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The Video Images Coding Method for Special-Purpose Info Communication Systems

IVAN TUPITSYA[1], VOLODYMYR KRYVONOS[1], SERGII KIBITKIN[2], ALBERT LEKAKH[3]
[1]Ivan Kozhedub Kharkiv National Air Force University, Kharkiv, CO 61000 Ukraine
[2]National Academy of the Security Service of Ukraine, Kyiv, CO 01001 Ukraine
[3]Science Center of Ivan Kozhedub Kharkiv National Air Force University, Kharkiv, CO 61000 Ukraine

Corresponding author: Ivan Tupitsya (e-mail: ivan20081982@gmail.com).

ABSTRACT The subject of research in the article is the methods of encoding video images in information and communication systems using wireless data transmission technologies. The shortcomings of applying existing video coding technologies are analyzed to ensure the required reliability for wireless communication technologies. The goal is to develop a method for encoding video data to ensure the required reliability of an information resource under the limited bandwidth of wireless communication channels. Objectives: to develop a method for transforming symbols of a video image alphabet, which, due to the reduction by structural feature, will allow for obtaining a more favorable representation of the encoded data; to develop a method for encoding the transformed data using lossless coding technologies to ensure the required reliability of aerial reconnaissance data. The following results were obtained: the use of the developed method of encoding video images allows the provision the required high reliability of video images, and provides a compactness of aerial reconnaissance data

KEYWORDS video image; alphabet; transformation; coding; compactness; wireless data transmission channel.

I. INTRODUCTION

To date, video data coding technologies are actively developing to obtain the necessary indicators of the quality of an information resource that circulates in information and communication systems [1-6]. Information and communication systems for special purposes are no exception, where the information resource is an important component of the information support system for security sector bodies. The main ones among them are electronic document management (text and scanned official documents, video data obtained through video surveillance, aero monitoring, etc.) [7-9].

This is because timely receipt of information makes it possible to provide conditions for a prompt response to relevant situations and create conditions for their prevention in the future. Accordingly, the reliability of the information received allows the creation of conditions to avoid erroneous decisions by the relevant security sector authorities. It should be noted that recently, in infocommunication systems for special purposes, such information support means as video images (static, dynamic) obtained using aero monitoring means are actively used [7, 9]. However, using aero monitoring tools (unmanned aerial vehicles) as sources of video data is associated with the need to consider several problematic factors. The main ones are the following [10-13]:

- constantly increasing volumes of transmitted video data [10];
- bandwidth of wireless channels for data transmission. Due to the bandwidth limitations of wireless communication channels, it becomes necessary to use technologies for compact data presentation of an information resource [10, 11];
- high quality of video images - to ensure the required level of data reliability of the video information resource [12, 13].

To solve the above problematic factors, a methodology based on the principles of JPEG algorithms is used [3, 10, 11, 14 - 19].

The use of the JPEG algorithm for encoding air reconnaissance data is due to the active integration of international standards into special-purpose information communication systems. Thus, the active use of unmanned aircraft systems of both domestic production and those provided by partner countries as part of international logistical assistance in the context of hostilities on the territory of Ukraine is accompanied by the active implementation of NATO standards in the process of forming and processing aerial reconnaissance data [20 - 23]. In turn, according to NATO standards, the use of the JPEG platform is envisaged to form digital images [20, 21].

However, the use of these coding technologies, although it allows balancing between quality and compactness indicators, has disadvantages. The main one is that exceptional cases of using this approach are the semantic elements loss that describe the object of interest because of compression [11, 24, 25]. This, in turn, decreases the decoded data reliability and, therefore, gives rise to the following situations:

- making erroneous decisions or complicating decision-making on the response of the relevant departmental bodies to crises;
- a decrease in the level of management efficiency of the relevant security sector bodies.

Thus, searching for new approaches to solve the above problematic factors becomes necessary.

Thus, ensuring the required information resource reliability for special-purpose information communication systems is an urgent scientific and applied problem.

The article aims to develop an encoding method for video data to ensure the required reliability for information resources in the limited bandwidth of wireless data transmission channels.

II. RELATED WORK

The analysis of the latest research and publications indicates that the main direction of solving the issue of increasing the reliability is the improvement of the already existing stages of video data processing [26-31].

Thus, to improve the quality of reconstructed images, work [26] proposes to improve the stages of external data restructuring - the stages of inverse quantization and discrete cosine transformation using deep machine learning technologies without using the classic approaches of the JPEG standard. This approach allows you to create conditions to eliminate artifacts of reconstructed video images. However, using the specified approach in real time in wireless video data transmission lines is complicated by the limitations of computing power on board the unmanned aerial vehicle.

The transformation of encoding images in JPEG format, proposed in [27], involves using a hybrid coding structure - repeated compression using predicted transformation domains. This approach allows for a gain in compression characteristics in combination with an increase in image quality. However, it significantly increases the algorithmic complexity due to the additional introduction of a significant number of stages of digital image processing, which leads to a significant increase in requirements for computing resources of on-board equipment.

In turn, to increase the reliability of digital images, work [28] proposes a method for removing MSARNet artifacts in JPEG format, which allows you to meet the requirements for computing power. However, it uses multi-stage processing, which leads to an increase in the algorithmic complexity of the proposed approach.

The transformation of the image encoding process proposed in [29] by excluding from the data preparation process for encoding the discrete-cosine transformation and using FBSE Fourier–Bessel series allows for improving the compression characteristics of the encoding algorithm. However, it does not consider the requirements for the reliability of reconstructed images in the conditions of information communication special-purpose systems using wireless video data transmission lines.

The fourfold increase in the size of the blocks into which the coded image is divided, proposed in [30], allows for improving the quality of processing and data confidentiality, but does not ensure the required level of integrity of the coded resource. In turn, the synthesis of discretization methods and the Gaussian filter proposed in [31] increases the compactness of coded data. However, it increases the algorithmic complexity by performing additional stages of processing the reconstructed data.

The compression method based on Ramanujan's orthogonal sums, proposed in [32], ensures the required level of quality of reconstructed images. The implementation of the mentioned approach involves the transformation of the discretization stage (discrete cosine transformation) in the JPEG algorithm - the use of discrete wavelet transformation based on orthogonal Ramanujan sums, which increases the requirements for the computing power of the on-board equipment of the unmanned aerial vehicle.

The work [33] proposes a method of image compression, the essence of which is to reduce the difference of color wavelets. This allows for improving the reconstructed image quality in comparison with the classic stages of processing implemented in the JPEG format. However, a problematic aspect of implementing the mentioned approach for wireless information communication systems is the growth of algorithmic complexity.

A comparative analysis of modern compression algorithms using auto encoders or generative competitive network architectures with algorithms of the JPEG family, studied in [34], shows that they have better results in evaluating compression characteristics at approximately the same level of reconstructed image quality. However, the problematic aspects of their use in wireless video data transmission lines include an increase in data processing time and artifacts in the reconstructed image.

In turn, the approach proposed in [35] for removing JPEG artifacts, the essence of which is to use the FDDNet network controlled by frequency decomposition, improves the quality of reconstruction of low-frequency image elements. However, implementing FDDNet on board an unmanned aerial vehicle requires additional equipment refinement.

The improvement of the quantization stage in the JPEG algorithm, proposed in [36], through the use of lattice-encoded quantization methods, allows for a significant gain in compression characteristics in comparison with the classical coding scheme, while ensuring approximately the same level of quality of reconstructed images. However, it leads to an increase in algorithmic complexity and, as a result, to an increase in the time for processing coded data.

Another direction for improving the quality of video resources in infocommunication systems is to improve the delivery process. Thus, in [37], an approach to data compression and transmission in the Internet of Things environment is proposed, the essence of which is to transform the remainder calculation system and the arithmetic coding method. A distinctive feature of the proposed approach is that the resulting residues are compressed in parallel using arithmetic coding and transmitted via parallel routes, if the latter are present. The proposed approach increases the processing speed due to parallel operation and provides a compression ratio depending on the data type.

In turn, in [38], recommendations are given on the use of compression methods in the construction of airborne remote sensing systems, with the main advantages and disadvantages of image compression methods from the point of view of implementation on an FPGA.

In [39], a data encoding method in wireless sensor networks is proposed, the essence of which is the transformation in the system of arithmetic in residues and multipath routing. This allows the effective use of the frequency band of the communication channel while reducing the message delivery time, reducing the number of modes of solution search by the wireless node, and increasing the accuracy of modeling of wireless sensor networks.

However, the experience of using UAVs in the interests of the security and defense sector indicates that today wireless sensor networks are practically not used to organize the process of delivering aerial reconnaissance data.

Thus, it can be concluded that many scientific studies aim to change the size of processed blocks, transform statistical coding methods, transform orthogonal transformations, use deep machine learning technologies, improving the data delivery process etc. However, their main disadvantages are the following: orientation to compression, that is, improvement of compression characteristics for a more compact presentation of coded data; a significant increase in the algorithmic complexity of implementation, which leads to a significant increase in data processing time; and increasing the requirements for computing power on-board equipment of unmanned systems.

Therefore, a fundamentally new approach to solving the specified scientific and applied problem is proposed - the data alphabet transformation without classical approaches.

III. DEVELOPMENT OF THE VIDEO IMAGES CODING METHOD FOR SPECIAL-PURPOSE INFO COMMUNICATION SYSTEMS

To increase the reliability of video images for wireless communication channels, it is proposed that a coding method be developed based on the synthesis of a transformation method of alphabet symbols of the aerial reconnaissance data and statistical coding methods.

Fig. 1 shows the structural and functional diagram of video coding with the proposed approach.

The video image coding method includes two stages:

1. At the first stage, the symbols transformation model of the original alphabet of video data is formed, considering the frequency estimate (assessment of the appearance probability of individual symbols) and the significance indicator. At this stage, the video alphabet is reduced. This reduces the psych visual superfluity of encoded video images.

2. At the second stage, efficient coding methods - group and Huffman codes- are proposed. At this stage, the structural and code redundancy of the encoded data is eliminated.

The implementation of the coding process in stages using the proposed approach is offered to investigate (Fig. 1).

1st stage: the original message (video image) is described by the following formula:

$$X(n) = \{x_1; \ldots; x_i; \ldots; x_n\}, i = \overline{1,n}, \quad (1)$$

Where x_i is i - th pixel of video image $X(n)$.

The alphabet $X(n)$ of video image $X(n)$ is described by the following formula:

$$X(m) = \{x_1; \ldots; x_i; \ldots; x_m\}, i = \overline{1,m}, \quad (2)$$

Where m is the symbols number of the video image alphabet.

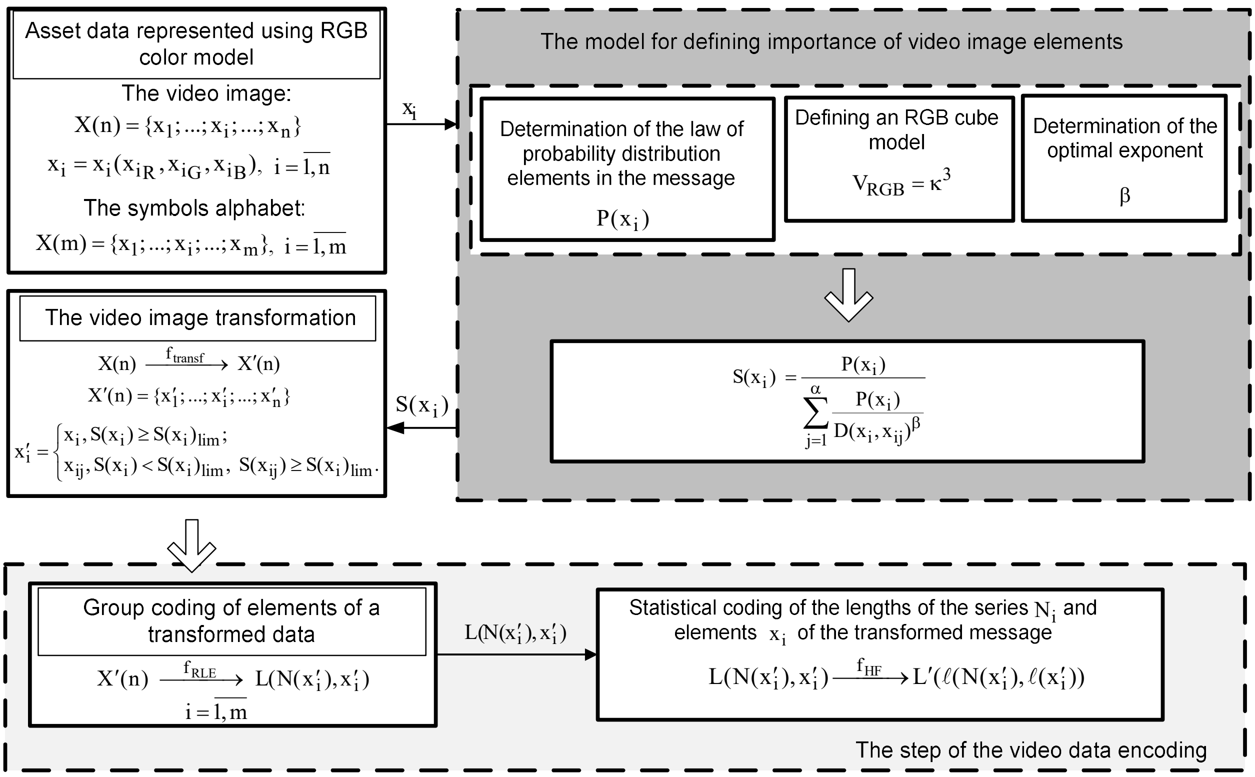

Figure 1. The structural-functional scheme of video coding using the proposed approach

Because at the initial stage, the elements' x_i original message $X(n)$ rendered using the RGB model, the elements

x_i will be described by the following expression:

$$x_i = x_i(x_{iR}, x_{iG}, x_{iB}) , \quad (3)$$

Where x_{iR} is component of the red element x_i;
x_{iG} is component of the green element x_i;
x_{iB} is component the blue of the element x_i.

To reduce the alphabet $X(m)$ of video image symbols, it is necessary to determine the significance of its elements.

The importance sign is used to quantify the importance of the elements of the original message. This gives the following expression:

$$S(x_i) = \frac{P(x_i)}{\sum_{j=1}^{\alpha} \frac{P(x_i)}{D(x_i, x_{ij})^{\beta}}} , \quad (4)$$

Where $S(x_i)$ is a sign of element importance of an original data;

$P(x_i)$ is the appearing probability of an element x_i in a video image $X(n)$;

x_{ij} are elements of a cube of the RGB model, $x_{ij} = x_{ij}(x_{ijR}, x_{ijG}, x_{ijB})$, $j = \overline{1,\alpha}$, $\alpha = 3(\kappa - 1)$;

$D(x_i, x_{ij})$ is length between the original message element x_i and elements x_{ij} the generated RGB cube.

The following expression calculates distance $D(x_i, x_{ij})$:

$$D(x_i, x_{ij}) = \sqrt{(x_{iR} - x_{ijR})^2 + (x_{iG} - x_{ijG})^2 + (x_{iB} - x_{ijB})^2} . \quad (5)$$

The elements x_i of the original message determine the significance threshold $S(x_i)_{\lim}$. It is a tool for adjusting the alphabetic power of the converted video data and, as a result, the image quality.

The initial data is described by the following expression when the original message $X(n)$ is transformed using the developed alphabet transformation model:

$$X(n) \xrightarrow{f_{transf}} X'(n), \; X'(n) = \{x'_1; ...; x'_i; ...; x'_n\} , \quad (6)$$

Where $f_{transf}(|X_{transf}(\nu)|, S(x_i)_{\lim})$ is the transformation function of the original video data;
x'_i is i - th element of the message $X'(n)$;
$X_{transf}(\nu)$ is the alphabet of the transformed message $X'(n)$;
$|X_{transf}(\nu)|$ is the message alphabet power $X'(n)$.

The following expressions calculate the transformation process of message $X(n)$ elements x_i:

$$x'_i = \begin{cases} x_i, S(x_i) \geq S(x_i)_{\lim}; \\ x_{ij}, S(x_i) < S(x_i)_{\lim}, \; S(x_{ij}) \geq S(x_i)_{\lim}. \end{cases} \quad (7)$$

2nd stage: the coding process is proposed to be carried out using the synthesis of the group coding method and the Huffman algorithm.

Group coding of elements of the transformed video data (elimination of structural redundancy) is done as follows:

$$X'(n) \xrightarrow{f_{RLE}} L(N(x'_i), x'_i) , \quad (8)$$

Where f_{RLE} is function of group coding of elements x'_i of the transformed video data;
$L(N(x'_i), x'_i)$ is the code sequence, which is formed as a result of group coding by the RLE algorithm, $i = \overline{1,m}$;
$N(x'_i)$ is a group of elements x'_i messages $X'(n)$.

The final stage in the implementation of the proposed approach is statistical coding of elements x'_i and series lengths $N(x'_i)$ using the Huffman method:

$$L(N(x'_i), x'_i) \xrightarrow{f_{HF}} L'(\ell(N(x'_i), \ell(x'_i)) , \quad (9)$$

Where f_{HF} is the entropy encoding function of the video image elements;
$L'(\ell(N(x'_i), \ell(x'_i))$ is the output code sequence;
$\ell(N(x'_i)$ is uneven code constructs that are assigned to series $N_i(x'_i)$ elements x'_i;
$\ell(x'_i)$ is uneven code constructs that are assigned to elements x'_i transformed message $X'(n)$.

Next, it is needed to determine an efficiency of the developed video coding method from the position of providing the necessary characteristics of compression and the reliability of video monitoring data.

III. RESULTS

Further, it is proposed to define the effectiveness of the developed method for coding video data (video images) from the position of ensuring the required reliability.

Several studies were carried out to evaluate the effectiveness of the video image coding method. The developed mathematical apparatus was modeled using software applications written in the Java programming language.

Test aerial photographs obtained from aerial reconnaissance using a first-class unmanned aerial vehicle were used as encoded data.

During experimental studies, a set of 200 aerial photographs with a resolution of 4K (4096 × 2160 pixels, typical resolution for digital television aerial reconnaissance systems installed on board a UAV of this type) was used.

Fig. 2 shows examples of typical aerial photographs that differ in the degree of saturation (weakly, medium, and highly saturated).

a) b) c)

Figure 2. Examples of typical test aerial photographs of reduced size, which differ in the degree of saturation: a) weakly saturation; b) medium saturation; c) highly saturation

As a quantitative assessment of the reliability of decoded video images, use the indicator of the mean squared error *MSE*.

To obtain adequate results for assessing the compression characteristics of the video image coding method, it is necessary to ensure the reliability of aerial reconnaissance data. This means that the acceptable level of distortion for a compressed video image should be close to zero. This is due to the relatively high semantic load of video image elements, which are obtained due to aerial reconnaissance in the interests of the security and defense sector.

The results of quantitative assessments (compression, reliability) of the application of the video images coding method are shown in Fig. 3 - 4.

As the initial data, images of various saturation levels (weak, medium, and highly saturated) were used.

The following initial data were used to model the process of encoded data alphabet reduction: 1) $\beta = 3{,}5$; 2) $\kappa = 9$; 3) $\alpha = 3(\kappa - 1) = 24$.

Analysis of the data shown in Fig. 3 - 4indicates that the developed coding method allows:

- to compress the studied aerial photographs by 2.87 times (average value). The average compression ratio for the highly saturated images is 2.3 times. In turn, this indicator is 3.6 times for the weakly-saturated aerial photographs. These results were obtained by reducing the power of the digital aerial photograph alphabet. At the same time, high quality is ensured, that is, the mean squared error MSE tends to zero, i.e. $\text{MSE} \to 0$;

- to increase the degree of compression of digital aerial photographs compared to existing coding methods. The developed method of encoding video images allows for an increase in the degree of data compression compared with the JPEG algorithm by 60.8% (average value). For the medium- and high-saturated digital aerial photographs, the compression ratio increases by 53%. In turn, the compression ratio increases by 76.2% for the weakly-saturated digital aerial photographs.

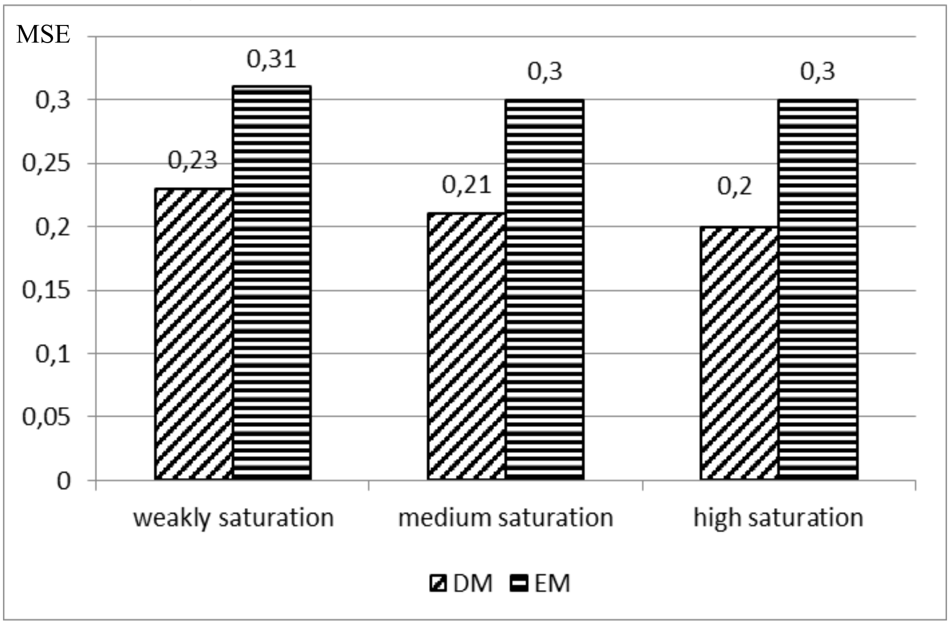

Figure 3. Diagram of a relation of the mean squared error *MSE* on a saturation of video images

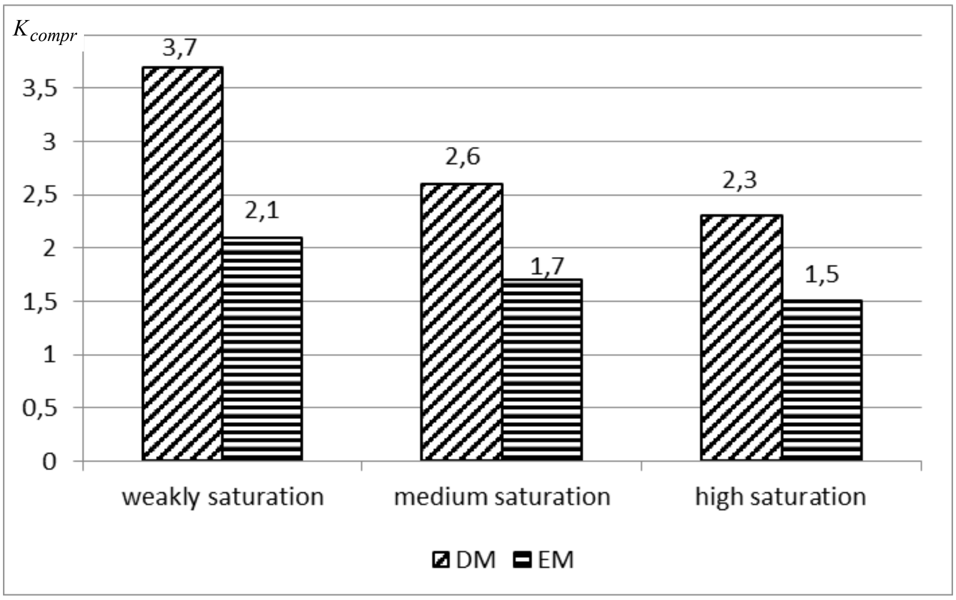

Figure 4. Diagram of the dependence of the compression ratio on the degree of saturation of video images

To compare the local pixel brightness intensity patterns between the original and reconstructed images, it is proposed to evaluate the quantitative SSIM (structural similarity index). The average values of the quantitative SSIM metric for the existing and developed methods are shown in Fig. 5.

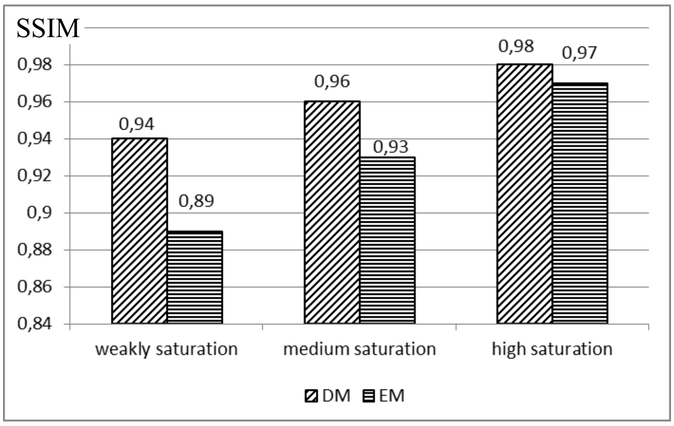

Figure 5. Diagram of the dependence of the index of structural similarity on the degree of saturation of the video image for the developed and existing methods.

Analysis of the data presented in Fig. 5 shows that the developed method has an advantage over the existing one in terms of the quantitative metric SSIM. This means that the required level of reliability of the reconstructed video images is ensured. In turn, the assessment of the efficiency of processing aerial reconnaissance data using the proposed and existing methods is presented in Fig. 6.

Analysis of the data shown in Fig. 6 shows that the existing method has an advantage over the developed one from 7 ms for highly saturated video images to 22.1 ms for weakly saturated video images. The average video image processing time is 81.4 ms. This means that conditions are created to ensure the processing of aerial reconnaissance data in real time.

Thus, the developed method of video image coding using the transformation of the alphabet of the initial data makes it possible to ensure greater compactness of aerial reconnaissance data. This ensures a correspondingly high quality of the reconstructed data (high level of reliability). As a result of the research carried out, a software product has been developed that implements all stages of the proposed approach.

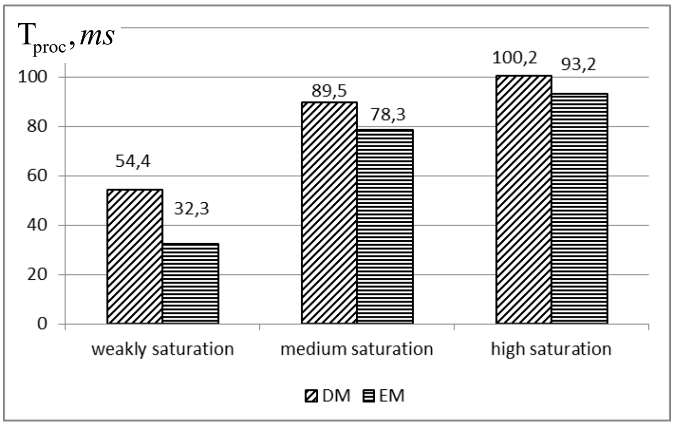

Figure 6. Diagram of the dependence of video image processing time on the degree of saturation for the developed and existing methods

VI. CONCLUSIONS

The video images coding method has been developed with a new approach to data processing - the alphabet transformation of encoded data (aerial reconnaissance data) by its reduction. The essence of the proposed approach is to transform the video image pixel alphabet to represent the encoded data better, followed by the synthesis of efficient coding methods.

The developed method of encoding video images using the alphabet transformation of the source data allows to obtain the following results:

The developed method of encoding video images using the alphabet transformation of the source data allows for obtaining the following results:

1. Provides the high reliability of aerial reconnaissance data (mean squared error for video images tends to zero) for special-purpose info communication systems. In turn, the structural similarity index of the reconstructed and original video image approaches unity.

2. Provides a more compact form of aerial reconnaissance data. The results of the conducted experimental studies indicate that for the analyzed conditions (initial data of experimental studies), the developed method has a gain in compression characteristics compared to the JPEG algorithm by an average of 60.8%.

3. Conditions are being created to ensure real-time processing of aerial reconnaissance data. The average video processing time is 81.4 ms.

Subsequent scientific research will be aimed at developing an adaptive method for compressing aerial reconnaissance data, which will allow monitoring the required performance indicators of video data delivery to create conditions for further integration of modern progressive technologies into the image processing process.

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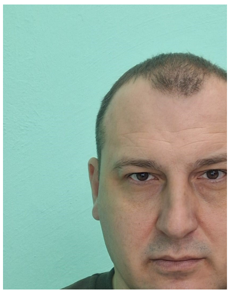
***IVAN TUPITSYA** is the Senior Lecturer of Department of Ivan Kozhedub Kharkiv National Air Force University, Kharkiv, Ukraine. He is PhD in Information Technology. Science interest: information technology, digital data processing, information and cyber security, artificial intelligence, computer vision, unmanned aerial systems. https://orcid.org/0000-0001-6806-4914. E-mail: ivan20081982@gmail.com. He has nearly 150 scientific publications and approvals. Among them are more than 10 articles indexed in the international scientific and metric databases Scopus and Web of Science Core Collection.*



***VOLODYMYR KRYVONOS** is the Head of Department of Ivan Kozhedub Kharkiv National Air Force University, Kharkiv, Ukraine. He is Candidate in Technical Sciences. Science interest: Digital Data Processing, artificial intelligence, computer vision, unmanned aerial systems. https://orcid.org/0000-0002-6511-6640. E-mail: kvn35@ukr.net.*

***SERGII KIBITKIN** is Docent of Department of National Academy of the Security Service of Ukraine, Kyiv, Ukraine. He is Candidate in Technical Sciences. The scientific interest includes digital data processing, artificial intelligence, computer vision, unmanned aerial systems. https://orcid.org/0000-0001-8007-4015. E-mail: sergejkibitkin@gmail.com*

***ALBERT LEKAKH** is the Head of research laboratory of Science Center of Ivan Kozhedub Kharkiv National Air Force University, Kharkiv, Ukraine. He is Candidate in Technical Sciences. The scientific interest includes Digital Data Processing, Information and Cyber Security. https://orcid.org/0000-0003-2848-2593. E-mail: super-albertlekakh@ ukr.net*