# INFORMATION TECHNOLOGIES

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## DEVELOPMENT OF A METHOD FOR USING COLOR IN MACHINE-READABLE OPTICAL CODES TO INCREASE THE INFORMATION CAPACITY

**pages 6–12**

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The possibility of increasing the capacity of QR codes by using color modules without adding new metadata is studied. A method for automatically determining the number of colors and their palette using image processing is proposed, which ensures compatibility with classical QR codes. A system is proposed that allows creating a QR code that uses 4, 8 or 16 colors in addition to the standard black and white version.

The main problem is the optimal use of the available color space to minimize errors when reading an informative image with an optical camera, compensate for the effects of uneven lighting and poor image quality, and ensure backward compatibility with the black and white version.

In the course of analyzing the use of different color spaces, the most promising perceptually uniform OKLCH space was determined. Algorithms for image preprocessing for correct decoding of information and an algorithm for encoding and decoding information using color have been developed.

The results obtained are explained by the distribution of the color gamut after the test reading of informative images, the number of errors and successful readings. Using the OKLCH color space, it was possible to read 60% of 16-color test images, while in HSL it was not possible to read any image due to color overlap. However, both spaces have a fairly high rate of successful reads in 4 and 8 color codes.

The use of color will allow the introduction of new standards for high-capacity color machine-readable codes without requiring changes to existing ones for additional metadata, while maintaining full backward compatibility and reliability of black and white codes. Increased information capacity in some cases allows to eliminate the need to be connected to the Internet, reduce the size of the code, and make it more visually appealing by using colors.

**Keywords:** optical identification, machine-readable code, QR code, image processing, color space.

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## USE OF GENERATIVE ARTIFICIAL INTELLIGENCE TO IMPROVE OUTPUT MESSAGE EFFECTIVENESS IN DECISION SUPPORT SYSTEMS FOR PROSUMERS

**pages 13–23**

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The object of this study is the use of generative artificial intelligence (GenAI) to create output messages in a decision support system (DSS) for prosumers. The research addresses the challenge of improving user experience (UX) by enhancing the effectiveness of DSS messages. A prototype DSS was developed for a specific private household equipped with solar panels. A rule-based message generation system was created as a baseline for comparison. An evaluation was conducted through surveys in Ukrainian and English. GenAI models from OpenAI and Anthropic were compared. Messages were assessed along two key dimensions of UX quality: usefulness and ease of comprehension.

The results indicate that GenAI can enhance the effectiveness of DSS recommendations for specific user groups without adverse effects. The Sonnet 3.5 model (Anthropic) generated messages that were rated as statistically more useful ($p < 0.05$) by female users in Ukrainian. Users preferred shorter messages in English, and Sonnet 3.5 outperformed GPT-4 (OpenAI) in terms of usefulness in both languages ($p < 0.05$).

The higher usefulness ratings can be attributed to more detailed recommendations while maintaining natural language. The English-language results were likely influenced by the fact that respondents were not native speakers. Differences between the models are associated with the specifics of their integration into the DSS.

The results prove the hypothesis that GenAI can improve the efficiency of DSSs by generating more useful but not more complex messages. These results

also indicate that GenAI's main advantage is in tailoring the DSS output to the needs of different user groups. The difference in results between the models highlights the need for proper testing of the developed AI solutions in specific contexts. The results will be used to develop a more efficient DSS for electricity prosumers.

**Keywords:** generative artificial intelligence, decision support system, prosumers, user experience, photovoltaics.

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## ANALYSIS OF SINUSOIDAL TRANSFORMATION MODEL OF DARK TONE DIGITAL IMAGES

**pages 24–28**

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The object of the study is the technological process of sinusoidal transformation of dark tones into a digital image, used at the stage of preparation for printing. One of the most problematic areas is posterization, which occurs with traditional power-law gamma transformation, creating noticeable bands on the image that distort its quality and limit the capabilities of the operator, technologist, and printer.

The study employed mathematical modeling and quantization of gradation characteristics to eliminate these shortcomings. A mathematical model of sinusoidal transformation was developed, describing the brightness of the image in the range of $0 \le L \le 255$ levels. A structural scheme of the simulator model was also created in MATLAB: Simulink, allowing for the calculation and plotting of gradation characteristics, optical density, and contrast sensitivity for different transformation frequencies.

As a result of the simulation, it was found that the sinusoidal transformation has significantly smaller initial quantization shifts (0.5–2 units) and first step lengths (1–2 levels) compared to the traditional gamma transformation (11–31 units and 10–15 levels, respectively). This eliminates posterization. The contrast sensitivity of the sinusoidal transformation increases up to 2.2, exceeding the constant value of 1 in the linear scale, which ensures improved tone perception. Thus, the proposed method demonstrates higher efficiency in reproducing images in both dark and light areas.

The results obtained demonstrate the absence of posterization in the sinusoidal transformation of dark tones. This is due to the proposed approach having several features, including a steeper gradation characteristic at the beginning of the range, which eliminates posterization of dark tones without losses in highlights. This ensures the ability to obtain high-quality images with improved gradation characteristics.

Compared to similar known methods, this provides advantages in the form of improved image quality and elimination of posterization, which is crucial for the quality preparation of images for printing. The results of the research and simulation modeling can be used to select optimal reproduction characteristics, ensuring improved perception of the printed image by the human visual system. This allows achieving high print quality without losses in detail and contrast, which is a significant advantage in the printing industry.

**Keywords**: image, modeling, sinusoid, simulator, gradation, optics, density, contrast, sensitivity, quality.

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## DEVELOPMENT OF AUTOMATED COLLECTION METHOD OF INITIAL DIAGNOSTIC INFORMATION FOR THE TECHNICAL SUPPORT SERVICE OF ORGANIZATION NETWORK USERS

**pages 29–36**

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The object of the study is the process of collecting initial diagnostic information by the technical support service (Service Desk/Help Desk) in organizations where IT infrastructure is a key element of business processes.

One of the most problematic areas is the manual and inefficient collection of accurate diagnostic data from users who often lack sufficient technical knowledge. This leads to significant delays at the primary diagnostics stage, increases overall system downtime, and directly impacts employee productivity, especially when network infrastructure problems arise.

In the course of the study, an approach is proposed that involves optimizing and automating the collection of primary network diagnostic information directly from the user's side. This method includes automatically checking the physical connection, obtaining correct network settings (IP address, DNS, etc.), and verifying resource accessibility over the network.

The expected result is a significant increase in the speed and quality of the technical support service's work. This is due to the fact that the proposed automated method minimizes the need for lengthy user questioning and sequential manual checks of settings. It has a number of features, in particular, a focus on automating data collection specifically from the network infrastructure, which is the foundation for the vast majority of IT services.

This approach allows to automate the collection of diagnostic data in an infrastructure built using equipment from different vendors and does not depend on the specific software implementation of network services, monitoring and logging services. Compared to similar known traditional methods, this approach provides such advantages as reduced downtime, a lower risk of significant financial losses for the company, and an increase in overall user satisfaction with the quality of IT services.

**Keywords**: automation, support, networks, diagnostics, API, Celery, Zammad, FastAPI, incident management.

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## DECISION-MAKING ON COMMAND QUERY RESPONSIBILITY SEGREGATION WITH EVENT SOURCING ARCHITECTURAL VARIATIONS

**pages 37–59**

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The object of the research is the process of selecting and evaluating architectural solutions, both at the design stage and during the migration of a software application's architecture, within the context of evolutionary architecture. The paper is focused on variations of the Command Query Responsibility Segregation (CQRS) with Event Sourcing (ES) architecture, which, in fact, is a family of architectural variations that differ in complexity, performance, development time, and the required expertise from developers. These differences have a significant impact on the development cost and maintainability of the software application. Moreover, changes in business requirements or technical context often necessitate migration among architectural variations, which may drastically increase costs if not planned properly.

In the absence of objective evaluation criteria, decisions are often based on expert judgment, which may be unavailable or insufficient. This work proposes a formal modeling approach for supporting CQRS with ES architectural variation selection and migration planning. The approach is based on classification of processes and breaking them down into smaller activities. This enables objective comparisons of architectural variations based on complexity and performance metrics.

The application of the approach is shown on two basic variations. Metrics were obtained, and a bitmap chart was built to visualize architectural applicability, depending on the project priorities. The score of mCQRS ranges from 39% to 53%, while that of Classical CQRS – 47–61%.

The proposed approach is applicable in projects where architecture evolution is expected. It is especially useful in organizations operating at Capability Maturity Models Integration (CMMI) Level 4 (Quantitatively Managed Organization) which is focused on predictability of quantitative performance improvement objectives.

**Keywords:** software architectures, software metrics, formal methods, support decision-making, CQRS, Event Sourcing.

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## DEVELOPMENT OF A MODEL OF RASTER POWER-LINEAR CONVERSION OF DIGITAL IMAGES OF LIGHT TONES

**pages 60–64**

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The object of research is the technological process of raster conversion of digital images based on power-linear transformation at the stage of preparation for printing.

The problem in the processes of prepress preparation is the lack of functionality in available computer image processing programs to construct the characteristics of the raster conversion, which are the main carrier of information about the image. Accordingly, this limits the capabilities of the reproduction process and leads to a loss of image quality on the print.

The work used the method of mathematical modeling, the theory of digital image conversion, and object-oriented programming. To solve the problems set, typical variants of power-linear transformation of digital images of different tonalities were constructed. In the process of the study, algorithms for raster transformation of different lineatures were developed, which are the main carrier of information about the image. Simulators for simulation modeling, analysis, and synthesis of power-linear transformation were built, ensuring high-quality tone reproduction of images of different lineatures.

A mathematical model of raster conversion of typical variants of power-linear conversion of digital images for light tones has been developed and new rasterization algorithms have been proposed. Based on them, a structural diagram of a simulator of raster power-linear conversion of images of light tones has been developed in the MATLAB:Simulink package, with which it is possible to calculate and construct gradation characteristics, rasterization characteristics and analyze their properties.

The proposed model of algorithms for raster power-linear conversion of digital images eliminates posterization of images in dark areas, which is an advantage of the developed new raster conversion algorithms using power-linear transformation.

The results of the conducted studies of raster tone reproduction can be recommended to operators and technologists for use in pre-printing processes at the stage of raster conversion of digital images.

**Keywords:** power-linear conversion, raster tone reproduction, simulator, gradation characteristics, raster conversion characteristics.

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# SYSTEMS AND CONTROL PROCESSES

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## DEVELOPMENT OF A DIAGNOSTIC PROCEDURE FOR ASSESSING THE PERFORMANCE OF A MAGNITOPLANE NAVIGATION SYSTEM

**pages 65–70**

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The object of research is the process of ensuring the reliability of high-speed magnetic levitation.

Navigation tasks of high-speed ground transport require high accuracy and reliability along with high speed of obtaining data on the location of the magnetic levitation. The problem to be solved is to ensure the integrity of the magnetic levitation navigation system by means of essential integration into its structure of the diagnostic subsystem, the basis of which is the phase ranging method.

It has been established that the diagnostic procedure for determining the operability of the navigation system of a high-speed vehicle in real time is fully ensured by the use of the phase ranging method. A method of continuous precision positioning of a high-speed magnetic levitation vehicle based on the phase ranging method for an arbitrary configuration in three-dimensional space of a fixed track structure, as well as a method of ensuring the integrity of the navigation system of a maglev train, has been substantiated. A new approach to solving the location problem is proposed, which allows using the train communication channel with the traffic control center as a distributed location sensor as an integral element of the radio wave information and control system.

The structure of the information packet cycle is proposed. The volume of the information flow and the degree of redundancy introduced into the information flow to ensure the required reliability of information transmission are determined.

The developed diagnostic procedure meets the requirements for the safety and reliability of operation of high-speed ground transport based on magnetic levitation technology, the movement of which is controlled using a navigation system topologically connected with the configuration of the track structure.

**Keywords:** magnetic levitation transport, phase ranging, navigation, diagnostics, generator, synchronization, signal.

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## DEVELOPMENT OF A FUZZY RISK ASSESSMENT MODEL FOR INFORMATION SECURITY MANAGEMENT

**pages 71–79**

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The object of research is the process of assessing information security risks of information resources during the functioning of information activity objects, which is the basis of effective security management.

One of the most problematic areas of classical probabilistic risk assessment models is high subjectivity in determining quantitative values of indicators. To eliminate these shortcomings, it is proposed to create universal, scalable and trainable risk assessment models based on qualitative characteristics. The study used an adaptive neuro-fuzzy logical inference system (ANFIS).

A mathematical model of information security risk assessment was obtained, which expands existing solutions by scaling. The approach used in the model allows to automatically adapt to dynamic changes in the functioning of the information activity object. The proposed model has the following features: automated generation of the rule base and retraining of the fuzzy system. The use of artificial neural networks to automate the adjustment of the parameters of the fuzzy system allows to avoid the subjectivity characteristic of expert assessments. This provides the ability to obtain current values of the information security risk level.

The conducted experimental studies quantitatively confirmed the effectiveness of the model, which demonstrated classification accuracy of up to 95% and a significant reduction in the mean square error to 0.01 compared to classical probabilistic models and traditional fuzzy expert systems. This is due to the fact that the proposed model has a number of features, in particular, automated generation of the rule base and the possibility of retraining the fuzzy system, which is provided by the use of artificial neural networks. Due to this, automatic adaptation to dynamic changes in the object and accurate obtaining of current values of the risk level are ensured. Compared to similar known models, this provides automated adjustment of parameters based on the results of retraining (with an error of > 1–2%) and reliable information security management by prioritizing protective measures and responding promptly to threats.

**Keywords:** information activity, risk, intellectual system, fuzzy logic, artificial neural network.

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## DEVELOPMENT OF AN IMAGE SEGMENTATION METHOD FROM UNMANNED AERIAL VEHICLES BASED ON THE ANT COLONY ALGORITHM UNDER THE INFLUENCE OF SPECKLE NOISE

**pages 80–86**

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The object of research is the process of segmenting an image from an unmanned aerial vehicle based on the ant algorithm under the influence of speckle noise.

Unlike the known ones, the image segmentation method based on the ant algorithm involves the imitation of the collective behaviour of agents (ants) capable of adapting to local features of the image. In addition, the pheromone marking mechanism contributes to a more distinct delineation of the boundaries between segments, which positively affects the accuracy of dividing the image into segments.

Speckle noise is a type of multiplicative noise that occurs in images formed using coherent radiation. Its appearance is due to the interference of reflected waves coming from different points of the same object, but with microscopic differences in phase. This leads to the appearance of a chaotic granular structure that distorts the image and complicates further analysis.

Experimental studies have shown that the segmentation method based on the ant algorithm provides a reduction in segmentation errors of the first kind on average from 6% (in the absence of speckle noise) to 30% (at a speckle noise intensity $\sigma = 15$). With an increase in the speckle noise intensity, the gain in the value of the segmentation error of the first kind increases. The segmentation method based on the ant algorithm provides a reduction in segmentation errors of the second kind on average from 5% (in the absence of speckle noise) to 32% (at a speckle noise intensity $\sigma = 15$). With an increase in the speckle noise intensity, the gain in the value of the segmentation error of the second kind increases.

The practical value of the segmentation method based on the ant algorithm lies in the possibility of segmentation under the influence of speckle noise. At the same time, a reduction in segmentation errors of the first and second kind is ensured in comparison with the known method.

**Keywords**: segmentation, unmanned aerial vehicle, ant algorithm, speckle noise, Sobel operator.

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## STOCHASTIC MODELING-BASED ADAPTIVE CONTROL FOR MARITIME DEFENSE IN SIMULATION COMPUTER GAMES

**pages 87–98**

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The object of the study is the modeling process of virtual adversary behavior and automated control systems for mine weapons in game-based naval combat scenarios, taking into account uncertainty and incomplete information, particularly in conditions of partial or erroneous functioning of the sensor system. One of the most problematic aspects is ensuring effective decision-making in situations where the sensor system exhibits Type I and Type II errors or its feedback is completely absent due to malfunctions or damage.

The study employs stochastic modeling methods, mathematical expectation estimation for all possible combat scenarios, and adaptive control algorithms that consider the accuracy of the sensor system and the a priori probability of enemy presence.

An adaptive control method for anti-ship defense and a corresponding implementation system have been developed, which includes an adaptive controller capable of performing the core computations in real time to determine optimal control actions for mine weapon deployment.

The results of numerical experiments were obtained for various scenarios: with fixed parameters, variable minefield density, sensor system accuracy changes, and different a priori probabilities of ship appearances. These experiments enabled a comprehensive evaluation of the method's effectiveness. The conducted experiments confirm that the proposed method enables effective control of mine weapons in the presence of Type I and Type II errors with probabilities ranging from 0 to 0.9 during the detection of enemy and neutral ships.

As a result, the proposed solution provides the capability for adaptive control of combat operations even under high uncertainty, enhances the realism of virtual adversary behavior in simulation games, and lays the groundwork for the development of intelligent automatic control systems in naval combat scenarios.

**Keywords:** simulation games, maritime defense, mine weapons, automatic control, stochastic modeling, mathematical expectation.

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## DEVELOPMENT OF HARDWARE-SOFTWARE MODEL FOR SIGNAL SPECTRUM COMPUTATION USING FAST FOURIER TRANSFORM BASED ON FPGA

**pages 99–107**

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The object of research is the implementation methods of an adaptive hardware-software model for signal spectrum analysis using Fast Fourier Transform (FFT), implemented on a Field-Programmable Gate Array (FPGA) followed by processing in the software part. This solution combines the advantages of hardware acceleration and software flexibility. The proposed model is aimed at solving the problem of creating an efficient tool for real-time signal processing, taking into account limitations in accuracy, latency, resource usage, and data retention for further processing and analysis. The model is designed with scalability in mind, both in terms of increasing the number of processing channels and extending the FFT length and precision level. Its development included stages of modeling, synthesis, debugging, and testing close to real-world conditions. The structure of the model was thoroughly designed, data representation formats and rounding procedures were optimized, and the FFT algorithm was adapted to the specifics of the chosen platform. Altogether, this ensured high accuracy of spectral analysis and efficient use of FPGA resources, as confirmed by experimental data. Practical testing of the system in real time was conducted, during which such parameters as result accuracy and power consumption were evaluated, considering the efficient use of logic elements and memory blocks. The obtained results logically reflect the advantages of the hardware-software implementation, the usage of optimized data formats and rounding procedures, as well as the successful adaptation of the FFT algorithm. This allowed achieving a balance between high spectral analysis accuracy at the level of 3.97 kHz with an FFT length of 16,384, a twofold reduction in the required memory size, and a 0.25 ms decrease in FFT result transmission time. The practical applications of the developed model cover a wide range of fields, including embedded signal processing systems, modern real-time measurement devices, as well as mobile or energy-efficient systems, where real-time processing under low power consumption is critical. Thanks to its versatility, the model can be integrated into more complex digital signal processing systems, expanding their functionality.

**Keywords:** model, Fast Fourier Transform, Field-Programmable Gate Array, Python, magnitude, rounding, accuracy, telecommunications.

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