.com	1.46%
kaldata.com	1.24%
forum.clubpolitika.com	1.24%

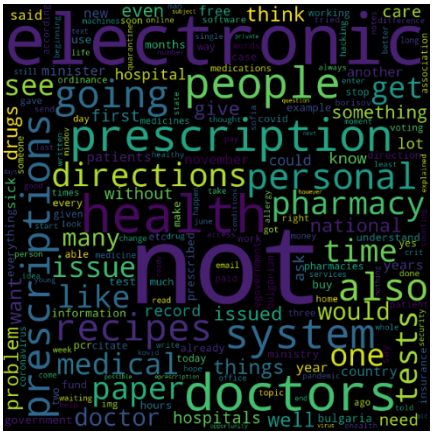


Fig. 1 *Most commonly used words in discussions about electronic prescriptions and medical referrals (word cloud)*

Word cloud visualizations like Fig. 1 are created for each of the ten groups of citizen comments. The size of words on the graph reflects their frequency (bigger words on the graph appear more frequently in text data). Such visualizations provide more context and are very helpful in gaining an insight into the contents of a given sample of textual data. Since the groups of comments are created based on keyword filtering, we already know the main topic in discussions part of a given group. Fig. 1 confirms that this group contains discussions mainly about health and electronic prescriptions/referrals (directions). The word "not" appears to be one of the most frequently used words in this group of comments which means that people have often used negation when sharing their opinion.

Table 2 reveals the dominant sentiments and emotions in the ten topics of public interest analyzed in the current study. For each public comment in a given group is calculated the Emotion Score (ES) for each sentiment and emotion. Then, each comment is associated to the most dominant sentiment/emotion category(-ies) based on the derived Emotion Scores. It is important to note that several emotions/sentiments might prevail in a given public comment. The dominance of emotions/sentiments calculated as a percentage is illustrated in Table 2. For example, the first row in Table 2 reveals that "fear" is a dominant emotion in 7.46% of all comments about E-government and E-governance. The sum of rows might exceed 100% due to the fact that one comment might be associated to more than one emotion/sentiment category.

The first observation that can be made based on the results in Table 2 is that people have predominantly used positive words in expressing their opinion. The usage of positive words (associated with positive sentiments) is far more frequent compared to the usage of negative words and this observation is valid for all the topics analyzed in the current study. In only two of the groups are observed similar frequencies of the comments expressing positive sentiments and those expressing negative sentiments – these are discussions about E-government and E-governance and electronic prescriptions and medical referrals. It can be seen from Table 2 that all emotions are represented in almost all of the analyzed topics. In only one of the groups (discussions about various administrative services) people haven't used any words associated with the emotions of surprise, joy and disgust.

In Table 2 with green color are indicated the most dominant emotions and sentiments in each of the analyzed topics. Obviously, the emotions of trust and anticipation prevail in almost all the topics of public interest. For example, "trust" is a dominant emotion in almost 70% of the comments associated to usage of personal identification code for online services (nevertheless, it should be noted that this group contains less than 30 observations). Still, other emotions could be also detected – for example, fear and anticipation are equally represented in public comments about electronic prescriptions and medical referrals. In discussions regarding the usage of online gradebooks, people have used words associated with the emotions of trust and joy, but also fear. It appears that the topic about electronic prescriptions and medical referrals contains more negative sentiments than rest of the groups (presence of sadness and fear is also detected). This observation is also supported by the findings made in the word cloud analysis in Fig. 1. Furthermore, in the other group related to healthcare services (e-Health/electronic health services) anger dominates in 14.29% of all comments. This is the only topic in which this behavior is observed but it should be noted that the group contains less than 30 observations.

Additional experiments are carried out with the aim of calculating the percentage of words in discussions on a given topic related to each emotion/sentiment category. Fig. 2 reveals that around 19% of words (with repetition) used in discussions about electronic prescriptions and medical referrals carry positive sentiments, while 15% are associated with negative sentiments. In rest of the groups, it is observed a much larger difference between the presence of these two sentiments (in favor of the positive sentiment category). This is another indication that the opinions in this particular group are rather divided. Similar graphs like Fig. 2 are produced for the rest of the analyzed topics. The additional experiments reveal analogous results as those reported in Table 2 - trust and anticipation are the most dominant emotions in citizen discussions about digital public services.

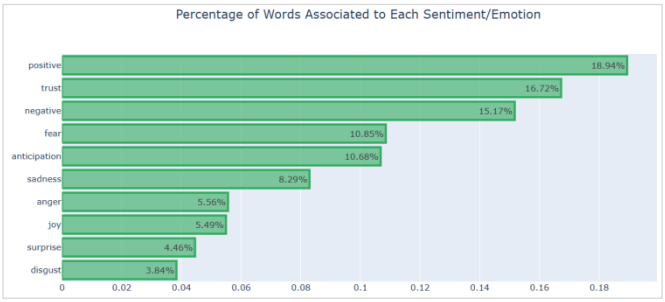


Fig. 2 *Percentage of words (with repetition) related to each emotion/sentiment category in discussions about electronic prescriptions and medical referrals*

5. Discussion and Conclusions

The main aim of the study is accomplished. Several topics related to digital transformation in the Bulgarian government sector are analyzed in detail and insights on public perception of aspects of the Bulgarian e-government are derived. Natural language processing techniques are used to discover the main sentiments and emotions contained in opinions freely expressed by citizens in popular Bulgarian social media websites. However, it is important to note that empirical results may not reflect the entire Bulgarian population, but rather people who frequently use social networks. Another limitation is that data are scraped from the Internet and then filtered according to a set of specific keywords. Therefore, the empirical study may not include all the available data in discussion forums related to the chosen topics of public interest.

The analysis reveals that the most dominant emotions conveyed in words people used to express their opinion are trust and anticipation. The last is valid for all the topics analyzed in the current study. This finding is not surprising since trust in the provided services is one of the most important factors which determines whether they will be used at all. Citizens anticipate efficient and reliable digital public services which will serve their needs and meet their expectations. Lack of trust in electronic public services will slow down the process of their adoption having a strong negative impact on digital transformation in general. Apart from the interesting insights on dominant emotions in public discussions, a result that rather came as a surprise is that few negative sentiments were detected in data. Apparently, people have not used many words associated to negative sentiments. However, this does not necessarily mean that they have not actually expressed a negative opinion since the NRC lexicon does not take into account negation.

Another limitation is that sentiment lexicons take into account only the words and phrases they contain. This means that citizens might have also used other words that express sentiments/emotions, however, these will be omitted in the analysis. Furthermore, some emotions might be better represented in the NRC lexicon (in terms of number of associated words) than others. A future direction of the current study is the utilization of pre-trained models and transfer learning for sentiment analysis in the government domain. Such approaches are suitable for unlabeled data and are able to capture the contextual meaning of words in text documents.

Table 2: *Dominance of sentiments and emotions in each group of discussions. For example, the first row reveals that "fear" is a dominant emotion in 7.46% of all comments associated to E-government and E-governance.*

Topic	Count	Positive	Negative	Fear	Anger	Anticipation	Trust	Surprise	Sadness	Joy	Disgust
E-government/E-governance	201	56.22%	34.83%	7.46%	3.99%	9.45%	23.38%	3.48%	4.48%	1.99%	2.49%
PIC/NRA/NSSI	26	34.62%	15.38%	3.85%	3.85%	15.38%	69.23%	3.85%	3.85%	3.85%	3.85%
Various administrative services	109	55.05%	21.10%	2.75%	0.92%	7.34%	37.61%	0.0%	4.59%	0.0%	0.0%
Electronic prescriptions and medical referrals	98	51.02%	34.69%	11.22%	2.04%	11.22%	37.76%	1.02%	6.12%	4.08%	1.02%
e-Health/Electronic health services	28	71.43%	28.57%	10.71%	14.3%	14.3%	28.57%	10.71%	10.71%	10.71%	10.71%
Distance learning in schools	1610	74.16%	12.92%	2.60%	0.75%	10.0%	21.68%	1.12%	2.11%	1.43%	0.99%
Distance learning in universities/Online lectures	249	82.73%	10.84%	1.61%	1.20%	16.06%	8.84%	1.20%	0.80%	3.21%	2.01%
Online enrollment in university/schools	77	80.52%	20.78%	3.89%	2.59%	3.89%	16.88%	1.29%	3.89%	2.59%	1.29%
Traditional classroom learning (face to face)	609	59.28%	22.17%	3.78%	0.66%	28.24%	21.02%	1.31%	3.45%	1.81%	1.15%
Usage of online gradebook	65	84.62%	6.15%	9.23%	6.15%	6.15%	44.62%	6.15%	6.15%	12.31%	6.15%

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