UDC 004.932:517.587

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IMAGE COMPRESSION BASED ON CLASSIFICATION CODING OF CONSTANT-PITCHED FUNCTIONS TRANSFORMERS

The subject *of research in the article are the processes of video image processing using an orthogonal transformation for data transmission in information and telecommunication networks. The aim is to build a method of compression of video images while maintaining the efficiency of its delivery at a given informative probability. That will allow to provide a gain in the time of delivery of compressed video images, a necessary level of availability and authenticity at transfer of video data with preservation of strictly statistical regulations and the controlled loss of quality. **Task:** to study the known algorithms for selective processing of static video at the stage of approximation and statistical coding of the data based on JPEG-platform. **The methods** used are algorithm based on JPEG-platform, methods of approximation by orthogonal transformation of information blocks, arithmetic coding. It is a **solution of scientific task-developed** methods for reducing the computational complexity of transformations (compression and decompression) of static video images in the equipment for processing visual information signals, which will increase the efficiency of information delivery. The following **results** were obtained. The method of video image compression with preservation of the efficiency of its delivery at the set informative probability is developed. That will allow to fulfill the set requirements at the preservation of structural-statistical economy, providing a gain in time to bring compressed images based on the developed method, relative to known methods, on average up to 2 times. This gain is because with a slight difference in the compression ratio of highly saturated images compared to the JPEG-2000 method, for the developed method, the processing time will be less by at least 34%. Moreover, with the increase in the volume of transmitted images and the data transmission speed in the communication channel - the gain in the time of delivery for the developed method will increase. Here, the loss of quality of the compressed/restored image does not exceed 2% by RMS, or not worse than 45 dB by PSNR. What is unnoticeable to the human eye. **Conclusions.** The scientific novelty of the obtained results is as follows: for the first time the method of classification (separate) coding (compression) of high-frequency and low-frequency components of Walsh transformants of video images is offered and investigated, which allows to consider their different dynamic range and statistical redundancy reduced using arithmetic coding. This method will allow to ensure the necessary level of availability and authenticity when transmitting video data, while maintaining strict statistical statistics. Note that the proposed method fulfills the set tasks to increase the efficiency of information delivery. Simultaneously, the method for reducing the time complexity of the conversion of highly saturated video images using their representation by the transformants of the discrete Walsh transformation was further developed. It is substantiated that the perspective direction of improvement of methods of image compression is the application of orthogonal transformations on the basis of integer piecewise-constant functions, and methods of integer arithmetic coding of values of transformant transformations. It is substantiated that the joint use of Walsh transformation and arithmetic coding, which reduces the time of compression and recovery of images; reduces additional statistical redundancy. To further increase the degree of compression, a classification coding of low-frequency and high-frequency components of Walsh transformants is developed. It is shown that an additional reduction in statistical redundancy in the arrays of low-frequency components of Walsh transformants is achieved due to their difference in representation. Recommendations for the parameters of the compression method for which the lowest value of the total time of information delivery is provided are substantiated.*

Keywords: images; compression; information intensity; orthogonal transformations.

Introduction

Problem statement. For information support of the visual information management system, there is a video service for the remote provision of video information services in a video monitoring system using unmanned systems. The product of the video service is the receipt of visual information (images) [1–3].

Many requirements are put forward for information support of control systems, which include remote video systems: increased efficiency; high-quality information content; reduction in the cost of obtaining information [4, 5].

The time cycle of the video service control system includes the time of delivery of visual information (images), the identification of objects of interest in the resulting image, the time for making decisions and bringing instructions to control objects [6, 7].

An analysis of the effectiveness of the use of video service systems, namely the assessment of time delays in bringing information to interested persons, allows us to assert that the delivery time of visual information (images) is a main characteristic of the information support process for control systems [5, 6]. Time delays in communicating information negatively affect the timeliness of decision-making, and, consequently, the entire management cycle. Reducing this time is the essence of increasing the efficiency of the service for remote provision of video information services in the control system.

Additionally, in a given time cycle, a significant component is the time of decision-making. However, this stage begins its countdown after the process of identifying objects of interest in the resulting image [8, 9, 13]. And how the information objects will be presented in this image will influence both the time of identification and the probability of correct identification, and, consequently, the effectiveness of decision-making in general [10–12].

Visual information (images), with a significant level of informativeness, characterized by a high degree of saturation with small details, color differences [14, 16, 20]. In the process of clarifying the tasks of identifying objects when reading information from images, requirements are put forward for increasing the resolution of the on-board digital optical system [21–23]. An increase in the resolution of the optical system increases the information intensity of the formed image, which can reach tens of Gbps [15, 17, 19]. Alternatively, due to the growth of information intensity of video information, there is a requirement to increase the performance of dedicated information transmission channels, which increases the cost of obtaining information [16–18].

Evaluation of compliance with the requirements for obtaining high-quality operational video information for control systems regarding the existing remote video service, taking into account the stage of identification of the obtained image, indicates that the existing capabilities of the on-board equipment of the unmanned complex do not provide the required time for image delivery in cases when the required level of resolution of the resulting image is set for the solution of the corresponding class tasks for identifying objects [24, 26, 31].

Here a **scientific and technical problem** arises: to ensure a decrease in the information intensity of the video stream of remote video systems at a given video image reliability.

Analysis of recent research and publications. Existing remote video systems use information technologies with the JPEG platform to reduce the time of video information delivery via dedicated video information transmission channels [25, 28]. Such technologies for providing information reduce information intensity by distorting information about the key features of identifying image objects, which leads to a decrease in the reliability of the received video information [27, 29, 30]. At the level of providing information in a digital image, there is an imbalance: the possibility of the required level of promptness of delivery of an image with questionable reliability of information is provided, and vice versa, providing the required level of providing information on the delivered image, its promptness of delivery is lost. This affects the reliability of information related to aging. This is explained by the peculiarity of the digital image and the peculiarity of modern image processing technologies in the system of providing video services [32, 35, 42]. For existing information technologies for coding video information, the gain in efficiency is compensated by a decrease in the image resolution, which leads to a decrease in the reliability of the resulting image and distortion of the quality of its information content [34, 37, 41].

Thus, the **purpose of the article** is to build a method of image compression while maintaining the efficiency of its delivery at a given informative probability. This creates conditions for ensuring structural and statistical regulations, and for ensuring the necessary level of availability and authenticity of video data.

Presentation of the main material

Development of efficiency criteria for a subsystem for processing and transmitting data for a remote video service. Remote video services use compact video presentation techniques to adapt to the performance of data transmission systems [33, 36, 39]. The main indicators of the quality of such methods are: compression ratio K_{com}, time spent on compression T_{com} and decompression T_{dcom}, an indicator of the degree of quality loss as a result of image compression and decompression. The standard error δ is used as such an indicator:

$$K_{com} = \frac{V_{or}}{V_{com}}, \qquad (1)$$

where V_{or} – original image volume;

V_{com} – compressed image size.

$$T_{com} = \frac{V_{or}}{U_{com}}, \qquad (2)$$

where V_{or} – original image volume;

U_{com} – image compression speed.

$$T_{dcom} = \frac{V_{com}}{U_{dcom}}, \qquad (3)$$

where V_{com} – original image volume;

U_{dcom} – image decompression speed.

$$\delta = \sqrt{\frac{\sum\limits_{i=1}^{N}\sum\limits_{j=1}^{M}(x_{i,j} - y_{i,j})^2}{N \times M}}, \qquad (4)$$

where $x_{i,j}$ – the values of the matrix elements of the original image, $y_{i,j}$ – the values of the matrix elements of the reconstructed image, $N \times M$ – is the dimension of the image.

An analysis of the use of remote video service and the main indicators of the quality of the compression process shows that as a criterion for the efficiency of the data processing and transmission subsystem, taking into account their compression, it is necessary to use a criterion that includes the compression time T_{com}, the image decompression time T_{dcom} and the transmission time of compressed T_{tr} images through communication channels [38-40]. Hence, the expression for evaluating the efficiency criterion will take the form:

$$T_{inf} = T_{com} + T_{tr} + T_{dcom}, \qquad (5)$$

where T_{inf} – total time for processing and transmitting video data.

$$T_{tr} = \frac{V_{com}}{U_{tr}}, \qquad (6)$$

where U_{tr} – video data transmission rate over the communication channel.

In accordance with expression (5), the most effective compression method will be the one for which, on the one hand, equality $\delta^{dev} \approx \delta^{exist}$ holds, and on the other hand, one of the systems of inequalities holds:

$$F_{com}^{(1)} = \begin{cases} K_{com}^{dev} \geq K_{com}^{exist} \\ (T_{com} + T_{dcom})^{dev} < (T_{com} + T_{dcom})^{exist} \end{cases}; (7)$$

or

$$F_{com}^{(2)} = \begin{cases} K_{com}^{dev} \leq K_{com}^{exist} \\ (T_{com} + T_{dcom})^{dev} < (T_{com} + T_{dcom})^{exist} \\ T_{inf}^{dev} < T_{inf}^{exist} \end{cases}; (8)$$

where K_{com}^{dev}, K_{com}^{exist} – the values of the compression ratios, respectively, for the developed and existing methods;

$(T_{com} + T_{dcom})^{dev}$, $(T_{com} + T_{dcom})^{exist}$ – values of the total time of compression and decompression, respectively, for the developed and existing compression methods;

T_{inf}^{dev}, T_{inf}^{exist} – values of the time to bring data, respectively, for the developed and existing compression methods;

δ^{dev}, δ^{exist} – values of the root-mean-square error indicator, respectively, for the developed and existing compression methods;

$F_{com}^{(1)}$, $F_{com}^{(2)}$ – efficiency functionals of the compression method.

This indicator is directly related to the assessment of the efficiency of information delivery and takes into account the peculiarities of the subsystems for processing and transmitting data with compression. Here, on the one hand, there is an additional increase in processing time due to the time spent on compression and decompression of the original images. On the other hand, an additional reduction in the time of transmission of video data through communication channels due to a decrease in the amount of presented data.

The estimation of the compression ratio of images and the time of their transmission through communication channels for various methods, depending on different classes of images, is shown, respectively, in Fig. 1 and Fig. 2 [14].
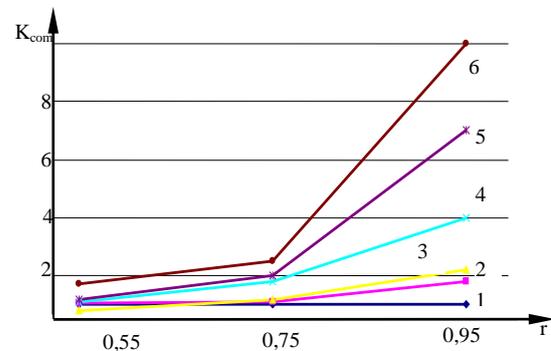

Fig. 1. Graphs of the dependence of the compression ratio K_{com} on the degree of correlation for different compression methods

In fig. 1, 2 shows the estimated compression ratio and transmission time for existing compression methods: 1 – no compression; 2 – methods of entropy coding; 3 – compression methods with the identification of the lengths of the series; 4 – illustrates compression techniques based on differential pulse code modulation (DPCM) and prediction; 5 – methods of interpolation compression; 6 – illustrates compression techniques based on preliminary 2D orthogonal transform.
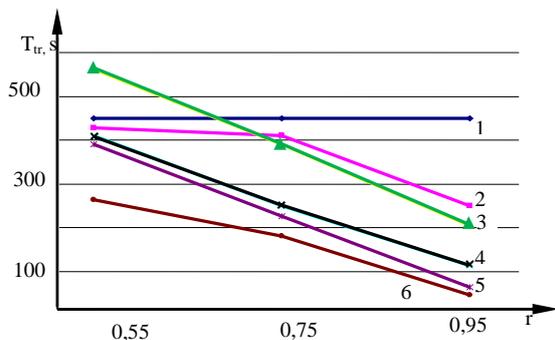

Fig. 2. Graphs of the dependence of the transmission time T_{tr} of compressed images through communication channels on the degree of correlation for different compression methods

Analysis of the graphs shown in Fig. 1, 2 shows that the existing compression methods do not provide a solution to the problem of prompt delivery of video information due to the low value of the compression ratio and the long processing time of weakly correlated images. This is due to low compression ratios and long processing times.

The highest compression ratio of image data is achieved on the basis of methods that take into account psycho-visual redundancy and two-dimensional correlations in the processed blocks. Therefore, it is proposed to build the improvement of compression methods using orthogonal transformations, which allow: to reduce the degree of correlations, to increase the degree of uneven distribution and to distribute the error over the entire processed fragment.

However, the existing compression methods based on orthogonal transformations have inherent disadvantages, which are:

– it is required to perform a large number of operations, both for the orthogonal transformation itself or for performing a wavelet transform, and for performing arithmetic coding;

– trigonometric functions are not reasonably used for the approximation of slob-correlated fragments of images.

This leads to an increase in processing time, to a decrease in the compression ratio of images, and to an increase in the loss of quality of the reconstructed images.

Therefore, in order to achieve this goal, it is necessary to solve a scientific and applied problem, which consists in the development of methods for reducing the computational (time) complexity of transformations (compression and decompression) of static video images in signal processing equipment for technical samples of remote video services..

Justification of the choice of a two-dimensional orthogonal transformation for the development of a method of video data compression. The development of a method for image compression is proposed to build on the basis of improving methods based on two-dimensional orthogonal transformations and entropy coding.

To substantiate the choice of two-dimensional orthogonal transformation of images, which provides a decrease in processing time and a decrease in the approximation error of weakly correlated images, it is necessary to compare different types of orthogonal transformation in terms of time costs for processing.

The following types of orthogonal transformation were analyzed:
- discrete cosine transform (DCT);
- discrete Walsh transform (DWT);
- discrete Haar transform (DHT);
- wavelet transform (WT).

The number of operations for various orthogonal transformations are summarized in Table 1 [14].

Table 1

Number of operations for orthogonal transformation types

Type	Number of operations		A type operations
	K_{+-}	$K_{\times/}$	
DCT	$NM\ell og_2 NM$	$NM\ell og_2 NM$	Real
DWT	$NM\ell og_2 NM$	-	Integer
DHT	$2(NM-1)$	NM	Real
WT	$\sum_{s=0}^{S-1}(\frac{NM}{2^s}-1)$	$\sum_{s=0}^{S-1}(\frac{NM}{2^s}-1)$	Real

DWT has a significant advantage here. The estimation of the gain in terms of processing time for different types of orthogonal transformation was carried out for a processor with a clock frequency of 800 Hz. The analysis showed that the minimum gain for DWT, relative to other types of conversion, is 3.6. This is due to the fact that, unlike DCT and DHT, the values of the elements of the Walsh basis matrix are integers taking only two values 1 and -1. Therefore, performing the Walsh transform is based only on integer addition and subtraction operations. In addition, the addition (subtraction) operations performed for the DCT and DHT

transformations are, respectively, real and partially real, which leads to an additional increase in processing time relative to the time required to perform integer addition (subtraction) operations for the Walsh transform.

For highly saturated images, the use of the basis of piecewise constant functions is more effective than the basis of trigonometric functions, if the complexity of machine implementation is used as a criterion, and, therefore, the simplicity in practical implementation, which is expressed in a decrease in the time complexity of the approximation.

The product of the interaction of image elements and orthogonal transformation functions is an image transformant. The transformant is characterized by the distribution of its informative elements in the low-frequency and high-frequency regions.

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The product of the interaction of image elements and orthogonal transformation functions is an image transformant. The transformant is characterized by the distribution of its elements that carry information content in the low-frequency and high-frequency regions.

An assessment of the informativeness of transformants of different types of orthogonal transformations is carried out by determining the amount of information per one component of the transformant.

To assess the informativeness of transformants of various types of orthogonal transformations, informational estimates of the statistical redundancy in the Haar and Walsh transformants are carried out.

The estimation of the amount of information in the components of the Haar and Walsh transformation vector was carried out on the basis of the known values of the variance σ_x^2 of the original image elements and the covariance function $K(x_i; x_t)$ of this image. For this, a mathematical model of Walsh transformants has been developed.

Each component $y(k; \ell)$ of the transform is obtained as a result of a linear transformation of the elements of the original block of the image. The component value for block sizes is found by the formula:

$$y(k; \ell) = \frac{1}{C_H} \sum_{i=1}^{n} f(k; i)_{tr} \, x(i; j) , \qquad (9)$$

where $f(k; i)_{tr}$ – the value of the matrix of discrete values of the k-th basis function of the orthogonal transformation;

$x(i; j)$ – values of ij-th elements of the block of the original image;

C_H – is the normalization factor.

In accordance with Lyapunov's theorem [14], at large values $n \geq 8$, the probability distribution of the values $y(k; \ell)$ of the quantity approaches the normal distribution law. Then, for the known values of the variance $\sigma(x)_{ij}^2$ of the values $x(i; j)$, the variance $\sigma(y)_{k\ell}^2$ of the values $y(k; \ell)$ is equal to:

$$\sigma(y)_{k\ell}^2 = \frac{1}{C_H^2} \sum_{i=1}^{n} f(k; i)_{tr}^2 \, \sigma(x)_{ij}^2 + 2 \sum_{i<t}^{n} K(x_i; x_t) , \quad (10)$$

where C_H^2, $f(k; i)_{tr}^2$ - nonrandom quantities;

$K(x_i; x_t)$ – covariance coefficient equal to:

$$K(x_i; x_t) = \sigma(x)_{ij} \, \sigma(x)_{tj} \exp(-\alpha(i-t)) ;$$

$\sigma(x)_{ij}$, $\sigma(x)_{tj}$ – standard deviation of elements located in the source block, respectively, at positions with coordinates $(i; j)$ and $(t; j)$.

α – reciprocal of constant exponent.

As a result of the orthogonal transformation, we obtain a vector $Y^{(\lambda)}$ consisting of the components $y(k; \lambda)$:

$$Y^{(\lambda)} = \{ y(1; \lambda), ... y(n; \lambda) \} . \qquad (11)$$

Then, if the components of the $Y^{(\lambda)}$ vector correspond to the normal distribution law, then the differential entropy is equal to:

$$H_{tr}^{(B)} = \int_{-\infty}^{\infty} ... \int_{-\infty}^{\infty} P(y(1; \lambda), ... , y(n; \lambda)) \times$$
$$\times P(y(1; \lambda), ... , y(n; \lambda)) , \qquad (12)$$

where $P(y(1; \lambda), ... , y(n; \lambda))$ – is the joint probability density of the vector $Y^{(\lambda)}$ components.

For the normal law of the probability distribution of quantities $P(y(1; \lambda), ... , y(n; \lambda))$ is equal to

$$P(y(1; \lambda), ... , y(n; \lambda)) = \frac{1}{\sqrt{(2\pi)^n \Delta_n \prod_{k=1}^{n} \sigma(y)_{k\lambda}^2}} \times$$
$$\times \exp\left(-\frac{1}{2\Delta_n} \sum_{u=1}^{n} \frac{D_{ku} \, y(k; \lambda) \, y(u; \lambda)}{\sigma(y)_{k\lambda}^2 \, \sigma(y)_{u\lambda}^2} \right), \quad (13)$$

where Δ_n – is the normalized correlation determinant $\left\|R(y_{k\lambda};y_{u\lambda})\right\|$ of matrix with order n;

D_{ku} – its algebraic complement;

$R(y_{k\lambda};y_{u\lambda})$ – normalized covariance function:

$$R(y_{k\lambda};y_{u\lambda}) = \frac{K(y_{k\lambda};y_{u\lambda})}{\sigma(y)_{k\lambda}\,\sigma(y)_{u\lambda}}.$$

Formula (12) for finding the value $H_{tr}^{(B)}$ taking into account expression (13) is equal to:

$$H_{tr}^{(B)} = 1{,}43\,\ell og_2\sqrt{(2\pi e)^n}\prod_{k=1}^{n}\sigma(y)_{k\lambda}^2\,\Delta_n. \quad (14)$$

If the cross-correlation of the vector components $Y^{(\lambda)}$ increases, then the correlation determinant in the limit tends to 0. Otherwise, when the cross-correlation of the vector components $Y^{(\lambda)}$ decreases, the correlation determinant increases and tends to 1. Then expression (14) takes the form

$$H_{tr}^{(B)} = \sum_{k=1}^{n}H_{k\ell}^{(B)} = \sum_{k=1}^{n}1{,}43\,\ell og_2\,\sigma(y)_{k\ell}^2\sqrt{(2\pi e)}, \quad (15)$$

where $H_{k\lambda}^{(B)}$ – the amount of information on average per $(k;\lambda)$-th component of the vector $Y^{(\lambda)}$:

$$H_{k\lambda}^{(B)} = 1{,}43\,\ell og_2\,\sigma(y)_{k\lambda}^2\sqrt{(2\pi e)}. \quad (16)$$

Since, as a result of the orthogonal transformation, the de-correlation of the original elements occurs, the condition $\Delta_n = 1$ is satisfied for the joint distribution of the components of the transformant. This means that the amount of information in transformants of a discrete orthogonal transformation is estimated by the formula (15). From the analysis of expressions (15) and (16), it follows that in order to estimate the values of $H_{tr}^{(B)}$ and $H_{k\lambda}^{(B)}$, it is necessary to determine the value $\sigma(y)_{k\lambda}^2$ of the variance, which depends on the values $f(k;i)_{tr}^2$ (type of basis functions) of the variance of the elements of the original image blocks and the correlation coefficients $f(k;i)_{tr}^2$.

For most constituents, the variance of the Walsh transform component will be less than the variance of the Haar transform component. Therefore, the amount of information $H(W)_{tr}^{(B)}$ per vector of components of the Walsh transform will be less than the amount of information $H(H)_{tr}^{(B)}$ per vector of components of the Haar transform:

$$H(W)_{tr}^{(B)} < H(H)_{tr}^{(B)}. \quad (17)$$

Consequently, as a result of the Walsh transform, an output sequence is generated that carries a smaller amount of information. This means that the Walsh transform has more potential for increasing the compression ratio when processing weakly correlated images than the Haar transform.

Image processing methods based on DCT and wavelet transforms result the use of algorithms of higher computational complexity and have a real type of mathematical operations, which, in turn, will increase the time spent on image processing. This results a high probability of non-compliance with the requirement to maintain its relevance in real time [1-3].

Development of a video data compression method with an orthogonal transformation subsystem. To solve this problem, a method of video information compression based on the classification coding of transformants of piecewise constant functions is proposed (Fig. 3).
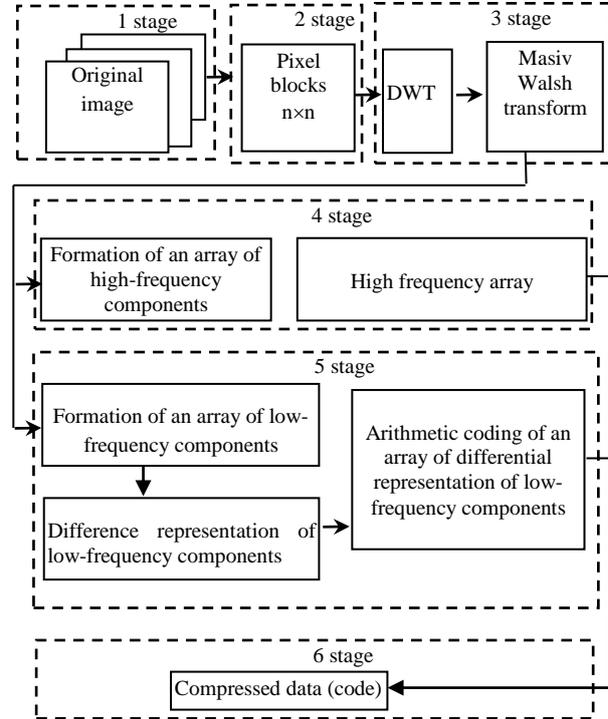

Fig. 3. Block diagram of the video information compression method based on the classification coding of transformants of piecewise constant functions

The proposed compression method includes a discrete orthogonal Walsh transform, with a preliminary

division of the original image into blocks of pixel $n \times n$ dimensions and integer arithmetic coding of the classified Walsh transformants.

The technology of the developed coding method includes several stages.

The first stage involves reading the original components of the image in $M \times N$ dimension.

The second stage involves the formation of three working matrices based on RGB color components. It is assumed here that each matrix of the color component is divided into blocks of $n \times n$ pixels (Fig. 4).

This is due to the non-stationary properties of the image in different parts of the frame and a large number of operations to perform orthogonal transformation for the entire image frame. Performing orthogonal transformations for local blocks will increase the degree of homogeneity of structural properties (degree of coherence) and reduce the number of operations for the Walsh transform.

In case of multiples of frame sizes $n \times n$, the number of blocks Z will be equal to:

$$Z = M \times N / n^2 . \qquad (18)$$

At the third stage of the compression process, a two-dimensional discrete Walsh transform is performed (Fig. 5).
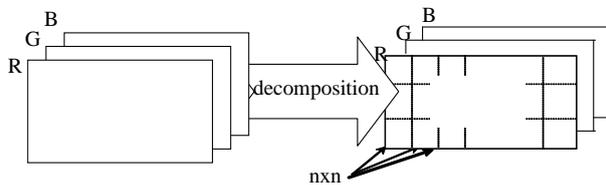

Fig. 4. The stage of splitting the matrices of color components of the original image into blocks of equal pixel $n \times n$ sizes
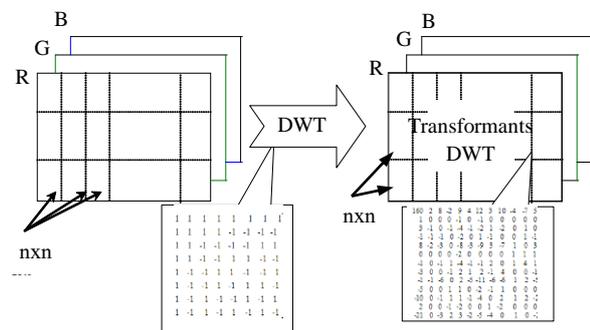

Fig. 5. Forming arrays of Walsh transforms

This stage is given by the expressions:

$$Y(n,n) = \frac{1}{n^2} F_W(n) \, X(n,n) \, F_W(n) ; \qquad (19)$$

$$F_W(k,\ell) = (-1)^{\sum_{\xi=0}^{\ell og_2 n - 1} \upsilon_\xi(k)\ell_\xi} ; \quad k,\ell = \overline{0, \, n-1}; \quad (20)$$

$$\upsilon_0(k) = k_{q-1}; \qquad \upsilon_1(k) = k_{q-1} + k_{q-2} ,$$

where $Y(n,n)$ – transformant of the orthogonal Walsh transform with dimension $n \times n$;

$X(n,n)$ – array of size $n \times n$, composed of elements of the original image;

$F_W(n)$ – column of the matrix of discrete values of the basis function of the Walsh transform.

As a result of performing the orthogonal Walsh transform on the image blocks, a sequence of transformants with the size $n \times n$ of elements is formed.

As a result of performing the orthogonal Walsh transform, in addition to reducing the degree of statistical relationships, a decrease in psycho-visual redundancy is carried out.

An additional increase in the compression ratio is possible by taking into account the features of the DWT transformants. These features are that:

1) the low-frequency and high-frequency components of the transformants of orthogonal transformations carry different amounts of information. The maximum value of the component falls on the first element of this matrix, located in the upper left corner;

2) the distribution laws of the probabilities of the appearance of the values of the low-frequency and high-frequency components of the transforms of the DWT transformation performed for realistic images are approximated, respectively, by the normal law and the Rayleigh distribution law.

Taking into account these features, in order to further increase the degree of image compression, it is proposed to organize separate processing of low-frequency and high-frequency components.

To further increase the value of the compression ratio, the classification coding of the Walsh transform transforms is used. The proposed coding is based on separating the low-frequency components of the transformants into a separate array of coefficients. Further, it is assumed that the high-frequency and low-frequency components of the transformants are processed separately, which takes into account their different dynamic ranges.

Before such processing, the amount of information $H_{тр}$ in the DWT transform was equal to [14]:

$$H_{tr} = - n^2 \, H_{tr}^{(W)} =$$

$$= - n^2 \sum_{y(k;\ell)=0}^{S_{tr}} P(y(k;\ell)) \, \ell og_2 P(y(k;\ell)) , \qquad (21)$$

where S_{tr} – power of the alphabet transformants, equal to the number of different component values;

$H_{tr}^{(W)}$ – the amount of information, on average per one component of the DWT.

Since the value that the low-frequency component takes differs from the values of other transformants, then, in the case of dividing the transformant, the amount of information $H_{tr}^{(B)}$ in the remaining components will be equal to:

$$H_{tr}^{(B)} = -(n^2 - 1) \sum_{y(k;\ell)=0}^{S_{tr}-1} P(y(k;\ell)) \; \ell og_2 P(y(k;\ell)) \; , \tag{22}$$

etc.:

$$H_{tr} = H_{tr}^{(B)} + P(y(1;1)) \; \ell og_2 P(y(1;1)) \; . \tag{23}$$

Since $P(y(1;1)) = \dfrac{1}{n^2}$, this ratio will take the form:

$$H_{tr} = H_{tr}^{(B)} + \frac{1}{n^2} \; \ell og_2 \frac{1}{n^2} \; . \tag{24}$$

Comparison of expressions (21) and (23) implies that:

$$H_{tr} > H_{tr}^{(B)} \; . \tag{25}$$

In order for the amount of information $H^{(N)}$ contained in the low-frequency component $y(1;1)$ to be less than the value $P(y(1;1)) \; \ell og_2 P(y(1;1))$, according to the expression:

$$H^{(N)} < P(y(1;1)) \; \ell og_2 P(y(1;1)) \; , \tag{26}$$

it is required to carry out additional processing of low-frequency components. For this, it is necessary to take into account the fact that low-frequency components are a characteristic of the average brightness in a fragment of the image. Moreover, this characteristic of local fragments is relatively uniform for adjacent parts of the image frame. In this regard, it is proposed to form arrays of low-frequency components.

Figure 6 shows the mechanism for the separate processing of the DWT coefficients.

When choosing a method for processing low-frequency components, it is necessary to take into account the fact that the human eye perceives a realistic image in terms of the frequency of color boundaries. Hence follows the importance of the low-frequency coefficients of the DWT transformant. Consequently, the loss of some of the low-frequency coefficients can lead to a significant loss of information.
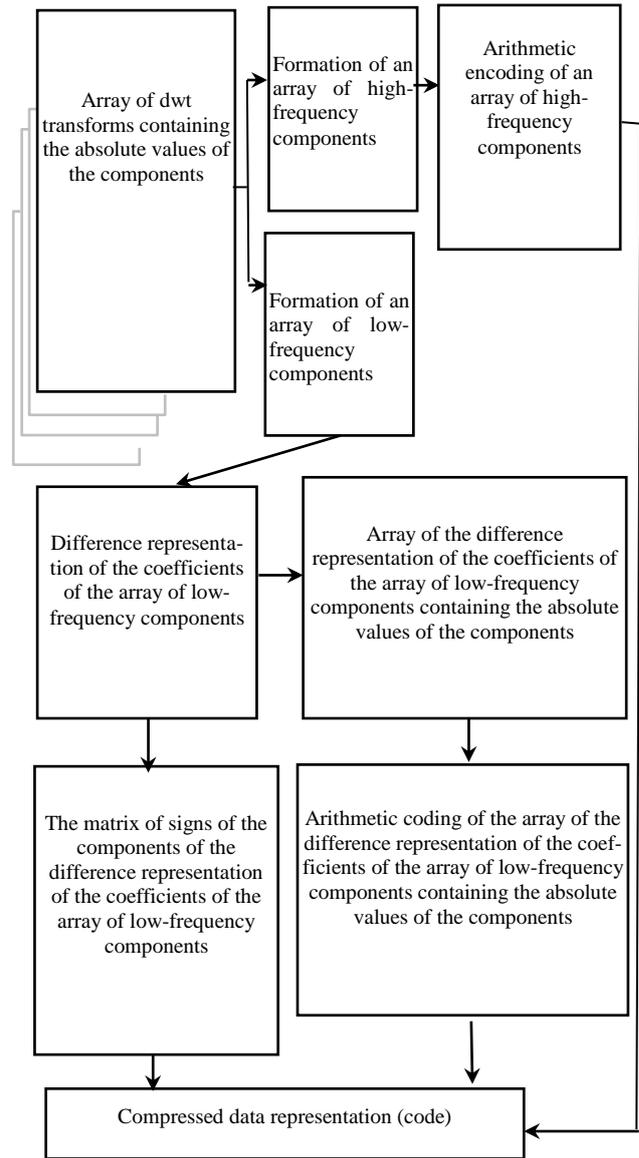

Fig. 6. Structural diagram of the mechanism for separate processing of DWT coefficients

Therefore, it is proposed to compress the arrays of low-frequency components based on the elimination of statistical redundancy by means of their arithmetic coding. The amount of information $H^{(H)}$ per element of the low-frequency components matrix is equal to:

$$H^{(N)} = - \sum_{y(k;\ell)=0}^{S_m^{(N)}} P_N(y(k;\ell)) \; \ell og_2 P_N(y(k;\ell)) \; , \tag{27}$$

where $S_m^{(N)}$ – the power of the array of low-frequency components, equal to the number of different component values;

$P_N(y(k;\ell))$ – the probability of occurrence of a low-frequency component with value $y(k;\ell)$.

This allowed to increase the compression ratio by 20%, which in turn led to a decrease in the amount of image data entering the communication channel (Fig. 7).

In fig. 7 shows the following compression methods: 1 – JPEG-2000; 2 – developed method; 3 – JPEG.
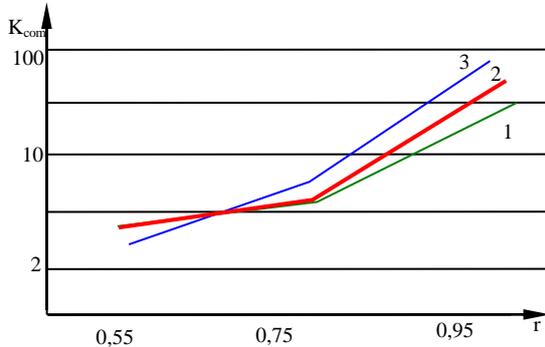

Fig. 7. Graphs of the dependence of the compression ratio K_{com} on the degree of correlation for developed and existing compression methods

To obtain on the receiving side of the original images with a minimum error, a reconstruction method has been developed that takes into account the features of the compression process, including: the classification of code combinations of the arithmetic code formed for the arrays of high-frequency components and arrays of low-frequency components of the Walsh transform. When forming the DWT transformant, it is taken into account that the low-frequency components are presented in a difference form. After forming the transform, the inverse two-dimensional discrete Walsh transform is performed.

The estimation of the compression ratio for highly correlated images (correlation coefficient at the level of 0.55) is given in Figure 8.
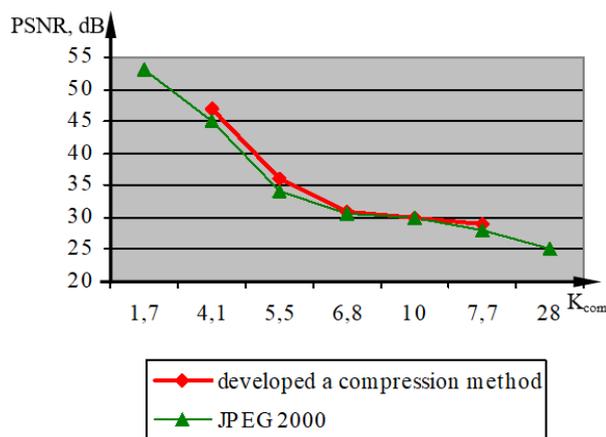

Fig. 8. Graphs of dependence of peak signal-to-noise (PSNR) on the degree of compression ratio K_{com} for developed and existing compression methods

The developed method has an advantage in the signal-to-noise ratio of 1-2 dB, compared to JPEG-2000.

Conclusions

Comparative evaluation of the developed and known methods of image compression allows us to assert:

The developed compression method based on classification coding and Walsh transforms provides:

1) in case of equality of RMS:

- gain in compression ratio relative to the method implemented in the JPEG format for highly saturated images by an average of 38 %;

- in comparison with the method implemented in the JPEG 2000 format, the gain in the compression ratio for low-saturated images is on average 14%, and for medium and highly saturated images the compression ratio does not differ significantly (on average it does not exceed 1 %);

2) the loss of quality of the compressed/reconstructed image does not exceed 2 % according to the RMS criterion or is not worse than 45 dB according to the PSNR criterion. Which is not perceptible to the human eye;

3) the developed compression method provides only an integer type of arithmetic operations, which significantly affects the speed of the compression algorithm and a decrease in round-off errors in computer calculations in comparison with existing compressors;

4) the gain in time for bringing compressed images based on the developed method relative to the known methods reaches, on average, 2 times. This gain is because, with a slight difference in the compression ratio of highly saturated images in comparison with the JPEG-2000 method, the processing time for the developed method will be at least 34% less. Moreover, with an increase in the volume of transmitted images and the speed of data transmission over the communication channel, the gain in time to finish for the developed method will increase.

Thus, the purpose of the article on ensuring the necessary level of availability and authenticity of information when transmitting video data is considered to be achieved.

For the first time, the method of classification (separate) coding (compression) of high-frequency and low-frequency components of Walsh transformants of a video image is offered and investigated that allows considering their various dynamic range and the statistical redundancy reduced with the use of arithmetic coding. This method will allow ensuring the necessary level of accessibility and authenticity when transmitting

video data while maintaining strict statistical regulations. It should be noted that the proposed methods fulfill the set tasks to increase the efficiency of information delivery.

At the same time, the method of reducing the time complexity of the conversion of highly saturated video images using their representation by the transformants of the discrete Walsh transformation was further developed. It is substantiated that the perspective direction of improvement of methods of image compression is the application of orthogonal transformations based on integer piecewise-constant functions and methods of integer arithmetic coding of values of transformant transformations.

It is substantiated that the joint use of Walsh transformation and arithmetic coding, which reduces the time of compression and recovery of images; reduces additional statistical redundancy. To further increase the degree of compression, a classification coding of low-frequency and high-frequency components of Walsh transformants is developed. It is shown that an additional reduction of statistical redundancy in the arrays of low-frequency components of Walsh transformants is achieved due to their difference representation. Recommendations on the parameters of the compression method for which the lowest value of the total time of delivery is provided are substantiated.

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КОМПРЕССИЯ ИЗОБРАЖЕНИЙ НА ОСНОВЕ КЛАССИФИКАЦИОННЫХ КОДИРОВКИ ТРАНСФОРМАНТОВ КУСОЧНО-ПОСТОЯННЫХ ФУНКЦИЙ

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Предметом исследований в статье являются процессы обработки видеоизображения с применением ортогонального преобразования для передачи данных в информационно-телекоммуникационных сетях. **Задача**: исследования известных алгоритмов селективной обработки статического видеоизображения на этапе аппроксимации и статистического кодирования данных на основе JPEG-платформы. Используемыми **методами** являются: алгоритм на основе JPEG-платформы, методы аппроксимации ортогональным преобразованием информативных блоков, арифметическое кодирование. Представлено **решение научной задачи**, направленной на разработку методов уменьшения вычислительной сложности преобразований (компрессии и декомпрессии) статических видеоизображений в аппаратуре обработки сигналов визуальной информации, что обеспечит повышение оперативности доведения информации. Получены следующие **результаты**. Разработан метод компрессии видеоизображений с сохранением оперативности его доставки при заданной информативной достоверности. Метод основан на на классификационном арифметическом кодировании трансформант Уолша.Что позволит при при сохранении структурно - статистической закономерности выполнить поставленные требования. Обеспечение выигрыша по времени доведения сжатых видеоданных на основе разработанного метода, по сравнению с известными методами, в среднем до 2 раз. Данный выигрыш обусловлен тем, что при незначительной разнице в коэффициенте сжатия сильнонасыщенных изображений по сравнению с методом JPEG-2000, для разработанного метода время обработки будет меньше минимум на 34%. Причем с ростом объемов передаваемых изображений и скорости передачи данных по каналу связи - выигрыш по времени, для разработанного метода будет увеличиваться. При этом, потеря качества сжатого / восстановленного изображения не превышает 2% по критерию RMS, или не хуже 45 дБ по критерию PSNR. Что не ощутимо для человеческого глаза. **Выводы**. Научная новизна полученных результатов заключается в следующем: впервые предложен и исследован метод классификационного (раздельного) кодирования (сжатия) высокочастотных и низкочастотных составляющих трансформант Уолша видеоизображения, позволяющая учитывать их разный динамический диапазон и статистическую избыточность, уменьшающуюся с использованием арифметического кодирования. Такой подход позволит при сохранении структурно - статистической закономерности обеспечить необходимый уровень доступности и достоверности при передаче видеоданных. Пердлагаемый подход выполняет поставленные завдачи по повышению оперативности доведения информации. При этом, получил дальнейшее развитие метод уменьшения временной сложности преобразования сильнонасыщенных видеоизображений с использованием их представления трансформант дискретного преобразования Уолша.

Ключевые слова: изображение; компрессия; информационная интенсивность; ортогональные преобразования.

КОМПРЕСІЯ ЗОБРАЖЕНЬ НА ОСНОВІ КЛАСИФІКАЦІЙНОГО КОДУВАННЯ ТРАНСФОРМАНТ КУСКОВО-ПОСТІЙНИХ ФУНКЦІЙ

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Предметом досліджень в статті є процеси обробки відеозображення з застосуванням ортогонального перетворення для передачі даних у інформаційно-телекомунікаційних мережах. **Метою** є побудова методу компресії відеозображень зі збереженням оперативності його доставки при заданій інформативній вірогідності. Що дозволить при збереженні структурно -статистичної закономірності та контрольованої

втрати якості, забезпечити виграш за часом доведення стиснутих відеозображень, необхідний рівень доступності та достовірності при передачі відеоданих. **Завдання:** дослідження відомих алгоритмів селективної обробки статичного відеозображення на етапі апроксимації та статистичного кодування даних на основі JPEG-платформи. Використовуваними **методами** є: алгоритм на основі JPEG-платформи, методи апроксімації ортогональним перетворенням інформативних блоків, арифметичне кодування. Представлено **рішення наукової задачі**, спрямованої на розробку методів зменшення обчислювальної складності перетворень (компресії і декомпресії) статичних відеозображень в апаратурі обробки сигналів візуальної інформації, що забезпечить підвищення оперативності доведення інформації. Отримані такі **результати.** Розроблено метод компресії відеозображення зі збереженням оперативності його доставки при заданій інформативній вірогідності. Що дозволить при збереженні структурно-статистичної закономірності виконати поставлені вимоги. Забезпечити виграш за часом доведення стиснутих зображень на основі розробленого методу, щодо відомих методів, в середньому до 2 разів. Даний виграш обумовлений тим, що при незначній відміні в коефіцієнті стиснення сильнонасичених зображень в порівнянні з методом JPEG-2000, для розробленого методу час обробки буде менше мінімум на 34%. Причому з ростом обсягів переданих зображень і швидкості передачі даних по каналу зв'язку - виграш за часом доведення для розробленого методу буде збільшуватися. При цьому, втрата якості стисненого / відновленого зображення не перевищує 2% за критерієм RMS, або не гірше 45 дБ за критерієм PSNR. Що ні відчутно для людського ока. **Висновки.** Наукова новизна отриманих результатів полягає в наступному: вперше запропонований і досліджений метод класифікаційного (роздільного) кодування (компресії) високочастотних і низькочастотних складових трансформант Уолша відеозображення, що дозволяє враховувати їх різний динамічний діапазон і статистичну надмірність, зменшувану з використанням арифметичного кодування. Такий підхід дозволить при збереженні структурно – статистичної закономірності забезпечити необхідний рівень доступності та достовірності при передачі відеоданих. Варто зазначити, що запропоновані підходи виконують поставлені завдання щодо підвищення оперативності доведення інформації. При цьому, одержав подальший розвиток метод зменшення часової складності перетворення сильнонасичених відеозображень з використанням їх представлення трансформантами дискретного перетворення Уолша. Обґрунтовано, що перспективним напрямком удосконалення методів стиску зображень є застосування ортогональних перетворень на основі цілочисельних кусково-постійних функцій, і методів цілочисельного арифметичного кодування значень трансформант перетворення. Обґрунтовано, що спільне використання перетворення Уолша і арифметичного кодування, яке дозволяє знизити час стиснення і відновлення зображень; скоротити додаткову статистичну надмірність. Для додаткового підвищення ступеня стиску розробляється класифікаційне кодування низькочастотних і високочастотних складових трансформант Уолша. Показано, що додаткове скорочення статистичної надмірності в масивах низькочастотних компонент трансформанти Уолша досягається за рахунок їх різницевого подання. Обґрунтовуються рекомендації щодо параметрів методу стиснення, для яких забезпечується найменше значення сумарного часу доведення інформації.

Ключові слова: зображення; компресія; інформаційна інтенсивність; ортогональні перетворення.

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