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QUALITY CONTROL SYSTEM FOR ANTICORROSIVE COATINGS OF STEEL PRODUCTS

Abstract. *As a result of the research, it was found that adding zinc oxide nanoparticles to acrylic lacquers can effectively retard corrosion of Fe37-3FN and UA10 steels in acidic concentrated and dilute environments. It has been established that when the chemical reaction retarder is applied, a predominantly dense phase of ferric metahydroxide is formed on the surface of steels, and the content of ferric carbide is not detected on the surface. It has been shown that nanoparticles cause better adhesion of the varnish to the surface.*

Key words: *zinc oxide nanoparticles, corrosion chemical reaction retarder, low alloy steel, high carbon steel, acrylic varnish.*

Introduction. Metals are widely used in our daily lives, and they are essential in all spheres of life. However, the surface of metal materials and the environment enter into chemical or electrochemical interactions, causing degradation or damage to the material (corrosion). Chemical reaction retarders for corrosion can be pre-applied to the metal or introduced directly into the aggressive environment. Due to the variety of aggressive environments, the first type of corrosion protection coating is easier to implement in practice. Corrosion protection by means of coatings is attractive because it is one of the most effective, flexible, cost-effective and simple strategies.

The characteristics of polymer coatings are often affected by their inherent porosity and defects that create pathways for aggressive substances, leading to mechanical and corrosion damage. One way to solve this problem is to use nanomaterial additives to polymer matrices.

The **aim** of the work is evaluation of the protective properties of chemical reaction retarders based on zinc oxide nanoparticles obtained by spray drying and acrylic varnish on the example of U10A and Fe37-3FN steel.

To achieve the set goal, the following tasks need to be addressed:

– Evaluation of the stability of chemical reaction retarders based on zinc oxide nanoparticles by gravimetry in a mixture of concentrated nitric and hydrochloric acids.

– Study of the morphology of steels with a chemical reaction retarder before and after corrosion by optical microscopy.

– Evaluation of the phase composition of the surface of steels with a chemical reaction retarder before and after corrosion.

– Construction of a mathematical model of the degree of corrosion of the damaged layer of steels.

Methods and Materials.

Preparation of nanoparticles. In the master's thesis, zinc oxide nanoparticles obtained by nanospray drying were used. Spray drying is a method of obtaining a dry powder from a liquid or suspension by rapid drying with hot gas. We used the NanoSprayDryer B-90 to obtain particles

from 300 nm to 10 μm in size from solutions or suspensions by drying or encapsulation with a yield of up to 90%. The particle size at the output depended on the selected spray nozzle.

The following spray drying parameters were used in the experiment: gas flow rate 103-105 l/min, relative spray intensity 45-59 %, T = 80 °C, P = 31 Pa. The nanopowders were collected from the cylinder and annealed at 250 ˚C for 1 hour.

Preparation of a chemical reaction retarder. A commercial dispersion of acrylic varnish was chosen as a polymer matrix for zinc oxide nanoparticles. The composition of the acrylic varnish mainly included a liquid polymer, an acrylic dispersion (polymers of prop-2-enoic and 2-methylprop-2-enoic acids and their derivatives).

The chemical reaction retarder was prepared and applied to the steel surface in two ways. First, acrylic varnish was mixed with zinc oxide (10 ml of acrylic varnish + 0.015 g of zinc oxide nanoparticles (0.15 wt. %)), then applied to the steel surface. The second method involved first applying zinc oxide nanoparticles (25 ml of water + 0.0375 g of zinc oxide nanoparticles (0.15 wt%)) from an aqueous suspension, drying at room temperature for 15 minutes, and then applying acrylic varnish.

The evaluation of the phase composition during the etching process was performed by obtaining X-ray phase diffractograms of the steel before and after etching (Shimadzy XRD-7000S X-ray diffractometer). X-ray tube: Cu, voltage 40 (kV), current 30 (mA). Diffraction was recorded in the range from 20 to 90 degrees (2θ) at a speed of 1°/min, step 0.03°.

The modeling results show the convenience of using two measures of corrosion: by the depth of damage to the structural material h and by the loss of its specific gravity m. The value of m is a measure of corrosion of the specific area of the surface layer of the product, and the value of h is a local characteristic of the depth of damage. These measures provide an objective assessment of the corrosion damage to the product based on modeling using systematized research data. The material functions included in the model relations and determined on the basis of systematized research data made it possible to obtain reliable results for assessing the damageability of Fe37-3FN and UA10 steels.

Conclusions. As a result of the study, it was found that adding zinc oxide nanoparticles to acrylic lacquers can effectively slow down the corrosion of Fe37-3FN and U10A steels in acidic concentrated dilute media. It has been established that when chemical reaction retarders are applied, a predominantly dense phase of ferric metahydroxide is formed on the surface of steels, and the content of ferric carbide is not detected on the surface. It is shown that nanoparticles cause better adhesion of the varnish to the surface.

References

1. Unnisa, C. N., & Sudha, D. (2024). Evaluation of Polyesters as Effective Corrosion Mitigators for Mild Steel in a Pool of Acidic Environments: A Comparative Approach. *Journal of Bio-and Tribo-Corrosion*, 10(4), 108.

2. Nguyen, C. T., Ly, L. T. N., Nguyen, T. X., Dao, H. P., Nguyen, S. A., et al. (2024). The effect of organotitanate-modified zinc oxide nanoparticles on some characteristics and anticorrosion protection properties of epoxy coating. *Journal of Coatings Technology and Research*, 1-14.

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MITIGATING EXPLOITATION OF SOFTWARE VULNERABILITIES IN PROGRAMMING LANGUAGE INTERPRETERS

Abstract. *The study describes the development of an exploit mitigation mechanism for programming language interpreters that implements object integrity and authenticity verifications to prevent the exploitation of software vulnerabilities. A threat model for programming language interpreters is defined, in particular, possible attacks arising from unauthorized changes in the object's properties are investigated. The programming language object integrity checks are created according to the developed threat model and consist of validating object address, object type, and other sensitive object properties. The developed software protection integrates into the source code of a programming language interpreter and effectively mitigates the exploitation of software vulnerabilities via using malformed objects.*

Key words: *exploit mitigation, software vulnerabilities, interpreted programming languages, sandboxing, security measures.*

Introduction. Interpreted programming languages are widely used in various domains of information technology because of the flexibility and ease of use of interpreters allowing embedding them in various environments. Such programming languages as Python and Lua are supported by many modern software for plugin development and scripting. JavaScript is primarily known as the language of the web, but apart from browsers, its interpreters are also embedded in cross-platform desktop and mobile applications using Electron and React Native frameworks. The versatility and adaptability of interpreted programming languages will likely keep expanding their presence in embedded systems and applications.

When dealing with untrusted content, the interpreter must be sandboxed to avoid unwanted code execution potentially resulting in a security breach. Sandboxed interpreters restrict usage of language features posing security risk and lower the security impact of untrusted code [1, 2]. However, a vulnerability in the interpreter itself would allow the bypass of sandbox restrictions and the obtaining of unlimited arbitrary code execution [2]. Despite the fact, that modern programming language interpreters are compiled with the support of DEP, ASLR, Control Flow Integrity, and CET exploit mitigation technologies, they cannot fully mitigate software vulnerability exploitation because the attack surface of programming language interpreters is broader than in other types of software. Software vulnerability that affects the integrity of object properties such as object type, object memory size, object methods pointers, etc. can potentially lead to arbitrary memory access or unlimited arbitrary code execution.

The **aim** of the work is to develop a method for verifying object authenticity and integrity in runtime to prevent exploitation of software vulnerabilities in programming language interpreters potentially resulting in unlimited memory access and unlimited untrusted code execution.

To achieve the set goal, the following tasks need to be addressed:

– investigate potential attack vectors that can be derived from object properties modification;
– develop a method for verifying object authenticity and identifying unauthorized changes in object properties;
– implement a working prototype of developed exploit mitigation technology that can be integrated into programming language interpreters with minimal source code patching.

Methods and Materials. The author researched software vulnerability exploitation techniques specific to programming language interpreters and modelled potential exploitation primitives that can be derived from the object properties modification. By overwriting the object

type address, it is possible to control object method pointers allowing to call arbitrary functions resulting in unlimited arbitrary code execution [3]. By modifying string or array object properties such as buffer location or buffer size it is possible to achieve arbitrary memory access which can potentially result in sensitive data disclosure or function pointers overwrite resulting in unlimited arbitrary code execution [4, 5].

Object properties modification may occur due to memory corruption issues (i.e., linear buffer overflow, out-of-bounds memory read/write, arbitrary address read/write) or improper memory management issues (i.e., use after free, double free, improper reference counting). Object address validity must be checked to ensure that the programming language interpreter cannot use an object that was not initialized in the intended way [4]. Also, in highly optimized programming language interpreters, object properties can be improperly used due to type confusion vulnerabilities arising from false assumptions in code optimization procedures [6].

The developed threat model defines the functional requirements of the exploit mitigation technology. An additional requirement is adaptability and ease of integration in programming language interpreter.

The proposed exploit mitigation technology is named ObjectVerifier. It validates an object and its properties by maintaining an object dictionary in RAM which is updated on object allocation, intended object properties change, and object deallocation. Object dictionary contains object address, object type address, and additional object properties that require integrity check. When using an object, the ObjectVerifier looks up its address in the object dictionary and compares its properties with the existing data stored in the object dictionary. If the object address is not found in the object dictionary or the object integrity check fails, then interpreter execution is aborted to prevent exploitation of software vulnerabilities.

Such an approach ensures that the object address is valid and object type and properties have no unauthorized changes.

The ObjectVerifier is implemented in C and consists of the core implementation and the header file to be included in the programming language interpreter. To integrate the solution into the interpreter, it is needed to define functions to get the object type and to get sensitive object properties based on the object type. Then, corresponding ObjectVerifier function calls that update information about object in the object dictionary are need to be added to the interpreter functions that allocate, use, and release objects and to the functions that change the protected properties of the object. The author successfully integrated the ObjectVerifier in the latest version of the CPython interpreter.

Testing of the ObjectVerifier integration in the CPython interpreter confirmed, that it effectively detects modification of protected object properties and mitigates exploitation of use after free and type confusion vulnerabilities.

The developed exploit mitigation technology can be integrated into interpreters for mitigating software vulnerability exploitation resulting in sandbox escape when running untrusted code.

Conclusions. The paper describes the process of development and implementation of ObjectVerifier, an exploit mitigation technology for programming language interpreters. The study involved investigating exploitation primitives that can be derived from the object properties modification caused by memory corruption or improper memory management issues. The author developed a method for verifying object authenticity and identifying unauthorized changes in object properties by maintaining an object dictionary which contains information about allocated objects and is used during object authenticity and integrity checks. The developed exploit mitigation technology can be integrated in the source code of programming language interpreters and prevents exploitation of software vulnerabilities via using malformed objects.

References

1. J. Ansel et al. Language-independent sandboxing of just-in-time compilation and self-modifying code. PLDI '11: Proceedings of the 32nd ACM SIGPLAN Conference on Programming Language Design and Implementation, 2011, 355-366. URL: https://doi.org /10.1145/ 1993498.1993540 (date of access: 20.10.2024).

2. Bytecode breakdown: unraveling Factorio's Lua security flaws. Memory Corruption. URL: https://memorycorruption.net/posts/rce-lua-factorio/ (date of access: 20.10.2024).

3. Exploiting logic bugs in Javascript JIT engines. Phrack Magazine. URL: http://www.phrack.org/issues/70/9.html#article (date of access: 20.10.2024).

4. Exploiting a Use-After-Free for code execution in every version of Python 3. pwn.win | A diary of security exploration. URL: https://pwn.win/2022/05/11/python-buffered-reader.html (date of access: 20.10.2024).

5. Code execution in Chromium's V8 heap sandbox. Anvbis. URL: https://anvbis.au/posts/code-execution-in-chromiums-v8-heap-sandbox/ (date of access: 20.10.2024).

6. Getting RCE in Chrome with incorrect side effect in the JIT compiler. The GitHub Blog. URL: https://github.blog/security/vulnerability-research/getting-rce-in-chrome-with-incorrect-side-effect-in-the-jit-compiler/ (date of access: 21.10.2024).

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APPLICATION AND MATHEMATICAL MODELING OF PIEZOCERAMIC ELEMENTS FOR INDUSTRY

Abstract. *Today, there are a number of devices that use many different elements, among which are elements based on piezoceramics. Piezoceramic products are widely used in various sectors of the national economy: in medicine, mechanical engineering, radio-electronic equipment, acoustic systems, ultrasonic transducers, etc. However, with the expansion of their application profile, the requirements for them are growing and becoming more stringent, which leads to the search for new advanced design and production technologies, but, in turn, this increases the cost of their production. To expand the application areas and improve the performance of piezoceramic materials, knowledge of their resistance to various external factors, such as humidity, temperature, mechanical stress, electrical stress, radiation, etc., is required.*

Key words: *piezoceramics, piezoelectric element, sensor, mathematical modeling, electrical impedance.*

Piezoelectric elements are ideal electromechanical transducers that are widely used in the production of piezoelectric ceramic components, assemblies, and devices. Many types of piezoelectric ceramics already function as components or assemblies and do not require additional modifications in many areas of science and industry.

For example, the automotive industry was among the first to use piezoceramic sound devices such as buzzers in turn signals, unlocked doors, piezoceramic burglar alarm sirens, and shock sensors. Piezoceramic buzzers compete with sirens that use inductive coils. Piezoceramic sirens have smaller dimensions and weight (2-3 times), lower power consumption (more than 2 times), and longer service life (several times).

The **purpose** of the research is to study the use of piezoceramic elements for industry and to calculate their mathematical models.

The reverse piezoelectric effect is used in shock sensors in car security systems. The sensors are securely mounted to the car body, and when the body is hit, the shock sensor converts the mechanical energy of the impact into an electrical signal that is processed and sent to the security system control.

Also, volume preservation sensors have been developed, which use piezoceramic emitters and receivers of ultrasonic waves. Operating in a continuous or pulsed mode, the piezoceramic ultrasound source creates an ultrasonic field in the protected volume, which is recorded by piezoceramic receivers and stored by the signal processing system.

For modern fuel supply and ignition of the fuel mixture, detonation sensors are installed on the vehicle engine. This ensures stable operation and saves fuel consumption.

Detonation sensors can be triggered while driving on uneven roads. To prevent false triggering, a bump sensor is installed in conjunction with the detector – a bimorphic piezoceramic element consisting of two connected flat piezoelectric elements that is triggered when the vehicle is driving on uneven roads and sends a corresponding signal to the electronic engine control system, which prevents the detector from triggering.

The parking sensor is a piezoceramic ultrasonic locator that propagates ultrasound with a frequency of ~ 40 kHz, which is reflected from obstacles, received by the sensor and converted into an electrical signal. The frequency of the time of emission and reception of signals in the electronic

unit of the system determines the distance of the vehicle to the obstacle, where information about the distance is displayed or in the form of sound signals.

Improvements are being made to piezoceramic actuators for diesel injection systems. Piezoelectric actuators are a multilayer piezoelectric ceramic package that converts an electrical signal into mechanical movement over short distances with greater accuracy and reproducibility. Such actuators are also designed for gasoline-powered vehicles.

Piezoelectric ceramic gyroscopes are widely used as speed, acceleration, rotation, and rotation sensors that can be used in cars for devices that control adaptive suspension, directional stability, chassis dynamics, headlight control, satellite vehicle control, airbags, and collision warning systems.

There are a number of projects using piezoceramic elements that have already been developed or are being developed to improve vehicle performance and control. These include the modernization of the ABS system, a fuel ignition system using piezoelectric transformers, a vehicle noise reduction system, fuel level sensors, and more. Today, to prevent wheel lock-up and slippage during braking, modern cars are equipped with an anti-lock braking system (ABS) that accurately measures the speed of each wheel and sends data to an electronic unit. ABS reduces the braking force of the locked wheel and allows it to spin so that the driver can steer the vehicle to prevent an accident.

The use of a piezo actuator instead of an electromagnetic valve in the ABS system allows for quick and accurate pressure reduction of the wheel brake hydraulic system.

The development of a system of volumetric plasma ignition of the fuel mixture in internal combustion engines based on a high-voltage, high-frequency electromagnetic pulse from a piezoceramic transformer mounted on the spark plug itself is promising.

Noise and vibration from moving vehicles is one of the global problems where traditional methods of reducing sound insulation are actively being used to combat it. However, these methods most often reduce external noise rather than noise from body vibrations.

Vibration damping using piezoceramics is based on the fact that piezoceramic receivers detect characteristic vibrations, where the signal from the receivers is processed in an electronic unit controlled by piezoceramic devices, creating vibrations in an out-of-phase with the existing vibrations, where vibration damping occurs.

A system is being developed to dampen chassis vibrations, based on a tensile rod and rod-support system made of carbon fiber composites and piezoceramic elements. It is assumed that this system will not only reduce noise and vibrations in the car interior, but also solve the problem of building a chassis that can actively compensate for uneven road surfaces. It is also possible to use piezoceramic-based composite materials that can be made in the form of a fabric, where the longitudinal threads are piezoceramic elements and the transverse threads are thin conductors-electrodes.

Before developing each piezoceramic element, a general model is designed, which takes into account what material it will consist of, what characteristics it will have, and for what conditions and environments it will be used. But the calculations of each parameter of the piezoelectric element during design are currently less reliable and multifaceted, which leads to extra time, additional material resources, and large deviations and errors.

Therefore, before manufacturing the piezoelectric element, we propose to perform mathematical modeling and perform the corresponding calculations using the Mathcad computer program. We consider mathematical modeling as a means of studying real systems by replacing them with more convenient experimental studies of systems (models) that retain the essential features of the original. Modeling approximates the description function, which is more convenient for the practical analysis of functions – models [1].

The study of the modeling object and the preparation of its mathematical description consists in establishing interactions between the characteristics of the process, identifying its initial and boundary conditions, and formalizing the process in the form of systems of mathematical relations [2].

At the research stage of object modeling, you need to perform the following steps:

- Analyzing the interaction between an object and its environment, identifying the characteristics of input influences and object reactions and classifying them as measurable or unmeasurable, controlling or interfering;
- Decomposition and study of the internal structure of the object;
- Study of the functional orderliness of an object, detection of input-output connections, formation of a set of object states;
- Collecting and verifying available experimental data at analogous facilities, conducting additional experiments if necessary;
- Classification of the modeled object as stationary or non-stationary; determination of the degree of influence of random factors on the object and the order of nonlinear relationships between the object's properties;
- Analytical review of literature; analysis and comparison of models of similar facilities built in the past;
- Analysis and synthesis of all accumulated material; formulation of a general plan for creating mathematical models [3,4].

For example, let's build a mathematical model in Mathcad, in which we will look for the electrical impedance $Z_{\text{ел}}(\omega)$ as one of the main parameters of the piezoelectric element. The experimental object is a piezoceramic disk of the PZT-19 type. The surfaces of the disk are metallized. One of the surfaces has zero potential, and the other is energized. The environment in which the disk is located is a vacuum, where there are no mechanical contacts with other objects.

The electric potential difference applied externally to the disk creates an external electric field, which, through the Coulomb force, affects the piezoceramic ions and demonstrates the reverse piezoelectric effect. The frequency is chosen to deform the disk to a greater extent than its thickness.

The electric current in the conductor connected to the disk surface and the electric potential generator precedes the parameters of the stress-strain state of the oscillating piezoelectric element. To fulfill the conditions, we take the generalized formula of Hooke's law in the inverse formulation:

$$\varepsilon_{ij} = s_{ijkl}^{E}\sigma_{kl} + d_{kij}E_k \,, \tag{1}$$

where ε_{ij} is deformation of the material;

s_{ijkl}^{E} is component of the elasticity tensor of piezoceramics;

σ_{kl} is stress applied to the material;

d_{kij} is piezoelectric module of the second kind;

After calculating the generalized formula of Hooke's law, we can get the expression in the form:

$$\sigma_3 = M^E \varepsilon_3 - e_{(\varepsilon)}E_3 \,, \tag{2}$$

where M^E is modulus of elasticity for uniaxial compression-tension mode along the thickness of the disk;

$e_{(\varepsilon)}$ is piezoelectric modulus for the uniaxial deformed state of the disk.

After finding the values M^E and $e_{(\varepsilon)}$ through the elastic moduli $c_{\alpha\beta}^{E}$ and piezomoduli $e_{k\alpha}$, we obtain the conditions that under uniaxial compression-tension of a disk with the properties of a transversally isotropic solid, Hooke's law takes the form:

$$\sigma_3 = \mathrm{c}_{33}^{\mathrm{E}}\varepsilon_3 - \mathrm{e}_{33}\mathrm{E}_3 \,. \tag{3}$$

To determine the stress E_3, let us take into account the condition of the absence of any bodies in the space in which the piezoceramic is located, which gives us the result:

$$E_3 = -\frac{e_{33}}{\chi_{33}^{\varepsilon}}\frac{\partial u_3}{\partial x_3} + \frac{e_{33}}{\alpha\chi_{33}^{\varepsilon}}\left[u_3\,(0) - u_3\,(-a)\right] - \frac{U_0}{\alpha}, \tag{4}$$

where $\frac{\partial u_3}{\partial x_3}$ is amplitude of harmonic changes during deformation;

χ_{33}^{ε} is electric steel;

α is thickness of the piezoelectric disk;

u_3 are amplitude values of harmonic variables over time;

U_0 is amplitude of the electric voltage.

Substituting the relation (4) into the general Hooke's law (3), we obtain:

$$\sigma_3 = c_{33}^D \frac{\partial u_3}{\partial x_3} - \frac{e_{33}^2}{\alpha \chi_{33}^{\varepsilon}} \left[u_3\,(0) - u_3\,(-a)\right] + \frac{e_{33}}{\alpha} U_0\,, \tag{5}$$

where $c_{33}^D = c_{33}^{\mathrm{E}}(1 + K_3^2)$ modulus of elasticity in the mode of constant electric induction.

The amplitudes of the alternating harmonics in time of the voltage tensor σ_3 and the displacement vector u_3 correspond to Newton's second law in the differential form, which has the form in this situation:

$$\frac{\partial \sigma_3}{\partial x_3} + \rho_0\, \omega^2\, u_3 = 0 \forall x_k \in V, \tag{6}$$

where ρ_0 is density of the piezoceramic disk;

$\omega = 2\pi f$ is circular frequency;

V is the volume of the piezoceramic disk.

Substituting equation (6) into expression (5) of the resulting voltage σ_3 we have

$$\frac{\partial^2 u_3}{\partial x_3^2} + \gamma^2\, u_3 = 0 \forall x_k \in V, \tag{7}$$

where $\gamma = \omega / \sqrt{c_{33}^D / \rho_0}$ is the wave number of elastic vibrations in the volume of the piezoceramic disk.

The solution to this expression can be written as:

$$u_3 = \gamma x_3 + B\, sin\, sin\, \gamma x_3\,. \tag{8}$$

The constants A and B are determined from the boundary conditions, which are Newton's third law in differential form.

Note that the piezoceramic object is in an environment where there are no free carriers of electric current. From this condition, $div\vec{D} = 0$, for this one we have $\frac{\partial D_3}{\partial x_3} = 0$, where $D_3 = e_{33}\varepsilon_3 + \chi_{33}^{\varepsilon} E_3$. Since the vertical components of D_3 of the electrical instruction do not depend on the values of the coordinates x_3, we obtain after integration:

$$D_3 = \frac{e_{33}}{\alpha} \left[u_3\,(0) - u_3\,(-\alpha)\right] - \frac{\chi_{33}^{\varepsilon}}{\alpha} U_0\,. \tag{9}$$

Substituting into the definition (9) of the vertical component D_3 the expression (8)

$$D_3 = -\frac{\chi_{33}^{\varepsilon} U_0}{\alpha \Lambda_0}, \tag{10}$$

where $\Lambda_0 = 1 - \frac{K_3^2}{1+K_3^2} \frac{tg\left(\frac{\gamma a}{2}\right)}{\left(\frac{\gamma a}{2}\right)}$;

$K_3^2 = \mathrm{e}_{33}^2 / (\chi_{33}^{\varepsilon} \mathrm{c}_{33}^{\mathrm{E}})$ is the square of the electromechanical coupling coefficient in the mode of thickness oscillations of a piezoceramic disk polarized along its thickness.

The electrical impedance $Z_{\text{ел}}(\omega)$ of the piezoceramic disk is determined using Ohm's law:

$$Z_{\text{ел}}(\omega) = \frac{U_0}{I_0} = \frac{1}{i\omega C_0^{\varepsilon}} \Lambda_0\,, \tag{12}$$

where $I_0 = -i\omega S D_3 = i\omega C_0^{\varepsilon} \frac{U_0}{\Lambda_0}$ is the amplitude value of harmonic changes in time of the electric current in the conductor due to the value of D_3 ;

$C_0^{\varepsilon} = S\chi_{33}^{\varepsilon}/a$ – dynamic electrical capacity.

According to formula (12), we construct a graph for a piezoceramic disk, where the value of the electrical impedance $Z_{\text{ел}}(\omega)$ in Ohms is plotted on the ordinate axis. And on the abscissa axis is the dimensionless value $\gamma a/(\omega)$.

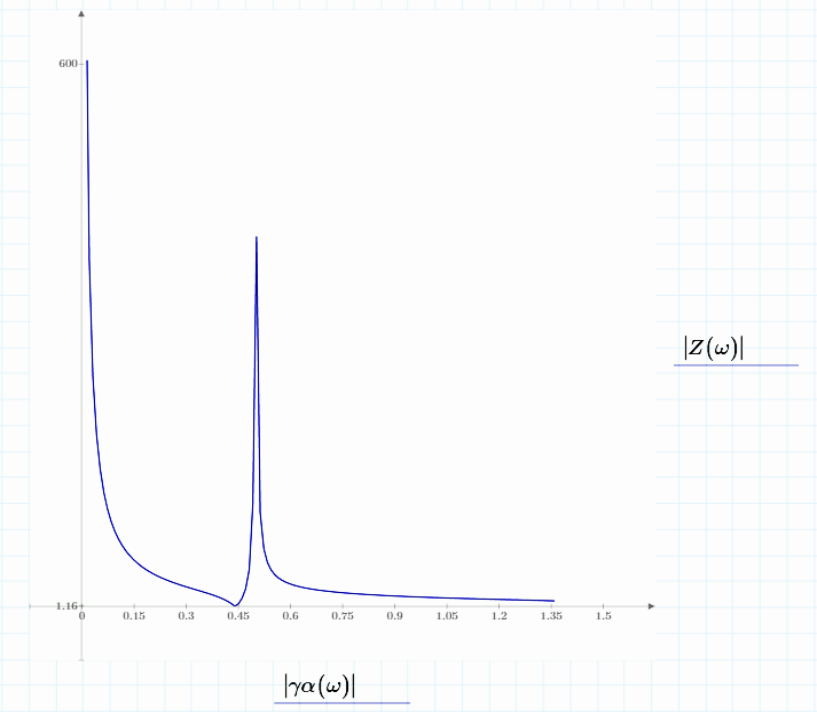

Fig. 1. Electrical impedance of piezoceramic disk

The graph shows that when the piezoelectric disk has a large resistance to inductive impedance, the impedance line moves toward the resistance line (X-axis) and the phase shift decreases. When more inductive resistance is created in the circuit with respect to the resistance, the impedance line moves toward the inductive resistance line (Y-axis) and the phase shift increases.

Conclusions. Thus, the work proves the importance of using piezoceramic products in various industries. The possibilities of using piezoceramics in the automotive industry, which can be used in relevant objects and objects, are presented. The basic possibilities of building a mathematical model are substantiated. For example, a mathematical model was built in the Mathcad mathematical environment, a piezoceramic disk of the PZT-19 type was taken as an object, a calculation was performed and a graph of the electrical impedance of piezoceramics was plotted. This showed the feasibility of using mathematical models and allowed for more complex and accurate calculations to solve complex piezoceramic elements in the construction of devices, components and assemblies.

References

1. Андруник В. А., Висоцька В. А., Пасічник В. В., Чирун Л. Б., Чирун Л. В. Чисельні методи в комп'ютерних науках [Numerical methods in computer science]: навч.посіб. Том 2. Львів: Видавництво «Новий світ -2000», 2020.

2. Дубовой В. М., Квєтний Р. Н., Михальов О. І., Усов А. В. Моделювання та оптимізація систем [System modelling and optimization]: підручник. Вінниця: ПП «ТДЕдельвейс», 2017.

3. Комп'ютерне моделювання процесів та систем. Чисельні методи [Computer modeling of processes and systems. Numerical methods]: підручник / С. П. Вислоух, О. В. Волошко, Г. С. Тимчик, М. В. Філіппова. Київ: КПІ ім. Ігоря Сікорського, Вид-во «Політехніка», 2021.

4. Півторак Д. О., Лазарєв Ю. Ф., Лакоза С. Л. Комп'ютерне моделювання процесів і систем [Computer modelling of processes and systems]: навч. посіб. для студ. спеціальності 151 «Автоматизація та комп'ютерно-інтегровані технології». КПІ ім. Ігоря Сікорського, 2021.

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MODERNIZATION OF THE ENERGY SYSTEM OF UKRAINE

Abstract. *The possibility of modernization of the energy system of Ukraine due to the transition of the electricity transmission voltage from 10 kilovolts to 20 kilovolts has been studied. It includes determining the advantages and rationality of energy modernization in this way. In some European countries, a medium voltage system of 10–20 kilovolts (kV) is used to distribute electricity. 20 kV distribution networks remain increasingly popular, especially in new projects, so they will not be able to reduce losses and improve system efficiency together with 10 kV. European cities are actively modernizing their networks in connection with new challenges, in particular due to the development of electric mobility and heat pumps, which increases the load on distribution networks. In these conditions, medium voltage (MV) systems become key to ensuring reliable and economical power supply, taking into account new technologies such as load management and energy conservation. These systems improve the efficiency of electricity supply and facilitate adaptation to modern energy challenges, such as the connection of renewable sources and electric vehicles. That is why I propose a method that is already working and has been tested by European countries, thanks to which our country will have even more chances to become the energy center of Europe.*

Key words: *reduced transmission losses; higher efficiency; support of new technologies.*

Introduction. The transition to a 20kV power system offers significant benefits, including increased energy efficiency, reduced costs, improved reliability and adaptation to future needs. Although grid modernization may require initial investment, in the long term these benefits contribute to lower operating costs and improved power quality.

The 20-kilovolt (kV) power system has a number of advantages compared to the 10-kV system that currently exists throughout Ukraine, except for some cities.

Key advantages: reduction of energy losses; increase in transmission power; reduction of the number of substations; reduction of infrastructure and maintenance costs; improved network reliability and stability; prospects for energy development.

Reduced transmission losses: at a higher voltage (20kV), the current in the line is lower for the same power, which leads to a decrease in heating losses (active losses). Higher efficiency: lower losses help increase the overall energy efficiency of the system. Higher line load: 20kV lines can carry more power without overloading compared to 10kV. Fewer constraints: the 20kV system allows expansion of substation capacities and the connection of new consumers without the need for large-scale network upgrades. Longer transmission distances: 20kV lines can transmit power over longer distances without the need for intermediate substations. This reduces the costs of construction and operation of additional substations. Fewer switching points: increasing the voltage reduces the number of switching devices required. Reduced copper and aluminum costs: since the current at 20kV is lower in the network, wires with a smaller cross-sectional area can be used, which reduces material costs. Less maintenance and repair costs: Due to the reduced number of equipment and greater reliability, 20kV networks are cheaper to maintain. Resistance to loads: the 20kV network better withstands sudden changes in load and voltage drops. Less risk of overloads: Due to lower current and increased power transfer capability, the risk of emergency overloads is reduced. Support for new technologies: 20kV networks are better suited for integration with renewable energy sources (solar and wind farms). Preparing for future loads: Increases in electricity demand (e.g. due to the development of electric vehicles) are easier to compensate for in networks with higher voltages. Less energy production losses: Reducing grid losses reduces the need for

electricity generation, which can reduce greenhouse gas emissions. Less visual impact: due to the possibility of using smaller equipment and reducing the number of substations.

The purpose of the work is to show how it is possible to effectively modernize the energy industry of Ukraine.

To achieve the set goal, the following tasks must be solved: to investigate the rationality of the transition of the power system from 10kV to the power system of 20kV.

The **aim** of the work is to develop a method for verifying object authenticity and integrity in runtime to prevent exploitation of software vulnerabilities in programming language interpreters potentially resulting in unlimited memory access and unlimited untrusted code execution.

To achieve the set goal, the following tasks need to be addressed:

– investigate potential attack vectors that can be derived from object properties modification;
– develop a method for verifying object authenticity and identifying unauthorized changes in object properties;
– implement a working prototype of developed exploit mitigation technology that can be integrated into programming language interpreters with minimal source code patching.

Methods and Materials. Ways to upgrade the power grid from 10 kilovolts (kV) to 20kV is a complex process that requires detailed planning and coordination. The key stages and steps to be taken for implementation are: technical analysis and design; investments and financial planning; replacement and modernization of equipment; changing substation settings; operational changes and staff training; transitional stage and testing.

Technical analysis and design. The current state of the network is evaluated. It is necessary to conduct an audit of the existing infrastructure to change weak points and some problems (lines, transformers, substations). Next is the design of the 20kV network. Engineers develop new network schemes, taking into account future load needs, placement of substations and the possibility of connecting new consumers.

Replacement and modernization of equipment. It is necessary to replace the old transformers designed for 10 kV with new ones that support 20 kV. If the existing cables are not designed for 20 kV, they must be replaced or reinforced. This is especially important in urban networks where underground cables are used. Switchboards and circuit breakers need to be upgraded to work with higher voltages.

Changing substation settings. Transformer substations must be equipped with equipment capable of operating at 20 kV, including new circuit breakers, protection relays and automated control systems (SCADA). Protective devices must be checked and updated to meet the requirements of the new voltage.

Operational changes and personnel training. Employees must be trained to work with new equipment and technologies related to 20 kV networks. Safety protocols and maintenance procedures must be updated to meet the requirements of the new system.

Investments and financial planning. If the modernization requires significant capital investment, it is important to develop a financing plan for the project, which may include government subsidies or private investment. Analysis of future benefits, such as reduced energy costs and increased network reliability.

Transitional stage and testing. Phased commissioning plan: to avoid disruptions, upgrades are carried out on top of each other in separate segments. After the new equipment is installed, testing is done to check the stability and reliability of the network.

There are examples of implementation, Spain and Portugal have already successfully implemented 20 kV transition projects in many cities, which made it possible to increase the stability of the network and integrate new technologies.

The main problems are the high cost of equipment and the need to coordinate with other city services when replacing underground cables.

Conclusions. The modernization of the 10-kilovolt (kV) distribution network to 20kV is a strategic step that has a decisive impact on increasing energy efficiency, reliability and flexibility of

electricity supply in the face of increasing demand and the integration of new technologies. The development of such networks ensures compliance with the modern requirements of current energy, which is special for the rapidly developing urban infrastructure. The transition to a 20kV network opens up additional opportunities for the modernization of energy infrastructure and the introduction of new technologies. This step is the basis for the development of intelligent energy networks (Smart Grid), i.e. 20kV networks are able to support the implementation of automated systems of monitoring and distribution of electricity. Taking into account the international experience and examples of implementation of this type of modernization by European countries, it shows the success of already implemented modernization projects, which is the best example for imitation and implementation.

This becomes expedient given that the power transmission networks of Ukraine need equipment replacement due to the end of the service life of most power transmission networks. It is better to invest more money in modernization than in exploitation, because modernization has many prospects in the development of energy and has to pay off, and exploitation will only give what we already have, namely big losses. Therefore, taking into account all the advantages and prospects, this particular method of modernization of the energy industry of Ukraine will be the best at the moment.

References

1. Розподільні електричні мережі напругою 20 кВ та ефективність їх роботи [Distribution electric networks with a voltage of 20 kV and their efficiency of their operation] / В.В.Кирик, Б.В. Циганенко, О.С. Яндульський. К.: «КПІ ім. Ігоря Сікорського», 2018. 233 с.

2. Бурикін О. Б., Кулик В. В. Перспективи впровадження розподільних мереж напругою 20 кВ в Україні [Prospects for the introduction of distribution networks]. 2017. https://conferences.vntu.edu.ua/index.php/all-feeem/all-feeem-2017/paper/download/3099/ 2340

3. Hengfengyou Electric Group. Advantages of medium voltage 20 kV distribution network. 2021. https://www.hengfengyou.com/zixun/705.html.

4. Zuo, J.; Zhou, S.; Xu, Z.; Gao, C.; Zheng, S.; Chen, P. Reliability Evaluation Method of Multi-Voltage Levels Distribution System Considering the Influence of Sense-Control Terminal Faults. Appl. Sci., 2023, 13(21), 11761. https://www.mdpi.com/2076-3417/13/21/11761.

5. Markus Miller, et al. Optimal medium voltage grid planning under consideration of dynamic current ratings of underground cables and e-mobility. 13th Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion (MEDPOWER 2022) https://doi.org/10.1049/icp.2023.0002.

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INTELLIGENT DATA ANALYSIS SYSTEMS FOR RESEARCH IN BEHAVIORAL ECONOMICS OF VIRTUAL ASSETS

Abstract. *The research focuses on the application of intelligent data analysis systems in the context of behavioral economics of virtual assets. The use of these methods allows to identification of behavioral patterns and determinants that influence investment decision-making. Various models, such as multiple and polynomial regression, ARIMA/SARIMA, as well as machine learning algorithms, in particular decision trees, Random Forest, and XGBoost, are evaluated from the perspective of behavioral economics research. The use of such methods will contribute to the creation of more accurate models that take into account the behavioral aspects of investors in the context of virtual assets.*

Key words: *virtual assets, behavioral economics, machine learning, forecasting models, cryptocurrencies.*

The development of blockchain technologies contributes to the growth of interest in virtual assets. They bring changes to traditional financial markets and affect the economy as a whole. The behavioral economics of virtual assets offers new aspects for understanding how behavioral factors influence investment decisions. Intelligent data analysis systems help scientists and practitioners better understand investor behavior.

The 20-kilovolt (kV) power system has a number of advantages compared to the 10-kV system that the problem lies in the need to develop and implement modern research methods that allow taking into account these aspects for more accurate forecasting and risk management in the virtual asset market.

Modern behavioral economics research is based on the use of intelligent data analysis systems and is relevant for price forecasting, determining behavioral patterns, analyzing social influences, etc.

Recent advances in the field of data mining and their widespread application in various fields, in particular in economics and social sciences, are published by scientists [1-7]. Thus, article [1] contains an overview of various methods. Emphasis is placed on the increasing complexity of data analysis due to the development of technologies. The authors consider the use of machine learning, natural language processing and other innovative technologies to increase the accuracy and speed of analysis. Article [2] focuses on discussing the importance of text mining. The authors note that processing useful information from large volumes of unstructured texts is a difficult task. They consider various methods and tools, in particular RStudio, Python, RapidMiner, and Orange, which are used for text data analysis. The authors emphasize that the introduction of new methods should improve and optimize work with text data. In this paper, authors Divya Chaudhary and Sushil Kumar Saroj explore the application of three machine learning algorithms—linear regression, support vector machines, and decision trees—to forecast the prices of major cryptocurrencies. The paper emphasizes that cryptocurrency price forecasts are becoming increasingly relevant due to increasing market volatility and investor interest. The authors use historical data to analyze prices and identify patterns. The paper provides practical recommendations for applying machine learning to forecast cryptocurrency prices. In paper [4], the authors analyze methods for forecasting cryptocurrency prices using various machine learning and deep learning algorithms. The authors compare the performance of statistical, machine learning, and deep learning models. The results show that deep learning models, in particular LSTM, demonstrate the best results. The paper also provides open access to the dataset and code to stimulate further research in this area. In the paper

[5], the authors explore the use of sentiment analysis and machine learning methods to forecast the prices of popular cryptocurrencies such as Bitcoin, Ethereum, Ripple, and Litecoin. The authors compare three different models—neural networks, support vectors, and random forests—based on social media (Twitter) and market data. The results show that neural networks demonstrate the best accuracy in predicting price movements. The paper emphasizes the importance of social sentiment analysis for predicting price movements in the cryptocurrency market, indicating the potential for further research in this area. In the paper [6], the authors propose a new cryptocurrency price forecasting scheme based on deep learning, taking into account interdependencies between coins. The study focuses on predicting Litecoin and Zcash prices using Gated Recurrent Units (GRU) and Long Short-Term Memory (LSTM) algorithms. The authors note that cryptocurrency price forecasts are difficult due to their volatility and dependence on many factors, including market sentiment and legal aspects. The proposed model demonstrates high accuracy in real time, compared to traditional forecasting methods. In [7], the study assesses how regulatory news and events have affected returns in cryptocurrency markets. It is shown that investors reacted less negatively to the most illiquid cryptocurrencies and to those that were exposed to greater risk of information asymmetry. The long-term impact of regulatory events is analyzed.

The analysis conducted indicates the need for further research to improve the accuracy of forecasting models.

The purpose of this study is to assess the effectiveness of intelligent data analysis systems in studying the behavioral aspects of virtual assets and determining their impact on investment decisions.

In our study, we predicted the price of Bitcoin based on social activity in networks. Using the methods of the intelligent data analysis system, we identified and analyzed the relationships between activity in social networks (in particular, publications containing words related to Bitcoin) and the price of Bitcoin. The methodology used included four main stages: “data collection and preparation”, “model building”, “forecasting and smoothing”, and “model evaluation”.

Step 1. Collection of Bitcoin price data and preparation of data from social networks. Bitcoin price data were downloaded using the yfinance library, which provides historical data on the market price of Bitcoin (symbol "BTC-USD"). The data range was from January 1, 2020 to October 1, 2024. We used a dataset of social media posts that contained various metrics such as the number of posts, the number of likes, shares, comments, and views (fields: post_count, digg_count, share_count, comment_count, play_count). Posts created after January 1, 2020 were selected to limit the time interval for analysis. Metrics were aggregated by day. The total number of posts and the sum of likes, shares, comments, and views were calculated for each day. Data was aggregated separately for all posts and for posts containing keywords related to Bitcoin. After aggregation, data from posts was merged with data on the Bitcoin price for the corresponding dates, which allowed us to build a prediction model based on social media activity. To correctly build the models, Bitcoin prices (Close) were scaled using the MinMaxScaler method. This allowed us to bring all values to the same interval, which contributed to the stable operation of the models.

Step 2. Model building. Models such as multiple linear regression, polynomial regression, ARIMA/SARIMA (Time series), machine learning models (Decision Tree, Random Forest, XGBoost), and Prophet were built.

Step 3. Forecasting and smoothing. After building the models, Bitcoin prices were forecasted on test data. To reduce fluctuations and sharp peaks in the forecasts, the moving average smoothing method (with a window of 7 days) was applied, which allowed us to obtain smoother and more realistic forecasts.

Step 4. Model evaluation. Two metrics were used to assess the quality of the models: 1) MSE (Mean Squared Error): which measures the average squared deviation between the actual and forecast values; 2) MAE (Mean Absolute Error): which measures the average absolute deviation between the actual and forecast values. A comparison of models for all publications and for publications with words about Bitcoin was also conducted. The model for all publications had a

slightly lower MAE, and the model for publications with words about Bitcoin showed a better result than MSE.

The study showed that the methods of intelligent data analysis systems are objective for conducting research on the behavioral economics of virtual assets. They provide the ability to process large amounts of information and identify behavioral patterns and determinants. Multiple linear regression was used to analyze the relationship between the price of Bitcoin and the number of publications in social networks, to determine the impact of different platforms on the price of Bitcoin. Polynomial regression was used to model nonlinear relationships between dependent and independent variables and to assess the impact of activity in social networks on the price of Bitcoin, taking into account more complex interactions. ARIMA/SARIMA time series - for forecasting the price of Bitcoin and including the number of publications in social networks as regressors in ARIMAX. Machine learning models (such as decision tree, Random Forest, XGBoost) were used for more complex analysis and forecasting, taking into account the interaction between different variables. Prophet model - to improve the accuracy of Bitcoin price forecasting based on the use of data from several social networks.

Thus, the methods of intelligent data analysis systems are modern and objective for research in the behavioral economics of virtual assets. They open up new opportunities for a deeper understanding of the virtual asset market. Our further research will be aimed at developing models that will take into account behavioral aspects in the context of the virtual asset market.

References

1. Zhang, C., Li, W., Zhang, H., Zhan, T. Recent Advances in Intelligent Data Analysis and Its Applications. Electronics. 2024. Vol. 13, No. 1. P. 226. DOI: https://doi.org/10.3390/electronics13010226.

2. Mohylna, M.V., Dubrovin, V.I. Intellectual Text Analysis: Applications and Free Software. Mathematical Modelling. 2022. Vol. 5, No. 2. DOI: https://doi.org/10.32782/mathematical-modelling/2022-5-2-5.

3. Chaudhary, D., Saroj, S.K. Cryptocurrency Price Prediction Using Supervised Machine Learning Algorithms. ADCAIJ: Advances in Distributed Computing and Artificial Intelligence Journal, 2023, 12(1), e31490. DOI: https://doi.org/10.14201/adcaij.31490.

4. Murray, K.; Rossi, A.; Carraro, D.; Visentin, A. On Forecasting Cryptocurrency Prices: A Comparison of Machine Learning, Deep Learning, and Ensembles. Forecasting 2023, 5(1), 196–209. DOI: https://doi.org/10.3390/forecast5010010.

5. Valencia F, Gómez-Espinosa A, Valdés-Aguirre B. Price Movement Prediction of Cryptocurrencies Using Sentiment Analysis and Machine Learning. Entropy. 2019; 21(6):589. DOI: https://doi.org/10.3390/e21060589

6. Tanwar, S., Patel, N.P., Patel, S.N., Patel, J.R., Sharma, G., Davidson, I.E. Deep Learning-Based Cryptocurrency Price Prediction Scheme with Inter-Dependent Relations. IEEE Access. 2021. Vol. 9, pp. 138633-138646. DOI: https://doi.org/10.1109/ACCESS.2021.3117848.

7. Chokor, A., Alfieri, E. Long and Short-Term Impacts of Regulation in the Cryptocurrency Market. The Quarterly Review of Economics and Finance. 2021. Vol. 81. P. 157-173. DOI: https://doi.org/10.1016/j.qref.2021.05.005.

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METHODOLOGY FOR ENSURING CYBER RESILIENCE IN THE CLOUD ENVIRONMENT AT THE ENTERPRISE

Abstract. *The paper discusses the provision of cyber resilience through policies. The study explains how the methodology can help enterprises build cyber resilience.*

Key words: *cyber resilience, progress model, maturity, cloud environment.*

Introduction. Due to the current dangerous cyber environment, cyber resilience is more necessary than ever. Enterprises are exposed to the risk of a cyber incident that is often overlooked. This makes cyber incidents one of the top risks for enterprises in the last few years. Currently, most specialists share the opinion that resilience should be formulated precisely in terms of cyber resilience. However, it still does not provide a single, universally accepted approach to ensuring cyber resilience in the cloud environment. One method of ensuring resilience emerges from a progress model used to help enterprises develop a strategy and program for changing cyber resilience policies.

Methodology. The methodology involves using semi-structured interviews to gather qualitative data for creating a cyber resilience progress model. This approach was used to collect data on the development of cyber resilience policies from three different categories of cyber security experts: providers, researchers and people, who responsible for implementing cyber security at enterprises. Experts should be chosen because of their extensive experience in the field to provide three different perspectives on the topic.

Previous studies have identified ten domains and thirty-three policies as crucial to cyber resilience [1, 2]. This data serves as the foundation for developing a cyber resilience model. Semi-structured interviews were created based on these findings, and the results were quantified and analyzed to assess policy progress over time.

To develop a progression model from the experts' perspective, the interviews are systematically organized to construct this model. Experts receive a document containing a table of domains and simplified policies, which serves as the interview script. This document also includes definitions of "cyber resilience" along with interview objectives, expected outcomes, and next steps:

1. Determine the starting point for each cyber resilience policy by considering the relationship between policies and personal experience. Assign an initial level to each policy on a scale from 1 to 5, where 1 represents the lowest maturity level and 5 represents the highest [3, 4].

2. Explain how these policies advance through each subsequent stage of the scale. For example, if a policy begins at the third level, describe its implementation at the third level, then at the fourth level, and finally at the fifth level.

Using this information, experts are interviewed sequentially, with each interview being recorded. The transcripts are then sent to the experts for verification, ensuring their ideas are accurately captured and avoiding errors or biased interpretations. Table 1 provides an overview of the progress model obtained from each expert.

Table 1. Overview of resulting progress models.

Domain	Policy	1	2	3	4	5
Domain-1	Policy-1		Initial policy description	Description of progression at level 3	Description of progression at level 4	Description of progression at level 5
	Policy-2			Initial policy description	Description of progression at level 4	Description of progression at level 5
	Policy-3		Initial policy description	Description of progression at level 3	Description of progression at level 4	Description of progression at level 5
Domain-2	Policy-4				Initial policy description	Description of progression at level 5
	Policy-5		Initial policy description	Description of progression at level 3	Description of progression at level 4	Description of progression at level 5
	Policy-6	Initial policy description	Description of progression at level 2	Description of progression at level 3	Description of progression at level 4	Description of progression at level 5

Analysis. The analysis follows Schmidt's five-stage methodology for semi-structured interviews [5], which includes:

1. Material-oriented formation of analytical categories involves thoroughly reading and understanding each record. During this stage, annotations are made to highlight the general concepts identified in the records.

2. Combining the analytical categories into a coding guide involves creating categories that summarize the various types of progression identified by experts. These progressions are identified by grouping common patterns found in expert responses during the interviews and assigning descriptive names to these patterns wherever possible.

3. Coding the material involves assigning a progression type to each policy and progression based on the records of each expert. During this stage, a single expert may assign multiple codes to each policy progression.

4. A quantitative analysis of the material is conducted in two parts: (1) assessing whether there is consensus on the initial maturity level of each policy, and (2) evaluating whether there is consensus on the progression type for each policy.

5. Detailed case interpretations involved creating a progression model by analyzing the most common starting point for each policy and its most frequent progression type (code). If the initial maturity level of a policy was consistent across experts, data with the lowest maturity level was used. In cases where progression types were related, a combination of both types was applied to build the progression model.

Conclusions. In today's cyber landscape, enterprices must prioritize cyber resilience, though its implementation is complex. Many approaches exist, but most merely list cyber resilience policies without offering guidance on prioritization. This paper aims to propose a cyber resilience progress model as a tool for enterprises.

The model helps businesses develop strategies based on specific descriptions that reflect their current state, or at least guide them toward achieving the broader objectives outlined at each stage of the progression model.

References

1. Carias J.F., Borges M.R.S., Labaka L., Arrizabalaga S., Hernantes J. Systematic Approach to Cyber Resilience Operationalization in SMEs. IEEE Access, 2020, vol. 8, pp. 174200-174221. DOI: 10.1109/ACCESS.2020.3026063.

2. Carias J.F., Borges M.R.S., Labaka L., Arrizabalaga S., Hernantes J. The Order of the Factors DOES Alter the Product: Cyber Resilience Policies' Implementation Order. Advances in Intelligent Systems and Computing, 2020, vol. 1267, Springer, Cham, pp. 306–315, DOI: 10.1007/978-3-030-57805-3_29.

3. Cybersecurity Capability Maturity Model (C2M2), 2014. URL: https://www.energy .gov/oe/articles/cybersecurity-capability-maturity-model-february-2014.

4. Sri Nikhil Gupta Gourisetti, Scott Mix, Michael Mylrea, Christopher Bonebrake, Md Touhiduzzaman. Secure Design and Development Cybersecurity Capability Maturity Model (SD2-C2M2): Next-Generation Cyber Resilience by Design. NCS '19: Proceedings of the Northwest Cybersecurity Symposium, 2019. DOI: https://doi.org/10.1145/3332448.3332461.

5. Schmidt C. The Analysis of Semi-structured Interviews. In: Flick U., von Kardoff E., Steinke I. (Eds.) A Companion to Qualitative Research. SAGE Publications, London, 2004, pp. 253–258, URL: https://hu.kln.ac.lk/units/rc/media/attachments/2021/09/17/a_companion_to_qualitative_ research.pdf.

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ANALYSIS OF THE EFFECT OF AIR POLLUTION ON THE CONDITION OF HUMAN HAIR BY SCANNING PROBE MICROSCOPY

Abstract. *The study examines the impact of polluted air and aggressive chemicals on the structural integrity of human hair using scanning probe microscopy (SPM). The findings indicate that dust particles and toxic compounds settling on the hair surface significantly disrupt the cuticle structure, reducing the hair's moisture retention capacity and increasing its brittleness. SPM allowed for a detailed examination of the cuticle's micro-relief, revealing damage caused by various chemical exposures, including ammonia-based dyes and chemical perms, while natural dyes such as henna were shown to smooth the hair surface. The results confirm the effectiveness of SPM in detecting micro-damage and emphasize the importance of avoiding aggressive chemical care products to maintain hair health and strength.*

Key words: *air pollution, hair, scanning probe microscopy, cuticle, structural damage.*

Introduction. Due to the current dangerous cyber environment, cyber resilience is more necessary than ever. he relevance of this research is driven by the fact that hair condition is an important indicator of human health, and maintaining its quality while preventing scalp and hair diseases is a critical objective in cosmetology and dermatology. It is well-known that hair health is significantly affected by air, water, nutrition, and hair care products. Polluted air is particularly harmful as it contains dust particles, toxic compounds, and heavy metals that can settle on hair surfaces, disrupting its natural structure. This study focuses on examining the impact of air pollution on hair using scanning probe microscopy (SPM), which allows for high-resolution and detailed structural analysis.

Literature review and problem statement. An analysis of the literature [1, 2] confirms that hair condition deteriorates due to various external and internal factors. External factors include environmental conditions such as air pollution with chemical compounds, improper care, the use of low-quality cleaning products, and thermal treatments (e.g., blow-drying or using flat irons). Internal factors like genetics, lifestyle, hormonal changes, and medication use also affect hair health. Studies conducted using scanning probe microscopy have demonstrated that low-quality shampoos and chemical treatments can alter the geometric parameters of the hair cuticle, leading to damage and increased dryness [3].

Research methods. Scanning probe microscopy in semi-contact mode with phase shift was used to visualize fine irregularities on the hair cuticle. The analysis included samples exposed to different conditions.

- *Hair exposed to polluted air*: Small dust particles and toxic compounds were found on the cuticle, altering its structure and reducing cuticle scale adherence, resulting in a rougher surface that compromises moisture retention.
- *Hair treated with ammonia-based dye*: These samples showed significant cuticle damage, with deep grooves and peaks resulting from chemical exposure to ammonia.
- *Hair after chemical perming*: The samples exhibited an uneven surface relief with numerous small depressions and peaks, indicating severe surface damage.

- *Gray hair*: Deep cuticle damage was found, indicating a natural reduction in structural strength with age.
- *Henna-dyed hair*: The cuticle structure became smoother and less damaged post-dyeing with henna.

Research Results. This study reveals significant effects of air pollution and chemical treatments on hair structure, assessed through high-resolution scanning probe microscopy (SPM). The detailed analysis highlights changes in cuticle structure, moisture retention, and overall hair integrity across various treatment conditions.

Air pollution effects on hair. Hair exposed to polluted air exhibited surface disruptions, including dust particles and toxic compounds that disrupted cuticle alignment, increased roughness, and impaired moisture retention. This led to dryness, brittleness, and increased susceptibility to further environmental damage. The findings emphasize the need for protective measures to counteract pollution's adverse effects on hair.

Ammonia-based dye damage. Hair samples treated with ammonia-based dyes showed deep grooves and lifted cuticle scales, indicating substantial cuticle degradation. These changes compromise hair strength, elasticity, and moisture retention, suggesting a need for alternatives or protective treatments to minimize damage from harsh dyes.

Chemical perming damage. Chemical perms created uneven cuticle textures with small depressions and peaks, which weakened hair and increased breakage risk. Damage was most severe in areas with already thin cuticle layers, highlighting the need for restorative treatments post-perm.

Gray hair characteristics. Gray hair samples showed deeper and more extensive cuticle damage, likely due to reduced melanin and structural proteins. Gray hair had more surface irregularities, contributing to its increased fragility, which suggests a need for targeted products for aging hair.

Henna as a protective dye. Henna-treated samples demonstrated smoother, more uniform cuticle surfaces, as opposed to the damage seen with ammonia dyes. Henna appears to strengthen the cuticle, reducing moisture loss and potentially offering color benefits without structural harm.

SPM effectiveness. SPM proved effective in detecting micro-damage with high precision, revealing small cracks and lifted scales that are typically undetectable with conventional microscopy. SPM's detailed imaging supports its utility in assessing fine structural changes in hair and evaluating damage from environmental and chemical exposures.

These findings provide a foundation for developing hair care strategies that minimize environmental and chemical damage, promoting healthier hair in adverse conditions.

Discussion of Results. The research findings underscore the detrimental effects of air pollution and certain hair treatments on hair structure, with scanning probe microscopy (SPM) providing invaluable insights into these structural impacts at the micro-level. The presence of dust particles and toxic substances on hair exposed to polluted air was shown to disrupt the natural alignment of cuticle scales, increasing the hair's roughness and reducing its moisture retention ability. This effect, evident in samples analyzed via SPM, reveals a critical aspect of air pollution's impact: as cuticle scales lift and the surface becomes rougher, hair becomes more prone to dryness, brittleness, and increased breakage. These results highlight the need for protective interventions to mitigate the effects of urban pollution on hair.

Additionally, the study revealed substantial structural damage from the use of aggressive chemical treatments, such as ammonia-based dyes and chemical perms. In ammonia-treated hair samples, SPM analysis identified deep depressions and protrusions on the cuticle surface, indicating significant breakdown of the hair's protective outer layer due to chemical exposure. These changes weaken the hair's resilience, decreasing elasticity and making it more vulnerable to environmental stressors. Conversely, henna—a natural dye—appeared to enhance cuticle smoothness in treated samples. This finding suggests that natural coloring agents may offer a protective effect by sealing cuticle layers, potentially contributing to better moisture retention and reduced damage over time.

The use of SPM allowed precise detection of micro-level damage across hair samples exposed to various environmental and chemical influences. Unlike traditional optical methods, SPM provides high-resolution visualization of minute structural differences in the hair cuticle. This capability to identify subtle variations, such as small cracks, lifted scales, and uneven surface reliefs, underscores the method's superiority in assessing the fine structural changes that might otherwise go undetected. These insights can inform the development of targeted protective measures and products designed to counteract or prevent these specific types of damage.

Conclusions. This study confirms that air pollution, containing dust and toxic compounds, negatively impacts hair structure by accumulating on the cuticle and causing structural disruption. Such pollutants create a rougher surface on the hair shaft, which hinders moisture retention and leads to increased dryness and brittleness. These findings emphasize the importance of protective measures against urban air pollution for maintaining hair health.

The structural integrity of hair was found to be compromised significantly by ammonia-based dyes and chemical perms. SPM analysis revealed deep grooves and peaks on treated hair surfaces, indicating profound cuticle damage. These structural changes contribute to reduced elasticity and durability of hair, increasing its vulnerability to further damage. As demonstrated, natural coloring agents like henna may mitigate some of this damage, promoting a smoother cuticle surface and offering potential benefits for long-term hair health.

The use of scanning probe microscopy was instrumental in detecting fine structural changes and assessing the micro-damage caused by environmental and chemical exposures. Its high-resolution capability proved essential in visualizing small-scale cuticle disruptions, which could not be identified with conventional microscopic methods. This level of precision affirms SPM as a valuable tool for hair research, allowing for a nuanced understanding of how various factors affect hair structure at the micro-level.

The results underscore the need for hair care products and regimens that prioritize protection against air pollution and reduce the impact of harsh chemical treatments. By identifying the specific mechanisms through which pollutants and chemicals affect hair, this study provides a foundation for developing targeted products that could strengthen the cuticle, improve moisture retention, and enhance overall hair resilience. These insights can guide the formulation of specialized hair care solutions aimed at minimizing structural damage and preserving hair health in polluted environments.

Given the substantial impact of environmental pollutants on hair, further research is recommended to explore the effectiveness of various protective treatments and products in mitigating these effects. Additionally, exploring natural alternatives to ammonia-based dyes and other aggressive treatments could yield valuable information on safe and effective hair care practices. Longitudinal studies on the cumulative impact of pollution and chemical exposure over time would also contribute to a deeper understanding of hair health in urban settings.

References

1. Li, B.S., Pasch, M.C., Maibach, H.I. (2018). Hair Disorders Induced by External Factors. In: John, S., Johansen, J., Rustemeyer, T., Elsner, P., Maibach, H. (eds) Kanerva's Occupational Dermatology. Springer, Cham. https://doi.org/10.1007/978-3-319-40221-5_26-2

2. Kesika, P., Sivamaruthi, B.S., Chaiyasut, C. Factors Affecting Hair Health. Encyclopedia. Available online: https://encyclopedia.pub/entry/40861 (accessed on 10 November 2024).

3. Tomita, Y., Ishikawa, M., Takigami, S. (2008). Effects of permanent waving and bleaching treatments on damage of human hair. Transactions of the Materials Research Society of Japan, 33(4), 865-868. Available online: https://www.jstage.jst.go.jp/article/tmrsj/33/4/33_865/_pdf (accessed on 10 November 2024).

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MUSCLE FOR A FLYING MINIROBOT

Abstract. *The aim of this work is to enhance the design of an actuator for a miniature flying insect-sized mini-robot by developing a new method of controlling its wings using a piezoelectric air emitter. The relevance of this research is associated with the development of a new method for controlling the wings for a miniature flying insect-sized mini-robot, as well as the creation of a new type of actuator unit for this purpose. Additionally, experimental prototypes have been created, and experimental investigations of the new actuator unit based on the piezoelectric air emitter have been conducted.*

Key words: *flying miniature robot, actuator, piezoelectric air emitter, monowing.*

Modern information technologies represent a symbiosis of a computer system and a technical tool [1]. A robotic system, namely a flying mini-robot, can be used as a technical tool. Today, small flying robots are employed for various tasks such as monitoring and pest control in agriculture, image processing in geological exploration, mining industry, and photogrammetry, natural disaster monitoring, search and rescue operations, terrestrial and underwater wildlife research, inspection of railway tracks and structures in smart cities, environmental monitoring, and maritime surveillance [2].

Robots the size of bees (~100 mg) impose significant constraints on the components used. One of the most crucial components of a miniature flying insect-sized mini-robot is the wing actuator. Conventional actuators used in larger robots, such as electric motors driving propellers in most quadcopter drones, are not efficient and power-dense when scaled down to the size of an insect. This is due to the fact that, at smaller scales, losses such as Coulomb friction and electrical resistance become more critical [3]. Therefore, the development of a new type of actuator is a critical task.

Another example of an insect-sized robot was developed by engineers at the University of Washington (USA). They introduced RoboFly (Fig. 1), a small 74-mm flying robot [4]. It can move through the air, walk on the ground and water, and is slightly heavier than a paperclip. RoboFly is powered by converting laser energy into electricity, sufficient to control its wings. Scientists irradiate a thin, nearly invisible laser beam onto a photovoltaic element, which transforms the laser light into electricity. The construction of this small robot involves minimal components, significantly simplifying assembly, and it is an application of the RoboBee technology.

The goal of this work is to improve the design of the actuator for a miniature flying insect-sized mini-robot by creating a new method for wing control using a piezoelectric air emitter. The obtained results can be utilized in the design of piezo actuators for insect-sized robots.

After a thorough analysis of the actuator designs used in insect-sized robots, we propose a new method for controlling the wings of a flying miniature robot. The essence of the new actuator unit's operation lies in wing control by influencing the air under certain pressure and with a specific frequency using an air emitter on a monowing. The functional diagram of the new actuator unit model is presented in Fig. 2.

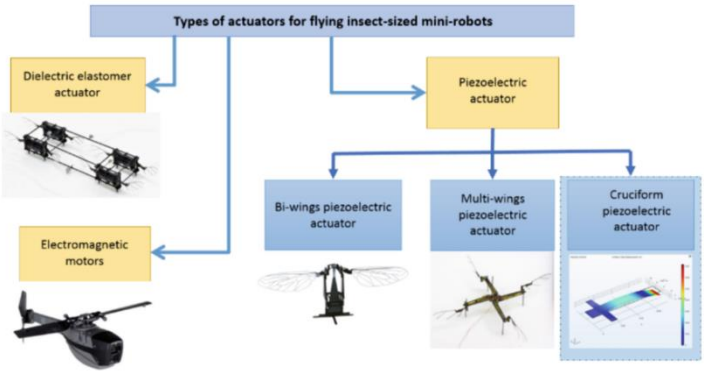


Fig. 1. Types of actuators for insect-sized flying robots.

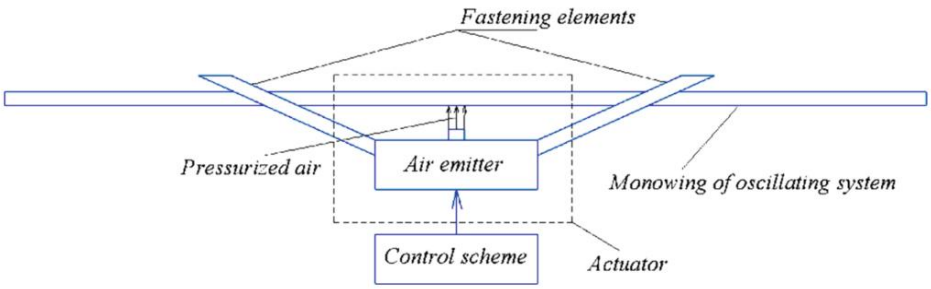
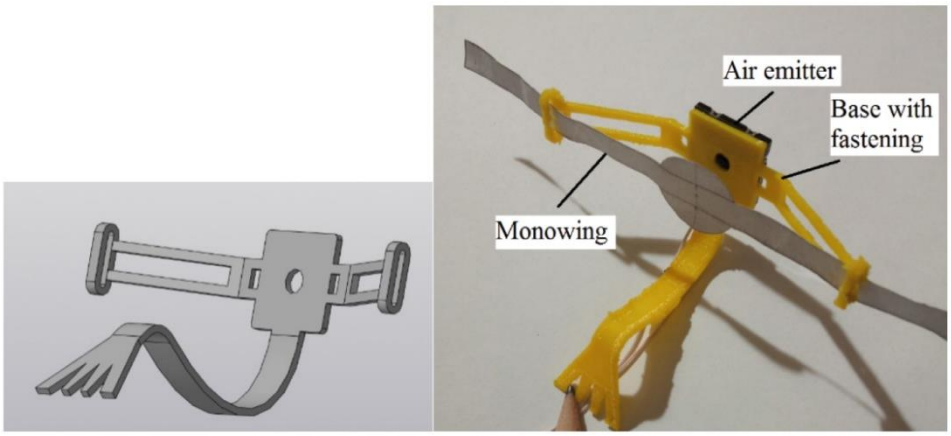


Fig. 2. Functional diagram of the insect-sized flying robot model with a new type of actuator based on a piezoelectric air emitter.

The operation principle of the proposed actuator is as follows. The control scheme based on a microcontroller generates pulses with a specific frequency and algorithm, which are then sent to the air emitter. The air emitter, in turn, starts generating pressurized air. At a certain distance from the air outlet, there is a monowing, which constitutes an oscillating system (a beam on two hinge supports) fixed on fastening elements. A portion of the monowing, after the mounting system, forms the wings. Therefore, the directed action of air at the center of the monowing results in a slight bending at the center and significant deflection at the ends. In other words, the wings begin to flap.

One of the key components of the new type of actuator for flying insect-sized mini-robots is the base with attachment for the monowing, the monowing itself, and the air emitter. Taking into account the aforementioned research, a model of the base with fastening for the monowing was created (Fig. 3a). Using a 3D printer, an experimental sample of the base with fastening for the monowing of the new type actuator was printed, and after installing the air emitter and the monowing, the structure looks like this (Fig. 3b).



a) b)

Fig. 3. Model of the base with fastening for the monowing of the new type actuator (a) and experimental prototype of the newly developed actuator for flying mini-robots based on a piezoelectric air emitter (b).

The structural features of modern designs of flying miniature robots, which can be one of the elements of information technologies, were analyzed. The main shortcomings of actuators, which are the primary components for achieving flight, were identified. A new method for transmittingforce through the directedmovement of airfrom the piezoelectric actuator to the robot's wing to facilitate its aerial ascent was proposed and verified for the first time. A model of the base with monowing fastening for the new actuator type was constructed and 3D-printed. The obtained results can be applied not only in the design of flying insect-sized mini-robots but also in the development of crawling and swimming miniature robots.

References

1. Aladwan, I.M., Bazilo, C., Faure, E.: Modelling and development of multisectional disk piezoelectric transducers for critical application systems. Jordan J. Mech. Indust. Eng. 16(2), 275–282 (2022).

2. de Lucena, A.N., da Silva, B.M.F., Gonçalves, L.M.G.: Micro aerial vehicle with basic risk of operation. Sci. Rep. 12, 12772 (2022). https://doi.org/10.1038/s41598-022-17014-4.

3. Wood, R., Finio, B., Karpelson, M., et al.: Progress on 'pico' air vehicles. Int. J. Robot. Res. 31(11), 1292–1302 (2012). https://doi.org/10.1177/0278364912455073.

4. Chukewad, Y.M., Singh, A.T., James, J.M., Fuller. S.B.: A new robot fly design that is easier to fabricate and capable of flight and ground locomotion. In: IEEE International Conference on Intelligent Robots and Systems (IROS) Madrid, Spain (2018). https://doi.org/10.1109/IROS.2018.8593972.

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IMPROVING THE ENERGY EFFICIENCY OF THE SUPPLY SYSTEM OF COMPRESSED AIR

Abstract. *An improved approach to improving the power utilization efficiency of compressed air supply systems in ammonia storage facilities, taking into account the evaluation and control of energy efficiency levels achieved after the implementation of energy saving measures. The practical significance of this study is that the implementation of the proposed energy saving measures will effectively address the fundamental problem of inefficient power utilization in compressed air systems. The analysis of this experience is valuable in addressing energy efficiency issues in industrial settings.*

Key words: *Compressed Air Systems, Regression Analysis, Energy Efficiency, Electricity Consumption, Energy Conservation, Baseline Energy Consumption.*

Introduction. Given the situation in Ukraine, the issue of energy saving is more relevant than ever. The primary objective of the initiative is to use fuel and energy resources as efficiently as possible, taking into account the current level of technological development. Since the greatest energy saving potential in Ukraine is concentrated in the industrial sector, increasing the energy efficiency of industrial enterprises will reduce Ukraine's dependence on energy imports and increase the profitability of its products. Compressed air production and supply is one of the most energy-intensive industrial processes, therefore energy saving issues in this sector urgently need to be addressed.

Energy efficiency measures require proper monitoring to ensure their effectiveness and to track savings from their implementation. Continuous monitoring of energy efficiency is therefore an integral part of compressed air system management.

The **aim** of the work is to increase the efficiency of electrical energy utilization in the compressed air supply systems of enterprises.

To achieve the stated research objectives, the following studies were carried out:

- Consider the general characteristics of compressed air supply systems and types of compressors. Determine which components are included in the system.
- Conduct a comparative analysis of centralized and decentralized compressed air supply schemes to determine which is better in terms of energy efficiency.
- Analyze and investigate the main existing measures for improving energy efficiency in compressed air supply systems. As a result of this analysis, identify the highest potential for energy savings.

Methods and Materials. Compressed air systems account for approximately 10% of industrial electricity consumption. Compressed air is primarily used as a component in technical processes at enterprises. The required pressure and air cleanliness, as well as the time of its consumption, are determined by the conditions of the specific process.

The compressed air system, regardless of its specific application, is divided into four main subsystems:

− compressed air production;
− compressed air storage;
− compressed air preparation;
− compressed air distribution.

Compressed air systems may also include auxiliary subsystems. Typically, any industrial facility has several compressors connected by a single compressed air preparation system, as well as an extensive pipeline network that distributes the compressed air. It’s important to note that some

equipment is equipped with its own built-in compressed air supply systems, which do not require an external source. Given the above, it is impossible to develop a single, universal compressed air supply system; therefore, each system must be designed according to the characteristics of the specific technological process and production conditions.

The type and design of a compressor affect both its efficiency and its operating costs for maintenance. There are two main groups of compressors classified by their operating principle: positive displacement compressors and dynamic compressors. Positive displacement compressors increase the pressure of a given amount of air by reducing the volume that the air occupies. This type of compressor is further divided into two main types—piston and rotary compressors. Dynamic compressors work by imparting speed to a continuous stream of air, which is then converted into pressure using either rotating elements or stationary diffusers or blades.

Choosing the correct compressed air supply scheme should be approached responsibly, as an incorrect choice will lead to increased electricity costs and frequent breakdowns of the compressor equipment. There are only two primary types of compressed air supply schemes: centralized and decentralized [2].

A centralized scheme means that compressed air is supplied to the workshops from a common compressor station. The main advantages of this system include the following: breakdowns, scheduled maintenance, or repairs do not impact the reliability of compressed air supply (provided there are backup compressors), and it requires less maintenance staff. The disadvantages of this supply scheme include: the long pipeline length, which can result in pressure losses, high inertia due to the use of large compressors that cannot respond quickly, the majority of pipelines are exposed outdoors in winter, which leads to freezing, and when the enterprise is underutilized, only part of the workshops operate, requiring large compressors whose operation is inefficient from an energy perspective. Planned maintenance requires backup compressors, and some users may require higher air pressure, which means maintaining a higher network pressure, leading to additional power losses.

In a decentralized system, consumers are supplied with compressed air by separate, smaller compressors installed directly next to the consumer. The advantages of this scheme include: reduced pipeline length, significantly lower costs, easier supply to remote consumers, the ability to install a compressor for each consumer based on their needs, and no longer having to worry about freezing; operating costs for compressed air are lower since there is no need for thermal insulation, sealing, or pipeline maintenance. The disadvantages of this system are: challenging redundancy, noise created by compressors installed in production areas, which poses a hazard for workers, and difficulties in system modernization.

Choosing the optimal air supply scheme depends on the specific conditions of a given enterprise and must be preceded by a full analysis of the situation, existing pneumatic lines, an energy audit of the entire production and compressed air supply chain, and consideration of both capital and ongoing expenses. A decentralized scheme is not a universal solution, and its application must be economically justified. When designing pneumatic systems, it is necessary to consider not only current consumers but also possible changes in the required amount of compressed air and the locations of consumption points [2].

Among all energy carriers, the compressed air system allows any enterprise to achieve immediate energy savings. Moreover, most energy-saving measures do not require significant capital investments [3]. Fig. 1 shows that after 10 years of compressor operation, the electricity costs required to run the system significantly exceed the initial investments. From Fig. 1, it is evident that maintenance accounts for 7% of total costs but is necessary to maximize the efficiency of any compressor. In a typical industrial enterprise, compressed air accounts for up to 10% of total energy expenditures. The main goal of the methods described here is to design or modify the compressed air system in a way that increases its energy efficiency.

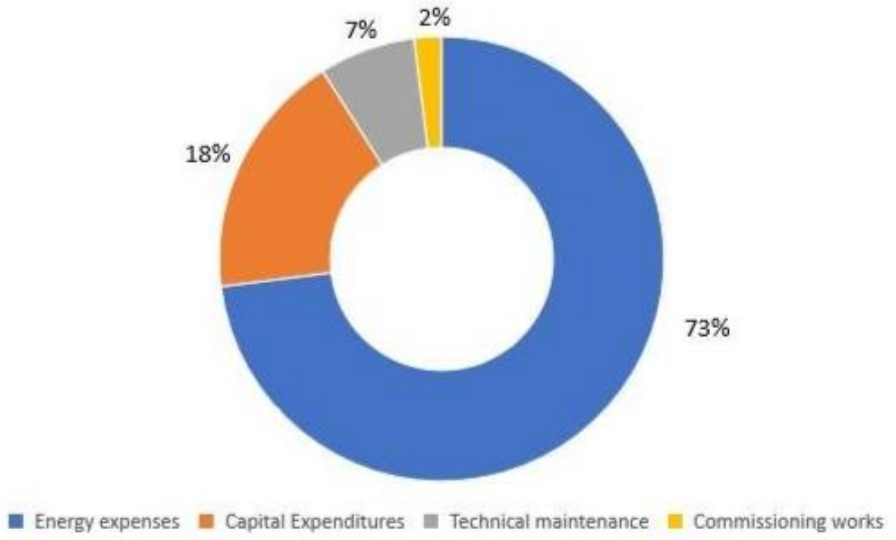

Fig.1 The costs associated with the operation of the compressor over 10 years of its use.

One of the most important characteristics of a compressed air system is pressure, the specific value of which is determined by a number of requirements depending on the application of compressed air. Typically, this value is a compromise between low and high pressure. In most cases, clients use a pressure of 6 bar (m), but pressure requirements can reach up to 13 bar (m). In many instances, the pressure in the system is chosen based on the maximum pressure required by the consumer [2]. In many cases, systems operate at pressures of 8 bar (m) or 10 bar (m), but most of the air supplied to consumers is compressed to 6 bar (m).

The proper practice is to select a pressure in the system that meets 95% of air demand and to install a small pressure booster for the remaining consumers. Operators can either refrain from using equipment that requires a pressure above 6 bar (m) or install two systems, one with a pressure of 6.5 bar (m) and the other designed for higher pressure.

The third fundamental question that needs to be addressed when designing a system is the selection of the pipe diameter and the location of the compressor. Difficulties or obstacles in air movement not only require the installation of long pipes but also lead to pressure loss. The use of welded pipelines helps reduce friction losses.

In a well-designed system, the pressure drop between the compressor and the final consumer is less than 10% of the pressure at the compressor outlet. This can be achieved by regularly monitoring the pressure drop, selecting dryers, filters, hoses, and connections with low pressure drop under calculated conditions, reducing the distance the air travels in the distribution system, and recalculating the required pipe diameter when compressed air consumption increases.

Research shows that most compressed air systems are characterized by moderate or large fluctuations in consumption. Therefore, there is significant potential for energy savings by equipping compressors with variable speed drives.

A priority task in designing high-efficiency motors is minimizing both electrical and mechanical losses to reduce the energy consumption of equipment. There are several classifications of electric motors in the world concerning energy efficiency. Within these classifications, high-efficiency motors belong to the highest categories, such as EFF1 and NEMA Premium.

In most companies, compressed air systems include several compressors. The overall energy efficiency of such systems can be significantly improved by implementing a central controller that can receive production information from the compressors and fully or partially manage their operating modes [1]. The management strategy implemented by the controller should take into account the characteristics of individual compressors, particularly the control modes they allow. The lower the operating pressure of the system, the more cost-effective the production of compressed air becomes. However, the system must be able to provide sufficient air pressure for all consumers at any time when needed. Reducing peak pressure can be achieved by improving the control system.

Most of the electricity consumed by industrial compressors is ultimately converted into thermal energy and released into the environment. In many cases, appropriate measures can be taken to recover a significant portion of this heat and use it for useful applications, such as heating air or water when needed.

Reducing leaks in compressed air systems has the potential for energy savings that significantly exceed all other reserves. The volume of leaks is directly proportional to the working pressure of the system. Leaks can occur in any compressed air system. In large systems that are properly maintained, unproductive power losses from the compressor due to leaks do not exceed 10%. For smaller systems, the corresponding value should not exceed 5%. Therefore, preventive maintenance programs for compressed air systems should include measures to prevent compressed air leaks and regular assessments of the extent of leaks. After detecting and eliminating a leak, a re-evaluation should be conducted.

Conclusions. A general overview of compressed air supply systems and types of compressors is presented. It is established that the system includes the following main components: compressed air production, storage, conditioning, and distribution.

A comparative analysis of centralized and decentralized compressed air supply schemes has been conducted, which shows that there is no universal solution for selecting a supply scheme. The choice between schemes should be based on a detailed analysis of air consumption patterns, system reliability, and techno-economic calculations.

The main existing measures to increase energy efficiency in compressed air supply systems have been analyzed and studied. The analysis reveals that the greatest energy-saving potential is associated with reducing compressed air leaks, as leaks lead to several other operational losses, such as system pressure drops, premature equipment wear, and unjustified increases in compressor power.

References

1. Дірк Кьовенер, Бруно Вільгельм, Анатолій Чернявський, Павло Пертко, Світлана Чеботарьова, Ганна Боднар, Аліна Рекрутяк. Міжгалузеві технології, що здатні підвищити енергоефективність українських промислових підприємств. https://saee.gov.ua/sites /default/files/blocks/2021-Cross-Cutting-Technologies-ukr.pdf.

2. Енергозбереження при виробництві стисненого повітря., [Електронний ресурс] – Режим доступу: http://um.co.ua/8/8-2/8-216648.html.

3. Compressed Air Leak Survey & System Energy Audit Report, [Електронний ресурс] – Режим доступу: https://www.permaweld.com/images/reports/compressed_air_survey_and_system_ energy_audit_report.pdf.

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REACTIVE POWER COMPENSATION FOR RESIDENTIAL CONSUMERS

Abstract. *The article is dedicated to evaluating the possibilities of implementing methods and technical solutions for reactive power compensation in the residential sector, particularly at the level of transformer substations and residential consumers, including individual houses and multi-story complexes connected to them. The article examines the level of reactive power consumption by household appliances with inductive loads and the potential consequences for the energy network in the absence of compensation measures. Various compensation methods, such as capacitor banks, are discussed with an assessment of their advantages and disadvantages for use in residential areas. The conclusions highlight the potential improvements in power quality upon implementing compensation systems in residential zones.*

Key words: *reactive power, compensation, residential sector, capacitor banks, power factor correction.*

Introduction. The overall consumption of reactive power by residential consumers is often underestimated due to its relatively small share compared to the industrial sector. However, residential consumers living in multi-story buildings and residential districts also contribute to reactive power consumption. The main sources of reactive power consumption in the residential sector include appliances such as air conditioners, refrigerators, washing machines, and other devices with inductive loads, the number of which is continuously increasing due to the overall growth in electricity consumption by residential consumers [1].

Reactive power compensation systems, which are predominantly used in industrial sectors, are rarely applied in residential premises. However, the implementation of such systems, like capacitor banks, can significantly improve the quality of electricity in residential areas.

Problem Statement. The absence of reactive power compensation measures in the residential sector negatively impacts the quality of electricity. Residential buildings connected to transformer substations may face issues such as voltage instability and a reduction in the power factor, ranging from 0.85 to 0.95, especially during peak consumption periods [2].

Without compensation, the distribution network experiences inefficiently increased energy costs. Therefore, it is necessary to implement measures and technical solutions for reactive power compensation to improve electricity quality for residential consumers.

Methods and Materials. To address the identified problem, it is proposed to apply solutions widely used in the industrial sector, namely, the installation of capacitor banks for reactive power compensation in the residential sector.

The level of reactive power consumption by a household can be assessed using the following calculation: as an example, let us assume that the total consumption of a single apartment is: Active power P = 3 kW per apartment, apparent power S = 3.5 kVA, power factor PF = 0.85.

The reactive power of the apartment can be calculated by the following equation (1).

$$Q = \sqrt{S^2 - P^2} = 1{,}8\ kVAR \quad (1)$$

In this equation, Q represents reactive power in reactive volt-amperes (VAR), S represents apparent power in volt-amperes (VA), and P represents active power in watts (W).

Thus, for the selected apartment example, the reactive power consumption will be established, which currently negatively impacts the network in the absence of compensation systems.

Installing such systems at the level of the 10/0.4kV step-down transformer substation supplying a group of consumers, or directly on the building's main distribution board, will

effectively address issues related to power quality. The use of capacitor banks will help maintain a stable power factor and reduce overall energy losses. Furthermore, the installation of systems with dynamic regulation of capacitor blocks will enable efficient real-time compensation depending on network load [3].

Conclusion. Reactive power compensation is an important step in improving energy efficiency and ensuring stable power supply to residential consumers. Reactive loads generated by household appliances with inductive components negatively affect power quality, leading to voltage fluctuations and a reduced power factor. The application of compensation technologies, such as capacitor banks, can significantly reduce these negative effects, stabilize the power grid, and reduce energy losses.

Implementing reactive power compensation in residential sectors using capacitor banks can reduce energy losses and improve power factor stability. Studies show that in multi-apartment buildings, particularly during peak hours, reactive power correction is critical for maintaining grid efficiency.

The inclusion of reactive power compensation in residential sectors using capacitor banks can lead to substantial energy savings and improvements in grid stability. It is recommended to integrate these systems in multi-story residential buildings, particularly in areas experiencing high power consumption during peak hours.

Given the experience of implementing reactive power compensation methods in the industrial sector, further research can focus on adapting these ready-made solutions for residential consumers. Installing compensation systems at the level of transformer substations or distribution boards in multi-story buildings will ensure the efficient operation of the power system under increasing load conditions.

References

1. Sofia Tsemekidi Tzeiranaki, Paolo Bertoldi, Francesca Diluiso, Luca Castellazzi. Marina Economidou Nicola Labanca, Tiago Ribeiro Serrenho, Paolo Zangheri. Analysis of the EU Residential Energy Consumption: Trends and Determinants. Energies 2019, 12, 1065. https://www.mdpi.com/1996-1073/12/6/1065.

2. Salim Adolfo Giha Yidi, Vladimir Sousa Santos, Kelly Berdugo Sarmiento, Jorge de la Cruz John E. Candelo-Becerra. Comparison of Reactive Power Compensation Methods in an Industrial Electrical System with Power Quality Problems. Electricity 2024, 5, 642-661. https://www.mdpi.com/2673-4826/5/3/32.

3. S. Sagiroglu, I. Colak, R. Bayindir - Power factor correction technique based on artificial neural networks. Energy Conversion and Management, 47(18–19), 2006, 3204-3215. https://doi.org/10.1016/j.enconman.2006.02.018.

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LEVERAGING ZABBIX FOR CYBERSECURITY

Abstract. *This study is devoted to the consideration of the possibilities of using monitoring technologies, specifically the Zabbix platform, in the context of improving information security. The study is aimed at analyzing how Zabbix can be used to detect threats, manage vulnerabilities, and automate incident response.*

Key words: *Zabbix, verification of settings, trigger testing, notifications, automated actions, effectiveness assessment, vulnerability monitoring, risk assessment, integration, vulnerability scanning, risk management, threat prioritization, reporting, automation.*

Introduction. In today's environment, cyber threats are becoming more complex and diverse, requiring constant monitoring of information assets and faster and more accurate response. Traditional methods for detecting and eliminating threats are not fast enough or effective enough, and they require human interaction with a large number of systems, which increases the likelihood of human error due to a lack of automation.

The aim. The purpose of this paper is to review the Zabbix monitoring system, assess its capabilities and prospects for improving overall cybersecurity if integrated into a computer system.

Methods and Materials. Zabbix is an open source software for monitoring a variety of IT components, including networks, servers, virtual machines (VMs), and cloud services. Zabbix provides monitoring metrics such as network utilization, CPU utilization, and disk space utilization.

Compatibility with other systems is manifested by the fact that the software monitors the operation of a large number of systems for data collection such as Zabbix agents, SNMP, IPMI, JMX, SSH, Telnet, HTTP(S), trackers, cloud APIs (AWS and Azure), external scripts, which allows you to monitor servers and other network equipment, Java applications and web services [1].

The system has a user-friendly web interface that greatly simplifies its configuration. In order to add a host to be monitored, you only need to specify its address and select one of the standard templates that already have some settings for a specific type of host. The ability to manually configure or edit the template is important, as it allows you to fine-tune the monitoring system for specific equipment or for better integration into the system.

To ensure timely response to events, thresholds are set at which triggers are activated, which can be configured to perform various tasks such as sending notifications, changing the status in the monitoring system, activating systems that will prevent the situation from worsening, such as starting the server room backup air conditioning system, sending an immediate shutdown signal to the device or disconnecting it from the network to stop a cyber-attack [2-4].

Integration with SIEM monitoring systems can transmit alerts and event data to the infrastructure to the SIEM via API, Syslog, and other protocols, which allows for real-time analysis of this data and correlation with other data to improve the accuracy of detecting potential threats and detecting anomalous behavior that is not always obvious from logs alone. It also makes it possible to use SOAR (Security Orchestration, Automation, and Response) to launch automatic actions based on Zabbix triggers, such as blocking an IP address or changing network policies [5].

To extend the capabilities, such as running external commands or collecting non-standard metrics, it is possible to use scripts, for example, you can implement the execution of prepared actions as a service restart. Scripts have the ability to work both locally and remotely via SSH and Telnet, which allows them to be used in monitoring Unix systems without using an agent.

External APIs, one of which is the JSON-RPC API provided by Zabbix, allows you to interact with other systems and manage its functions remotely, such as editing and deleting hosts, triggers,

templates, events and editing other settings, automating the addition and updating of hosts, scaling virtual environments and updating configurations based on events, integrating with SIEM, ITSM and cloud platforms [6-9].

Automation of threat response is performed to respond to events and cyber incidents in a timely manner, which can include blocking access, restarting services or devices, and applying access policies. As an appliance, when the system detects abnormal IP address activity, it can automatically block its access to the network until the event is verified by a human, notify security teams of the incident, and generate a report for a quick assessment of the situation.

The human factor is reduced by automating processes and routine tasks, standardizing responses, continuous monitoring and rapid response outside of business hours, and minimizing human interaction with the system, allowing cybersecurity professionals to devote more time to more complex problems [10].

Using this monitoring system, we are able to conduct regular scans of systems and applications to monitor and identify known vulnerabilities, including outdated software, incorrect configurations, or insecure network services. By integrating with vulnerability databases such as NVD (National Vulnerability Database) and CVE (Common Vulnerabilities and Exposures) to track current threats and automatically notify administrators, it is also possible to automate updates and patching to reduce the risk of attacks. It's important to add monitoring tools that allow you to set up alerts to prioritize critical vulnerabilities, especially those exploited by active vulnerabilities.

With the help of triggers, you can configure Zabbix risk analysis to prioritize events by severity, allowing the security team to respond to the most critical risks first. For example, detecting the exploitation of a known vulnerability. To increase productivity and provide detailed risk analysis based on various factors, data is transferred to SIEM [11].

For more information, Zubbix generates informative dashboards to display risks and vulnerabilities in real time and in an easy-to-understand manner. Additionally, a history of events and trigger statuses is maintained to track and respond to past incidents.

Zabbix has the ability to manually or scriptedly create test events that initiate triggers. This will allow you to check the triggering of triggers when thresholds are reached and determine whether the events are processed as expected. It will also allow you to evaluate the conditions for triggering triggers to fine-tune thresholds to eliminate false positives. Based on the test results, the automation algorithm is configured, actions are added or changed to achieve maximum protection, and scripts and settings are updated to ensure timely and adequate response to incidents.

To evaluate the effectiveness, you can configure scenarios for checking the execution of automated actions: By blocking IP addresses or running scripts, you can make sure that there are no delays, no impact on other components, and that the actions performed are correct. After analyzing the results of automated responses, statistics are collected to evaluate the effectiveness. For example, to check how often automatic blocking prevents intrusions, whether services are restarted on time [12].

Conclusions. The article discusses the features of using the Zabbix monitoring system, evaluates its capabilities and prospects for use, approaches to monitoring network assets, integration with other cybersecurity tools, considers the possibilities for automating responses to threats and incidents, considers vulnerability management and risk assessment, and the possibilities for convenient verification and testing of the effectiveness of settings. The system under consideration has proven to be a multifaceted and flexible tool for simplifying threat monitoring in computer systems, which can increase the overall level of cybersecurity of the system by interacting with other solutions such as SIEM, automating routine tasks and responding to threats, reducing the workload of the cybersecurity center staff, and reducing the risks associated with the human factor.

References

1. Zabbix Documentation: Overview of Zabbix https://www.zabbix.com/documentation/1.8 /en /manual/about/overview_of_zabbix.
2. Zabbix Documentation: 1 Configuring a host https://www.zabbix.com/documentation /current/en/manual/config/hosts/host.
3. 3 Triggers https://www.zabbix.com/documentation/current/en/manual/config/triggers.
4. 2 Triggers expression https://www.zabbix.com/documentation/5.2/en/manual/config/ triggers/expression.
5. Zabbix Integrations https://www.zabbix.com/integrations.
6. Zabbix Documentation: 8 Scripts https://www.zabbix.com/documentation/6.0/en/manual /web_interface/frontend_sections/administration/scripts.
7. Zabbix Documentation: 3 Scripts https://www.zabbix.com/documentation/current/en/ manual/web_interface/frontend_sections/alerts/scripts.
8. Zabbix Documentation: 7 Scripts https://www.zabbix.com/documentation/5.0/en/manual /web_interface/frontend_sections/administration/scripts.
9. Zabbix Documentation: 19 API https://www.zabbix.com/documentation/current/en/ manual/api.
10. Zabbix Documentation: 2 Actions https://www.zabbix.com/documentation/current/en/ manual/config/notifications/action.
11. Zabbix Documentation: 4 Trigger severity https://www.zabbix.com/documentation/current /en/manual/config/triggers/severity.
12. Zabbix Documentation: 1 Preprocessing testing https://www.zabbix.com/documentation /current/en/manual/config/items/preprocessing/testing.

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INTEGRATION OF COMPUTER VISION INTO ROBOTIC TECHNICAL SYSTEMS USING THE YOLO PLATFORM

Abstract. *Computer vision is a critically important component of modern robotic systems and control systems, enabling high-precision perception, analysis, and interaction with the environment. The implementation of such technologies opens up new opportunities for safer and more productive work, significantly impacting the development of artificial intelligence and the automation of industries. This paper addresses the introduction of new approaches to object recognition based on the YOLOv8face platform, implementing the system on the Raspberry Pi microcomputer, which enables various projects where high precision and compactness of technical solutions are crucial.*

Key words: *computer vision, YOLO, robotic systems, face recognition.*

Introduction. The integration of computer vision into modern technical systems significantly enhances their functionality and automation, allowing for tasks that require detailed image analysis and object recognition. Computer vision is becoming critically important in many fields, including industry, medicine, security, and automotive transport. The relevance of this research is driven by the growing need for automated systems that can quickly and accurately process large volumes of information. The implementation of such technologies opens up new opportunities for safer and more productive work, significantly affecting the development of artificial intelligence and the automation of industries. In modern conditions, increasing productivity and quality of image processing is a critical task for achieving competitiveness. Manufacturing processes involving computer vision help quality control systems detect defects and automate product sorting, enhancing overall efficiency and productivity.[1] In the security field, face and object recognition technology provides new capabilities for access control and video surveillance systems. As technologies evolve, it is important to note that computer vision is also foundational for new innovations in areas such as virtual reality and augmented reality, where accurate perception of the environment is necessary for an interactive experience. In recent years, advancements in deep learning technologies have significantly improved results in the field of computer vision, particularly in object recognition tasks. The application of neural networks, especially the YOLO architecture, enables highly accurate object detection in real time. This technology provides greater efficiency and speed compared to traditional methods, such as Haar Cascade-based algorithms. Thus, the implementation of computer vision in various fields becomes not only relevant but also a necessary condition for the further development of intelligent systems.

Methodology. The project is focused on creating an accessible solution that can be used in resource-constrained environments. For face detection, the YOLOv8 model was used, which provides speed and accuracy in detection. YOLO is noted for its ability to simultaneously consider spatial and scale characteristics of objects, allowing for high accuracy in real time. The choice of YOLO architecture was driven by its advantages over traditional methods, such as Faster R-CNN, particularly shorter processing times and greater speed. For face recognition, the LBPH (Local Binary Patterns Histograms) method is employed, which works effectively with small datasets.[2]

The system is implemented on a Raspberry Pi platform, ensuring compactness and mobility. The use of OpenCV provides flexibility in video and image processing. The developed solution offers a new approach to building face recognition systems using the YOLOv8 architecture and the LBPH methodology on the compact Raspberry Pi platform.[3] This research demonstrates the possibility of integrating a computationally efficient YOLO-based algorithm for real-time applications in resource-constrained devices. Unlike traditional OpenCV-based methods, using YOLO allows for achieving high accuracy in face detection with lower latencies, thus enhancing the reliability of the system in conditions requiring quick responses, such as access control and video surveillance.

The main algorithm of the system includes:

- Loading the YOLO model for real-time face detection.
- Processing video streams from a webcam.
- Detecting faces and recognizing them.
- Displaying information about recognized faces on the screen or synthesizing voice responses, including greeting messages for familiar individuals.

When recognizing a person, the voice assistant can accept and process a voice command. If the command is spoken by another person who is not recognized, the assistant remains silent. The voice assistant can also be integrated into robotic systems, significantly expanding the possibilities for real-time interaction with users. In low-performance devices like the Raspberry Pi, using YOLO is particularly beneficial, as it addresses issues of insufficient power while providing adequate speed and accuracy of processing [4].

Results and discussion. The developed system successfully recognizes faces with high accuracy and sufficient speed. Tests showed that the system can operate effectively under various lighting conditions and from different viewing angles. Real-time trials confirmed that the system provides fast detection and accurate identification, making it useful in environments where high processing speed is needed, such as access control systems. The system demonstrated its effectiveness in real-time, which is crucial for many applications in the fields of security, access control, industrial automation, and more. This is an important aspect for many applications in security, where lighting conditions can vary. By integrating a voice assistant, the system offers a new level of interaction that can be beneficial in various applications, from security to domestic systems. Voice control can significantly enhance user convenience and ensure interactivity, which is relevant in the development of smart homes and other intelligent systems.

Research in this area opens new horizons for implementing more complex systems that can adapt to user needs and provide intuitive solutions.

Conclusions. As a result of the completed work, a face recognition system based on the YOLO platform has been successfully developed, demonstrating high accuracy and speed in real time. The use of Raspberry Pi as a platform for implementing this technology showed that significant results can be achieved even in resource-constrained devices. The system can find wide applications in the fields of security, protection, industrial automation, and intelligent systems. Future research prospects include improving recognition algorithms, expanding the face database, and integrating with other sensor technologies to enhance user interaction. Given the ongoing development of artificial intelligence technologies, this work underscores the importance of computer vision in the modern world and offers new opportunities for its use across various fields. The implementation of such systems could significantly change approaches to automation and security, as well as enhance the efficiency of manufacturing processes, which is critically important in today's competitive environment.

References

1. L. Zhou, L. Zhang and N. Konz, "Computer Vision Techniques in Manufacturing," in IEEE Transactions on Systems, Man, and Cybernetics: Systems, vol. 53, no. 1, pp. 105-117, Jan. 2023, doi: 10.1109/TSMC.2022.3166397.

2. A. Kumari Sirivarshitha, K. Sravani, K. S. Priya and V. Bhavani, "An approach for Face Detection and Face Recognition using OpenCV and Face Recognition Libraries in Python," 2023 9th International Conference on Advanced Computing and Communication Systems (ICACCS), Coimbatore, India, 2023, pp. 1274-1278, doi: 10.1109/ICACCS57279.2023.10113066.

3. Vardhini PH, Reddy SPRD, Parapatla VP. Facial recognition using OpenCV and Python on Raspberry Pi. In: Proceedings of the 2022 International Mobile and Embedded Technology Conference (MECON), 480–485, IEEE, Noida, India.

4. R. Bousmaha, S. Laouedj, L. Aggoune and S. M. Benslimane, "YOLOv7-Face: A Real-Time Face Detector," 2023 International Conference on Networking and Advanced Systems (ICNAS), Algiers, Algeria, 2023, pp. 1-6, doi: 10.1109/ICNAS59892.2023.10330470.

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DEVELOPMENT OF AN END-TO-END ENCRYPTED MESSAGING CHATBOT

Abstract. *This paper describes the development of a chatbot that implements end-to-end encryption to ensure message confidentiality. Technologies such as React, Firebase, Elliptic Curve Cryptography (ECC), and CryptoJS contribute to the creation of a secure environment for information exchange. The study highlights the architectural and technical foundations of the chatbot, detailing encryption protocols and data flows to maintain interaction privacy. Through the examination of real-time data processing and user authentication strategies, the chatbot demonstrates an advanced approach to information protection, making it a reliable solution for privacy-sensitive applications.*

Key words: *chatbot, end-to-end encryption, React, Firebase, ECC, CryptoJS, information security.*

Introduction. In today's world, where information security is increasingly vital, end-to-end encrypted chatbots offer an effective solution for safeguarding data privacy. The development of digital communications has increased the need for reliable encryption methods that prevent unauthorized access to confidential information. This paper examines the implementation of a chatbot that uses end-to-end encryption and the technologies supporting this process. By integrating recognized cryptographic protocols and modern frameworks, the chatbot provides a secure data-sharing platform that addresses common vulnerabilities in online communications. [1, 2].

The chatbot's architecture includes a multi-layered approach to security, starting from user authentication and proceeding to encrypted message exchange. A key component is the use of Elliptic Curve Cryptography (ECC), which provides robust encryption with efficient performance, especially for devices with limited computing power [3]. ECC's low computational cost combined with a high level of security makes it ideal for this application, strengthening the chatbot's ability to maintain a secure communication channel without compromising speed. This research aims to show how a systematic approach to data flow security and encryption design can contribute to advancing the field of information security, addressing common challenges in digital privacy.

Methodology. To develop a reliable and secure end-to-end encrypted chatbot, we focused on integrating ECC and AES encryption in the React and Firebase environments. The study tests ECC's performance and security in real-time data processing, considering factors such as encryption speed and compatibility with Firebase's database structure. The methodology includes testing the efficiency of key generation, storage, and retrieval processes to ensure chat data protection.

By analyzing the flow of messages through encrypted channels and observing the React-based interface's responsiveness, the study assesses the system's ability to meet real-time encryption requirements. Additionally, Firebase's real-time data synchronization capabilities are tested to ensure consistent and secure message delivery across different devices. The following technologies were used in the work:

React - serves as the foundation for creating the user interface, simplifying the creation of a dynamic and interactive user experience. React's component architecture enables efficient state management and event handling, making it a popular choice among developers for building scalable

applications. Its modular structure also simplifies debugging and maintenance, providing a seamless user experience;

Firebase - as a real-time database solution, Firebase ensures fast data storage and retrieval, essential for chat applications where message updates must be instant. Firebase's built-in security features allow real-time data synchronization between different clients, ensuring secure storage and message transmission;

Elliptic Curve Cryptography (ECC) - The ECC algorithm provides a high level of data protection by generating a key pair for each user. The small size of ECC keys ensures a high level of security without significant resource consumption, making it suitable for real-time applications where speed is crucial;

CryptoJS - for message encryption and decryption, the CryptoJS library implements the AES algorithm, which is a widely accepted standard for information protection. AES provides reliable encryption with manageable key sizes, making it compatible with various devices.

Bot Architecture. User Authentication: The authentication process starts with verifying user data stored in the Firebase database. This step ensures that only authorized users have access to the chatbot. Upon successful login, users gain access to the encrypted messaging system. Authentication plays a critical role in maintaining a secure environment, preventing unauthorized access to the chat.

Key Generation and Storage: Users' encryption keys are stored in Firebase in encrypted form, allowing the bot to perform encryption and decryption directly on the user's device. Each user receives a unique private key, ensuring secure message encryption that can only be decrypted by the recipient.

Message Encryption: Before sending, the bot generates a shared secret key based on the ECC keys of the sender and receiver. This key is then used with the AES algorithm to encrypt the message, securing data during transmission. The message remains encrypted until it reaches the recipient, protecting it from interception.

Message Decryption: Upon receiving a message, the bot uses the shared secret to decrypt it, allowing the recipient to view the original text. This decryption process ensures that only the intended user can see the message content, preserving communication privacy.

Results and Discussion. The proposed chatbot architecture successfully provides end-to-end encryption for message transmission. The dynamic React interface enables the handling of encrypted messages, and Firebase database integration ensures fast and reliable data access. The compact size of ECC keys provides strong encryption without significantly reducing performance, proving its feasibility for real-time applications.

During testing, the bot demonstrates robust encryption and decryption processes, with minimal data transmission delays, meeting the requirements of a fast chat interface. AES-based encryption further ensures that messages remain protected, and the integration of the CryptoJS library simplifies encryption, enabling secure communication even on mobile devices.

Moreover, the bot's architecture shows resilience against common security threats, such as man-in-the-middle attacks, as messages remain encrypted during transmission. This resilience is critical for environments where message privacy is a priority.

Conclusions. Developing an end-to-end encrypted chatbot illustrates the application of modern technologies to ensure information security. Through the use of React, Firebase, ECC, and CryptoJS, the chatbot emerges as a reliable tool for secure message exchange. Lightweight and efficient ECC-based encryption enhances protection while preserving performance, making it ideal for real-time communication. This research demonstrates the potential for integrating powerful cryptographic methods into a user-friendly interface, promoting secure digital interactions.

Future research may focus on expanding the chatbot with multi-factor authentication, such as biometric verification, which will further enhance security by combining various user identification factors. Integrating additional security layers will significantly improve protection against unauthorized access and reinforce the role of end-to-end encryption in information security.

References

1. Yang, J., Chen, Y.-L., Por, L.Y., & Ku, C.S. (2023). A Systematic Literature Review of Information Security in Chatbots. Applied Sciences, 13(11), 6355

2. Kalyan Kumar, D., Shaguftha, M., Sujinth, P.V., Praveen Kumar, M.N., & Karthikeya, N. (2024). Implementing a Chatbot with End-To-End Encryption for Secure and Private Conversations. International Journal for Modern Trends in Science and Technology, 10(2), 130-136

3. Hankerson, D., Menezes, A.J., Vanstone, S.: Guide to Elliptic Curve Cryptography. Springer, New York (2004). https://doi.org/10.1007/b97644

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DEVELOPMENT OF AN ANTI-SPOOFING METHOD FOR IMAGES IN BIOMETRIC SECURITY SYSTEMS USING ML

Abstract. *The integrity and technical security of biometric authentication systems are critical in applications that require protection against mobile access to high-security areas. The main technical security issue is the vulnerability to spoofing attacks, where fraudulent biometrics deceive the system. This study proposes to use the ratio of facial landmarks from real-time video streams to improve live person detection in security systems. By analyzing responses to interactive prompts and calculating facial landmark ratios, the system aims to more reliably distinguish between genuine and fake interactions. This approach leverages advanced real-time image processing techniques to enhance accuracy in environments where traditional static biometric systems often fail. Utilizing dynamic response analysis further helps in mitigating the risks associated with spoofing by requiring active participation from the subject, therefore adding an additional layer of security.*

Key words: *technical protection of information, biometric security, machine learning, human detection, spoofing attacks.*

Introduction. In security systems, especially in biometric authentication, spoofing attacks, where unauthorized users provide fake biometrics, are a growing threat to the integrity of the security system. Traditional security measures are often insufficient against sophisticated methods that mimic biometric characteristics. This highlights the need for reliable, adaptive live presence detection systems. Advances in machine learning have improved image processing techniques, which is crucial for improving the detection of real human presence. The pervasive integration of biometric systems in everyday applications, from mobile phones to border security checkpoints, makes the improvement of these systems not just a technical challenge but also a crucial societal need. The analysis of various facial features shows promise. This technique potentially detects anomalies indicative of forgery by analyzing changes in the ratios of facial landmarks, a method supported by Hadid et al. (2014) and Erdogmus and Marcel (2013), who demonstrated the usefulness of dynamic methods and real-time analysis to improve forgery detection in face recognition systems [1, 2]. As biometric technologies become increasingly embedded in our digital interactions, enhancing the accuracy and security of these systems becomes paramount. Indeed, the reliability of biometric identification directly impacts not only personal security but also national and international security infrastructures. This study aims to evaluate the correlation of facial landmarks analyzed using machine learning to improve liveness detection by developing a framework capable of withstanding advanced forgery tactics. By exploring the latest findings in artificial intelligence, this study contributes to ongoing discussions and developments in secure biometric authentication. The insights gained from this study are expected to inform future strategies and technologies in the field, aiding in the continuous effort to safeguard biometric systems against evolving threats.

Methodology. This study investigates the usefulness of landmark ratio analysis on human faces to improve spoofing and substitution detection in biometric security systems. We analyze video data capturing various facial expressions to identify key features. To ensure the accuracy of

the analysis, the preprocessing of the raw data includes normalization steps to account for differences in lighting, orientation and scale. This preprocessing helps to minimize external influences that can affect the accuracy of landmark detection. Post-processing involves the use of state-of-the-art computer vision techniques to recognize faces and then extract facial landmarks. This stage is critical because it transforms raw video data into structured data points that can be quantitatively analyzed. Ratio calculations involving distances between facial landmarks, such as the eye-mouth ratio, have been useful in previous studies on attention and emotion recognition [3]. The selection of specific ratios, particularly those that have proven effective in detecting subtle facial movements, will be based on their sensitivity to variations in live and non-live interaction. These ratios will be analyzed to identify characteristic patterns that reliably indicate a live presence. The effectiveness of the identified ratios will be evaluated by comparing their performance in accurately distinguishing between genuine and fake interactions. This evaluation will focus on the accuracy and robustness of the methodology under various testing conditions that reflect typical scenarios encountered in security systems.

Results and discussion. This study explores the usefulness of landmark ratio analysis on human faces to improve spoofing and substitution detection in biometric security systems. We analyze video data capturing various facial expressions to identify key features. To ensure the accuracy of the analysis, the preprocessing of the raw data includes normalization steps to account for differences in lighting, orientation, and scale. This pre-processing helps to minimize external influences that can affect the accuracy of landmark detection. Post-processing involves the use of state-of-the-art computer vision techniques to recognize faces and subsequently extract facial landmarks. This stage is critical because it turns raw video data into structured data points that can be quantitatively analyzed. Ratio calculations involving distances between facial landmarks, such as the eye-mouth ratio, have been useful in previous studies on attention and emotion recognition [3]. The selection of specific ratios, particularly those that have proven effective in detecting subtle facial movements, will be based on their sensitivity to variations in live and non-live interaction. These ratios will be analyzed to identify characteristic patterns that reliably indicate a live presence. The effectiveness of the identified ratios will be evaluated by comparing their performance in accurately distinguishing between genuine and fake interactions. This evaluation will focus on the accuracy and robustness of the methodology under various testing conditions that reflect typical scenarios encountered in security systems.

Conclusions. This study aims to explore the potential of facial landmark ratios, such as the ratio of eye and mouth landmarks, as indicators for detecting a living person in biometric security systems. The results show that the proposed approach to analyzing biometric facial features is an effective tool for distinguishing between living people and countering spoofing attacks. The adaptability of this methodology to real-time data processing and machine learning algorithms opens the way for continuous improvement, making it a reliable solution in dynamic security environments. In addition, integrating this system into multimodal biometric systems that include voice, fingerprint, or iris recognition can potentially offer an even more secure authentication system. Supplementing a biometric security system with additional feature analysis will significantly improve protection against spoofing attacks and increase the reliability of security systems.

References

1. Hadid, A., et al. (2014). Biometric Liveness Detection: Challenges and Research Opportunities. IEEE Security & Privacy Magazine, 12(5), pp. 63-72. DOI: https://doi.org/10.1109/MSP.2015.116.

2. Erdogmus, N., & Marcel, S. (2014). Spoofing Face Recognition With 3D Masks. IEEE Transactions on Information Forensics and Security, 9(7), 1084-1097. https://doi.org/10.1109/TIFS.2014.2322255.

3. Soukupová, T., & Čech, J. (2016). Real-time eye blink detection using facial landmarks. Proceedings of the 21st Computer Vision Winter Workshop.

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UTILIZING RUBY FOR MACHINE LEARNING WORKFLOWS

Abstract. *his research investigates the application of Ruby as an alternative to Python for machine learning tasks. While Python dominates machine learning with its extensive libraries, Ruby's flexibility and integration potential with Python-based tools open up new possibilities for data-driven applications. This study presents an NLP model designed to detect sarcasm in article titles using Ruby.*

Key words: *machine learning, ruby, artificial intelligence, natural language processing (NLP).*

Introduction. Python is the go-to language for machine learning, known for its extensive libraries and strong community support. However, Ruby, primarily recognized for its role in web development, presents unique advantages that make it a compelling alternative for machine learning workflows. Ruby boasts a large community and a variety of web development frameworks (such as Rails, Hanami, Sinatra, and Grape). Moreover, one of Ruby's defining features is its support for metaprogramming - the ability to write code that generates other code [1, p. 3]. This capability positions Ruby as a promising tool for addressing machine learning challenges and integrating solutions within existing infrastructures. While Python-based solutions can also be integrated into Ruby projects as separate microservices, this approach often requires modifying infrastructure and establishing communication between services.

The **aim** of the work is to determine the possibilities of using Ruby for resolving machine learning tasks.

To achieve the set goal, the following tasks need to be addressed:

- explore existing Ruby tools and libraries which can help with machine learning tasks;
- develop Ruby-based NLP model to detect sarcastic articles in RSS feed.

Tools and Libraries. Ruby v3.2.3 was used as a basic version in this work. Research was made in the field of existing tools and libraries which can help in resolving some of the machine learning problems such as linear regression, k-means clustering and NLP. Results are shown in Table 1.

Table 1. Ruby tools and libraries for machine learning

Gems	Frameworks	Wrappers
Ruby Linear Regression	Rumale	TensorFlow Ruby
KMeans Clusterer	Eps	Torch
RubyFann		liblinear-ruby
		ruby-openai
		PyCall

Based on the above results was decided to use next tools:

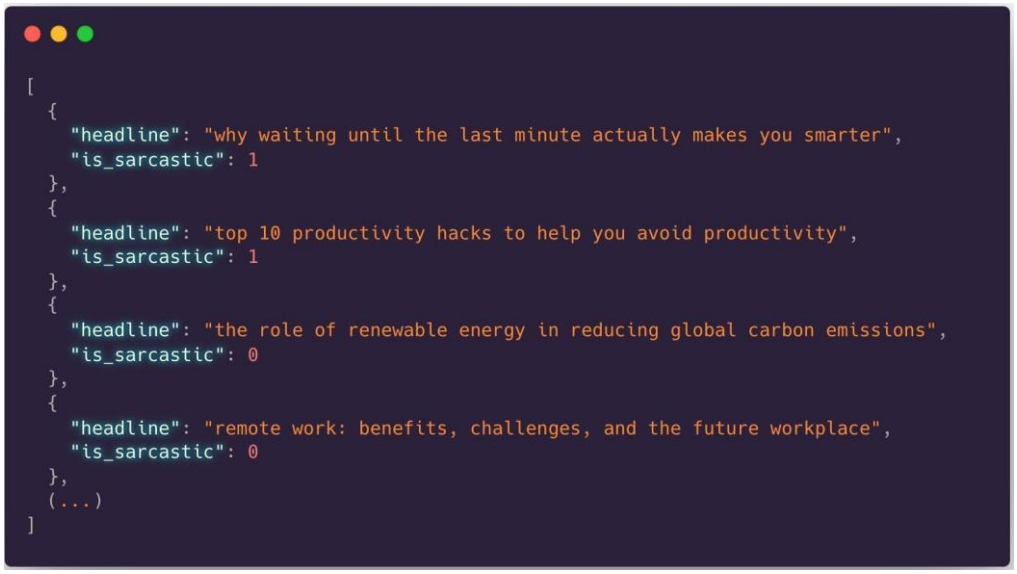
- PyCall - it enables interoperability between Ruby and Python, facilitating seamless machine learning model integration [2].
- TensorFlow - an end-to-end platform for machine learning from Google [3].

Development process. To demonstrate the use of Ruby with Python-based machine learning models, consider a content platform where article titles are classified for sarcasm. Platform admins don't populate the content by themselves. Instead, the platform has integrations with multiple RSS feeds. The task is to analyze the article titles and predict if a particular article is a serious or sarcastic one. Sarcasm detection in text presents a unique challenge for NLP models, making it a valuable case study for Ruby's capabilities.

Using the PyCall library enabled seamless integration with the TensorFlow Python module [4], allowing to build a machine learning model. JSON-formatted data was then used for model training and testing, as outlined below:

- Training set: 45 serious titles and 45 sarcastic titles.
- Testing set: 25 serious titles and 25 sarcastic titles.

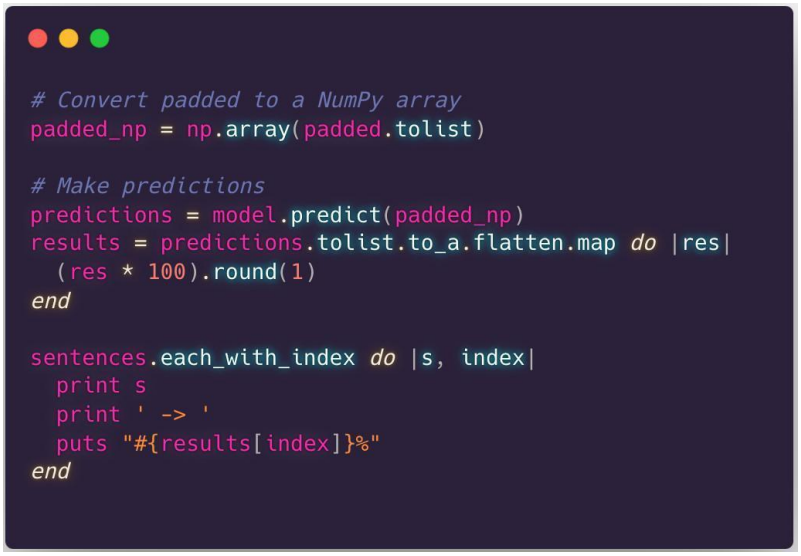
An example of the data format is shown in Fig. 1.



```
[
  {
    "headline": "why waiting until the last minute actually makes you smarter",
    "is_sarcastic": 1
  },
  {
    "headline": "top 10 productivity hacks to help you avoid productivity",
    "is_sarcastic": 1
  },
  {
    "headline": "the role of renewable energy in reducing global carbon emissions",
    "is_sarcastic": 0
  },
  {
    "headline": "remote work: benefits, challenges, and the future workplace",
    "is_sarcastic": 0
  },
  (...)
]
```

Fig. 1. Example of training data in JSON format

In Fig. 2 is shown Ruby code to demonstrate an interaction between Ruby and Python objects. While *padded_np*, *model* and *predictions* are Python objects, *sentences* is a Ruby object as well as *map* and *each_with_index* are Ruby methods.



```
# Convert padded to a NumPy array
padded_np = np.array(padded.tolist)

# Make predictions
predictions = model.predict(padded_np)
results = predictions.tolist.to_a.flatten.map do |res|
  (res * 100).round(1)
end

sentences.each_with_index do |s, index|
  print s
  print ' -> '
  puts "#{results[index]}%"
end
```

Fig. 2. Piece of code which analyzes incoming data

Results of the program is shown in Table 2.

Table 2. Prediction results

Article Title (content of *sentences* array)	Sarcasm Prediction
The Future of Artificial Intelligence in Healthcare: Opportunities and Challenges	4.2%
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Embrace Chaos: a Foolproof Guide to Ignoring All Life Advice	95%

Conclusion. Ruby proves to be a feasible alternative for machine learning tasks, particularly within existing Ruby-based infrastructures. However, certain limitations and dependency on Python libraries still remain.

References

1. Perrotta P. Metaprogramming Ruby 2: Program Like the Ruby Pros (Facets of Ruby). Pragmatic Bookshelf, 2014. 280 p.

2. GitHub - mrkn/pycall.rb: Calling Python functions from the Ruby language. GitHub. URL: https://github.com/mrkn/pycall.rb (date of access: 21.10.2024).

3. TensorFlow. TensorFlow. URL: https://www.tensorflow.org/ (date of access: 21.10.2024).

4. Module: tf | TensorFlow v2.16.1. TensorFlow. URL: https://www.tensorflow .org/api_docs/python/tf (date of access: 21.10.2024).

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FORENSIC EXAMINATION OF OBFUSCATED CODE

Abstract. *This article discusses the critical role of obfuscation in protecting software code from reverse engineering and analysis, with a particular focus on its implications in digital forensics. Obfuscation transforms source or executable code into a form that retains functionality but obscures its logic, making forensic analysis a complex and resource-intensive process. The article highlights the challenges experts face when investigating obfuscated code, especially in environments like PHP and JavaScript, where obfuscation is commonly used to conceal sensitive algorithms or malicious activities. It also explores modern deobfuscation methods, including static and dynamic analysis, and the growing use of artificial intelligence to automate this process. Despite advancements, fully automated deobfuscation remains challenging, as obfuscators continuously evolve, demanding ongoing innovation in forensic tools and techniques.*

Key words*: digital forensics, obfuscation, computer viruses.*

Obfuscation, as a method of hiding software source code, is widely used to complicate its analysis and reverse engineering. Forensic experts who examine software source code must have a solid understanding of programming, obfuscation methods and algorithms, as well as tools for decoding and deobfuscation.

It is important to note that obfuscation, or code obfuscation, is the process of transforming source code or executable code into a form that retains its functionality but complicates or prevents analysis, understanding of the working algorithm, and modification during decompilation.

The primary task of a forensic expert investigating obfuscated software code is to identify the methods used and restore the original code and/or program logic. Various tools are used for this, such as dynamic analysis, static analysis, and symbolic execution. Each of these methods has its own advantages and limitations, so the expert must rely on their experience to select the most effective approach depending on the specific conditions and type of obfuscation.

One of the main challenges is that obfuscation can be applied at different levels of a program, including the source code, bytecode, and machine code. This requires experts to have an exceptionally deep understanding of how computer systems and architectures work. Moreover, modern obfuscators may employ complex and multi-layered protection methods, making their analysis even more difficult.

Deobfuscation is the process of reversing obfuscated code back to its original or more understandable form. This procedure is crucial in the field of computer forensics, as it allows experts to analyze malware and other obfuscated programs. Obfuscation is often used to protect intellectual property and conceal malicious activities, making the ability to deobfuscate code critical for detecting and neutralizing threats.

The main goal of the deobfuscation process is to restore readable source code that allows a better understanding of a program's functionality. This includes identifying and removing obfuscation methods such as convoluted control flows, redundant or masked instructions, and complex encryption schemes. Specialized tools and techniques, such as execution analysis, step-by-step debugging, reverse engineering, and symbolic execution, are used to effectively process and analyze obfuscated code [1,2].

Static analysis involves examining the code without executing it, which helps to identify the program's structure and the obfuscation techniques used. Dynamic analysis, on the other hand, involves executing the code in a controlled environment to observe its behavior and gather data on the actual instructions being executed. The combination of these methods enables more efficient deobfuscation of complex software code.

The deobfuscation process can be complex and time-consuming, as modern obfuscators employ increasingly sophisticated protection methods. Moreover, deobfuscation may require significant computational resources and time, making this process even more challenging. Therefore, it is essential to continuously improve deobfuscation methods and tools to keep pace with the advancement of technologies.

One of the key aspects of deobfuscation is the automation of the process, which significantly enhances the efficiency and speed of analysis. Modern deobfuscation tools often use machine learning and artificial intelligence to automatically detect and recognize obfuscation patterns. This allows for a significant reduction in the time required for analysis and improves the accuracy of the results. However, full automation of deobfuscation remains a challenging task, as obfuscators are constantly evolving and adapting to new analysis methods [2].

In the PHP programming language, server-side code that contains confidential algorithms or data is most often subjected to obfuscation. This can include authentication functions, user data processing, interaction with databases, and other important components of web applications. Obfuscation of these elements helps hide the program's logic and structure, making it more difficult for attackers to reverse engineer and identify vulnerabilities.

In JavaScript, obfuscation most commonly targets client-side code that runs in the user's browser. This includes scripts that implement interactive elements on web pages, manipulate the DOM, and handle client-side data processing functions. JavaScript obfuscation is increasingly used to complicate the analysis of malicious code, which can be deployed on websites. Attackers use obfuscation to conceal their malicious actions, such as data theft or the execution of unauthorized operations on the client side.

Obfuscation in PHP and JavaScript shares many common aspects but differs depending on the specific execution environment of the code. In the case of PHP, obfuscation focuses on protecting server components, which are executed on the server and are usually not directly accessible for viewing by users. Meanwhile, JavaScript obfuscation is aimed at confusing client-side code, which runs in the browser and can be easily viewed and modified by users.

In both cases, the primary obfuscation technique involves changing the names of variables, functions, and classes to meaningless or random sequences of characters. This complicates the understanding of the program's logic and the relationships between its components. Additionally, malware often employs encryption and steganography to hide important data or code. For example, parts of the code may be encrypted and decrypted only during execution, making their analysis in a static state nearly impossible. These methods allow attackers to conceal the true nature of their programs and complicate detection and investigation.

Dynamic obfuscation methods, such as code modification during execution, are also widely used in malicious software. These methods may involve functions that generate or alter code in real-time, depending on the execution environment or user actions. This allows malware to adapt to various conditions and evade security mechanisms. For instance, malicious software may execute certain actions only in the presence of specific system conditions, making its detection and analysis even more challenging. The use of such obfuscation techniques significantly enhances the effectiveness of malware and makes it a powerful tool in the hands of attackers.

Hackers actively use obfuscation as an effective means of concealing their actions and confusing program code. This allows them to complicate the analysis of malicious software and

significantly increase their chances of avoiding detection. This is particularly relevant for client-side code, such as JavaScript, which runs in the browser, where obfuscation serves as the first barrier for security and digital forensics specialists.

Successful investigation of such threats often depends on the ability of experts to carry out effective deobfuscation. The process of returning the code to a readable state is critical for understanding the logic of the malicious software, identifying its vulnerabilities, and developing countermeasures. However, the continuous improvement of obfuscation methods, especially dynamic ones, presents new challenges for experts, requiring modern tools and an intellectual approach to analysis.

Therefore, the success of forensic analysis of malicious software largely depends on the effectiveness of deobfuscation. The advancement of automated methods for decrypting and analyzing code is becoming a key factor in the fight against cyber threats. Specialists must constantly refine their skills and use the latest technologies not only to detect but also to stay ahead of criminals who employ increasingly sophisticated obfuscation techniques.

References

1. T. Holt, A. Bossler, K. Seigfried-Spellar. Cybercrime and Digital Forensics. NY:Routledge, 2018. ISBN: 978-1-138-23872-5.

2. A. Mohanta, A. Saldanha. Malware Analysis and Detection Engineering A Comprehensive Approach to Detect and Analyze Modern Malware. California: Apress Media, 2020. ISBN: 978-1-4842-6192-7.

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METHODOLOGY FOR INFORMATION LEAK RESEARCH

Abstract. *This article explores the application of data loss prevention systems, log analysis, and machine learning techniques to improve information security. Key aspects of implementing Data Loss Prevention (DLP) to control the movement of confidential information, log analysis methods for monitoring system activity and their role in automating incident response, as well as the role of machine learning in detecting new threats are discussed. Examples and recommendations illustrating the effectiveness of an integrated approach to data protection were created.*

Key words: *Data Loss Prevention, log analysis, machine learning, information security, threat response automation, network monitoring.*

Introduction. With the development of technology, ensuring information security is becoming an increasingly important aspect for any company. It does not matter whether it is a company that is just starting its journey or a company that has been a leader for many years. Data Loss Prevention (DLP) systems, log analysis, and machine learning are indispensable components of modern security. DLP controls the transmission of sensitive information, log analysis tracks user behavior and detects potential threats in real-time, and machine learning enables organizations to adapt to new types of threats.

Statement of the problem. Data leakage is a serious threat to organizations. Such a mistake can lead to multi-million losses, and in the worst case to the closure of the company. Modern cybersecurity techniques such as DLP, log analysis, and machine learning algorithms are needed to prevent data leaks and control access to sensitive information. The main task is to integrate these solutions into a single system for increased security and rapid response to threats, which will significantly increase the company's level of security against criminals.

The primary **goal** of the research is to explore ways to improve information security through the integrated use of DLP, log analysis, and machine learning to detect threats, reduce data leakage risks, and automate incident response.

Methodology. DLP systems enable organizations to track and control the movement and access of sensitive information, thereby reducing the risk of accidental or malicious data leakage. The main types of DLP include:

- Endpoint DLP – protects endpoint devices such as computers and mobile devices.
- Network DLP – monitors network traffic and blocks the transmission of sensitive data.
- Cloud DLP – protects data in cloud applications [1, 2].

Log analysis is critical to security monitoring and threat detection by providing:

- Detection of suspicious activities.
- Audit and save records for further analysis.
- Rapid response to incidents [3].

Machine learning algorithms offer new opportunities to detect anomalies and adapt to new threats (Gartner):

- Advantages: ability to detect new types of threats and automate processes.
- Disadvantages: requires large amounts of data for training and optimized response processes [4].

Practical examples of integrated DLP algorithms, log analysis and machine learning demonstrate the improvement of information security due to the rapid detection and prevention of data leakage, the use of distributed computing resources and cloud technologies [5].

Conclusions. Data loss prevention, log analysis, and machine learning techniques play a critical role in ensuring data security for organizations. Through integration, automated solutions and advanced threat detection methods, these tools provide powerful capabilities to protect sensitive information, which in turn makes the company more attractive in the eyes of the potential customer. A comprehensive approach to data security is recommended, and this approach includes the techniques discussed earlier, namely DLP, log analysis, and machine learning. The implementation of these systems will make it possible to improve the security of information assets.

References

1. What is data loss prevention (DLP)? [Електронний ресурс]. Режим доступу до ресурсу: https://www.microsoft.com/en-us/security/business/security-101/what-is-data-loss-prevention-dlp.

2. Cloud DLP (Data Leak Prevention): The Essential Guide [Електронний ресурс]. Режим доступу до ресурсу: https://www.nightfall.ai/guide/the-essential-guide-to-cloud-data-leak-prevention-dlp.

3. Microsoft Security Blog [Електронний ресурс]. Режим доступу до ресурсу: https://www.microsoft.com/en-us/security/blog/.

4. Gartner® Emerging Tech: Top Use Cases for AI in Threat Detection, Investigation and Response [Електронний ресурс]. Режим доступу до ресурсу: https://mixmode.ai/analyst-research/gartner-emerging-tech-top-use-cases-for-ai-in-threat-detection-investigation-and-response/.

5. Cybercrime Magazine [Електронний ресурс]. Режим доступу до ресурсу: https://cybersecurityventures.com.

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PSYCHOLOGICAL MANIPULATIONS IN CYBERSPACE: MECHANISMS OF SOCIAL ENGINEERING IMPACT ON POTENTIAL VICTIMS

Abstract. *This research examines social engineering as a critical cybersecurity threat that exploits human psychological vulnerabilities rather than technical system weaknesses. The study analyzes the fundamental nature of social engineering attacks, investigates their primary methodologies including phishing, vishing, smishing, pretexting, tailgating, and baiting, and examines notable case studies such as the Sony Pictures compromise, Google and Facebook fraud schemes, and the 2020 Twitter incident. We present a comprehensive framework for protection against social engineering attacks, emphasizing the importance of educational programs, source verification procedures, access differentiation, multi-factor authentication, and technical protection measures. The findings highlight that while the human factor remains the most vulnerable link in cybersecurity, a systematic approach to user awareness and security implementation can significantly mitigate social engineering risks.*

Key words*: social engineering, cybersecurity, psychological manipulation, phishing, information security, cyber-attacks, human factor, security awareness, digital fraud prevention, cyber defense strategies.*

Introduction. In the era of digitalization, a significant portion of personal and business data is stored in digital format. Parallel to the development of information technology, cybercrime methods are also being perfected. Social engineering has become the most effective tool for gaining unauthorized access to confidential information – a complex of psychological techniques aimed at influencing human consciousness to obtain desired access to information systems or personal data [1]. In this study, we will analyze the essence of social engineering, examine its key methodologies, investigate cases of successful attacks, and propose effective strategies to counter such threats.

Social engineering represents a complex of psychological manipulations aimed at overcoming technical security systems by exploiting the human factor. Instead of using technical means of hacking, cybercriminals exploit natural human weaknesses: credulity, carelessness, or insufficient awareness.

The main objective of social engineering is to create conditions under which the victim voluntarily discloses confidential information or performs potentially dangerous actions. Such manipulations can be carried out through various communication channels: telephone conversations, email correspondence, messengers, or personal contacts [2].

Main Techniques of Social Engineering:

Phishing is the most common social engineering technique that involves sending fraudulent messages imitating official communication from trusted organizations - banks, social networks, or government institutions. The goal is to prompt the victim to follow malicious links or disclose confidential data.

Vishing (Voice Phishing) is the technique involves making phone calls during which criminals impersonate support staff, financial institutions, or law enforcement officials to extract confidential information.

Smishing (SMS Phishing) is the technique is based on sending SMS messages urging recipients to follow specified links or call certain numbers to resolve "urgent problems," for example, with banking services.

Pretexting is a manipulative technique based on creating a plausible scenario (pretext) to obtain confidential information. May include fictitious security checks or requests to update personal data.

Tailgating is a physical social engineering technique that involves penetrating secured premises by exploiting employee trust, for example, passing through a controlled area following an authorized person.

Baiting is a technique that exploits victims' natural curiosity by planting infected information carriers (such as USB drives) in accessible places. When such a device is connected to a computer, attackers gain system access [2].

High-Profile Cases of Social Engineering:

Microsoft 365 phishing scam steals user credentials (2021). In April 2021, security researchers discovered the BEC scam, where the recipient receives a blank email with the subject "price review" and an attachment that looks like an Excel file. It is actually a .html file that when opened redirects the user to a malicious website. This site displays a pop-up asking you to re-enter your Microsoft 365 credentials, and the information you enter is sent to fraudsters who use it.

Google Drive collaboration scam (2020). In late 2020, a novel but simple social engineering scam emerged that exploited Google Drive's notification system. The fraud begins with the creation of a document containing malicious links to a phishing site. The scammer then tags their target in a comment on the document, asking the person to collaborate.

$100 Million Google and Facebook Spear Phishing Scam (2013-2015). The biggest social engineering attack of all time (as far as we know) was perpetrated by Lithuanian national, Evaldas Rimasauskas, against two of the world's biggest companies: Google and Facebook. Rimasauskas and his team set up a fake company, pretending to be a computer manufacturer that worked with Google and Facebook. Rimsauskas also set up bank accounts in the company's name.

The scammers then sent phishing emails to specific Google and Facebook employees, invoicing them for goods and services that the manufacturer had genuinely provided – but directing them to deposit money into their fraudulent accounts. Between 2013 and 2015, Rimasauskas and his associates cheated the two tech giants out of over $100 million.

Twitter Incident (2020). In summer 2020, cybercriminals using vishing compelled company employees to grant access to internal systems. This led to the compromise of influential persons' accounts, including Barack Obama, Elon Musk, and Joe Biden, to spread fraudulent schemes [3].

Strategies for Protection Against Social Engineering:

Educational Programs: systematic training of personnel and users remains the most effective protection method. It is critically important to develop skills in recognizing phishing attacks, suspicious communications, and calls.

Source Verification: when receiving suspicious messages or calls, it is necessary to independently verify information through official communication channels with the organization supposedly making the contact.

Access Differentiation: implementing the principle of restricted access to confidential information based on business necessity helps minimize potential risks.

Multi-Factor Authentication: implementation of additional security levels through SMS verification or specialized applications significantly reduces the risk of unauthorized access even if passwords are compromised.

Comprehensive Technical Protection: timely updates of antivirus software and the use of cryptographic data protection methods provide an additional security level in case of potential system compromise [4].

Conclusions. Social engineering poses a particular threat in cybersecurity due to its exploitation of psychological vulnerabilities rather than technical system deficiencies. However, a comprehensive approach to user training, implementation of modern protection measures, and development of information security culture can significantly reduce the risks of successful attacks. It's worth remembering that the human factor remains the most vulnerable link in the cybersecurity system, so countering social engineering must begin with raising user awareness.

References

1. Stewart, A. Social Engineering Attacks: Cybercriminal Tactics & Psychology. 2024. URL: https://www.techbrain.com.au/social-engineering-attack-psychology/#:~:text=In%20the%20cyber%20security%20landscape,that%20breach%20their%20own%20security.

2. Henea, M. Exploring the psychological underpinnings of social engineering attacks. 2024. URL: https://cognisys.co.uk/blog/social-engineering-attacks/.

3. 15 Examples of Real Social Engineering Attacks. 2023. URL: https://www.tessian.com/blog/examples-of-social-engineering-attacks/.

4. Social engineering, an invisible threat: trends and developments. 2023. URL: https://www.altospam.com/en/news/social-engineering-an-invisible-threat-trends-and-developments/.

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ULTRASONIC TECHNOLOGY FOR PRODUCING FUNCTIONAL BEVERAGES TO REHABILITE AND PREVENT POST-TRAUMATIC STRESS DISORDERS

Abstract. *This project focuses on the design, manufacture, and application of ultrasonic equipment in the production of innovative multi-nutrient functional beverages. These beverages are specifically developed to boost military personnel's mental stability and energy levels, which is crucial for maintaining high levels of combat effectiveness in life-threatening situations over extended periods. This is especially relevant for those experiencing post-traumatic stress disorders during their rehabilitation. The significance of this project extends beyond the military sphere, benefiting many civilians, including a large number of children.*

Key words*: functional beverages, post-traumatic stress disorder (PTSD), ultrasonic systems, intensification, extraction.*

Introduction. Military operations and related contexts tend to exacerbate post-traumatic stress disorder (PTSD), prompting research to address the issue. Military personnel endure extreme psychological and physical stress. These stressors often lead to cognitive impairments, such as PTSD [1]. Although pharmaceutical treatments are available, they are not always the best option due to low efficacy, side effects, accessibility, or economic impact [2]. Research has also shown potential for nutritional therapy [3] in rehabilitation and PTSD prevention, particularly those caused by military actions [4].

The study **aims** to develop highly efficient multi-component ultrasonic oscillation systems, in particular, an energy-saving automated poly-frequency ultrasonic system to intensify extracting biologically active substances from plant materials while producing multinutrient functional beverages for complex rehabilitation and prevention of post-traumatic stress disorders, increasing stress resistance levels, which will be valuable for improving public health, medicine, food, and military defense capabilities of Ukraine.

Materials and Methods. From a technological standpoint, beverages are the most convenient model for developing new products, including those utilizing natural plant materials [5]. Multinutrient beverages not only provide nutritional value but also offer a range of health benefits. They contain functional ingredients that enhance human body's adaptive capabilities in response to negative factors [6].

All ultrasonic technologies deploy the effects of ultrasound interacting with the medium. Powerful ultrasound induces several specific effects in liquid media, such as cavitation and intense micro- and macro-flows. These effects lead to rapid and efficient mixing of the medium's components, formation of stable emulsions, extraction of soluble components from particles in the liquid, swelling and breakdown of these particles [7].

Results. To implement ultrasonic technologies in extraction of plant raw materials to produce functional beverages, the authors have developed the following proposals:

- a design for a multi-frequency ultrasonic system to intensify the extraction process;
- a technology for designing piezoelectric elements for instrument engineering, food industry, and the agro-industrial complex;
- a methodology to increase the power of ultrasonic intensification systems;
- a methodology for multi-frequency ultrasonic extraction;
- theoretical principles for connecting and coordinating oscillatory systems of different physical natures (electromechanical, electrical, mechanical htr);
- criteria for designing highly efficient ultrasonic oscillatory systems.

Conclusions. The outcome of the present study is developing experimental samples of ultrasonic equipment, experimental samples, and technology for producing multi-nutrient functional beverages to be introduced to the diet for treating stress disorders, particularly those caused by military actions.

Acknowledgements. The data presented in this paper have been obtained as implementation of the experimental scientific and technical project titled “Development of an automated ultrasonic system for extracting plant raw materials to produce multi-nutrient functional beverages for rehabilitation and preventing post-traumatic stress disorders” (national registration number: 0124U000713, 2024-2025) under development at Cherkasy State Technological University.

References

1. Escarfulleri, S., Ellickson-Larew, S., et al. Emotion regulation and the association between PTSD, diet, and exercise: a longitudinal evaluation among US military veterans. European journal of psychotraumatology, 2021, 12(1),1895515.

2. Briony Sayers, et al. Exploring the potential of prebiotic and polyphenol-based dietary interventions for the alleviation of cognitive and gastrointestinal perturbations associated with military specific stressors. Journal of Functional Foods, 2021, 87, 104753.

3. Agans R.T., Giles G.E., et al. Evaluation of Probiotics for Warfighter Health and Performance. Frontiers in Nutrition, 2020, 7, 70.

4. Bersani F.S., et al. Novel Pharmacological Targets for Combat PTSD-Metabolism, Inflammation, the Gut Microbiome, and Mitochondrial Dysfunction. Military Medicine, 2020, 185, 311 – 318.

5. Rana Muhammad Aadil, Ume Roobab, Amna Sahar, Ubaid ur Rahman, Anees Ahmed Khalil. 7 - Functionality of Bioactive Nutrients in Beverages. Nutrients in Beverages, Academic Press, 2019, 12, 237-276.

6. Sugajski M., Buszewska-Forajta M., Buszewski B. Functional Beverages in the 21st Century. Beverages, 2023, 9, 27.

7. Nitya Bhargava, et al. Advances in application of ultrasound in food processing: A review. Ultrasonics Sonochemistry, 2021, 70, 105293.

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IMPROVING THE CONTROL SYSTEM OF AN UNMANNED VEHICLE

Abstract. *This work explores advancements in control systems for autonomous vehicles, focusing on the application of video data processing to enhance spatial orientation, object detection, and trajectory prediction. By implementing a cascade approach, which combines object localization, segmentation, and analysis of key points using deep neural networks, the research demonstrates a significant improvement in the control system's ability to assess vehicle orientation and movement in real-time. The developed system minimizes dependency on costly sensors like LiDAR, making autonomous vehicle technology more accessible and reliable in diverse conditions.*

Key words*: autonomous driving, control system improvement, video data processing, deep learning, spatial orientation, object detection.*

Introduction. In recent years, autonomous vehicle technologies have evolved rapidly, addressing critical issues in transportation safety by reducing reliance on human drivers. Autonomous driving aims to minimize human error, which is often cited as a leading cause of traffic accidents globally. The development of effective, sensor-independent vehicle orientation and trajectory prediction methods remains a priority, especially for reducing costs and enhancing system reliability. Currently, most orientation estimation systems heavily rely on active sensors such as LiDAR and radar, which present cost, range, and integration challenges in commercial applications. This study proposes a video-based control system improvement for autonomous vehicles that relies on advanced video data analysis, reducing the need for active sensors while maintaining accuracy in object detection and spatial orientation.

The primary objective of this research is to enhance the control system for autonomous vehicles by developing a video-based orientation and trajectory estimation method. This approach employs a cascade structure to analyze video data in real-time, ensuring accurate vehicle orientation and reducing dependency on active sensors. The cascade model combines several layers of analysis, including object localization, image segmentation, and key point recognition, providing a multi-step framework to assess the spatial positioning of objects surrounding the vehicle.

Methods and Materials. The study integrates various methods, including digital image processing, machine learning, and statistical analysis, to improve the control system's accuracy and robustness. The system architecture is designed with several critical components: Object Localization: Utilizing convolutional neural networks (CNNs) for initial object localization, the system detects relevant objects in the environment and classifies them based on their spatial positioning. The CNN-based approach allows the system to distinguish between stationary and moving objects, improving prediction reliability in dynamic scenes. Image Segmentation: The segmentation process divides the detected objects into regions of interest. This step uses polar coordinate transformation and weighted graph shortest path algorithms to isolate objects even in low-light or high-noise conditions, significantly enhancing detection precision. Key Point Recognition: By analyzing the inner layers of pre-trained CNN models, key points on the vehicle and surrounding objects are identified to determine object boundaries. This step ensures that the system can adapt to various architectures, providing stable object recognition even in scenes with complex background details. Trajectory Prediction: The control system calculates trajectory predictions based on the orientation and movement data obtained from previous steps. Utilizing

temporal and spatial data, the system can anticipate potential collision risks, making timely adjustments to vehicle positioning.

The proposed cascade approach was tested in a simulated environment replicating various road conditions and traffic scenarios. Key results include: Improved Orientation Estimation: The cascade approach achieved an average increase of 10% in correct orientation predictions compared to traditional methods, demonstrating superior accuracy in positioning objects within the vehicle's environment. Enhanced Segmentation Precision: By utilizing the polar coordinate transformation, the segmentation method achieved a 6% increase in the Jaccard similarity coefficient over established models like GrabCut and DeepLabv3. This improvement ensures more reliable segmentation results under challenging conditions such as rain, fog, or low lighting. High Accuracy in Key Point Localization: The proposed key point recognition method achieved a 10% improvement in the correct localization of object boundaries, surpassing benchmarks like WPOD-NET and Mask-RCNN. This increase in accuracy supports more effective object detection, leading to more reliable vehicle control decisions. Effective Trajectory Prediction: The cascade approach successfully integrated trajectory prediction, with results showing a 5% increase in accurate direction assessments. This improvement allows the control system to make more precise adjustments to vehicle speed and direction, increasing safety in dynamic traffic environments.

Conclusions. The research demonstrated that video-based analysis could significantly improve autonomous vehicle control systems, especially in areas where active sensors are not feasible or cost-effective. By integrating a cascade approach, which includes object localization, segmentation, and key point analysis, the control system can assess spatial orientation with high accuracy and predict object trajectories effectively. The proposed improvements offer a scalable solution that could reduce costs and enhance reliability in autonomous driving applications.

The developed system has implications for the broader implementation of autonomous vehicle technology, making it accessible for consumer and commercial markets by reducing dependence on expensive active sensors. Future research could focus on integrating additional data sources, such as GPS and IMU data, to further enhance system robustness and adaptability across diverse driving environments.

References

1. Horn, B. K. P., Schunck, B. G. Determining optical flow. Artificial Intelligence, 1981.

2. Simonyan, K., Zisserman, A. Very deep convolutional networks for large-scale image recognition. arXiv preprint, 2014.

3. Girshick, R., Donahue, J., Darrell, T., Malik, J. Rich feature hierarchies for accurate object detection and semantic segmentation. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, 2014.

4. He, K., Zhang, X., Ren, S., Sun, J. Deep residual learning for image recognition. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, 2016.

5. Redmon, J., Farhadi, A. YOLOv3: An incremental improvement. arXiv preprint, 2018.

6. Chen, L.-C., Papandreou, G., Kokkinos, I., Murphy, K., Yuille, A. L. DeepLab: Semantic image segmentation with deep convolutional nets, atrous convolution, and fully connected CRFs. IEEE Transactions on Pattern Analysis and Machine Intelligence, 2018.

7. Ren, S., He, K., Girshick, R., Sun, J. Faster R-CNN: Towards real-time object detection with region proposal networks. Advances in Neural Information Processing Systems, 2015.

8. Long, J., Shelhamer, E., Darrell, T. Fully convolutional networks for semantic segmentation. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, 2015.

9. Zhao, H., Shi, J., Qi, X., Wang, X., Jia, J. Pyramid scene parsing network. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, 2017.

10. Cordts, M., Omran, M., Ramos, S., Rehfeld, T., Enzweiler, M., Benenson, R., Franke, U., Roth, S., Schiele, B. The Cityscapes dataset for semantic urban scene understanding. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, 2016.

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SYSTEM FOR DETERMINING THE MECHANICAL STRENGTH OF SAFETY GLASS

Abstract. *The research is focused on the development and implementation of a diagnostic system for assessing the mechanical strength of protective glass using advanced optical methods. The proposed system is based on optical interferometry and laser analysis techniques, enabling precise, non-contact evaluation of glass strength in real-time. The conducted studies demonstrated that the system provides high accuracy in strength determination (error margin of 1.5-3%) and effectively detects microcracks and surface defects. The developed design solutions, including a cooling system and a resonant circuit for the heating inductor, ensure stable device operation during extended diagnostic sessions. This system can be applied for quality control of protective glass across various industries, including display manufacturing and fiber-optic components, ensuring high levels of product reliability and safety.*

Key words*: mechanical strength, protective glass, optical interferometry, laser analysis, quality control.*

Introduction. Protective glass is fundamental to modern technologies, including displays for electronic devices, automotive optics, and fiber-optic communication lines. Its physical properties, such as mechanical strength, scratch resistance, transparency, and hardness, are critically important to ensuring durability and safety during use. Today's growing quality requirements for protective glass, driven by technological advances, encourage the search for new materials, strengthening methods, and effective techniques for assessing mechanical strength. As noted in [1], the perception of glass as a fragile material is shifting due to strengthening technologies that provide high durability and resistance. This study focuses on developing a system for diagnosing the mechanical strength of glass in real-time during production, thereby enhancing product quality.

Literature Review and Research Challenges. The analysis of recent scientific literature [1, 2] shows that mechanical strength is a key attribute of glass across various applications. In fiber optics, the strength of glass fibers directly affects the efficiency and longevity of communication networks, while in displays for mobile devices and monitors, scratch and damage resistance extends screen lifespan. Most existing research focuses on general strengthening techniques, such as thermal and chemical treatment, which improve glass strength; however, limited attention is given to real-time diagnostic methods for strength assessment during manufacturing [2]. This underscores the importance of optical methods, such as interferometry and laser diagnostics, for real-time quality control.

Methods for Assessing Mechanical Strength. To develop an effective system for diagnosing the strength of protective glass, several methods were selected to provide accurate and reliable results.

– *Optical interferometry.* This method is used to study surface stresses and microcracks that significantly affect glass strength. Interferometry enables high-precision imaging of the surface, detecting defects that may reduce mechanical strength. The use of interference waves allows the

detection of even minor surface deformations. The accuracy of interferometry, with a margin of error not exceeding 1.5%, makes it ideal for quality control and maintaining process stability [3].

– *Laser analysis.* The laser method is highly informative and enables non-contact diagnostics, a crucial advantage for large-scale production. A laser beam detects structural defects and captures minor material changes, such as microcracks, which may compromise strength. The use of a laser emission amplifier achieves high sensitivity to changes in the material's optical properties, improving diagnostic accuracy and speed to 2-3% [2].

Research Results. The development of the diagnostic system included several key stages:

– *Strength assessment accuracy.* The proposed optical methods achieved high accuracy in determining the mechanical strength of protective glass. Compared to other methods, the device achieved accuracy levels within 1.5-3%, confirming the effectiveness of interferometry and laser analysis for evaluating mechanical strength.

– *Surface analysis.* The developed system allows for a detailed examination of the glass surface for microcracks and defects. This is achieved through a high-sensitivity laser system that detects even minimal deviations in glass structure. This approach enables rapid identification and correction of potential weak points in the product, ensuring stable operational performance.

– *Cooling system.* To maintain device stability, an effective cooling system for the power components of the power supply unit was designed. Cooling prevents overheating of power elements and ensures stable performance even during extended diagnostic sessions. Additionally, a resonant circuit was developed for the heating inductor, optimizing energy consumption during device operation.

Discussion of Results. Experimental results demonstrated that the developed system can be effectively used to monitor the quality of protective glass at all stages of production. The use of optical interferometry and laser analysis significantly increases the accuracy and speed of strength assessment, a critical factor for mass production. Recent studies in the literature [3] confirm that interferometry and laser diagnostics are promising for material quality control, and this system greatly simplifies the defect monitoring process in glass products. Comparisons with other diagnostic systems indicate that the developed device is competitive in terms of accuracy and can be used for a wide range of glass products.

Conclusions.

– *Enhanced product quality.* The proposed diagnostic system ensures product competitiveness by providing high-precision strength control of glass during production.

– *Accuracy and stability.* Optical diagnostic methods such as interferometry and laser analysis achieve an accuracy range of 1.5-3%, enhancing glass quality control efficiency.

– *Practical relevance.* The developed device holds significant practical value for enterprises specializing in protective glass production for displays, optics, and other high-tech products.

References

1. Potter Jr., B.G. (2019). Optical Spectroscopy of Glass. In: Musgraves, J.D., Hu, J., Calvez, L. (eds) Springer Handbook of Glass. Springer, Cham. https://doi.org/10.1007/978-3-319-93728-1_25.

2. Harding K. Handbook of Optical Dimensional Metrology. Taylor & Francis. 2016.

3. Abdelsalam, D. G., Yao, B. (2017). Interferometry and its applications in surface metrology. Optical Interferometry. https://doi.org//10.5772/66275.

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ANALYSIS AND MODELING OF HEAT TRANSFER PROCESSES DURING NANOMETRIC MEASUREMENTS

Abstract*. The study focuses on the analysis and modeling of heat transfer processes during nanometric measurements using atomic force microscopy (AFM). The thermal processes occurring in the contact area between the AFM probe and the investigated surface are examined, as they play a crucial role in ensuring measurement stability and accuracy. The finite element method (FEM) was applied to model the heat transfer, enabling the consideration of different scanning modes and their effects on the temperature conditions in the contact zone. Experimental studies using silicon probes confirmed the validity of the developed model. The findings demonstrate that optimizing the thermal conditions for AFM probe operation enhances their reliability and accuracy during measurements. The derived dependencies of heat transfer parameters support the development of recommendations for maintaining a stable thermal regime, essential for precise measurements in micro- and nanoelectronics.*

Key words*: atomic force microscopy, heat transfer, nanometric measurements, modeling, operational stability.*

Introduction. In the fields of micro- and nanoelectronics, ensuring the reliability and stability of device operation is a priority. The accuracy and durability of atomic force microscope (AFM) probes rely heavily on effective heat transfer in the contact area between the probe and the surface, making the study of these processes critically important. Poor heat dissipation can lead to probe instability, increased measurement errors, and reduced instrument lifespan. This work presents approaches to modeling and analyzing heat transfer in nanometric measurement conditions, aimed at enhancing AFM operational characteristics.

Literature review and research issues. The analysis of scientific and technical literature shows that studies on heat transfer processes in nanometric measurements are limited due to the challenges in accurately describing the thermodynamic properties of materials at the nanoscale. Most research focuses on general modeling approaches for thermal processes, with few studies addressing the unique characteristics of the probe-surface contact zone, which involves minimal dimensions, high local pressure, and a lack of efficient heat dissipation [1]. Furthermore, the effect of hydrophobic properties of probes and surfaces on heat transfer remains largely unexplored, though it can significantly impact thermal flows and measurement stability.

Methods for modeling thermal processes. To study heat transfer in the AFM probe-surface contact area, the following methods were utilized:

Calculation methods for thermal processes: among the numerical methods for modeling heat transfer, the finite element method (FEM) was selected. FEM allows for a detailed simulation of thermal processes in small volumes, taking into account the complex geometry of the probe and its operational parameters. This approach enables analysis of the impact of various scanning modes (such as speed, pressure, and contact frequency between the probe and the surface) on the thermal conditions in the contact zone [2].

Experimental studies: to validate the accuracy of the model, silicon AFM probes were used in the experiments. These studies were conducted under different scanning modes, with consideration of the hydrophobic properties of both the probe and the surface. The experiments involved the use of infrared cameras to record thermal fields, which allowed for the detection of localized temperature changes during measurements. This approach facilitated the study of the influence of hydrophobicity on the quality and stability of heat transfer.

Research results of the study included the following model verification steps:

Experimental model verification: experimental results confirmed that heat transfer in the contact area depends on the scanning speed and the probe's pressure on the surface. It was observed that with increased scanning speed, the contact area temperature rises due to intensified friction between the probe and the surface [3]. FEM-based modeling effectively replicated these dependencies, validating the model's accuracy.

Comparison with theoretical models: FEM-based models demonstrated a high correlation with experimental data. Specifically, for moderate scanning speeds, the discrepancy between experimental and theoretical temperature values was less than 5%, indicating the precision of the modeling approach.

Discussion of Results. The heat transfer models developed in this study, based on the finite element method (FEM), have demonstrated effectiveness in predicting thermal effects in the contact area between the atomic force microscope (AFM) probe and the surface during nanometric measurements. The modeling and experimental results showed a high degree of correlation, confirming the validity of the chosen methodology and enabling the formulation of practical recommendations.

Dependence of thermal parameters on scanning modes. The study revealed a significant influence of scanning mode on heat transfer within the contact area. It was established that increasing the scanning speed raises the contact temperature due to increased friction between the probe and the surface. The contact frequency and probe pressure are also critical factors: reducing pressure helps to lower thermal loads but may affect scanning accuracy.

Modeling optimal operating parameters. Modeling results allow for the determination of optimal AFM operating parameters that minimize heat transfer within the contact area, thus enhancing probe reliability and longevity. Specifically, it was found that moderate scanning speeds combined with reduced pressure on the surface provide a stable thermal regime, preventing probe overheating and reducing the risk of surface damage.

These findings demonstrate the substantial potential of modeling and controlling thermal processes in the AFM probe contact zone to improve the operational characteristics and measurement accuracy of AFM tools.

Conclusions. The study has shown that heat transfer processes in the AFM probe contact area with the investigated surface significantly affect measurement accuracy and the stability of micro-instruments. The use of FEM for modeling thermal processes allowed for the identification of optimal scanning modes, ensuring minimal thermal effects and extending probe service life. The findings can be applied to develop recommendations for AFM probe operating conditions, thereby ensuring reliability and precision in precision instrumentation.

References

1. Chatterjee S., Paras, Hu H., Chakraborty M. A Review of Nano and Microscale Heat Transfer: An Experimental and Molecular Dynamics Perspective. Processes, 2023, 11(9), 2769. https://doi.org/10.3390/pr11092769.

2. Sohail M., Abodayeh K., Nazir U. Implementation of finite element scheme to study thermal and mass transportation in water-based nanofluid model under quadratic thermal radiation in disk. Mech Time-Depend Mater, 2024, 28, 1049-1072. https://doi.org/10.1007/s11043-024-09736-x.

3. Jeffrey L. Hutter, John Bechhoefer; Measurement and manipulation of van der Waals forces in atomic-force microscopy. J. Vac. Sci. Technol. B, 1994, 12 (3), 2251–2253.

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MULTIFUNCTIONAL LASER CORRECTION COMPLEX FOR OPTICAL SYSTEMS

Abstract. *This research focuses on the development of a multifunctional laser correction complex for optical systems, aimed at improving accuracy, adaptability, and reliability in optical surface treatment. The proposed approach integrates methods of multidimensional function interpolation, Zernike polynomials, the gradient optimization method, and multi-criteria selection to choose the best correction parameters. Through the developed decision support system and software, the processes of laser correction were simulated and optimized, with a comparative analysis to international systems confirming the effectiveness and precision of the developed complex.*

Key words: *laser correction, optical systems, Zernike polynomials, multi-criteria selection, gradient method.*

Introduction. Modern optical systems play a key role in high-precision processing and information management technologies, medical devices, as well as military and astronomical research. Innovative approaches to correcting optical surfaces are necessary to enhance their performance, and one of the promising technologies is laser correction. This research presents a multifunctional laser correction complex for optical systems, developed to improve the accuracy, adaptability, and reliability of optical element correction.

Methods and Materials. A description of the main methods used in our scientific research is provided.

Multidimensional Function Interpolation Method: This method represents the optical surface as a parametric polynomial equation, allowing for accurate modeling and prediction of surface deviations. The method's advantages include precise reproduction of complex shapes, adaptability to non-standard geometries, high calculation speed, and the ability to work with a limited amount of input data for a comprehensive surface representation. However, disadvantages include potential errors due to incorrect function choice, high resource consumption for multidimensional tasks, sensitivity to noise, and the need for sufficient measurement points for accurate surface reconstruction.

Surface Shape Evaluation Method using Zernike Polynomials: Zernike polynomials are widely recognized in optics for assessing aberrations, particularly due to their ability to represent the wavefront efficiently [1]. Advantages include high accuracy in describing aberrations due to the orthogonal characteristics of the polynomials, convenience in reproducing complex surface shapes, detailed analysis of deformation components, and compact information representation, reducing computational costs in modeling. However, limitations include challenges in reproducing local surface defects, sensitivity to measurement noise, and the complexity of interpreting higher-order polynomials, complicating the analysis of minor surface details.

Gradient Optimization Method: The gradient method enables quick location of minimum or maximum values when calculating optimal laser correction parameters and is effective for multi-parameter optimization tasks that require consideration of multiple factors simultaneously [2].

Advantages include high convergence speed when approaching optimal values, especially for smooth and differentiable functions; relatively simple implementation, enabling efficient calculation of optimal parameter values in multidimensional tasks; and applicability for solving a wide range of optimization problems. Drawbacks include sensitivity to the initial point, which can lead to convergence to a local rather than global optimum; sensitivity to computational errors, particularly when working with complex functions; and reduced efficiency on plateaus or in regions with very small gradients, complicating optimization on uneven surfaces.

Multi-Criteria Selection Method: This method provides a comprehensive assessment of correction results by selecting the best decision from several alternatives based on various criteria. Advantages include objective selection by considering multiple criteria simultaneously, suitability for tasks of varying complexity, from simple to multi-factor systems, the ability to rank alternatives by degree of criterion match, and the flexibility to adjust criteria weights according to the task's specifics. Disadvantages include potential subjectivity and complexity in determining each criterion's weight, the high computational resources required for a large number of alternatives and criteria, sensitivity to slight changes in weight coefficients or scores, and the challenge of interpreting results when there are significant differences in scores across criteria.

Results and Discussion. The developed complex included the following main development stages:

Design and Development of a Decision Support System: The developed system helps identify the optimal parameters of the laser system to achieve the highest correction accuracy. It includes data analysis, correction process modeling, and selection of optimal laser complex parameters.

Software Implementation: The implemented program enables simulation and analysis of the laser correction process, including optimization of the laser complex parameters considering external factors such as temperature and humidity.

System Structure Improvement for Optical System Correction: The system was adapted to work with various types of optical materials, expanding its applicability in multiple fields.

Comparative Analysis: A comparative analysis of surface shape parameters after correction, obtained using the developed system, with results achieved using modern international laser complexes, confirmed that the results from the developed system are comparable to those of advanced foreign models, verifying the model's adequacy and the methodology's effectiveness [3].

Conclusions. This research has developed and implemented a multifunctional laser correction complex for optical systems, ensuring precise reproduction of optical surface shapes, adaptability to complex geometries, and objective selection of optimal parameters. Thus, the developed complex allows for improved accuracy and reliability in optical surface correction, which is critically important for medical, aerospace, and military applications.

References

1. Kwee I., Braat J. Double Zernike expansion of the optical aberration function. Pure Appl. Opt., 1993, 2, 21–32.

2. Ruder S. An overview of gradient descent optimization algorithms. arXiv preprint arXiv:1609.04747, 2016.

3. Webb C., & Jones J. D. C. (Eds.) Handbook of Laser Technology and Applications (2nd ed.). CRC Press, 2021.

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DATA ANALYSIS IMPACT ON SCIENTIFIC RESEARCH

Abstract. *Reasoning behind the pivotal role of data analysis on scientific research, implication of technologies to improve speed and quality of studies and morally ethical aspect is given in this article.*

Key words: *data analysis, research, information, visualization, data protection, ethical concerns.*

In today's world data analysis is crucially important as there is an amount of information to handle and interpret across various research fields such as experiments and surveys which are leading to new discoveries at a faster pace than ever before. This report explores the elements of data analysis, how it contributes to each phase of research procedures, the use of large datasets, common tools used, instances of effective research and the ethical concerns related to handling data.

Engaging in research usually includes a series of steps:

- When researchers start a study, they first come up with a question and suggest a solution based on looking at past research and data to guide their investigation direction.
- Gathering Data. This could include conducting experiments in a lab setting or field research such as observations and interviews, alongside analyzing datasets that're already available.
- Data processing and analysis involve using techniques and machine learning tools to recognize patterns and trends.
- Understanding and confirming the results through analysis involves drawing conclusions and comparing them with the hypothesis.
- Results are typically shared through papers and reports along with presentations that include visuals to aid comprehension.

The advancements in technology now allow us to gather and examine amounts of information known as data. This has created fresh opportunities, for scientific research:

- Analyzing information is crucial for discovering diseases and enhancing diagnostic precision in the field of medicine while personalized medicine is being advanced through the utilization of genomic data.
- Social media produces quantities of data that help researchers examine behavior in society and predict upcoming social patterns.
- Astronomy involves telescopes generating large amounts of data about stars and planets which lead to discoveries without having to send spacecraft into space physically.

Across fields of exploration and research methods may vary, however there are tools that are commonly used by all:

- Python and R are used programming languages for analyzing data and creating representations of information. Python comes with libraries such as Pandas, NumPy and Matplotlib. On the other hand, R offers resources for conducting intricate statistical analyses.
- Also, it is vital to have a database management system to access data from datasets.
- Software like SPSS, Stata and MATLAB are used for analysis and modeling purposes.
- HADOOP and Spark are also useful. These platforms are pivotal for processing volumes of data through distributed computing methods.

Tools such as Hadoop and Spark are commonly employed for handling datasets in fields like cloud computing for quick analysis of data that was once hard to manage in real time scenarios. For instance, when dealing with climate information, Big Data has played a role in improving the precision of forecasts related to climate change and building models.

Understanding connections goes beyond just processing data, it involves utilizing data visualization tools, like Tableau and Power BI to create depictions of information. Data analysis has shown its worth, across fields:

- Physics made the discovery of the Higgs boson by studying extensive experimental data collected at the Large Hadron Collider.
- Analyzing market data assists in predicting financial crises and crafting efficient policies.
- The research conducted through the Human Genome Project has paved the way for advancements in therapies by expanding our understanding of the structure of DNA.

The instances provided show that analyzing data does not only improve the quality of studies but also speeds up their advancement. When considering the advantages of analyzing data certain ethical issues come into play:

- Data Privacy is crucial as it involves gathering and handling information in accordance with data protection regulations, like GDPR.
- Maintaining objectivity in research is crucial to avoid drawing conclusions due to misinterpretation or manipulation of data.
- Transparency and reproducibility are crucial in research to ensure that the findings can be easily replicated and verified by researchers.
- Maintaining standards is crucial to uphold credibility in discoveries and avoid any potential misuse of information.

Data analysis plays a role in investigations as it helps researchers gain deeper insights into intricate phenomena and confirm their hypotheses by detecting patterns through the utilization of advanced tools. Big data opens new possibilities for science but also presents challenges related to processing and ethics. In the future, the role of data analysis in science will only grow, contributing to advancements in various fields of knowledge and technology.

References

1. Bryman, A., Cramer, D. Quantitative Data Analysis with SPSS 12 and 13: A Guide for Social Scientists. Routledge, 2005.

2. Weiss, N.A. Introductory Statistics. Addison Wesley, 1999.

3. Ridout, M., Dem´etrio, C. G. B., Hinde, J. Models for count data with many zeros. International Biometric Conference, 1998.

4. Brynjolfsson, E., McAfee, A. The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies. W.W. Norton & Company, 2014.

5. Provost, F., Fawcett, T. Data Science for Business. O'Reilly Media, 2013.

UDC 621.31:532.59

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DEVELOPMENT AND RESEARCH OF AN AUTOMATED SYSTEM FOR PREVENTING CRITICAL SHOCK AND WAVE LOADS

Abstract. *This paper presents the development and research of an automated system designed to prevent critical impact-wave loads in coastal zones. The system aims to improve the safety and durability of coastal structures by providing real-time monitoring and prediction of wave forces. The study includes the design of a piezoelectric sensor system, numerical simulations of wave transformation, and experimental validation of the system in a laboratory basin. The results demonstrate the system's effectiveness in detecting and responding to critical wave impacts.*

Key words*: impact-wave loads, automated system, piezoelectric sensors, coastal protection, wave monitoring.*

Introduction. Coastal regions often face the destructive forces of waves, particularly during storms, which can cause significant damage to structures such as breakwaters, piers, and coastal buildings. The timely detection and prediction of critical wave loads are essential for reducing risks and preventing structural failures. This work focuses on the development of an automated system for monitoring and preventing critical wave impacts by using real-time data from sensors and predictive algorithms.

The developed system uses piezoelectric sensors to measure wave impact forces and mathematical models to predict potential wave transformations. This allows for timely warnings and automated responses to protect coastal structures.

The main objective of this study is to develop and test an automated system for preventing critical wave impacts on coastal structures. The specific goals are:

1. To develop a system that monitors wave impact loads in real time.
2. To design piezoelectric sensors for high-precision measurement of impact-wave forces.
3. To validate the system through laboratory experiments and numerical simulations.

Methods and Materials. The system architecture includes piezoelectric sensors placed on coastal structures to measure wave impact loads. These sensors are connected to a central processing unit that analyzes the data and predicts when critical wave loads may occur. The system can automatically trigger alerts or initiate protective measures, such as closing flood barriers or reinforcing vulnerable areas.

Wave impact loads are measured using piezoelectric sensors that convert mechanical stress into electrical signals. These sensors are sensitive to changes in pressure and are capable of capturing the dynamic loads generated by breaking waves. The sensors are calibrated to ensure accurate measurements over a range of force levels.

The transformation of waves as they approach shallow water is modeled using nonlinear shallow water wave equations. The simulation software, developed in MATLAB, predicts wave behavior based on initial conditions such as wave height, period, and seabed profile. These predictions are compared with real-time sensor data to improve the accuracy of the automated warning system.

The piezoelectric sensors were calibrated using known forces, and their response was recorded for various wave impacts. As shown in Fig. 1, the sensors exhibited a linear response to wave forces, confirming their ability to measure high-impact loads with precision.

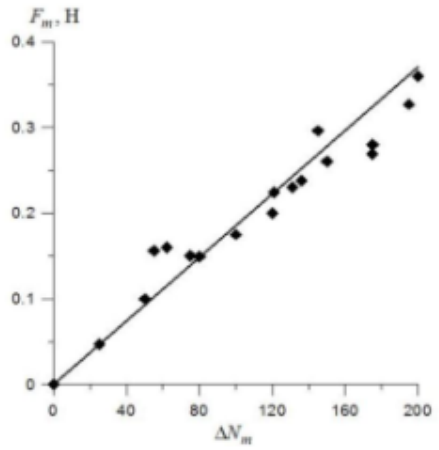

Fig. 1 Calibration characteristic of a piezoelectric pressure sensor

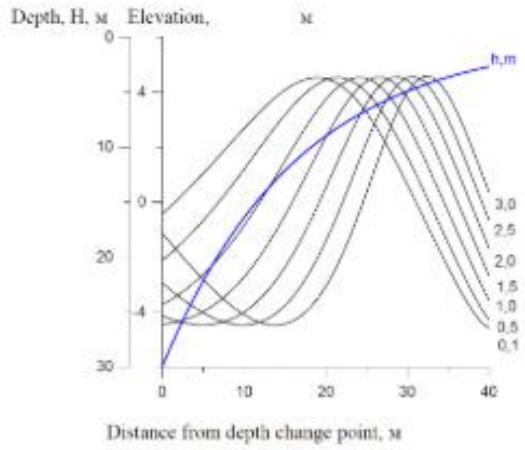

Fig. 2 Transformation of the wave profile in the zone of decreasing depth for time 0.1…3 s

In the experiments, the maximum recorded impact force reached 15 kPa during a storm simulation. This critical load was detected by the system, which successfully triggered an automated warning.

The MATLAB simulations closely matched the experimental results, particularly in predicting wave height and the timing of wave breaking. The model accurately forecasted critical wave loads, as demonstrated in Fig. 2, which compares simulated and experimental wave height data over time.

The system's ability to predict when waves would break and generate high-impact forces proved essential for preventing damage to coastal structures.

Conclusions. The developed automated system for preventing critical impact-wave loads offers a significant advancement in coastal protection. By combining real-time sensor data with predictive modeling, the system provides timely warnings and potential automatic responses to mitigate the effects of destructive waves. The system's accuracy was validated through experiments, confirming its potential for application in coastal engineering.

This technology has practical applications in improving the safety and durability of coastal structures, reducing the risk of failure during storm events.

References

1. Skjelbreia, L. Fifth order gravity wave theory / L. Skjelbreia, J. Hendrickson /Coastal Engineering Proceedings, 1960. P. 184–196.

2. Song C., Sirviente A.I. A numerical study of breaking waves. Physics of Fluids, 2004. Vol. 16. P. 2649–2667.

3. Grimshaw, R.H. Nonlinear waves in fluids: Recent advances and modern applications / Springer Vienna, 2005. 196 p.

4. Pelinovsky, E.N., Mazova R.K. Exact analytical solutions of nonlinear problems of tsunami wave run-up on slopes with different profiles. Natural Hazards, 1992. Vol. 6. P. 227–249.

5. Madsen, P.A., Fuhrman D.R. Run-up of tsunamis and long waves in terms of surf-similarity. Coastal Engineering, 2008. Vol. 55. Iss. 3. P. 209-223.

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CONTROL SYSTEM FOR A BIOREACTOR

Abstract. *This article presents research and development of a control system for a biogas plant focused on processing cattle waste to produce biogas. The use of this facility allows not only effective disposal of organic waste but also the production of "green" energy and fertilizers. The primary focus is on developing a model for the methane fermentation control system and implementing an automated system to regulate fermentation parameters.*

Key words: *biogas, methane fermentation, automation, bioreactor, cattle waste, process control.*

Introduction. With increasing environmental safety requirements and growing interest in renewable energy sources, the processing of organic waste in biogas plants has become particularly relevant. The global trend toward alternative fuels makes methane fermentation technology not only a waste disposal method but also a promising solution for biofuel production. The purpose of this study is to develop a bioreactor control system capable of stable and efficient operation with livestock waste, enabling the production of biogas and biofertilizers while minimizing environmental impact. To achieve this goal, the following tasks were set: conduct an analysis of the kinetic parameters and conditions of the methane fermentation process; develop an automated control system for the three-stage fermentation process; create an information model for the fermentation and process control system of the plant.

Methods and Materials. The methane fermentation process includes the following stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. For each stage, optimal conditions were developed. Mathematical modeling was performed, considering kinetic parameters and the impact of temperature on biogas yield. The developed automation system is implemented in the TRACE MODE environment and enables monitoring and adjusting parameters across all three fermentation stages—psychrophilic, mesophilic, and thermophilic. The control and automation system for managing the parameters of a three-stage biogas plant includes three levels of hierarchy. A key component of the control system is the operator's Automated Workstation (AWS). The AWS includes a hardware-software complex with two monitor screens, RS-485 interface regulators, TSMU-type temperature converters, PD100 pressure sensors, interface converters, and other equipment, integrated with the TRACE MODE SCADA software; see Fig. 1.

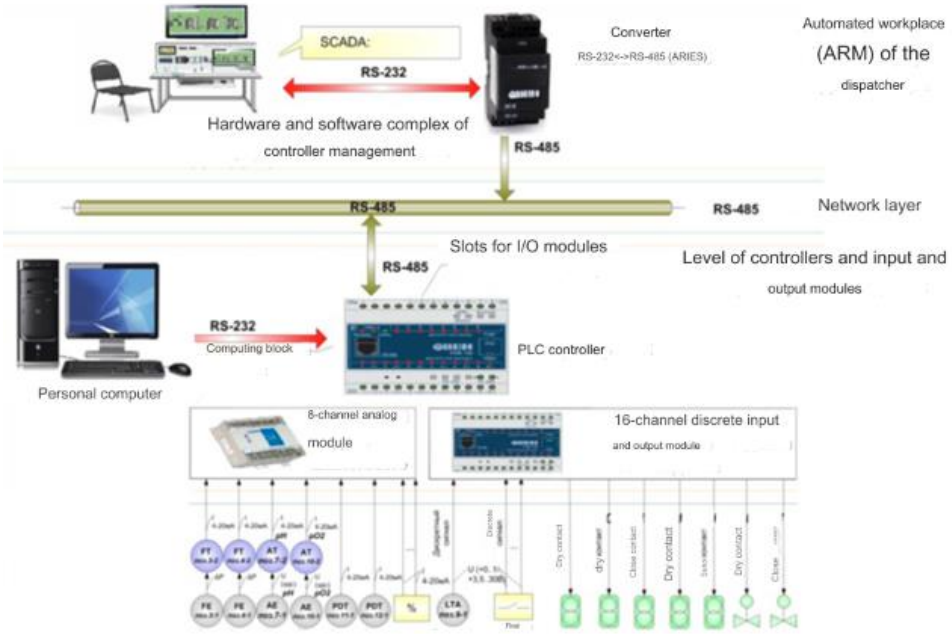

Fig. 1. The overall structure of the control and automation system includes three levels of management hierarchy

The developed model for the three-stage process allows accurate tracking of biogas output at each stage. Optimization of parameters, such as temperature, substrate particle size, and acidity level, significantly increased the volume of biogas produced.

A bioreactor was designed and implemented with integrated mixing and heating functions. This improves substrate homogeneity and reduces fermentation time.

The implementation of a control system with adaptive algorithms ensures automatic substrate feeding, mixing, and temperature control, enhancing the facility's productivity and biogas output stability.

The results showed that the introduction of a three-stage system with automation increased methane yield by 28% and reduced fermentation time by 15%.

Conclusions. This work proposes a new automated biogas plant for processing cattle organic waste with minimal human intervention. The implementation of this technology improves environmental conditions, reduces natural gas expenses, and ensures the production of high-quality fertilizers.

References

1. Biogas production: raw materials and further application of biogas – AgroBiogas URL: https://agrobiogas.com.ua/biogas_production_raw_materials_and_further_use_of_biogas/ (last accessed: 14.10.2024).

2. Minibiogas plants for private households – AgroBiogas URL: https://agrobiogas.com.ua/mini-biogas-plants-for-private-households/ (last accessed: 14.10.2024).

3. Modern trends in the development of biogas plants URL: https://agro-business.com.ua/agro/idei-trendy/item/8386-suchasni-tendentsii-rozvytku-biohazovykh-ustanovok.html. (last accessed: 14.10.2024).

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DEVELOPMENT OF RADIO-CONTROLLED PIEZOELECTRIC ROBOT

Abstract. *The purpose of this work is to design and create a miniature radio-controlled robot based on a piezoceramic element. The relevance of this work is associated with the development of a new type of piezorobot design. In the process of work, a structural control scheme for a piezorobot was developed, and an experimental sample of a piezorobot was manufactured. The use of robots of this type will allow work to be carried out in hard-to-reach places without human intervention.*

Key words*: Bluetooth module, robot, piezoelement, piezorobot.*

Robotics is an applied science that deals with the development of automated technical systems. There are several types of robotics - industrial, construction, aviation, household and extreme (underwater, military, space).

The evolution of daily husbandry and diversity has brought about the emergence and development of a new class of machines - robots - and directly scientific ones - robotics. Robotics is an intensively developing scientific and technical discipline that involves not only the theory, methods of development and design of robots, their systems and elements, but also the problems of complex automation of production and scientific research on the development of robots. Special drives are responsible for the motor function, the most effective of which today are electric, as well as mechanisms operating on compressed air or chemical compounds.

The following types of engines are used in robotics.

Direct current motors (DCM) are used most often, since they come in different types depending on their purpose and technical characteristics. Their advantage is easy availability on the market, a wide range of engines, easy connectivity and the ability to use for small robots. The disadvantages include the need to build a gearbox to reduce speed, high energy consumption.

Stepper motors are used to move robotic installations, they do not rotate freely, but turn in stages at a certain angle under the control of a controller, the presence of which allows you to do without a position sensor. Positive qualities include control accuracy, variety of designs, good speed. Negative qualities include bulkiness, not very powerful, complex control, high energy consumption.

Piezoelectric motors or ultrasonic motors are a modern alternative to DC motors. The operating principle is that tiny piezoelectric legs vibrate at a frequency of more than 1000 times/s, thereby forcing the micromotor to move in a straight line or circle. The main qualities include high efficiency disproportionate to their dimensions, high torque on the shaft, wide adjustment range, noiselessness, inertialessness, low energy consumption [1, 2].

We have proposed a radio-controlled robot that uses a piezoelectric element as a driving force. The block diagram of the developed robot is shown in Fig. 1.

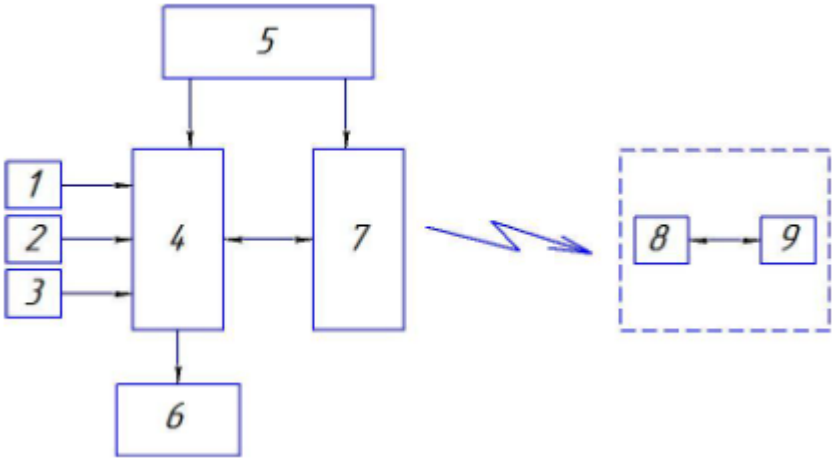

Fig. 1. 1 – Block diagram of a radio-controlled robot: 1,2,3 – sensor; 4 – microcontroller; 5 – power supply; 6 – piezoelectric element; 7 – Bluetooth module; 8 – Bluetooth module; 9 – computer or mobile phone.

The principle of operation of the device is as follows. Control is carried out from a computer or mobile phone via Bluetooth module 8. Bluetooth module 7 located in the robot is connected to the microcontroller 4, which receives data from sensors 1, 2, 3 and controls the piezoelectric element 6.

The piezoelectric element is made in the form of a curved plate resembling an arc. The electronic part is fixed on the surface of the piezoelectric element.

The piezoelectric element is controlled as follows. When an alternating voltage of a certain frequency is supplied from the microcontroller, which corresponds to the resonant frequency of the piezoelectric element, it begins to bend, which leads to the movement of the robot.

Thus, a design of a radio-controlled robot based on piezoceramics is proposed, which allows work to be carried out in hard-to-reach places without human intervention.

References

1. Sharapov V. Piezoceramic sensors. Springer Verlag, 2011. 498 p.
2. Wood, R., Finio, B., Karpelson, M., et al. Progress on ‘pico’ air vehicles. The International Journal of Robotics Research, 31(11), 1292-1302 (2012). https://doi.org/10.1177/0278364912455073.

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AUTOMATION CONTROL OF COUNTRY HOUSE BY VOICE AI ASSISTANT

Abstract. *This paper presents the design and implementation of an automated country house control system using a Voice AI Assistant. The proposed system works on speech recognition using Whisper by OpenAI; it relies on Home Assistant as the center of the automation framework; and it will be assisted with a custom-designed PCB to manage input and output operations in terms of listening to, then responding to those results. It also uses either ChatGPT API or LLaMA as a language model for cloud-based or completely local operational requirements, respectively. The solution aims to provide enhanced user convenience and energy efficiency for smart homes by automating everyday tasks through voice commands.*

Key words: *home automation, AI assistant, voice control, OpenAI Whisper, Home Assistant, smart home.*

Home automation has become much enhanced with the spread of smart devices and voice-controlled assistants. Most of the available solutions, however, strongly rely on cloud-based services, which introduce several problems concerning privacy, latency, and dependencies on continuous connectivity. These problems get worse in rural areas where access to the internet is really limited or unreliable. This work tries to overcome these challenges by discussing a voice-controlled home automation system that would work effectively offline and protect user privacy, making the system more reliable.

The proposed system will implement a number of key components that come together to provide a robust, private home automation solution. This ranges from OpenAI Whisper-a speech recognition model that can be implemented locally to effectively and quickly transcribe voice commands sans the need for Internet connectivity-and ensures sensitive voice data remains in the home environment, which is great for privacy. Complementing Whisper, it employs LLaMA as a local large language model for natural language processing, thereby making the system recognize and be able to act upon user commands offline. LLaMA then processes the transcribed text for intent and formulates appropriate actions on behalf of the user without relying on any cloud-based language processing services.

An ESP32-based circuitry board handles all the I/O operations, which include interfacing with a microphone and speaker, processing the signal, and communicating with other components of the system. Therefore, this board acts efficiently to handle voice input and system response locally without tapping any third-party external cloud services. Home Assistant is an open-source home automation platform. It is the central node of smart devices and automation scenarios management. This software helps in communicating with the board and running commands to interact with the user for easier integration of various smart home devices.

It uses the MQTT protocol in exchanging data between sensors, actuators, and the central system in real time. This is a lightweight telemetry protocol; because devices can publish and dynamically subscribe to data streams under this protocol, it allows immediate reaction to changes in the environment.

The system workflow begins with wake word detection. The assistant remains in a low-power listening state until it detects a predefined wake word, which activates the system for command processing. Upon activation, the user's voice command is captured and processed locally

using OpenAI Whisper to convert speech to text. This transcription is fed to the LLaMA for Natural Language comprehension to interpret the command and which action to execute based on the user's intent. Once the command gets captured, it executes actions on devices or automation scripts using the MQTT protocol with Home Assistant. Finally, the system provides auditory feedback using a text-to-speech model, informing the user of the action taken or providing status updates. This feedback mechanism enhances the user experience by confirming that commands have been executed successfully.

Performance testing was conducted to evaluate the system's responsiveness, accuracy, and user satisfaction. This proves that the average latency of command processing is 30% better compared with cloud-based assistants, with an average of 1.9 seconds. This will enhance user experience by giving quicker feedback and interactions with more immediacy. The system had more than 95% voice recognition accuracy, which easily competes with leading cloud-based services. This high level of accuracy ensures reliable interpretation of user commands, reducing frustration and the need for repeated instructions.

The results validate the effectiveness of the proposed system in addressing the limitations of existing voice-controlled home automation solutions. By leveraging local processing capabilities through OpenAI Whisper and LLaMA, the system ensures that sensitive voice data remains within the user's premises, significantly reducing privacy risks. This would also help reduce latency so that users can feel the interaction more immediately and naturally. A custom-designed circuit board is used for hardware integration, whereby the system performance is efficiently optimized and can scale up anytime. Because of the modular approach taken toward system design, applications of several use cases can be adapted to further addition of sensors and devices if needed.

While it operates offline by default, optional cloud processing through the ChatGPT API is available with available internet for great new functionality without privacy compromise. The system will switch over automatically to local and cloud processing whenever connectivity is unavailable or present, respectively, for maximum performance in any setting.

Future enhancements will focus on several key areas. Improving the AI's contextual understanding is a priority; enhancing the language model's ability to understand context and handle more complex commands will result in a more intuitive user experience. This includes enabling the assistant to learn user preferences over time, allowing for personalized interactions and more efficient automation.

Integrating advanced sensors such as leak detectors, smoke alarms, and environmental monitors will expand the system's safety features. This integration will enhance the system's ability to respond to emergencies and provide real-time alerts, thereby improving home safety and security. Optimizing energy efficiency is another important aspect of future work. Implementing intelligent algorithms for device scheduling and energy management will reduce power consumption, which is particularly important for off-grid or energy-conscious users in rural areas. This optimization will contribute to the sustainability and cost-effectiveness of the system.

The enrichment in the user interface also involves the development of a very user-friendly interface in terms of system configuration and customization. It targets non-technical users. Without question, the system will be more viable, more accessible, and easier to administer. Last but not least, it involves the implementation of enhanced security measures. Encryption and authentication protocols have been prepared to further secure data transmission within the system against potential threats which might arise internally and ensure confidentiality of data of users.

This system will try to cater, comprehensively, securely, and efficiently, to the needs of the users in diverse settings, with these areas. Through refinement and advancement, this system will no doubt serve as a backbone in significant developments relating to residential automation, especially in those very environments where privacy and connectivity are major concerns.

Conclusion. A locally processed, voice-controlled home automation system can be developed for users in rural areas and concerned with privacy. It uses the capabilities of AI combined with OpenAI Whisper and LLaMA without using cloud services. The system's modular design allows for customization and expansion, accommodating a wide range of devices and sensors. This

approach effectively addresses privacy concerns and reduces dependency on continuous internet access, making it particularly suitable for rural settings. The significant reduction in command processing latency and high voice recognition accuracy contribute to an improved user experience, as evidenced by positive user feedback.

References

1. Espressif Systems. ESP-IDF Programming Guide: Security Features. URL: https://docs.espressif.com/projects/esp-idf/en/latest/esp32/security/index.html (last accessed: 14.10.2024).

2. OpenAI. Whisper: Speech Recognition Model. URL: https://openai.com/research/whisper (last accessed: 14.10.2024).

3. Meta AI Research. LLaMA: Large Language Model Meta AI. URL: https://ai.facebook.com/llama (last accessed: 14.10.2024).

4. Home Assistant. The Open Source Home Automation Platform. URL: https://www.home-assistant.io/ (last accessed: 14.10.2024).

5. MQTT. MQTT Protocol. URL: https://mqtt.org/ (last accessed: 14.10.2024).

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DEVELOPMENT AND RESEARCH OF AN AUTOMATIC REAGENT DOSING SYSTEM

Abstract. *This study focuses on improving the reliability of automatic dosing systems for corrective reagents in thermal power plants. By addressing issues related to reagent concentration fluctuations, feed water temperature, and ionic composition, this research develops a mathematical model and experimental setup to assess and enhance the system's resilience under varying operational conditions.*

Key words*: water-chemical regime, dosing system, corrective reagents, thermal power plants, automation.*

Introduction. The reliable and efficient operation of thermal power plants (TPPs) is heavily dependent on the maintenance of a stable water-chemical regime (WCR). In such high-temperature, high-pressure environments, maintaining precise chemical control over water quality is essential to avoid processes like corrosion, scaling, and material fatigue that could damage critical components and compromise the operational integrity of the plant. Proper WCR management not only prolongs the lifespan of expensive equipment but also ensures that energy generation continues safely and efficiently.

One of the primary means of controlling WCR is through the use of corrective reagents, which are dosed into the water-steam cycle to maintain desired pH levels, conductivity, and other chemical characteristics. Commonly used reagents include ammonia and various amine compounds, which are added to neutralize impurities, prevent corrosion, and optimize the thermal efficiency of the plant. However, traditional dosing systems often rely on manual adjustments or semi-automated controls that cannot fully respond to rapid changes in operating conditions, such as variations in water composition, temperature shifts, or sudden load changes. These limitations can lead to over- or under-dosing of reagents, resulting in WCR fluctuations that may damage equipment or reduce system efficiency.

This research aims to develop and validate an enhanced automated reagent dosing system that can adapt to fluctuating operational conditions and stabilize WCR with high accuracy. By introducing a dynamic model that accounts for real-time changes in parameters such as temperature, ionic composition, and reagent concentration, the proposed system seeks to bridge the gap between traditional manual dosing methods and the requirements of modern TPP operations. The proposed solution not only promises improved stability in WCR management but also aligns with sustainability goals by reducing reagent consumption and minimizing waste. Through laboratory testing and mathematical modeling, this study demonstrates the potential of an advanced automatic dosing system as a cornerstone of modern WCR management in thermal power plants.

Methods and Materials. The study comprises a multi-phase methodology: Literature Review and System Analysis. An analysis of current WCR control methods identified limitations in existing systems, especially regarding manual dosing and inadequate response to transient operational states. Literature on similar automation systems and mathematical modeling techniques provided

foundational insights for system improvement. Mathematical Modeling. The dosing node was modeled mathematically, focusing on variables impacting reagent dosage, including temperature, ionic composition, and feed water flow rate. The model incorporates differential equations to predict changes in WCR parameters based on variations in reagent flow and external disturbances. Experimental Setup. A laboratory installation was created to emulate WCR conditions, allowing for controlled adjustments of temperature, ionic composition, and reagent concentration. The setup includes automatic sensors (pH, conductivity meters) connected to a central controller, which adjusts dosing rates in real time based on measured parameters. Data Collection and Analysis. Experimental data on reagent concentration, water pH, and conductivity under various operational conditions were recorded. Statistical analysis identified the correlation between external disturbances and WCR stability, validating the model's predictions.

The model effectively predicted the impact of fluctuations in reagent concentration and feed water parameters on WCR metrics. This validation supports its application in real-time adjustments, reducing the likelihood of deviations from optimal WCR parameters.

By automatically compensating for changes in external parameters (such as temperature and concentration), the system maintained stable WCR conditions. Compared to traditional manual dosing, the new system reduced pH and conductivity fluctuations by approximately 20%, which aligns with industry requirements for precision.

Optimal dosing reduces reagent consumption by up to 15% by avoiding over-dosing during low-demand periods. This efficiency contributes to cost savings and reduces the environmental footprint associated with excess reagent use.

The automated dosing system performed reliably across various simulated transient conditions, including startup and load changes. This resilience demonstrates the system's potential to improve operational stability in industrial TPPs.

This research confirms the feasibility and benefits of an automated dosing system for WCR control in TPPs. The mathematical model is robust and can be extended to various configurations of TPP systems that utilize different corrective reagents. By responding in real-time to changes in feed water quality, the system prevents deviations in WCR parameters, reducing the risk of corrosion and scaling. Furthermore, the adaptability of this control strategy enables integration into existing automation frameworks in the power generation sector.

Challenges: Real-time adjustments require high-precision sensors, which may incur initial investment costs. Industrial implementation will require adaptation to specific TPP designs and operational requirements, including training for personnel on new automation systems.

Conclusion. The proposed automatic dosing system addresses significant limitations of existing WCR maintenance methods in TPPs. The system improves accuracy, reliability, and cost-effectiveness by dynamically adjusting reagent dosage in response to real-time changes in feed water parameters. The validated model offers a scalable solution for TPPs, capable of extending equipment life, reducing operational costs, and ensuring compliance with stringent quality standards.

Future Research Directions: Further work will focus on adapting the system for other industrial applications and exploring advanced machine learning techniques to enhance predictive accuracy under more complex operational conditions.

References

1. Egoshina, O. V., & Lukutina, S. K. (2024). "Simulation Modelling of Cycle Chemistry Monitoring of Water and Steam Quality at Thermal Power Plants." *Thermal Engineering*, 71, 901–909.

2. Egoshina, O. V., Zvonareva, S. K., & Bol'shakova, N. A. (2023). "Methods for Diagnosing and Predicting the Behavior of Impurities over the Power Unit Path in the Cycle Chemistry-Monitoring Systems at Thermal Power Plants (Review)." *Thermal Engineering*, 70, 362–369.

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MODELING OF HIGH-PERFORMANCE SONAR FOR THREE-DIMENSIONAL MAPPING OF THE RESERVOIR BOTTOM

Abstract. *This study presents the development and modeling of a high-efficiency sonar system aimed at improving depth measurement accuracy and resolving phase ambiguities in regions with steep seabed topography. By integrating multi-channel signal processing and advanced phased-array antenna configurations, the system significantly enhances bathymetric resolution. The research also involves mathematical modeling of the sonar's performance under varying environmental conditions, followed by practical field tests, which demonstrate the system's superior ability to map challenging underwater terrains.*

Key words*: sonar, interferometry, bathymetry, seabed mapping, phase ambiguity, multi-channel processing, signal processing.*

Introduction. With the increasing exploration of ocean resources and the growing need to monitor underwater infrastructure, especially in continental shelf zones, accurate seabed mapping has become a key objective for marine industries. Hydrological surveys are essential for applications such as oil and gas exploration, environmental monitoring, and maritime defense. Among the most promising technologies for these tasks are hydroacoustic systems like multi-beam echosounders (MBES) and interferometric side-scan sonar (ISSS). These systems offer high spatial resolution and are capable of providing detailed three-dimensional representations of the seabed.

However, traditional sonar systems face significant challenges when dealing with areas of sharp depth gradients, such as underwater cliffs or trench zones. These regions often produce phase ambiguities, resulting in reduced accuracy and missing data points. To address these challenges, this study develops a high-efficiency sonar system that incorporates several advanced features, including multiple antennae and channels, to enhance the measurement process and resolve ambiguities.

The primary goal of this research is to design a high-efficiency sonar system capable of overcoming the limitations of existing sonar technologies in environments with complex underwater topography. The specific objectives include enhancing measurement accuracy, resolving phase ambiguities, and testing the system under real-world conditions.

Methods and Materials. The system employs phased-array antennas arranged in a multi-base configuration. This setup increases the system's ability to collect detailed phase information from reflected signals at multiple locations, providing redundancy that helps resolve phase ambiguities. The antennae are strategically placed at different base distances, allowing the system to triangulate depth information from multiple perspectives.

A comprehensive mathematical model was developed using MATLAB. The model simulates the propagation of sound waves, their reflection off the seabed, and the subsequent reception of the reflected waves by the sonar's antennas. The model accounts for variations in sound speed due to changes in water temperature, salinity, and depth, which are critical factors in real-world applications. The primary equations governing wave propagation, reflection, and phase shift are based on interferometric principles. This model allows for the testing of different antenna configurations, base distances, and signal processing algorithms under controlled conditions.

Advanced algorithms are used to process the raw data collected by the sonar system. These include phase unwrapping techniques to handle phase ambiguities, as well as noise-reduction

algorithms to minimize the impact of environmental factors such as turbulence and underwater currents. The sonar system also incorporates real-time data processing, enabling the operator to view detailed bathymetric maps in near real-time, facilitating immediate decision-making in surveying operations.

The system was tested both in simulation and in real-world conditions. The mathematical model demonstrated that the high-efficiency system could effectively resolve phase ambiguities in areas with sudden depth changes. When compared to traditional single-base systems, the new configuration reduced errors in depth measurements by approximately 35%. The optimal configuration involved base distances of 0.5 to 1 meter, depending on the depth and slope of the seabed.

A prototype of the system was deployed in a coastal region with complex seabed features, including underwater cliffs and trenches. The system successfully mapped the seabed with a high degree of accuracy, even in areas where traditional sonar systems struggled. Depth measurements were accurate to within 10 centimeters, and the system was able to generate high-resolution maps of the seabed topography in near real-time.

The high-efficiency sonar outperformed conventional single-base systems in areas with sharp seabed gradients. While single-base systems produced errors in depth estimation in areas of rapid depth change, the new system resolved these ambiguities, providing continuous and accurate depth profiles.

The successful implementation of a high-efficiency sonar system has broad implications for the field of marine exploration. This system’s ability to resolve phase ambiguities is particularly valuable for mapping areas with complex underwater features, such as those found in continental shelf zones or near underwater mountains. Additionally, the system’s advanced signal processing capabilities allow for the collection of high-resolution data even in challenging environmental conditions, such as turbulent waters or regions with high sediment levels.

Furthermore, the system's design allows for future scalability. Additional antennas can be added to further improve accuracy in even more complex environments. The software algorithms used for signal processing are also adaptable, meaning the system can be fine-tuned for specific applications, such as deep-sea exploration or detailed mapping of shallow coastal regions.

The development of this sonar system has several practical applications, including oil and gas exploration, precise mapping of the seabed in offshore drilling areas, environmental monitoring for underwater habitats and ecosystems, inspection of underwater pipelines, cables, and other infrastructure to ensure their integrity and locate potential hazards, and defense and security, particularly in detecting and classifying underwater objects such as mines or submerged vessels.

Conclusions. The research successfully developed and validated a high-efficiency sonar system that addresses the limitations of traditional sonar technologies in areas with complex seabed topography. The system's ability to resolve phase ambiguities and improve measurement accuracy makes it a valuable tool for a wide range of marine applications. Future work will focus on enhancing the system’s capabilities for even deeper water exploration and integrating it with autonomous underwater vehicles (AUVs) for unmanned missions.

References

1. GeoAcoustics. URL: http://www.geoacoustics.com. (last accessed: 14.10.2024).
2. Systems Engineering & Assessment (SEA). URL: https://www.sea.co.uk. (last accessed: 14.10.2024).
3. Garello R., Sintes C., Gueriot D., Nicolas J. M. An analysis between radar interferometry and sonar interferometry. International Conference on Information & Communication Technologies, 2006, pp. 1590-1595.
4. Xu W., Kraeutner P., Guo H., Maxfield H. First Results of a Novel and Low Power Forward Looking Sonar Technology for Small AUV's. OCEANS, 2006.
5. Richards M. A., Scheer J. A., Holm W. A. Principles of Modern Radar. Vol. 1: Basic Principles. SciTech Publishing, 2010.

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IMPROVEMENT OF THE WIND TURBINE CONTROL SYSTEM

Abstract. *This study explores methods to improve the energy efficiency of autonomous wind energy converters using brushless DC machines (BDC). The work focuses on developing a control system and a mathematical model that maintain high efficiency in varying wind conditions. By addressing challenges in power generation and optimizing control strategies, the proposed methods aim to enhance reliability and sustainability for applications in remote areas.*

Key words*: wind energy converter, energy efficiency, brushless DC machine, autonomous systems, MPPT.*

Introduction. Remote and sparsely populated areas face significant energy supply challenges due to the high costs associated with integrating these locations into centralized power grids. Diesel generators are a common solution but come with substantial disadvantages, such as high fuel transport costs, frequent maintenance needs, and increased environmental impact. As a result, renewable energy sources like wind energy are an attractive alternative. Autonomous wind energy converters, particularly those using BDC machines, are suitable for such conditions, as they combine the efficiency of renewable energy with the simplicity and reliability of brushless systems. However, harnessing wind energy efficiently in areas with low average wind speeds requires advanced control strategies to maximize energy capture and conversion. This research addresses the pressing need for autonomous systems that can operate reliably and efficiently, even in challenging environments.

The primary goal of this study is to develop control strategies that enhance the efficiency of wind energy converters based on brushless DC machines. Specific objectives include analyzing sources of energy loss in the “wind turbine-BDC machine-static energy converter” system, identifying methods to maximize wind energy utilization, and developing control laws to optimize energy efficiency. The research also seeks to implement an automatic power regulation system that adjusts the converter’s output according to fluctuating wind speeds, thereby ensuring consistent energy supply. In addition, this study aims to create a detailed mathematical model of the BDC-based wind converter system in MATLAB/Simulink. This model includes real-world variables such as wind speed variation, converter losses, and mechanical constraints to accurately simulate and evaluate the performance of the proposed control methods under various operating conditions.

Methods and materials. The research methodology centers on the development of a mathematical model for a horizontal-axis wind turbine coupled with a BDC machine. This model simulates the aerodynamic properties of the turbine and the electrical characteristics of the BDC machine, incorporating factors such as magnetic and electrical losses that affect efficiency. To maximize energy capture, a maximum power point tracking (MPPT) algorithm is employed, which dynamically adjusts the system to operate at optimal points across a range of wind speeds.

The control system developed in this study consists of two main components: speed regulation and power regulation. Speed regulation is achieved by adjusting the turbine’s rotational speed to maintain the optimal tip speed ratio, which maximizes energy extraction from the wind.

Power regulation involves modulating the output of the BDC machine to ensure stable power delivery, compensating for fluctuations in wind speed. This dual-loop control structure—speed control as the outer loop and power control as the inner loop—ensures that the system responds swiftly to changes in wind conditions, thereby reducing energy losses. Simulations are conducted in MATLAB/Simulink, which provides an integrated environment for developing and testing control algorithms. This setup allows for comprehensive testing of the system's performance under simulated real-world conditions, including variable wind speeds and diverse environmental factors that can affect energy conversion efficiency.

The simulation results indicate that the proposed control strategies significantly improve the energy efficiency of the autonomous wind energy converter. The MPPT algorithm demonstrates high effectiveness in tracking the maximum power point, allowing the system to capture a greater proportion of available wind energy compared to traditional methods. Through optimized speed and power regulation, the system maintains high energy efficiency across a broad spectrum of wind speeds, even under rapidly changing wind conditions.

The BDC-based system achieves a 15% increase in energy capture in low-wind conditions compared to standard configurations. The dual-loop control system minimizes losses by maintaining precise control over the BDC machine's output, allowing the turbine to operate near its optimal performance range consistently. This performance improvement is attributed to the system's ability to adjust quickly to fluctuations in wind speed, thereby enhancing the coefficient of power utilization (CP) for the wind turbine. Additionally, the system achieves stable energy output with minimal fluctuations, making it a reliable source of energy for off-grid applications. The control model developed in MATLAB/Simulink provides a useful tool for analyzing various operational scenarios and further refining the control algorithms to optimize performance.

Conclusions. The findings of this study underscore the potential of advanced control strategies to enhance the efficiency and reliability of autonomous wind energy converters based on brushless DC machines. The dual-loop control structure, combined with an optimized MPPT algorithm, effectively addresses the challenges posed by variable wind conditions, enabling the system to achieve higher energy efficiency and operational stability. The mathematical model and simulation framework developed in this research offer a valuable foundation for further studies and practical implementation in small-scale, autonomous wind energy systems.

The successful application of these methods could lead to more reliable and sustainable energy solutions for remote regions, where conventional grid connections are often impractical. By increasing energy capture and minimizing losses, this study contributes to the advancement of renewable energy technologies, specifically for off-grid and isolated applications. Future research will focus on field testing of the proposed control system to assess its real-world performance. Additionally, further refinements to the control algorithms will be explored, including adaptive adjustments to respond to diverse environmental conditions and incorporating additional variables such as wind turbulence and temperature variations.

References

1. Plantić, Marčič, Beković, Štumberger. Sensorless PMSM Drive Implementation by Introduction of Maximum Efficiency Characteristics in Reference Current Generation. Energies. 12 (18), 2019.

2. W. Torki, F. Grouz, L. Sbita, Vector control of a PMSG direct-drive wind turbine, International Conference on Green Energy Conversion Systems (GECS), 2017.

3. Verde, A. et al. A new method for characterization of small capacity wind turbines with permanent magnet synchronous generator: An experimental study. Heliyon, 4, e00732, 2018.

4. Jakub Bukala, Krzysztof Damaziak, Krzysztof Kroszczynski, Marcin Krzeszowiec, Jerzy Malachowski. Investigation of parameters influencing the efficiency of small wind turbines. Journal of Wind Engineering and Industrial Aerodynamics, Volume 146, pp. 29-38, 2015.

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DEVELOPMENT AND RESEARCH OF A CONTROL SYSTEM FOR A ROD SUBMERSIBLE PUMP

Abstract. *his study focuses on the development of a control system for rod pump installations (RPI), which are widely used in the oil industry for extracting fluids from low-output and complicated wells. The system aims to optimize fluid supply and diagnose malfunctions by analyzing the power consumption signals from the electric motor driving the installation. By using power consumption data, the proposed system minimizes the need for physical sensors, reducing both operational costs and complexity. The analysis of power consumption allows for real-time fault detection, improving the reliability and efficiency of oil production.*

Key words*: rod pump, oil extraction, control system, diagnostics, power consumption analysis, dynamic level regulation.*

Introduction. Rod pump installations (RPI) are among the most common types of equipment used for extracting oil, particularly from low-output wells and those with various complications such as high-water content, sand production, and increased viscosity of the well fluid. In Russia, more than 40% of all oil wells are equipped with such installations. The relevance of improving control systems for RPIs arises from several challenges, including increasing energy costs, the wear of mechanical components, and the need for reliable operation in remote areas with minimal maintenance.

Traditional methods for managing RPIs involve monitoring multiple physical parameters, such as pressure, dynamic fluid level, and pump speed, using various sensors. However, these systems have several drawbacks, including high costs for installation and maintenance, sensor failure, and the complexity of signal processing. Moreover, existing diagnostic methods, which include dynamometer graphs and other sensor-based techniques, often lack precision and are not always suitable for continuous real-time monitoring.

The goal of this study is to develop a control system that regulates the fluid supply of the RPI and diagnoses equipment malfunctions using the analysis of power consumption signals. This system reduces the reliance on physical sensors and simplifies maintenance and operation. The research focuses on two primary functions: Optimizing the fluid supply to maintain maximum well productivity with minimal wear on equipment. Providing real-time diagnostics to detect faults such as rod breakage, gas lock, or plunger sticking based solely on power consumption data.

Methods and Materials. The control system is designed based on the analysis of electrical power consumption data from the electric motor that drives the rod pump installation. The proposed method utilizes the fact that changes in mechanical load on the pump directly affect the power consumption profile. The main components of the system include: Mathematical modeling of the RPI: A comprehensive simulation model was developed using MATLAB Simulink. The model includes the productive reservoir, the wellbore, the pump jack mechanism, and the three-phase asynchronous motor. The system simulates various operational conditions, including normal and faulty operations, to study their effects on power consumption. Data analysis algorithms: Various algorithms were developed to process the power consumption signals and detect patterns indicative of common faults. These patterns were correlated with specific types of mechanical malfunctions, such as rod or valve failures, gas intrusion into the pump chamber, and sticking of the plunger.

Power consumption signal processing: The system records real-time data from the electric motor, including instantaneous power, current, and voltage. This data is then filtered to eliminate noise and processed to extract diagnostic features, such as signal peaks and phase shifts, which are indicative of mechanical issues.

To validate the system, several faults were simulated within the model: Rod breakage characterized by a sudden drop in power consumption as the load on the pump decreases. Gas lock detected by irregular fluctuations in power consumption due to the erratic movement of the plunger in the presence of gas bubbles. Plunger sticking identified by a prolonged increase in power consumption during the plunger's motion cycle, as more energy is required to overcome the increased resistance.

The simulation results demonstrated the effectiveness of using power consumption data to diagnose faults in RPI systems. For each type of malfunction, distinct power consumption patterns were observed, allowing for their identification with high accuracy. For instance: Rod breakage was clearly identifiable by a sharp decrease in power consumption during the upward stroke of the pump. Gas intrusion led to significant irregularities in the power profile, which were easily distinguishable from normal operational signals. Plunger sticking showed a distinct increase in energy consumption over time, as the system struggled to maintain normal operation.

By implementing this system in a real-world environment, it is possible to reduce the number of physical sensors required for monitoring the system. The proposed method also provides a continuous, real-time analysis of the system's health, making it possible to detect issues early and avoid costly repairs or unplanned downtime.

In addition to fault diagnostics, the system also regulates the fluid supply by maintaining an optimal dynamic fluid level in the well. This is achieved by analyzing the power consumption signal and adjusting the motor's speed to ensure that the pump operates at maximum efficiency without overloading the system.

The reduction in the number of physical sensors not only cuts costs but also increases the overall reliability of the system, as there are fewer components that can fail. The system's reliance on readily available electric power data makes it easily implementable in both new installations and retrofitted older systems.

Conclusions. The research demonstrates the viability of using power consumption signals to control rod pump installations and diagnose mechanical faults. The developed system offers several key benefits: Cost reduction by minimizing the need for physical sensors, the system reduces both installation and maintenance costs. Increased reliability with fewer sensors, the system is less prone to sensor failure and related downtime. Real-time diagnostics the system provides continuous monitoring, enabling the early detection of faults and preventing serious damage to the equipment. Efficiency improvements the regulation of fluid supply based on dynamic fluid level optimization ensures that the RPI operates at peak efficiency, extending the lifespan of the equipment and reducing energy consumption.

The proposed control system has been tested in a simulated environment and has shown promising results. Future work will focus on field trials and further refinement of the diagnostic algorithms to handle more complex operational conditions. Additionally, integration with existing SCADA systems will be explored to provide operators with a user-friendly interface for monitoring and controlling multiple RPIs simultaneously.

References

1. D.S. Torgaeva, M.P. Sukhorukov, Y.A. Shinyakov, N.A. Shalyapina. Development of a Sucker Rod Pumping Unit Simulation Model. International Journal of Engineering and Advanced Technology (IJEAT). – 2019. Vol. 9, Issue 1. P. 4403–4409.

2. Sam G. Gibbs, Doneil M. Dorado, Kenneth B. Nolen, Eric S. Oestreich, Jeffrey J. DaCunha. Apparatus for analysis and control of a reciprocating pump system by determination of a pump card. Patent US8036829B2.

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THE MAIN TYPES OF MODELS IN MACHINE LEARNING

Abstract. *This article provides an overview and analysis of machine learning models, focusing on the distinctions between discriminative and generative approaches. Special attention is given to recent advancements and applications of diffusion models across various fields. The paper emphasizes the implementation characteristics of different machine learning models and their applications, which will enable the future development of methods and information technologies to support the effective creation of artificial intelligence systems.*

Key words*: machine learning, generative models, discriminative models, diffusion models, artificial intelligence, data science.*

Machine learning has become an essential part of modern engineering and science. ML models have emerged as important tools in many fields of knowledge. These applications range from obvious uses in computer engineering to medicine, biology, physics, and other disciplines [3]. Additionally, the development of generative models has contributed to the wider adoption of machine learning models. This progress has become possible with the accumulation of big data and improvements in hardware for model training.

The aim of this article is to analyze machine learning models, highlighting the characteristics and differences between discriminative and generative approaches in terms of their implementation and application.

Common approaches to classifying machine learning models include categorization by learning method or by the problem being solved. When considering learning methods, machine learning is typically divided into supervised, unsupervised, semi-supervised, and reinforcement learning [15].

It is essential to emphasize the importance of initially categorizing all machine learning models into two broad classes: discriminative and generative models. These major classes can then be further subdivided based on their training methods or the tasks they address. This classification has become increasingly necessary in the current research landscape, where a significant portion of machine learning studies focuses on generative models. The explosive growth in this field can be observed through the number of publications on the subject (Fig. 1).

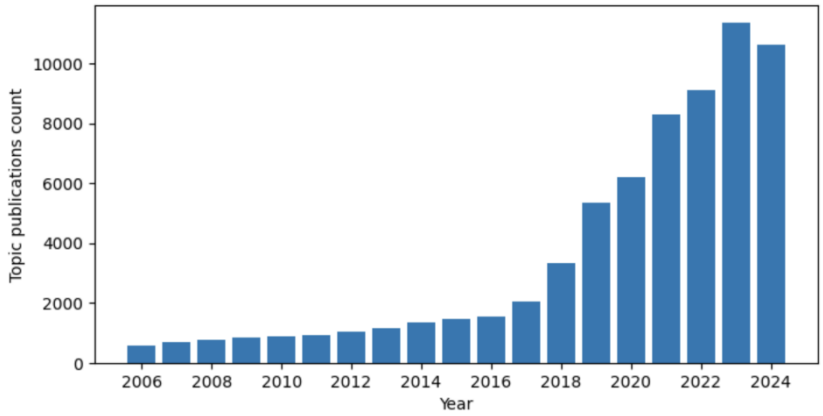

Fig. 1. Number of publications in the Web of Science database by year using the keyword "generative" as of October 14, 2024

Generative models are designed to create new elements from a given distribution, while discriminative models always provide an evaluation for a specific input. In mathematical terms,

discriminative tasks can be represented as a function f that approximates the true probability: $f(x) \approx p(y|x)$, where y is the event whose probability is being estimated, and x is the known information [4]. On the other hand, generative models estimate the overall data distribution $f(x) \approx p(x)$ or approximate the joint distribution of known and unknown variables $f(x) \approx p(x, y)$[4].

The challenge of understanding data distribution from a limited set of examples is complex. However, researchers have developed numerous diverse and innovative approaches to address this issue. Among the most notable methods are Autoregressive Models [18, 9], Variational Autoencoders [7], Generative Adversarial Networks [4], Normalizing Flows [13], and Diffusion Models [16]. Each of these approaches has spawned a wide array of variations, improvements, and generalizations. For instance, the concepts underlying Autoregressive Models formed the foundation for the first GPT model [12] and continue to serve as the basis for all contemporary large language models.

Diffusion models have emerged as a versatile concept applicable to various types of continuous data. The modification known as latent diffusion [14] has become the foundation for numerous contemporary models across different domains. These include text-to-image models [11, 2], text-to-video models [1, 5], and medical models [19, 10], among others.

Diffusion models have received various theoretical justifications [16, 17, 6] and a promising generalization in the form of flow matching [8]. The diffusion models approach allows viewing the generation process as learning a vector field transition between a Gaussian distribution and the target data distribution. The main drawback of diffusion models is the iterative process of transitioning to the target distribution, which in some cases requires hundreds of neural function computations. Nevertheless, this approach holds potential for further research and development. Future studies may lead to more generalized and deterministic methods of converting Gaussian noise into samples from a specified distribution. These advancements could potentially address the current limitations of diffusion models and expand their applicability.

In conclusion, machine learning, especially generative models like diffusion models, has seen significant advancements. These models show great promise across various fields but face challenges such as computational intensity. Future research may lead to more efficient and versatile models, potentially revolutionizing areas from computer science to medicine. The ongoing evolution of generative models highlights the dynamic nature of machine learning and the need for continued innovation in this rapidly growing field.

References

1. Blattmann, Andreas, et al. Align Your Latents: High-Resolution Video Synthesis with Latent Diffusion Models. arXiv:2304.08818, arXiv, 27 Dec. 2023, https://doi.org/10.48550/arXiv.2304.08818.

2. Chen, Junsong, et al. PixArt-α: Fast Training of Diffusion Transformer for Photorealistic Text-to-Image Synthesis. arXiv:2310.00426, arXiv, 29 Dec. 2023, https://doi.org/10.48550/arXiv.2310.00426.

3. Choudhary, Kamal, et al. "Recent Advances and Applications of Deep Learning Methods in Materials Science." Npj Computational Materials, vol. 8, no. 1, Apr. 2022, pp. 1–26, https://doi.org/10.1038/s41524-022-00734-6.

4. Goodfellow, Ian. NIPS 2016 Tutorial: Generative Adversarial Networks. arXiv:1701.00160, arXiv, 3 Apr. 2017, http://arxiv.org/abs/1701.00160.

5. He, Yingqing, et al. Latent Video Diffusion Models for High-Fidelity Long Video Generation. arXiv:2211.13221, arXiv, 20 Mar. 2023, https://doi.org/10.48550/arXiv.2211.13221.

6. Ho, Jonathan, et al. Denoising Diffusion Probabilistic Models. arXiv:2006.11239, arXiv, 16 Dec. 2020, https://doi.org/10.48550/arXiv.2006.11239.

7. Kingma, Diederik P., and Max Welling. Auto-Encoding Variational Bayes. arXiv:1312.6114, arXiv, 10 Dec. 2022, https://doi.org/10.48550/arXiv.1312.6114.

8. Lipman, Yaron, et al. Flow Matching for Generative Modeling. arXiv:2210.02747, arXiv, 8 Feb. 2023, https://doi.org/10.48550/arXiv.2210.02747.

9. Oord, Aaron van den, et al. Pixel Recurrent Neural Networks. arXiv:1601.06759, arXiv, 19 Aug. 2016, https://doi.org/10.48550/arXiv.1601.06759.

10. Pinaya, Walter H. L., et al. Brain Imaging Generation with Latent Diffusion Models. arXiv:2209.07162, arXiv, 15 Sept. 2022, https://doi.org/10.48550/arXiv.2209.07162.

11. Podell, Dustin, et al. SDXL: Improving Latent Diffusion Models for High-Resolution Image Synthesis. arXiv:2307.01952, arXiv, 4 July 2023, https://doi.org/10.48550/arXiv.2307.01952.

12. Radford Alec, Narasimhan Karthik, Salimans Tim, Sutskever Ilya, et al. Improving language understanding by generative pre-training. 2018. https://cdn.openai.com/research-covers/language-unsupervised/language_understanding_paper.pdf

13. Rezende, Danilo Jimenez, and Shakir Mohamed. Variational Inference with Normalizing Flows. arXiv:1505.05770, arXiv, 14 June 2016, https://doi.org/10.48550/arXiv.1505.05770.

14. Rombach, Robin, et al. "High-Resolution Image Synthesis with Latent Diffusion Models." 2022 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), 2022, pp. 10674–85, https://doi.org/10.1109/CVPR52688.2022.01042.

15. Sah, Shagan. Machine Learning: A Review of Learning Types. 11 July 2020, https://doi.org/10.20944/preprints202007.0230.v1.

16. Sohl-Dickstein, Jascha, et al. Deep Unsupervised Learning Using Nonequilibrium Thermodynamics. arXiv:1503.03585, arXiv, 18 Nov. 2015, https://doi.org/10.48550/arXiv.1503.03585.

17. Song, Yang, and Stefano Ermon. Generative Modeling by Estimating Gradients of the Data Distribution. arXiv:1907.05600, arXiv, 10 Oct. 2020, https://doi.org/10.48550/arXiv.1907.05600.

18. Uria, Benigno, et al. "Neural Autoregressive Distribution Estimation." Journal of Machine Learning Research, vol. 17, no. 205, 2016, pp. 1–37, http://jmlr.org/papers/v17/16-272.html.

19. Xu, Minkai, et al. Geometric Latent Diffusion Models for 3D Molecule Generation. arXiv:2305.01140, arXiv, 1 May 2023, https://doi.org/10.48550/arXiv.2305.01140.

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IMPROVEMENT OF THE CHARGING SYSTEM OF A LITHIUM-ION BATTERY

Abstract. *This paper focuses on the development of an electronic control unit (ECU) for lithium-ion batteries (LIBs) in power systems, addressing challenges related to the accurate assessment of state-of-charge (SOC) and state-of-health (SOH). Existing systems often rely on complex algorithms that require high computational resources, making them unsuitable for real-time applications in low-power systems. The proposed solution simplifies the mathematical model while maintaining high accuracy, making it suitable for real-time assessments on resource-constrained microcontrollers.*

Key words: *lithium-ion battery, state of charge, state of health, power systems, control unit, mathematical modeling, real-time monitoring.*

Introduction. Lithium-ion batteries (LIBs) have become the primary energy storage solution in many applications due to their high energy density and long lifecycle. However, their performance is highly dependent on environmental conditions and operational cycles. Accurate monitoring and management of SOC and SOH are critical for ensuring the longevity and reliability of battery systems.

Existing battery management systems (BMS) provide basic functionality such as voltage and temperature monitoring but often fall short in evaluating SOC and SOH with the required accuracy. Moreover, the high computational complexity of current algorithms, such as Kalman filtering and neural networks, makes their implementation on low-power hardware difficult. Thus, there is a need for a control unit that can perform these assessments in real-time with limited computational resources.

Objective of the research. The primary goal of this research is to develop an ECU that can accurately estimate the SOC and SOH of LIBs in real-time, even under the constraints of microcontrollers with limited processing power and energy availability. The system should also be robust to the effects of battery degradation and environmental variations, including temperature and self-discharge.

To achieve this goal, the following tasks were addressed:

1. Review of current methods for SOC and SOH estimation in battery management systems and analysis of their computational complexity and accuracy.
2. Development of a mathematical model for LIBs with low computational complexity, capable of real-time numerical calculations on microcontrollers.
3. Creation of an algorithm for SOC and SOH assessment that operates efficiently within the limited processing power of microcontrollers.
4. Validation of the developed method through both mathematical modeling and experimental testing.
5. Development of technical solutions for integrating the algorithms into an ECU with consideration of system constraints and power efficiency.

Methods and materials. The research builds upon existing work in the field of lithium-ion battery modeling, particularly using equivalent electrical circuit models. The most common of these is the Thevenin model, which uses resistors and capacitors to simulate the dynamic behavior of the battery during charge and discharge cycles. However, the complexity of such models often makes them impractical for real-time applications.

To reduce computational complexity, we propose a modified Thevenin model with spline functions that interpolate the battery's behavior at different states of charge and temperature ranges. This approach allows for a more efficient computation of the battery's parameters without sacrificing accuracy.

The SOC estimation algorithm integrates this mathematical model with real-time current and voltage measurements. The algorithm uses a simplified version of the Kalman filter to adjust the SOC estimate based on the measured data, while also accounting for the battery's self-discharge and degradation over time.

The SOH estimation is based on the comparison of the current battery performance with its original capacity and internal resistance. The model continuously updates the battery's state parameters as it undergoes charge-discharge cycles, allowing for accurate prediction of battery degradation.

All simulations were performed using MATLAB Simulink to validate the theoretical model. Additionally, a test bench was developed to experimentally verify the accuracy of the model and the proposed algorithms under real operating conditions.

The simulations showed that the proposed mathematical model of the LIB, combined with the SOC and SOH estimation algorithms, achieves a high level of accuracy while maintaining low computational demands. The model's accuracy for SOC estimation was found to be within ±7%, and for SOH estimation within ±10%, across a wide range of operating temperatures and discharge rates.

The use of lithium-ion batteries in various applications presents unique challenges due to the need for high reliability over extended periods. Traditional battery management systems, which rely on complex algorithms or ground-based monitoring, are not always suitable for real-time applications.

The proposed ECU overcomes these limitations by offering a low-power, low-complexity solution for real-time SOC and SOH estimation. The use of spline functions and simplified filtering techniques allows the system to run on microcontrollers with minimal computational overhead, while still providing accurate and reliable data for decision-making.

This approach can be extended to other battery chemistries and applications, where the need for efficient and reliable power management is critical. The system's flexibility also allows for the integration of additional features, such as thermal management or more advanced fault detection.

Conclusions. The developed ECU for lithium-ion batteries offers a significant improvement in the real-time monitoring of SOC and SOH. The use of a simplified mathematical model and low-complexity algorithms ensures that the system can operate efficiently on microcontrollers with limited processing power and energy consumption, while still providing accurate assessments of the battery's health and charge state.

Future work will focus on further optimizing the algorithms for different battery chemistries and exploring ways to integrate advanced diagnostic features into the control unit.

References

1. Goebel K., Saha B., Saxena A., Celaya J.R., Christophersen J.P. Prognostics in battery health management. IEEE Instrumentation & Measurement Magazine, vol. 11, no. 4, pp. 33-40, 2008.

2. Cai L., Meng J., Stroe D.-I., Luo G., Teodorescu R. An evolutionary framework for lithium-ion battery state of health estimation. Journal of Power Sources, Volume 412, pp. 615-622, 2019.

3. Xing Y., Ma E.W., Tsui K.-L., Pecht M. (2013) An ensemble model for predicting the remaining useful performance of lithium-ion batteries. Microelectronics Reliability, Volume 53, Issue 6, pp. 811-820, 2013.

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CONTROL SYSTEM FOR URBAN TRAFFIC LIGHT NETWORK

Abstract. *This study focuses on developing and implementing IoT technologies to modernize traffic light systems in urban environments. The objective is to reduce traffic congestion, minimize environmental impact, and improve road safety. By integrating IoT-based adaptive traffic light control and data analytics, the proposed system adjusts signal phases in real time, allowing for a more responsive approach to traffic flow. Experimental modeling demonstrates substantial improvements in vehicle throughput and reductions in wait times, illustrating the potential of smart traffic light systems to transform urban mobility.*

Key words*: IoT, traffic lights, urban traffic, adaptive control, intelligent transportation systems, traffic congestion, GIS integration.*

Introduction. Urbanization and the growth of vehicle usage have intensified traffic congestion in metropolitan areas, affecting the environment and public health. Traditional traffic light systems, which rely on fixed timings and predefined cycles, lack adaptability to fluctuating traffic volumes throughout the day. This inefficiency results in longer travel times, increased fuel consumption, and higher emissions.

Intelligent traffic management systems, particularly those integrating IoT (Internet of Things) technology, present a potential solution by enabling real-time data collection and dynamic traffic signal adjustments. This study explores the design and simulation of an IoT-based traffic light management system, utilizing GIS (Geographic Information System) data and machine learning algorithms to create an adaptive network of “smart” traffic lights capable of responsive adjustments based on real-time traffic conditions.

The primary objective is to develop a smart traffic light control system that adapts in real time to current traffic patterns, aiming to reduce congestion and improve traffic flow. The system focuses on optimizing signal phase durations at intersections by integrating IoT sensors and machine learning models that process and respond to real-time traffic data. This study also seeks to address scalability, considering the potential application of these systems in multiple intersections across high-density urban areas.

Methods and Materials. The approach includes a combination of software simulations and hardware modeling. Software Simulation in AnyLogic: The AnyLogic platform is used to simulate traffic flows and model the adaptive control of traffic lights. This simulation environment allows the integration of GIS data to map real intersections and traffic patterns. Through these simulations, various scenarios are tested to evaluate the effectiveness of dynamic adjustments in traffic signal phases.

Microcontroller Integration: For hardware implementation, Siemens microcontrollers (LOGO! 230 RCE and S7-1200) serve as the basis for creating programmable traffic light controllers. These devices are chosen for their reliability and scalability, providing a robust platform

for IoT connectivity. The microcontrollers interface with sensors and data inputs to adjust light timings dynamically.

Data Collection and Processing: Real-time traffic data is sourced through GPS systems, inductive loop sensors, and camera-based vehicle counting. This data is processed using machine learning algorithms to predict congestion and adapt signal timing. Key algorithms include decision trees and neural networks that analyze historical and real-time data to adjust traffic flow.

Adaptive Control Algorithms: Machine learning models, particularly reinforcement learning, are trained to recognize traffic congestion patterns and predict optimal signal timings. The algorithms are designed to minimize queue lengths and maximize the efficiency of vehicle throughput at intersections. For example, if sensors detect increased vehicle density on a particular road, the green light duration is extended, while neighboring lights adjust to prevent conflicting flows.

The simulated system demonstrates a 20-30% improvement in traffic flow efficiency compared to traditional fixed-timing systems. Traffic Flow Enhancement: Traffic simulations indicate that the adaptive traffic light system can increase vehicle throughput by adjusting green light durations to match peak traffic volumes. The “green wave” effect, where consecutive traffic lights synchronize to allow continuous vehicle movement, reduces stop-and-go patterns, lessens fuel consumption, and minimizes emissions.

Reduced Wait Times: The adaptive system effectively reduces average wait times by responding to real-time traffic conditions. Vehicles on less congested roads experience shorter red light durations, while highly congested roads receive extended green phases, improving overall intersection performance.

Environmental Impact: Reduced idling time and smoother traffic flow contribute to lower emissions of greenhouse gases. The system’s real-time adaptability is expected to play a significant role in achieving sustainable urban transport solutions.

Scalability: The proposed model allows for the integration of additional intersections and sensors, making it feasible for large-scale implementation in smart city projects. By connecting multiple intersections in a network, the system can manage urban traffic more cohesively, potentially incorporating emergency vehicle prioritization and pedestrian safety features in future expansions.

Conclusion. The implementation of IoT technologies in traffic light systems represents a significant advancement in urban traffic management. Through adaptive control and real-time responsiveness, the proposed system demonstrates substantial improvements in traffic flow and environmental outcomes. Integrating this technology within urban infrastructure aligns with smart city initiatives aimed at creating more sustainable, efficient, and safer cities. Future work includes refining machine learning algorithms for greater predictive accuracy and expanding the system’s capabilities to accommodate complex intersection layouts and emergency response needs.

References

1. Ghazal, B., ElKhatib, K., Chahine, K., Kherfan, M. (2016). "Smart Traffic Light Control System." 2016 Third International Conference on Electrical, Electronics, Computer Engineering and their Applications (EECEA), 140-145.

2. Wei, H., Zheng, G., Yao, H., Li, Z. (2019). "IntelliLight: A Reinforcement Learning Approach for Intelligent Traffic Light Control." Proceedings of the 24th ACM SIGKDD International Conference on Knowledge Discovery & Data Mining, 2496-2505.

3. Gershenson, C. (2005). "Self-Organizing Traffic Lights." Complex Systems, 16, 29-53.

4. Li, L., Lv, Y., Wang, F.-Y. (2016). "Traffic Signal Timing via Deep Reinforcement Learning." IEEE/CAA Journal of Automatica Sinica, 3(3), 247-254.

5. El-Tantawy, S., Abdulhai, B. (2013). "Multiagent Reinforcement Learning for Integrated Network of Adaptive Traffic Signal Controllers (MARLIN-ATSC): Methodology and Large-Scale Application on Downtown Toronto." IEEE Transactions on Intelligent Transportation Systems, vol. 14, no. 3, pp. 1140-1150.

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ARTIFICIAL INTELLIGENCE APPLICATIONS IN THE ENERGY SECTOR FOR IMPROVING POWER SYSTEM MANAGEMENT

Abstract. *This article delves into the transformative potential of artificial intelligence (AI) in revolutionizing the energy sector, particularly in optimizing power system management for enhanced efficiency, reliability, and stability. By embedding AI in electricity demand forecasting, the energy industry could drastically reduce the risk of network overloads, streamline generation processes, and diminish the costs associated with energy reserves. Furthermore, intelligent algorithms could be harnessed to autonomously distribute electricity between conventional and renewable energy sources, thus significantly bolstering overall energy efficiency.*

Key words**:** *artificial intelligence, power engineering, automation, management, optimization, forecasting.*

Introduction. In power infrastructure, timely fault detection and swift issue resolution are paramount. AI offers unprecedented capabilities for automating network monitoring, enabling the real-time analysis of massive data streams to detect anomalies—potentially signaling equipment malfunctions or degradation. For instance, unusual voltage shifts, temperature spikes, or erratic current behavior may hint at latent risks. Not only can AI systems flag these deviations, but they can also predict the likelihood of a failure, empowering companies to prevent accidents, schedule maintenance precisely, and avoid unnecessary inspections or shutdowns. The result? A notable improvement in network reliability, fewer unexpected outages, and a significant reduction in operational and maintenance expenses.

Problem Statement. The relatively slow adoption of AI within the energy sector poses major challenges to forecasting, managing, and maintaining power systems. Foremost is the unpredictability of demand: poor forecasting can lead to network stress during peak periods or energy waste when usage is low, forcing companies to maintain large reserves that inflate costs and impair system flexibility. Compounding this are inefficiencies in energy generation and distribution, as a lack of automation hampers optimal deployment of resources, especially renewables. This results not only in elevated production costs but also in unnecessary environmental degradation. The absence of advanced fault diagnostics further heightens the risk of accidents. Without AI-driven anomaly detection, equipment failures can go undetected until they escalate, leading to supply disruptions and costly repairs. Consequently, energy companies are often compelled to perform routine maintenance – even when equipment functions optimally—driving up costs and reducing operational efficiency. Traditional, AI-deficient networks are also ill-equipped for the seamless integration of smart grids, which offer automated energy consumption regulation, flexible pricing, and reduced network strain [1].

This gap prevents consumers from realizing cost savings and restricts energy companies from allocating resources with optimal precision. Ultimately, the lack of AI leaves the energy sector more vulnerable to disruptions, less efficient, and economically constrained, underscoring an urgent need for advanced technologies that can boost both stability and productivity.

Methods and Materials. The application of AI opens up a range of possibilities, particularly in demand forecasting. By analyzing electricity consumption data, AI can predict demand patterns in real-time with exceptional accuracy. For example, algorithms can anticipate spikes in demand on hot days when air conditioners are heavily used or adjust for seasonal shifts in consumption. This allows power companies to more precisely determine production needs, lowering the likelihood of failures and reducing reserve energy expenses. AI not only enables demand prediction but also facilitates optimal, real-time production and distribution scenarios. By leveraging AI analytics, the

system can dynamically balance generation across various sources—whether natural gas, coal, nuclear, or renewables such as solar and wind power. In cases where renewables falter due to natural conditions, AI can redistribute supply by increasing output from traditional plants or drawing on stored reserves to avert shortages. For instance, during cloudy or windless days, the system might ramp up conventional generation to fill the gap, safeguarding stability and reducing costs. Moreover, machine learning algorithms allow for intelligent resource allocation by automatically fine-tuning production in response to fluctuating demand [2].

This ensures optimal energy distribution across traditional and renewable sources, enhancing efficiency across the board. AI's capacity to detect network anomalies and preemptively diagnose faults also shortens repair times and bolsters network reliability [3].

Additionally, AI-driven insights into equipment conditions enable precision scheduling for maintenance, further lowering repair costs and minimizing unexpected failures.

Conclusion. Integrating AI into the energy sector paves the way for innovative, efficient power system management. Intelligent demand forecasting algorithms mitigate the risk of network overloads, reduce reserve energy expenses, and synchronize production with real-time needs. By automating energy generation and distribution, AI maximizes resource utilization, especially renewables, which decreases dependency on fossil fuels and minimizes environmental impact. Moreover, AI-based diagnostics provide prompt detection and prevention of faults, reducing emergency repairs and cutting maintenance costs. This paradigm shift from regular maintenance to on-demand service enhances infrastructure longevity and resilience. AI also facilitates the growth of smart grids, which autonomously regulate consumption, allow for flexible tariffs, and relieve network strain. Overall, AI technologies stand as the cornerstone of a future-ready energy sector: one that is more stable, cost-effective, and environmentally sustainable, equipped to meet the demands of our rapidly evolving world.

References

1. Sungjoo Chung and Ying Zhang. Artificial Intelligence Applications in Electric Distribution Systems: Post-Pandemic Progress and Prospect. Appl. Sci. 2023, 13(12), 6937. https://www.mdpi.com/2076-3417/13/12/6937.

2. Qingtian Gao, Qi Dong; Linxiong Chen. Application of Artificial Intelligence in Electrical Automation Control: Review and Prospect. 7th International Conference on Automation, Control and Robots (ICACR), 2023. https://ieeexplore.ieee.org/document/10314639.

3. Ibrahim Alhamrouni , Nor Hidayah Abdul Kahar, Mohaned Salem,Mahmood Swadi, Younes Zahroui, Dheyaa Jasim Kadhim, Faisal A. Mohamed andMohammad Alhuyi Nazari. A Comprehensive Review on the Role of Artificial Intelligence in Power System Stability, Control, and Protection: Insights and Future Directions. Appl. Sci. 2024, 14(14), 6214. https://www.mdpi.com/2076-3417/14/14/6214.

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TECHNOLOGIES OF SUPERCONDUCTIVITY AND THEIR POTENTIAL IMPACT ON THE FUTURE OF ELECTRICAL ENGINEERING

Abstract. *This article explores the potential impact of superconductivity technologies on the future of electrical engineering. Superconductors, especially high-temperature superconductors (HTS), possess the ability to transmit electrical energy with zero losses when cooled to critical temperatures. The integration of this technology presents substantial potential for energy systems, enabling the reduction of power transmission losses and enhancing the overall efficiency of electrical grids. Particularly in large urban centers where energy demand is continuously growing, the application of superconductivity technologies may prove crucial. This paper analyzes the prospects for the application of superconductors in various branches of electrical engineering, discussing the possible economic, technological, and environmental outcomes associated with this technology.*

Key words: *Superconductivity, electrical engineering, high-temperature superconductors, energy efficiency, power transmission.*

Introduction. High-temperature superconductivity (HTS) represents one of the most promising breakthroughs in modern energy technology. Superconductors facilitate the transfer of electrical energy from generation centers to consumers without losses, achieved through the cooling of conductors and maintaining temperatures below critical thresholds. This process mitigates energy losses and improves grid efficiency, making HTS technology particularly significant for large cities with steadily increasing power needs [1].

However, despite the advantages that superconductivity technologies could bring, several technological and economic challenges persist, primarily those related to maintaining required temperatures throughout extensive and branched network sections.

Problem Statement. The use of conventional materials for power transmission, such as copper and aluminum, inherently results in energy losses, especially over long distances. This issue is particularly pressing in large cities and industrial facilities, where high energy loads lead to losses that may account for up to 10% of total power consumption. Increasing energy demand also impacts the environment due to the need for greater electricity production. Integrating superconducting materials into electrical systems can significantly reduce these losses, enhance efficiency, and reduce associated costs.

Methods and Materials. Superconducting materials, particularly high-temperature conductors, can be applied in various electrical components, including generators, transformers, and power transmission cables. The core of this technology involves the use of HTS materials, such as copper-based ceramic oxides, which retain superconducting properties at temperatures reached through cooling with liquid nitrogen (-196 °C), thus minimizing cooling expenses. Integrating superconductivity in urban grids could reduce energy losses by 15-20%, leading to considerable energy savings [2].

The primary approach for incorporating superconductors into existing infrastructure involves deploying advanced cryogenic cooling systems based on liquid nitrogen, which are capable of maintaining critical temperatures and ensuring reliable, loss-free power transmission over long distances. Furthermore, superconductors can enhance grid stability by improving load management during peak demand hours and easing the strain on current infrastructure. However, the high costs associated with production and installation remain a significant barrier, necessitating the development of cost-effective solutions and new materials to facilitate widespread adoption [3].

Conclusion. Superconductivity technologies hold substantial potential for improving energy efficiency, stability, and reliability in electrical systems. Integrating superconductors into power transmission networks could lead to significant reductions in energy losses, improved grid stability, and effective management of peak load periods, especially in large metropolitan areas. Although currently feasible on a limited scale, broader implementation faces challenges, primarily due to high costs associated with the production, installation, and maintenance of superconducting materials. Continued research is essential to reduce these costs, develop materials that can function at higher temperatures, and optimize technological processes to make superconductivity viable for large-scale applications.

References

1. Brian Marchionini, Yutaka Yamada, Luciano Martini, Hiroyuki Ohsaki. High-Temperature Superconductivity: A Roadmap for Electric Power Sector Applications. 2017. https://ieeexplore.ieee.org/document/7859266.

2. Sabine Kellner, Oliver Rüger, Carmen Voigt, Frank Machalett, Frank Schmidl, - Influence of Varying Gold Nanoparticle Distributions on Structural and Superconducting Properties of Thin YBCO Films. 2021. https://ieeexplore.ieee.org/abstract/document/9353231.

3. Brian G. Marchionini, Luciano Martin, Hiroyuki Ohsaki. High Temperature Superconductor-Based Technologies as Enabler for Efficient and Resilient Energy Systems. 2019. https://ieeexplore.ieee.org/abstract/document/8684297.

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ANALYSIS OF MATERIALS FOR THE PRODUCTION OF WIND TURBINE BLADES

Abstract. *The paper analyses materials for the manufacture of wind turbine blades, including stainless steel, aluminium, aluminium alloys and titanium alloys. The requirements for materials used for the manufacture of wind turbines are considered. The materials are evaluated in accordance with the requirements.*

Key words: *alternative energy, wind energy, wind turbine blade, materials for wind blade.*

Introduction. The use of alternative energy sources is becoming increasingly widespread in the modern world. In particular, one of the most common areas of alternative energy is wind power. Recently, there has been an increase in the number of wind power plants due to the many advantages it has over other energy sources [1]. The efficiency and durability of wind turbines directly depend on the quality and characteristics of the materials used to make their key components, such as blades. Due to the increasing size and power of modern wind turbines, there is a need to use lighter, stronger and more corrosion-resistant materials that can withstand high mechanical loads. Therefore, the aim of this study is to determine the most suitable material for the manufacture of wind turbine blades.

Let us consider the main factors that affect the efficiency of wind turbines. From the above factors, the main ones can be identified, which include the following:

1. The material from which the wind turbine blades are made.
2. The shape of the wind turbine blades.

The following requirements are imposed on the materials from which wind turbine blades are made (Fig. 1).

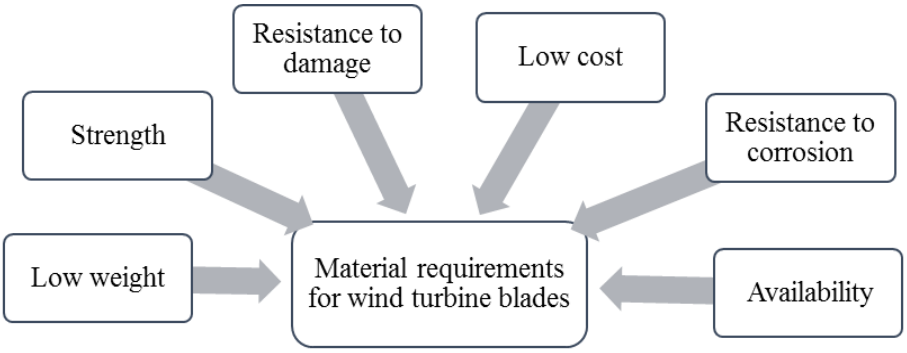

Fig. 1. Material require ments for wind turbine blades

In general, wind turbine blades are made of: stainless steel, aluminum, aluminum alloys, titanium alloys. Approximate calculations of these parameters for blades with dimensions of 2 x 0.5 m, the wall thickness - 0.02 m and for a conical shape were carried out in order to compare the cost and weight of wind turbine blades. The results are shown in Table 1.

Table 1. The results compare weight and cost of wind turbine blades with dimensions of 2 x 0.5m, the wall thickness is 0.02 m for a conical shape [3,4]

Requirements / Material	Weight (kg)	Cost (UAN)
Stainless steel	282,13	12696
Aluminum	95,22	3808
Aluminum alloys	96,137	15747

Titanium alloys	158,77	80973

The data obtained allow for a discrete assessment of materials for blade manufacturing, which makes it possible to select the most optimal material in accordance with the requirements. Table 2 shows the results of the assessment of materials in accordance with the requirements [2,3]. A diagram of the results of the discrete assessment of the analysis is shown in Fig. 2.

Table 2. The results of the discrete assessment of materials in accordance with the requirements for them

Material / Requirements	Stainless steel	Aluminum	Aluminum alloys	Titanium alloys
Resistance to damage	medium	medium	medium	high
Strength	high	medium	medium	high
Resistance to corrosion	high	high	high	high
Availability	high	high	high	low
Average weight	medium	low	low	medium
Average cost	medium	low	medium	high

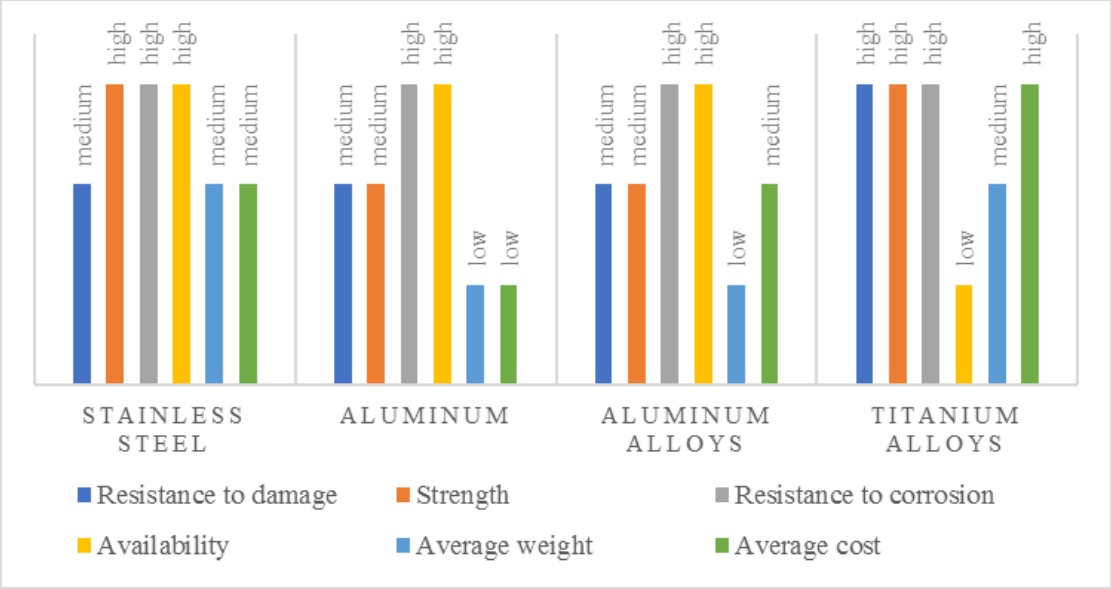

Fig. 2. The results of the discrete assessment of the analysis

Conclusions. The analysis shows that aluminum is the most suitable material for wind turbine blades. It combines high corrosion resistance, strength, affordability, and low weight, making it the best choice for use under wind loads. These advantages are clearly demonstrated in Fig. 2.

References

1. Топтун А., Басараб О. Особливості застосування інформаційних технологій в системах управління комплексами альтернативної енергетики // Тези доповідей VII Міжнародної науково-практичної конференції «Інформаційні технології в освіті, науці і техніці» (ІТОНТ-2024). – С. 82–84.

2. Копань В. С. Композиційні матеріали. – К.: Унів. вид-во «Пульсари», 2004. – 200 с.: іл. – Бібліогр.: с. 190–196. – ISBN 966-7671-81-X.

3. Півняк Г., Шкрабець Ф., Нойбергер Н., Ципленков Д. Основи вітроенергетики: підручник / М-во освіти і науки України, Нац. гірн. ун-т. – Д.: НГУ, 2015. – 335 с.

4. Murray G., White C. V., Weise W. Introduction to Engineering Materials. CRC Press, 2007. – 320 с.

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ANALYSIS OF TYPES AND METHODS FOR GENERATING QUANTUM SECRET KEYS

Abstract. *This research focuses on analyzing the primary methods for generating and transmitting single photons to create quantum keys. Special emphasis is given to quantum key distribution (QKD) protocols, examining their advantages and limitations. The paper presents modern approaches for implementing quantum cryptographic systems that provide a high level of security.*

Key words*: quantum cryptography, quantum key distribution, single photons, encryption protocols, quantum security.*

Introduction. The increasing level of cyber threats requires the adoption of novel approaches for information security. Quantum cryptography, based on the principles of quantum mechanics, offers a method for absolute data security.

Objective of the study: Develop and analyze methods for generating quantum keys for secure information exchange in telecommunication systems.

Object of the study: Processes of generating and transmitting quantum keys.

Subject of the study: Quantum key distribution (QKD) methods and single-photon generation technologies.

Methods and Materials. Quantum protocols form the foundation of modern quantum cryptography. Among them, the BB84 protocol is widely used due to its effective use of photon polarization states to achieve secure key distribution. BB84 employs four polarization states of photons for key transmission:

- Vertical (0°).
- Horizontal (90°).
- Diagonal (+45°).
- Anti-diagonal (-45°).

When an unauthorized party attempts to intercept the key, the quantum state is altered, allowing detection of the interference. The scheme of quantum key distribution under the BB84 protocol is shown in Figure 1.

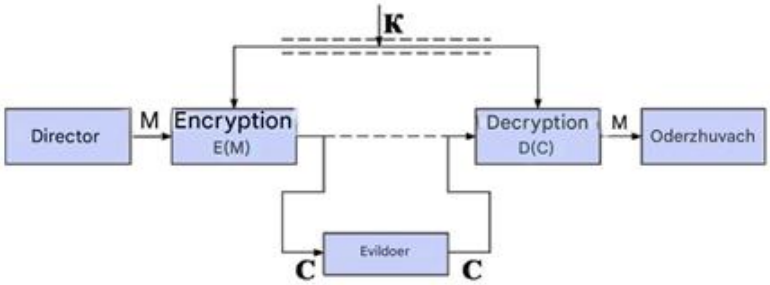

Fig. 1. Quantum Key Distribution Scheme Using BB84 Protocol

Single-photon generation is crucial for effective quantum key distribution. Current technologies include:

- Avalanche Photodiodes: High sensitivity and precision in single-photon detection.

• Quantum Dots: Enable stable and controlled single-photon emissions.

The quantum state of a photon can be mathematically described by the equation (1):

$$\psi = \alpha |0\rangle + \beta |1\rangle \quad (1)$$

where |0⟩ and |1⟩ represent basis states, and α and β are amplitude coefficients corresponding to these states.

A quantum key distribution system was implemented and tested using fiber-optic channels. Experiments demonstrated the system's ability to transmit keys over distances up to 150 km with minimal error rates, highlighting its viability for practical use in telecommunications.

The key advantages of the system include:

• High Accuracy: Detection probability of interference exceeds 95%.

• Resilience to Attacks: Protocols like BB84 effectively detect "man-in-the-middle" attacks.

• Real-Time Transmission Capability: High throughput supports real-time key distribution.

• Impossibility of cloning quantum states: Due to the principles of quantum mechanics, it is impossible to copy quantum states without altering their nature. This makes it impossible to intercept information without disrupting it.

• Key secrecy based on physical laws: Quantum cryptography provides security based on the laws of physics rather than mathematical algorithms, making it secure even against future high-power computers, particularly quantum computers.

• Protection against quantum attacks: Quantum cryptography is inherently resistant to quantum computer threats, especially attacks that could compromise traditional cryptographic algorithms.

• Automatic detection of interception: If an interception attempt is made, the system can automatically detect changes in the quantum state of particles and issue a security alert. •

• Minimization of data compromise risk: Using the principle of one-time pads (OTP), even if an attacker intercepts the message, it remains incomprehensible as it is encrypted with a random key.

Conclusions. The research results show that quantum cryptography is a promising approach for ensuring reliable information security based on the physical principles of quantum mechanics. Quantum key distribution protocols, particularly BB84, provide a high level of security due to their ability to detect interception. Modern single-photon generation technologies enhance the accuracy and stability of quantum key transmission. Further improvements in generation and protection methods will expand the application of quantum cryptography across various fields.

References

1. Scarani, V., Bechmann-Pasquinucci, H., Cerf, N. J., et al. (2009). The security of practical quantum key distribution. Rev. Mod. Phys., 81(3), 1301-1350. https://doi.org/10.1103/RevModPhys.81.1301 (last accessed: 31.10.2024).

2. Lo, H.-K., Curty, M., Tamaki, K. (2014). Secure quantum key distribution. Nature Photonics, 8, 595-604. https://doi.org/10.1038/nphoton.2014.149 (last accessed: 31.10.2024).

3. Wehner, S., Elkouss, D., Hanson, R. (2018). Quantum internet: A vision for the road ahead. Science, 362(6412), eaam9288. https://doi.org/10.1126/science.aam9288 (last accessed: 31.10.2024).

4. Pirandola, S., Andersen, U. L., Banchi, L., et al. (2020). Advances in Quantum Cryptography. Advances in Optics and Photonics, 12(4), 1012-1236. https://doi.org/10.1364/AOP.361502 (last accessed: 31.10.2024).

5. Diamanti, E., Lo, H.-K., Qi, B., et al. (2016). Practical challenges in quantum key distribution. npj Quantum Information, 2, Article 16025. https://doi.org/10.1038/npjqi.2016.25 (last accessed: 31.10.2024).

6. Xu, F., Ma, X., Zhang, Q., et al. (2020). Secure quantum key distribution with realistic devices. Rev. Mod. Phys., 92(2), 025002. https://doi.org/10.1103/RevModPhys.92.025002 (last accessed: 31.10.2024).

7. Pirandola, S., Braunstein, S. L. (2016). Physics: Unite to build a quantum internet. Nature, 532, 169-171. https://doi.org/10.1038/532169a (last accessed: 31.10.2024).

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ANALYSIS OF AUTOMATION OF TECHNOLOGICAL PROCESSES BY ROBOTIC MANIPULATORS

Abstract. *The study analyzes the technical characteristics of existing serial manipulator robots and their control systems in continuous technological processes. The characteristics important for integration into the automation system and the execution of required operations are identified. Directions for optimizing the control system are formulated.*

Key words: *manipulator robot, control system, synchronization, automaton, optimization.*

Introduction. The automation of the production process is of great importance to society. It allows for increased productivity and quality of production, reduces human involvement in the production process, and enables the human resource to be utilized in more beneficial areas. Automation in areas with harmful working conditions helps to reduce or completely eliminate the impact of negative factors on humans.

For the broader implementation of automation systems, the global industry develops, manufactures, and uses serial automation complexes with possible programming for specific tasks and needs. Mass production of uniform manipulator robots reduces the cost per unit of equipment, which increases the possibilities for using automated units. However, this leads to the introduction of mechanisms in technological processes that have excessive characteristics (node mass, drive power, dimensions). Non-optimal characteristics lead to increased inertia of moving elements of robots, slower movement, and higher energy consumption.

The aim of the study is to analyze the technical characteristics of control systems for manipulator robots in continuous technological processes, determine the characteristics important for integration into the automation system and the execution of required operations, and establish directions for optimizing the control system.

To achieve this goal, the following tasks need to be solved:

- research and analysis of the technical characteristics and control systems of manipulator robots used by the global industry;
- determination of important control system characteristics for the implementation of robots in continuous technological processes.

The global industry uses a wide variety of manipulator robots. They can be classified by technical characteristics and by types of control systems.

The main technical characteristics of manipulator robots include:

- load capacity: ultra-light (up to 1 kg); light (more than 1 to 10 kg); medium (more than 10 to 200 kg); heavy (more than 200 to 1000 kg); ultra-heavy (more than 1000 kg);
- number of degrees of mobility: low (up to 3 degrees of mobility); medium (4-6 degrees of mobility); high (more than 6 degrees of mobility);
- speed of movement of the working body: low-speed - with linear speeds along individual degrees of mobility up to 0.5 m/s; medium-speed - with linear speeds over 0.5 to 1 m/s; high-speed - with linear speeds over 1 m/s;
- working area;
- trajectory tracking error.

Currently, in the global industry, robots with 4-5 degrees of mobility and a load capacity of 5 to 80 kg are more commonly used [1].

According to the control system, robots are divided into 3 types:

1. Rigidly programmed. The trajectory and algorithm do not automatically adjust when conditions change. However, the robot itself can be reprogrammed.

2. Reprogrammable. Training is performed in the first work cycle. In subsequent cycles, the control system can adjust actions.

3. Flexibly programmed. Capable of independently forming a program according to the task and information about the object. They have a sufficiently powerful sensor structure, self-learning software, and a control system capable of processing and executing operations [2].

Consider an example based on the use of a manipulator robot in the technological process of packaging liquid into containers - capping filled containers with a screw cap [3]. The task of the robot is to track the moving container, synchronize with the linear speed of movement and coordinates of the container, fix the cap on the neck of the container, and screw it to the specified torque.

The control system and robot characteristics may have requirements depending on the needs of the technological process: the cycle speed of one operation, the coordinates of the robot's working body movement, the robot's useful load (the mass of the working body and the load in interaction with the object). Considering the requirements, the analysis and selection of the robot are performed based on the following important characteristics:

- working area;
- speed of movement;
- load capacity.

The control system, in turn, is required to be reprogrammable (learns in the first cycle, in subsequent cycles, it should adjust its actions).

Conclusions. The paper discusses the main types of manipulator robots, their control systems, and the requirements for their implementation in automation systems of continuous technological processes. Using the example of capping filled containers with a screw cap in continuous linear motion, important parameters and characteristics of the automation system were established.

References

1. Denysiuk V.Yu. Automation of production processes in instrument making [Electronic manual]. Lutsk National Technical University, 2017.

2. Types of industrial robots. URL: https://www.evsint.com/uk/industrial-robots-types/ (accessed on 12 November 2024)

3. ALBERTINA Machinery. Robotic Capping Machine for screw-on caps. URL: https://www.youtube.com/watch?v=7O1aYrACYgg (accessed on 12 November 2024).

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IMPROVEMENT OF AN AUTOMATED QUALITY CONTROL SYSTEM FOR OPTICAL PARTS

Abstract. *This study presents the design and development of a quality control system for optical components. The system utilizes structured optical radiation (SOR), produced by diffraction optical elements (DOE), to achieve high precision in the visualization and analysis of surface quality and geometric parameters of optical parts. Experimental data confirm the efficiency of the developed method in both qualitative and quantitative visualizations, enabling contactless inspection with high accuracy.*

Key words*: quality control system, structured optical radiation, diffraction optical elements, contactless inspection, optical components, surface analysis.*

Introduction. Ensuring the quality of optical components is crucial in industries such as telecommunications, medical devices, and high-precision instrumentation. Optical components must meet stringent requirements for surface quality, transparency, and dimensional accuracy. Traditional methods of quality control, such as mechanical measurements or interferometry, often have limitations in terms of speed, precision, and the ability to inspect complex surfaces. This work proposes a novel approach using structured optical radiation (SOR) combined with diffraction optical elements (DOE) for high-precision, contactless quality control of optical parts.

The main objective of this study is to develop and evaluate a system capable of inspecting the quality and geometric parameters of optical components without physical contact, ensuring both accuracy and reliability. The use of SOR enables the detection of surface defects, irregularities, and deviations in geometric shape that might affect the performance of the optical parts.

The primary goal of this research is to design a comprehensive quality control system based on structured optical radiation (SOR) and diffraction optical elements (DOE). This system aims to provide high-precision inspection of surface quality and geometric parameters of optical components. The focus is on the development of an advanced image processing algorithm to automatically detect surface defects and measure critical dimensions such as curvature, flatness, and overall geometry.

Methods and Materials. The developed system uses a coherent light source to generate structured optical radiation. A laser with a wavelength of 532 nm and power output of 2.3 mW is directed through diffraction optical elements (DOE) to produce structured light patterns, such as grids or lines. These patterns are projected onto the surface of the optical components being inspected.

The reflected or scattered light from the surface is captured using high-resolution digital cameras. The images are then processed using specialized software, which applies edge-detection algorithms to analyze the geometric properties and surface quality of the optical components. The system is capable of detecting even minor defects such as scratches, pits, or deviations from the required surface curvature.

The core components of the system include a 532 nm laser, diffraction optical elements, a high-resolution camera, and custom-developed image processing software. The software enables real-time analysis of surface characteristics, providing immediate feedback on the quality of the optical components.

The system was tested on a variety of optical components, including lenses, mirrors, and prisms. The structured optical radiation was projected onto the surfaces, and the resulting images

were captured for analysis. The system demonstrated the ability to detect surface defects as small as 1 micron, as well as deviations in geometric parameters such as curvature and flatness.

The accuracy of the system in measuring critical dimensions was validated by comparing the results with traditional interferometric measurements. The system achieved a measurement error of less than 0.5%, which is within acceptable industry standards for optical component quality control. The system also proved effective in inspecting complex surfaces, such as aspherical lenses, where traditional methods often face limitations.

The contactless nature of the system minimizes the risk of damage to the delicate optical surfaces, making it ideal for inspecting components during manufacturing without interrupting the production process. The ability to perform real-time analysis allows for immediate feedback, enabling manufacturers to correct defects early in the production process, thereby reducing waste and improving overall efficiency.

The developed quality control system offers several key advantages over traditional methods. First, its contactless approach eliminates the risk of damaging sensitive optical surfaces during inspection. Second, the use of structured optical radiation provides highly detailed visualizations of surface irregularities, allowing for precise defect detection. The integration of advanced image processing algorithms further enhances the system's ability to automatically identify defects and measure critical dimensions.

One of the system's main limitations is its sensitivity to reflective surfaces, where excessive scattering can reduce measurement accuracy. Additionally, the system is currently optimized for components up to 1 meter in diameter; larger components would require scaling the optical setup. Future work will focus on enhancing the system's capabilities to handle highly reflective surfaces and larger components.

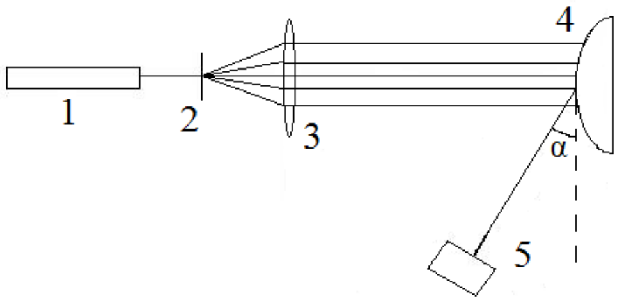

Fig. 1. Principle diagram of the experiment (top view): 1 – laser, 2 – DOE, 3 – lens, 4 – surface to be investigated, 5 – digital camera

The schematic diagram of the experiment is shown in Figure 1. The radiation of a semiconductor laser (1) with a wavelength of 532 nm and a power of 2.3 mW propagates along the optical system's axis, passes through a diffractive optical element (DOE) (2), which can generate various diffraction patterns, and is focused by a lens (3) onto the surface under study (4). The scattered radiation is recorded using a digital camera (5).

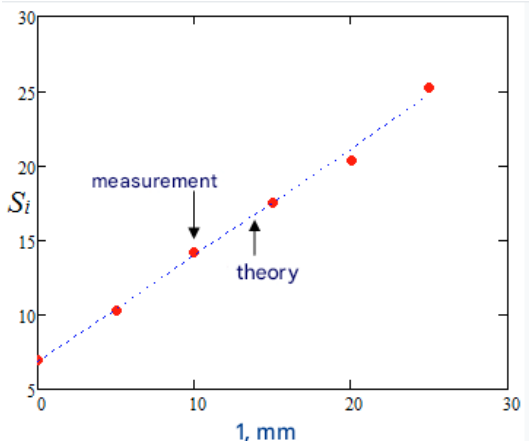

Fig. 2. Comparison of the results for measuring the distance between circular beams

After conducting mathematical modeling and experiments, a comparison of the measurement error results was carried out, as shown in Figure 2. As can be seen from the graph, the results align closely.

Conclusions. The developed optoelectronic system provides a high level of accuracy in determining the geometric parameters of objects, which is critically important for modern scientific and technical tasks. Experiments have shown that the average measurement error does not exceed 0.8%, and in some cases, it is as low as 0.5%. This makes the system suitable for applications requiring exceptional precision, such as quality control or materials research.

Special attention was given to ensuring the accuracy of optical element measurements, particularly for diffractive optical elements (DOE) and lens systems. It was found that even slight misalignments (up to 50 μm) could increase measurement errors by up to 5%, which is unacceptable for high-precision applications. Therefore, an automatic calibration algorithm was integrated into the system, ensuring alignment accuracy with an error margin of no more than 10 μm.

Additionally, the impact of the system's mechanical characteristics on measurement accuracy was analyzed. Mechanical stability is achieved through the use of rigid mounts for optical components and anti-vibration platforms. Experiments demonstrated that the system maintains measurement accuracy even under mechanical vibrations with amplitudes of up to 0.2 mm.

The implementation of modern digital image processing methods significantly reduced the influence of external factors, such as uneven lighting or temperature changes, ensuring measurement stability. The system operates efficiently under substantial temperature fluctuations (from -10°C to +50°C), with accuracy deviations not exceeding 0.3%.

Thus, the proposed optoelectronic system can be effectively used in fields such as mechanical engineering, electronics, and aviation, where a high level of measurement accuracy is required. Future research will focus on enhancing data processing algorithms, expanding system functionality, and integrating artificial intelligence methods for automating calibration processes and real-time result analysis.

References

1. Salvi J., Armangué X., Batlle J. A comparative review of camera calibrating methods with accuracy evaluation. Pattern recognition, 2002, 35, 7, 1617-1635.

2. Тимчик Г.С., Філіппова М.В., Маркін М.О. Технологія оптичного виробництва виробництва [Optical production technology]. Навчальний посібник для студентів ВНЗ. К.: НТУУ "КПІ", 2016.

3. Best Practices for Quality Control in Optical Components. URL: https://www.uqgoptics.com/best-practices-for-quality-control-in-optical-components/ (last accessed: 14.10.2024)

4. Wang Y., Zhdanov A., Potemin I.S., Zhdanov D. Providing the quality control in manufacturing of optical elements. Proceedings Volume 11185, Optical Design and Testing IX, 1118518 (2019). URL: https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11185/2537844/Providing-the-quality-control-in-manufacturing-of-optical-elements/10.1117/12.2537844.full (last accessed: 14.10.2024).

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MODELING AND DEVELOPMENT OF A SYSTEM FOR NON-CONTACT MEASUREMENT OF MECHANICAL CHARACTERISTICS OF THE ELECTRIC DRIVE

Abstract. *This study focuses on the development and simulation of a contactless sensor system for measuring mechanical parameters of electric drives. The research involves comparing various sensor designs, constructing mathematical models, and conducting simulations to evaluate the sensor's performance and its impact on the overall system. The work demonstrates that the newly developed sensor surpasses traditional methods in terms of accuracy and reliability, particularly in industrial applications requiring precise torque control.*

Key words: *electric drive, torque control, contactless sensor, magnetic-elastic sensors, mathematical modeling, ANSYS Maxwell, MATLAB Simulink.*

Introduction. Modern industrial processes require increasingly precise control over mechanical parameters such as torque in electric drives. Traditional methods of torque measurement, such as strain gauges with contact rings or indirect methods relying on phase current and voltage measurements, have significant limitations. Contact methods are prone to wear and inaccuracies due to mechanical friction, while indirect methods may introduce measurement errors in dynamic or non-stationary conditions. Given these limitations, the development of a contactless measurement system is critical for improving accuracy and reducing the maintenance demands on electric drives in various industrial sectors.

The purpose of this study is to design and simulate a system for contactless measurement of mechanical parameters, particularly torque, in electric drives. The developed system aims to be more accurate and reliable than existing solutions. The research also investigates the impact of the sensor on the performance of the entire electric drive system and provides recommendations for its practical implementation.

The main objective is to develop a reliable and accurate contactless sensor system for measuring mechanical parameters in electric drives, with a specific focus on torque control. This involves comparing various sensor designs, conducting simulations to identify the most suitable model, and validating the sensor's effectiveness through mathematical modeling and experimental setups.

The tasks include:

A comprehensive analysis of current methods for torque measurement in electric drives.

Selection and simulation of different sensor constructions to identify the optimal design.

Development of a mathematical model to simulate the sensor's impact on the electric drive system.

Design of test benches for further experimental validation.

Methods and Materials. An analysis of traditional methods for measuring the mechanical parameters of electric drives was conducted, including indirect methods, strain gauges with slip rings, and photoelastic transducers. However, all these methods have several significant drawbacks:

- Indirect methods: High measurement error due to changes in motor characteristics during operation.
- Strain gauges with slip rings: Contact wear and limitations on the maximum shaft speed.
- Photoelastic transducers: Installation complexity and low accuracy.

To overcome these limitations, a contactless magnetoelastic sensor was selected.

The developed ring-shaped magnetoelastic sensor, with a doubled number of measuring poles, offers several advantages:

- High noise immunity: The doubled number of measuring coils allows the device to effectively filter external electromagnetic interference.
- Compactness: The design enables integration into systems with limited space.
- Reliability: The absence of contact elements extends the device's service life.

Magnetic field simulation results showed that the sensor design ensures uniform field distribution around the entire shaft perimeter (Fig. 1).

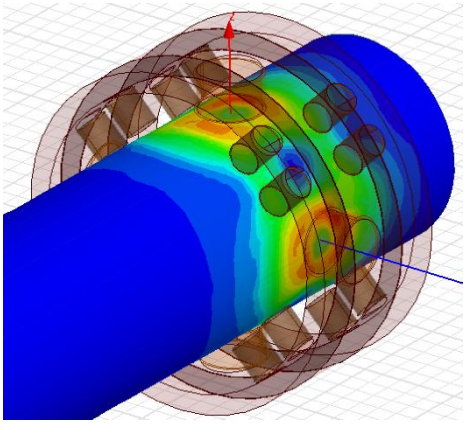

Fig. 1. Magnetic fields in the ring sensor with a doubled number of poles

An electric drive model was built in MATLAB Simulink, including two operating modes:

- Ideal mode (no sensor error considered).
- Real mode (accounting for the characteristics of the developed sensor).

A comparison of time-domain characteristics showed that peak torque deviations during sudden load changes did not exceed 2.3%, which is within the allowable error range (Fig. 2).

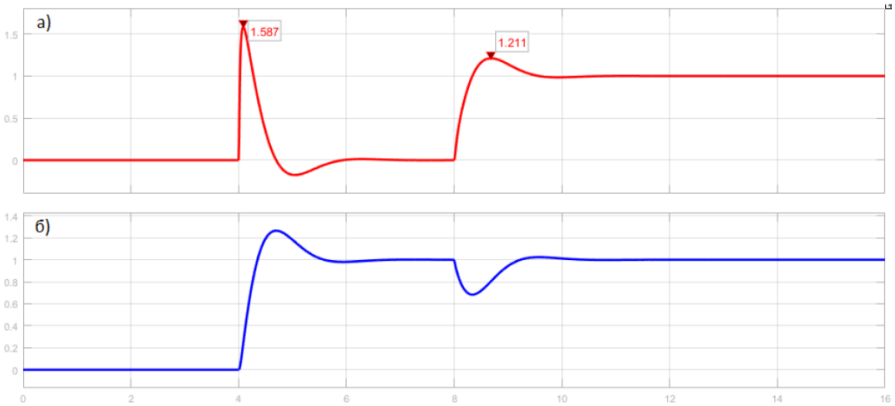

Fig. 2. Time-domain characteristics of torque and speed with the sensor

To validate the developed sensor, two types of test benches were created:

- Manual test bench: Allows basic measurements and sensor calibration.
- Automated test bench: Provides simulation of complex operating modes and recording of dynamic characteristics.

Tests on the benches demonstrated that the system operates reliably when measuring torque in the range of 500–700 Nm, ensuring high measurement accuracy and a fast response to load changes.

Special attention was given to the analysis of transient processes. The system effectively recorded torque changes with minimal delays, which is critical for applications in dynamic systems such as rolling mills and conveyor lines.

Figure 3 shows the transient processes during load changes, indicating that the torque stabilization time does not exceed 0.5 seconds.

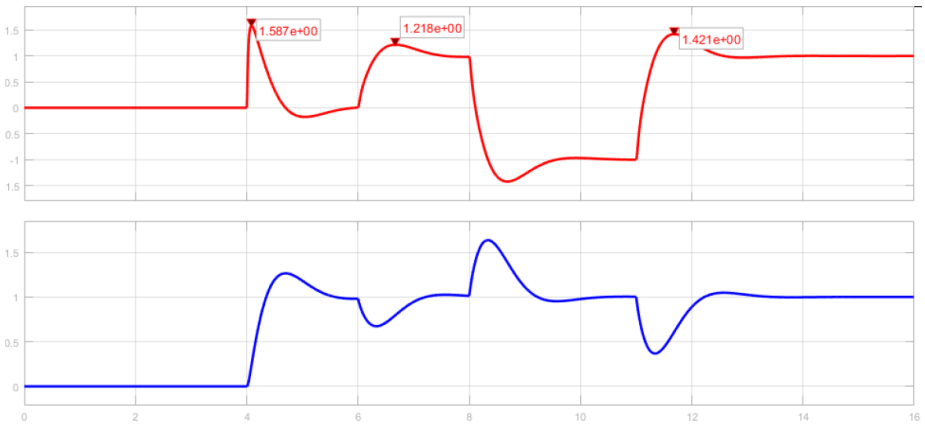

Fig. 3. Transient processes during load changes

Mathematical modeling demonstrated that incorporating the sensor into the control loop does not significantly affect the overall system dynamics. Regulation parameters remain stable, and the accuracy of maintaining the set torque improves.

Conclusions. The developed contactless system for measuring mechanical parameters in electric drives has demonstrated high accuracy, with a measurement error not exceeding 2.3%, and excellent sensitivity, ensuring precise torque control within the range of 500–700 N·m. The optimal sensor design was identified as a ring-shaped model with double poles, offering enhanced accuracy, reliability, and high resistance to noise.

Modeling and testing confirmed that the proposed system can be integrated into a wide range of industrial applications, including metallurgical plants, automated assembly lines, and transportation systems, without compromising the performance of electric drives. Due to its fast response time and resistance to external interference, the system is well-suited for dynamic processes that require precise parameter control.

Future work will focus on experimental validation of the sensor using the designed test benches, as well as exploring its potential applications in various industrial processes to enhance their efficiency and reliability.

References

1. Brandl M., Haas F., Marik R. Contactless Torque Sensor. Mechatronic Principle and Prototype Development for Automotive Applications. In Proceedings of the 6th International Conference on Informatics in Control, Automation and Robotics - Intelligent Control Systems and Optimization, pages 55-61.

2. Nouman M., Khoo S. Y., Mahmud M. A. P., Kouzani A. Z. Recent Advances in Contactless Sensing Technologies for Mental Health Monitoring. IEEE Internet of Things Journal, vol. 9, no. 1, pp. 274-297, 2022.

3. Моделювання електромеханічних систем. Математичне моделювання систем асинхронного електроприводу [Modelling of electromechanical systems. Mathematical modelling of asynchronous electric drive systems]: навчальний посібник / О. І. Толочко. – Київ, НТУУ «КПІ», 2016. 150 с.

4. Системи керування електроприводами [Electric drive control systems]. Видання 2: Навч. посібник з дисципліни «Системи керування електроприводами» (для студентів спеціальності 151 «Автоматизація та комп'ютерно-інтегровані технології» денної і заочної форми навчання). Краматорськ: ДДМА, 2018. 225 с.

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IMPROVEMENT OF THE THERMAL REGIME CONTROL SYSTEM IN INDUSTRIAL PREMISES

Abstract. *The paper presents a comprehensive analysis of the automation of thermal mode control in industrial premises. This includes identifying the key problems associated with the loss of thermal energy in heating systems and providing solutions to improve the accuracy and efficiency of energy consumption monitoring. The proposed system integrates real-time measurement and control, allowing for more effective management of heating systems, especially in energy-intensive industrial buildings. Additionally, the work outlines the development of a mathematical model for assessing heat transfer coefficients and heat accumulation, thereby improving the operational efficiency of industrial premises.*

Key words*: thermal energy, heating systems, heat transfer, industrial premises, automation, real-time monitoring, energy efficiency.*

Introduction. In today's energy-conscious world, the need for efficient thermal energy management is more relevant than ever, especially in industrial environments where heating systems account for a significant portion of energy consumption. According to recent studies, industrial buildings often experience substantial heat losses due to the inefficiencies in their heating systems and the lack of continuous monitoring. This issue is particularly critical in regions with extreme climates, where heating systems operate at full capacity for extended periods, leading to higher operational costs and a greater carbon footprint. Furthermore, existing methods for assessing heat consumption are often based on outdated norms and fail to consider the specific characteristics of individual premises, such as their design, usage, and the presence of secondary heat sources like industrial equipment.

The urgency of addressing energy inefficiency is also supported by regulatory measures aimed at reducing energy consumption and improving building energy performance. However, many of these regulations focus on new buildings, while a vast number of older industrial facilities continue to operate without adequate thermal control mechanisms. This paper seeks to fill this gap by proposing a system for automating the control of thermal regimes, which can be retrofitted into existing structures to enhance their energy efficiency.

The primary objective of this research is to develop an automated system for controlling the thermal regime in industrial buildings. The system aims to continuously monitor and adjust the internal climate of the premises by measuring key parameters such as room temperature, heat transfer through external and internal barriers, and the efficiency of heating systems. Additionally, the system accounts for secondary heat sources, which are common in industrial settings but are often neglected in conventional heat monitoring approaches.

To achieve this, the following specific tasks were undertaken:

1. Develop a mathematical model to describe heat transfer processes within the industrial premises, considering both external environmental conditions and internal heat sources.
2. Design algorithms for real-time measurement and control of heat transfer coefficients and energy accumulation within building materials.
3. Integrate temperature sensors and control algorithms into a functional automated system capable of operating under industrial conditions.

4. Validate the system through experimental testing in real-world settings, comparing the energy savings and operational efficiency to existing solutions.

Methods and materials. A mathematical model was developed in this study to account for the nonlinear nature of heat exchange between the main components of the system: heating devices, walls, windows, and the external environment. The model also includes the impact of secondary heat sources, such as industrial machinery and equipment that emit heat. The key advantage of this model (Fig. 1) is its ability to account for dynamic temperature changes and adapt to various operating conditions.

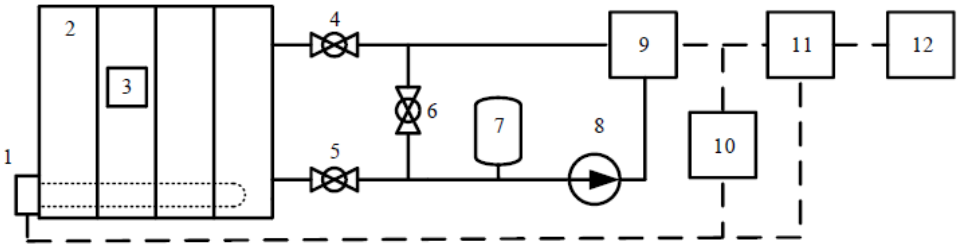

Fig. 1. Heat balance model of the room

The implementation of the developed automation system resulted in a 15–20% reduction in energy consumption (Fig. 2). This was achieved through:

- Precise regulation of heating devices based on changes in external temperature.
- Utilization of heat emitted by industrial equipment to maintain the required microclimate.
- Reduction of heat energy losses through building envelopes.

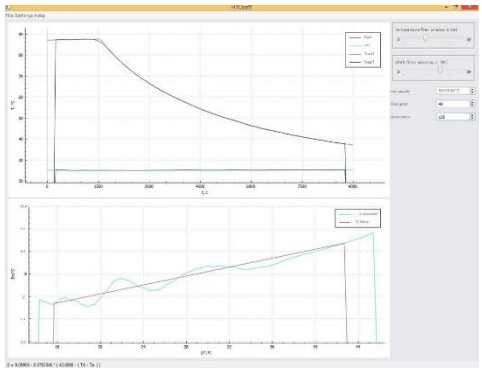

Fig. 2. Experimental energy consumption graphs

Industrial equipment that emits heat was found to be a significant energy source, previously unaccounted for in the heat balance. The system allowed for reduced heating device load during active machine operation, leading to energy savings. For instance, in production areas with high heat emissions from machinery, the intensity of heating systems was reduced by 10–15%. Figure 3 presents a graph of heat emission during the shutdown of a working machine.

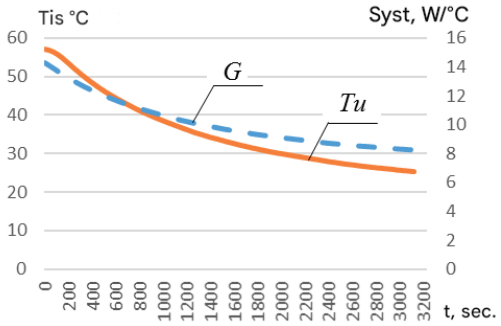

Fig. 3. Heat emission graphs from equipment

A key component of the system is continuous thermal monitoring using a network of sensors. Sensors are placed at critical points within the premises, providing a comprehensive view of temperature distribution and insulation efficiency. Dynamic temperature regulation ensured more

stable and comfortable working conditions for employees. Temperature fluctuations in the premises decreased, positively impacting labor productivity.

The system collects and stores historical data on the thermal regimes of the premises. This enables long-term analysis of the efficiency of building materials and heating systems. For example, these data can help identify specific wall or window sections that require additional insulation.

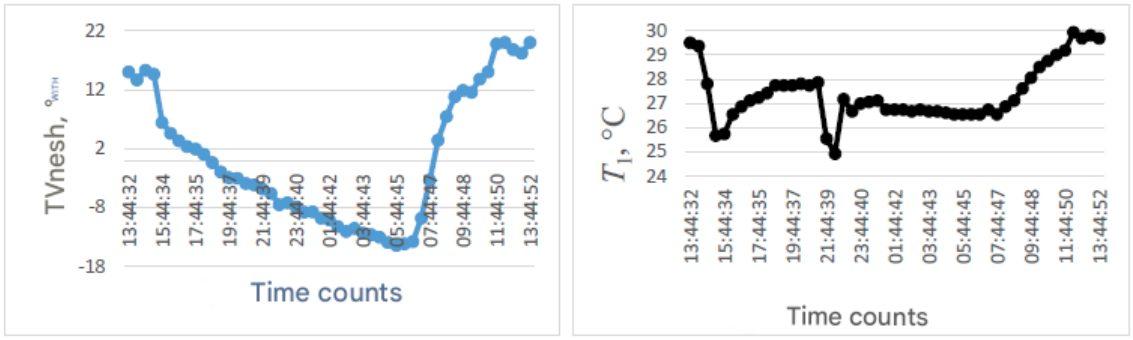

Fig. 4. Temperature variation graph throughout the heating season

The model accurately estimated heat transfer coefficients for different materials used in the construction of the premises. This allowed for precise calculations of heat energy losses through walls, windows, and other structural elements. The heat transfer estimation error was less than 5%, which is a significant improvement over traditional methods.

The implementation of the automated control system provided several practical benefits:

- Reduced operating costs due to decreased need for manual intervention.
- Timely problem detection: the system identifies potential issues early, such as insulation degradation or equipment malfunctions.
- Adaptability to various conditions: the system can be configured for different building types and production processes.

Conclusions. The research successfully demonstrated the benefits of automating the control of thermal regimes in industrial premises. By continuously monitoring the internal and external conditions and dynamically adjusting the heating system's performance, the automated control system was able to achieve significant energy savings while maintaining optimal thermal conditions for industrial operations. The inclusion of secondary heat sources in the control algorithms was particularly beneficial in industrial environments, where heat-emitting machinery can significantly impact the overall energy balance.

The proposed system has the potential for widespread application in industrial facilities, especially in regions with extreme climates, where the energy costs associated with heating are high. The flexibility of the system allows it to be adapted to different building types and configurations, making it an ideal solution for both new and existing industrial structures.

Further research could explore the integration of additional environmental sensors, such as humidity and air quality monitors, to enhance the system's capabilities. Additionally, future developments could focus on expanding the system's use of artificial intelligence and machine learning to predict and optimize energy consumption based on historical data and predictive models.

References

1. Єнін П.М., Швачко Н.А. Теплопостачання (частина І "Теплові мережі та споруди") [Heat supply (Part I "Heating networks and facilities")]. Навчальний посібник. К.: Кондор, 2007, 244 с.

2. Боженко М.Ф. Джерела теплопостачання та споживачі теплоти [Heat supply sources and heat consumers]: навч. посіб. / М. Ф. Боженко, В. П. Сало. – Київ : ІВЦ «Політехніка», 2004. – 192 с.

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DEVELOPMENT AND RESEARCH OF A SYSTEM FOR CONTROLLING THE CONCENTRATION OF EXPLOSIVE DUST AND GAS COMPONENT OF THE ATMOSPHERE

Abstract. *This paper focuses on the development and experimental study of an optical-electronic system (OES) for monitoring explosive dust-gas atmospheres. The system employs dual-spectrum measurements for early detection of fire events while maintaining resilience against optical interference and dust. The proposed solution significantly reduces false alarms, ensuring accurate fire detection in hazardous environments.*

Key words*: optical-electronic system, fire detection, explosive atmosphere, spectral analysis, dust concentration, optical interference.*

Introduction. Explosive dust-gas atmospheres pose a critical safety risk in industries like mining, chemical plants, and power stations. Conventional fire detection systems often struggle in such environments due to high levels of dust and optical interference, leading to false alarms or missed detections. The development of an OES using dual-spectrum measurements addresses these challenges, providing reliable early-stage fire detection.

The goal of this research is to design and validate an OES capable of maintaining high detection accuracy in challenging industrial conditions.

Methods and Materials. The system integrates spectral pyrometry and paraxial optics to measure emissions across different wavelengths. MATLAB and ANSYS Maxwell were used for modeling system performance under varying conditions, including high dust concentrations and interference from industrial light sources.

Key Formulas Used:

1. Spectral Transmission and Absorption:

The transmission $\tau(\lambda)$ of light through a medium is defined as (1):

$$\tau(\lambda) = \frac{I(\lambda)}{I_0(\lambda)} = \exp(-k_\lambda \cdot l) \tag{1}$$

where $I(\lambda)$ is transmitted light intensity, $I_0(\lambda)$ is incident light intensity, k_λ is spectral absorption coefficient, l is path length through the medium.

2. Spectral Ratio for Fire Detection:

The system calculates the spectral ratio RRR as follows (2):

$$R = \frac{I_1}{I_2} \tag{2}$$

where I_1 and I_2 are the intensities in two spectral bands. This ratio helps distinguish between fire signals and external noise.

3. Signal-to-Noise Ratio (SNR) (3):

$$\text{SNR} = \frac{\mu_s}{\sigma_n} \tag{3}$$

where μ_s is mean signal value, σ_n is standard deviation of noise.

The proposed OES is based on a dual-spectral-ratio method. It features a three-channel optical system for improved accuracy and noise rejection. The system (Fig. 1) demonstrated the following characteristics:

- Detection time: less than 5 ms, crucial for early fire detection.
- Detection probability: exceeding 95%, even under conditions with significant dust and optical interference.

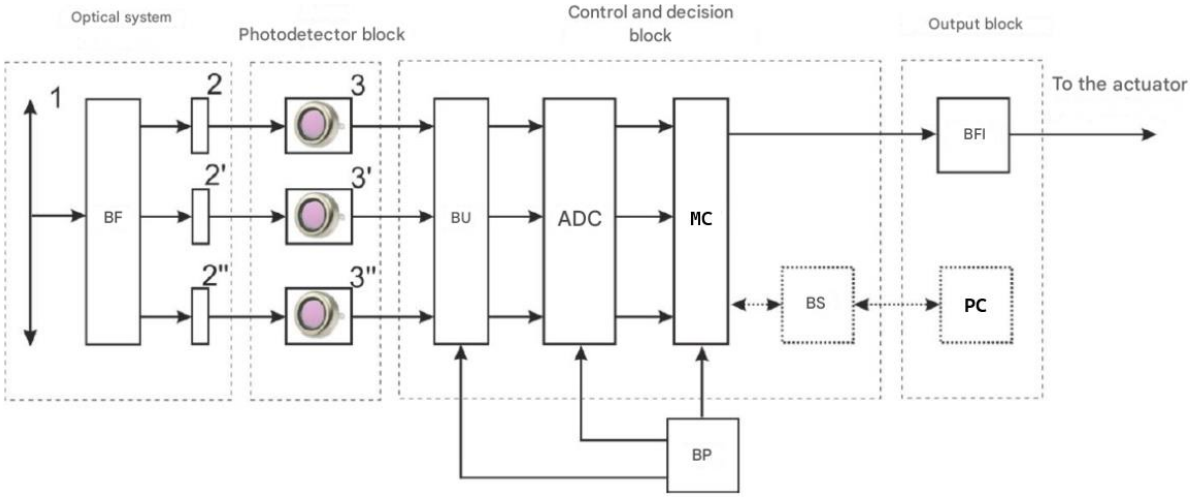

Fig. 1. Structural Diagram of the OES

One of the core functionalities of the OES is its ability to accurately determine dust concentration using spectral-ratio methods (Fig. 2). By measuring the absorption and scattering effects at two distinct spectral bands, the system can isolate the impact of dust on the signal.

In laboratory tests, the OES accurately measured dust concentrations ranging from 0.01 g/m³ to 0.5 g/m³.

Spectral filtering ensured minimal signal distortion, even in environments with varying dust particle sizes and densities.

The measured intensity after passing through a dust-laden medium was modeled using (4):

$$I_d = I_0 \cdot e^{-k_d \cdot l} \tag{4}$$

where k_d is dust-specific absorption coefficient.

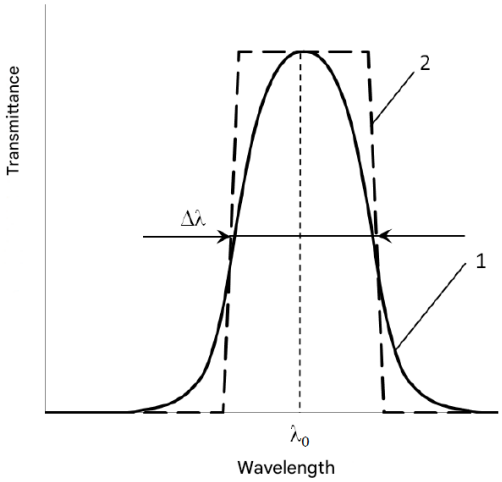

Fig. 2. Spectral Response Under Varying Dust Concentrations
1 – typical characteristic; 2 – presentation of characteristics in a simplified form

The system's (Fig. 3) performance was further validated in environments with artificial light sources. Industrial lighting, such as LED and incandescent lamps, introduced significant optical noise, yet the OES successfully distinguished between true fire signals and interference.

Probability of false detection due to optical noise was reduced to less than 5%.

The intensity ratio approach used is given by (5):

$$R_{opt} = \frac{I_{fire}}{I_{ambient}} \quad (5)$$

where I_{fire} and $I_{ambient}$ represent fire and ambient light intensities, respectively.

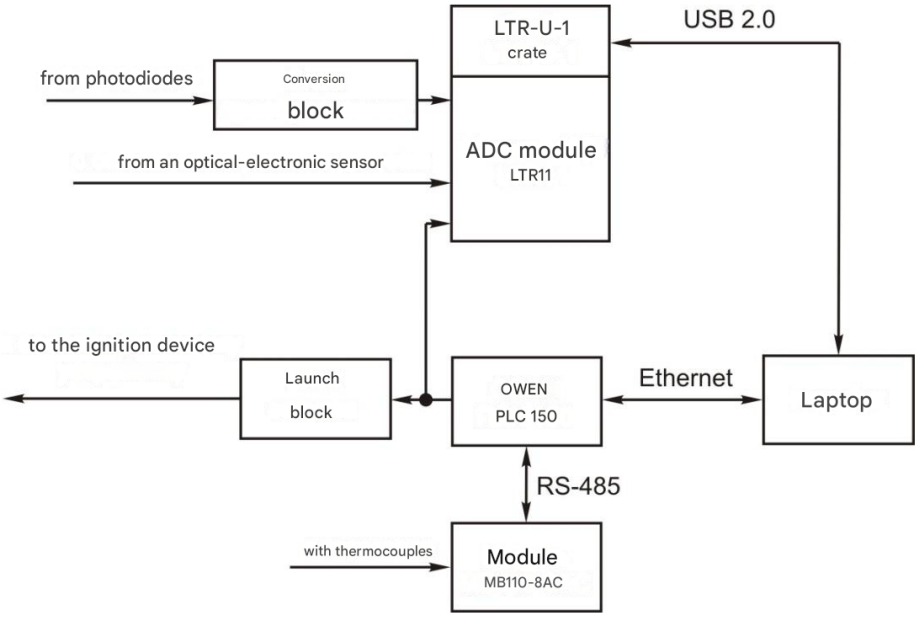

Fig. 3. Block diagram of an automated control system

The system's practical application was tested in a controlled industrial chamber simulating environments found in mining and power stations. Key outcomes include:

- Detection range: Up to 35 meters for small ignition sources.
- Consistency: Reliable operation in dusty and poorly lit environments, with negligible delay or accuracy loss.

Conclusions. This research successfully developed and validated an optical-electronic system for detecting fires in explosive dust-gas atmospheres. Key outcomes include:

- Fast response time (<5 ms).
- High fire detection probability (>95%).
- Robust performance in dusty and optically noisy environments.
- Detection range: Effective up to 35 meters.

The system's resilience and accuracy make it an ideal solution for enhancing industrial safety, with potential applications in mining, chemical plants, and power stations. Future research will focus on further optimizing the system and expanding its applicability.

References

1. Radu M. A., Avram L., Matei D. I. Development of methods for assessing the safety of dust removal facilities in environments with a danger of explosive atmosphere. MATEC Web of Conferences 373, 00024 (2022).

2. Popa C. M., Păun F. A., Gabor D. S. Aspects regarding the explosion risk assessment of installations in atmospheres with combustible dust. MATEC Web of Conferences 354, 00010 (2022).

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DEVELOPMENT AND RESEARCH OF A MICROPROCESSOR CONTROL SYSTEM FOR AN ELECTRICAL MEASURING ROBOT

Abstract. *This paper discusses the development of a microprocessor-based control system for a precision measurement robot, which ensures precise object positioning in the working area and high-accuracy external signal measurement. The system is based on the use of an ATMega16 microcontroller that controls the robot's actuators and processes data from sensors. For synchronization and data exchange with a PC, the UART interface is used. The paper presents system performance results in various modes and provides algorithms for controlling the actuators.*

Key words: *microprocessor, measurement robot, precision positioning, ADC, UART, control algorithms.*

Introduction. In recent years, automation has played a significant role across various industries and scientific fields. Microprocessor systems enable high precision in operations, automate control and measurement processes, which is crucial for minimizing human error and increasing productivity. Microcontrollers are now widely used in robotics, particularly in the development of precision measurement robots.

Measurement robots are used for accurate measurements of environmental parameters, objects, and processes. In such systems, ensuring precise positioning of the robot within the working area is critical for improving measurement accuracy. Microprocessor systems equipped with analog-to-digital converters (ADCs) convert analog sensor signals into digital data, facilitating further processing.

The objective of this work is to develop a control system that combines high measurement accuracy, reliability, and ease of use.

The main goal of this work is to design a microprocessor-based control system for a precision measurement robot, ensuring precise object positioning in the working area and enabling interaction with a personal computer for data processing and analysis.

Research Tasks:

1. Analyze modern methods and algorithms for object positioning in automated systems.
2. Develop a software algorithm for controlling the robot's actuators.
3. Implement the conversion of analog sensor signals into digital data using ADC.
4. Ensure synchronization and data exchange between the microprocessor system and the PC via the UART interface.

Methods and Materials. The system is based on the ATMega16 microcontroller, which interfaces with the sensors and the robot's actuators. The built-in 10-bit ADC, connected to eight inputs, is used for measuring analog signals. Data is transmitted to the computer via UART, allowing the user to control the robot in real time.

The control algorithm for the actuators includes the following steps:

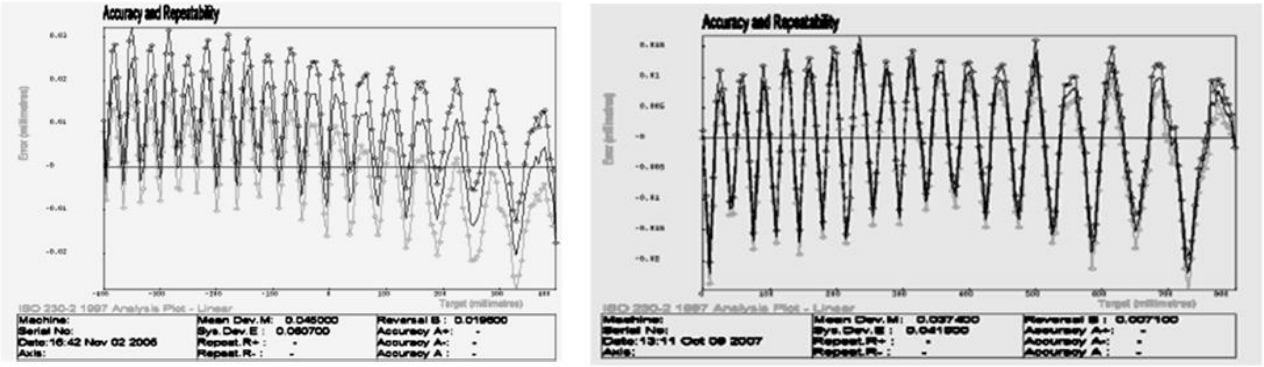
1. System initialization (LCD display, UART, ADC).
2. Processing sensor signals.
3. Controlling the robot's movement based on commands received from the PC via UART.
4. Performing measurements using the ADC.
5. Transmitting data to the PC for processing.

Thanks to the application of precision control algorithms, high positioning accuracy of the robot in the working area was achieved. The use of the ATMega16 microcontroller, which provides real-time processing of sensor data, allowed for stable control of the robot's movement without failures and significant deviations from the trajectory. The actuator control algorithm supports working with different types of motors, ensuring smooth movement and accuracy up to a few millimeters.

Results of comparing positioning accuracy in different modes of system operation:

- Mode 1: Absence of external interference – accuracy up to 1 mm.
- Mode 2: Operation under temperature changes – accuracy up to 2 mm.
- Mode 3: Operation under electromagnetic interference – accuracy up to 2.5 mm.

The positioning accuracy of the measurement robot system was evaluated based on multiple measurements in accordance with ISO 230-2:2014 standards, using the ML-10 laser interferometer. The results indicate that the positioning accuracy along the X and Y coordinates falls within acceptable limits, with a deviation not exceeding 42 µm after structural optimization (Fig. 1a and 1b).



a b

Fig. 1. Comparison Before and After System Improvement

These graphs illustrate a significant reduction in system errors following the implementation of structural modifications.

Results After System Enhancement:

- Y-coordinate accuracy improved from 61 µm to 42 µm.
- Accumulated backlash error decreased from 20 µm to 7 µm.

Reliability forecasting was conducted through lifecycle analysis of the system. The evaluation of the mean time between failures (MTBF) indicated that the system could operate for over 10,000 hours, meeting high reliability standards for automated control systems.

Key Factors Influencing Reliability:

- High number of components: hundreds, sometimes even thousands.
- Complex structural organization: featuring cyclic connections and multifunctional elements.

Thus, the system demonstrated high operational stability even under challenging conditions, maintaining minimal deviations from the specified parameters.

The UART interface (Universal Asynchronous Receiver-Transmitter) plays an important role in the system, as it provides two-way data exchange between the microcontroller and the PC. This allows the user to control the robot in real time, issuing commands for movement, stopping, or changing the direction of motion. At the same time, data about the system's status and measurement

results are sent to the PC. During testing, a stable data exchange rate of 9600 baud was achieved, which allows for prompt information transfer without significant delays.

The system was tested under various conditions, including the presence of electromagnetic interference and temperature changes. It was found that due to optimized signal processing algorithms and the stability of the ADC operation, the system maintains high measurement accuracy even in the presence of external factors. For example, when operating under temperatures varying from 20°C to 40°C, the measurement accuracy deviation did not exceed 0.5%.

During testing, it was established that the proposed control system for the electric measuring robot can be successfully used in industrial environments for measurement automation. The system can also be integrated into scientific experiments where precise measurement and positioning of objects are important.

Conclusions. The developed microprocessor-based control system for a precision measurement robot ensures high-accuracy object positioning in the working area and efficient measurement processing. The use of ADC and the UART interface allows the system to be integrated into various automated environments. This system can be beneficial in industrial and scientific settings where high measurement accuracy and process automation are required.

References

1. Робототехнічні системи: проєктування і моделювання [Robotic systems: design and modelling]: навчальний посібник для здобувачів ступеня бакалавра, за освітньою програмою «Інформаційне забезпечення робототехнічних систем» спеціальністю 126 «Інформаційні системи та технології» / М. М. Поліщук, М. М. Ткач ; Київ : КПІ ім. Ігоря Сікорського, 2021. – 112 с.

2. Friedman, C.P., Wyatt, J.C., Ash, J.S. (2022). Measurement Fundamentals: Reliability and Validity. In: Evaluation Methods in Biomedical and Health Informatics. Health Informatics. Springer, Cham, pp. 129–154.

3. Danner, D. (2016). Reliability – The precision of a measurement. GESIS Survey Guidelines. Mannheim, Germany: GESIS – Leibniz Institute for the Social Sciences.

4. Senvar O., Firat S.U.O. An Overview of Capability Evaluation of Measurement Systems and Gauge Repeatability and Reproducibility Studies. International Journal of Metrology and Quality Engineering. 2010, 1(2), 121–127.

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IMPROVEMENT OF THE AUTOMATING SYSTEM OF THE THERMAL ENERGY PRODUCTION FACILITY

Abstract *The purpose of this work is to improve the automated control system of a thermal energy production facility to improve the quality of control in terms of both hydraulic and thermal parameters: bringing operating modes to optimal levels in order to increase energy efficiency, reduce the negative impact of operating personnel errors, and prevent premature failure equipment. The issue of dynamic detection of malfunctions and diagnostics of breakdowns of nodes and aggregates based on real-time monitoring of parameters is also considered.*

Key words: *automation of centralized heating, optimization of industrial water heating boilers, fault detection and diagnosis, real-time performance monitoring.*

During the operation of thermal energy production facilities (in our case, with low-temperature water heating boilers of medium and large capacity on methane and solid fuel), the issue of economical use of resources is very acute. This applies to both energy components (fuel, electricity) and basic means of production, as well as human labour. Today, this is especially relevant for Ukraine.

The minimization of gas and electricity consumption is mainly achieved through the reconstruction of facilities with the installation of more modern equipment that requires fewer man-hours for maintenance, and in many cases can even operate autonomously with remote or periodic physical control. At the same time, the requirements for the quality of technological process management are increasing. And since we have a huge shortage of both personnel in general and, unfortunately, the level of education and competences, there is still a certain decrease in efficiency, a reduction in the service life of equipment, and the occurrence of accidents and downtimes. As a result, the quality of heat supply deteriorates, there is a lack of profit and capital costs increase. Therefore, it is necessary to improve equipment control systems in such a way as to achieve optimal operating parameters in automatic mode, increase the "survival" of boiler rooms, and also prevent attempts to set clearly incorrect parameters or harmful operating modes.

Consider a simplified diagram of one of the objects (Fig. 1), which contains the following main parts:

- two natural gas boilers (K1, K2);
- two network pumps (one of them is equipped with a frequency converter) on the supply line T1. Installing them on this pipeline and adjusting the rotation speed allows you to reduce electricity consumption and use boiler room equipment designed for lower pressure — which means reducing the cost of equipment and its repair;
- bypass jumper from the return pipeline T2 past the boilers to the supply T1.

Feeding the system with a coolant out through the return pipeline with maintenance of the set pressure (P2) by a separate system of make-up pumps, which is not shown here. Filtered, softened water with the addition of sodium sulfite to remove free oxygen is used as a coolant.

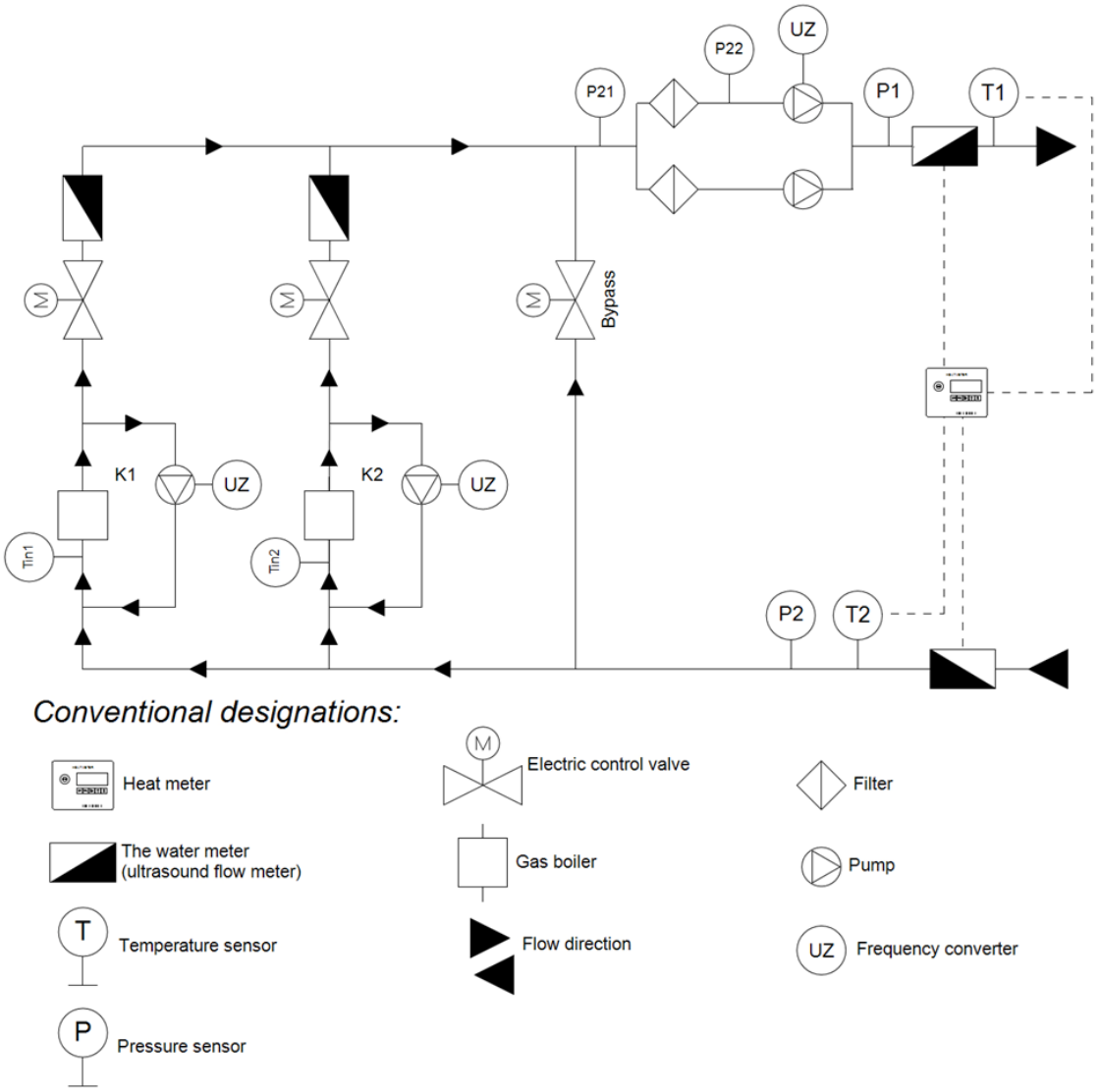

Fig. 1. A simplified diagram of one of the thermal energy production facilities

If heat production is necessary, the mains pump is started and the boiler is switched on. Since boilers of this capacity are usually not made of stainless steel, in order to avoid corrosion due to condensation of combustion products, it is necessary to maintain such an operating mode in which the temperature of the coolant at the boiler inlet (Tin) will be above the dew point (55...65°C). For this purpose, a frequency-regulated circulation mixing pump is installed near each boiler in this scheme, which returns part of the coolant from the boiler outlet to the inlet; Also, at the outlet of each of the boilers there is a control valve with an electric drive, which can reduce the flow of coolant through the boiler if it is too cold. Each boiler is equipped with a PID regulator and tries to maintain the temperature of the coolant at the outlet after it, set manually by the operator or the general controller of the boiler room. The mains pump operates from the frequency converter at a manually set frequency (instead, it must regulate the P1-P2 pressure drop at the output of the boiler room).

The first problem occurs when the boilers are cold and the valves at their outlets are almost completely closed - the pressure at the inlet of the mains pump (pressure at sensor P22) drops, and can reach NPSH ("Net Positive Suction Head" or cavitation margin) or even zero/negative values that are dangerous for the pump unit, the protection will be activated and the pump will be turned off. In order to prevent such a critical decrease in the pressure at the pump inlet, it is necessary to regulate the flow of the heat carrier with the help of a bypass jumper. In the case of a boiler room with only one boiler, some successfully manage this process by opening the jumper by a percentage that corresponds to the closing percentage of the boiler outlet. Of course, when one more boiler is

added to such a system (or many more of them) without changing the logic of the general regulation, the system stops working - the consumption of coolant due to additional boilers is not taken into account in the jumper control system. And here I see at least two ways — either to take into account the position of the valves at the outlets of all the boilers of the boiler room, add a sum of hydraulic resistances of them and put the jumper in the appropriate position; or using the regulator to maintain the pressure (P22) at the inlet of the mains pump not lower than the permissible NPSH. I consider the disadvantage of the first method to be the need to collect information about the position of all boiler valves, taking into account their hydraulic resistances, heat utilizers (economizers), as well as the characteristics of boilers pumps; in the second case, we will need to determine exactly what pressure must be maintained at point P22. It may be good to combine both methods, and add some that will be found empirically or in this work during calculations.

The second problem is the use of many PID controllers where, in authors' opinion, better regulation can be achieved without them. After all, even after the parameters of such a regulator are almost perfectly set, if some conditions changed (for example, manually limited the maximum value of the burner power; or there will be a significant change in the flow of the coolant through the boiler) – the regulator becomes a generator of significant unwanted fluctuations in the system, overregulation appears or vice versa.

The heat meter at the exit from the boiler room measures the flow rate V and the temperature of the supply (T_1) and return (T_2) coolant. Accordingly, the currently required thermal power of the installation can be calculated using the formula (1) [1]:

$$Q = Vc_p(T_1 - T_2), \quad (1)$$

where Q is the heat flow (in [kW]); V is volume flow of water (in [m³/s]); c_p is specific heat capacity of water (here given in [kJ/(m³·K)]); T_1 and T_2 are the temperature of the coolant on the supply line and the return line (in [°C]), respectively.

Now you can, knowing the characteristics of the gas burner and the required power, set its operating point directly on the boiler controller or burner without PID regulation (and if necessary, turn on the next boiler in the cascade, etc.).

And thirdly, draw your attention to the fact that often at heat generation facilities, some parameters are completely duplicated (for example, temperature sensors T_1 and T_2 of the common boiler controller and heat meter sensors in the same pipelines), and part of the parameters may be estimated with a certain accuracy indirectly on the basis of available measurements [2]. With such a huge set of data, we can use mathematical methods to diagnose suspicious deviations in real time and notify in advance that something is going wrong in our system.

Thus, we have identified at least three main shortcomings of existing boiler plant equipment management systems, and proposed conceptual methods and methods that will allow to increase the energy efficiency of the equipment, extend the service life and detect malfunctions in advance. This information can be useful both to practicing heating engineers and to automation specialists of similar facilities.

References

1. Kvalsvik, K., Hanne, K. (2018) Linear optimization of district heating systems. Description of an upgraded district heating module for eTransport. SINTEF Academic Press. ZEN Report No 9. Available at: https://hdl.handle.net/11250/2594858

2. Baldi, S. et al. (2017) Real-time monitoring energy efficiency and performance degradation of condensing boilers. Energy conversion and management, 136, pp. 329–339. Available at: https://doi.org/10.1016/j.enconman.2017.01.016

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