Date of publication SEP-30, 2022, date of current version AUG-02, 2022.
www.computingonline.net / computing@computingonline.net

Print ISSN 1727-6209
Online ISSN 2312-5381
DOI 10.47839/ijc.21.3.2692

Compression Coding Method Using Internal Restructuring of Information Space

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ABSTRACT The subject of the study in this article is data transmission processes of the video information resource in the information communication systems of the air segment under the conditions of errors in the data transmission channel. The purpose of the article is the development of the method of compression coding in order to ensure an increase in the level of reliability of video information resources under the conditions of errors in communication channels. The following tasks are identified: to develop a method of compression coding using structural decomposition of statistical space; analyze the effectiveness of the developed method from the standpoint of ensuring the required level of reliability. The following results are obtained: the developed method of encoding video information allows increasing the level of reliability in the conditions of the transmission of video information resources in the information communication systems of the air segment due to the localization of the action of errors.

KEYWORDS video information resource; restructuring; quantitative sign; coding; reliability; communication channel.

I. INTRODUCTION

To date, the main trend in the development of algorithms used to encode multimedia data is the direction that determines the improvement of compression characteristics [1-7]. It should be noted that modern video data coding technologies are implemented on the basis of the JPEG platform, which quite actively uses a statistical approach at the final stage of data processing [8-13]. However, the use of the specified approach in the conditions of the use of air segment information communication systems is associated with a number of problematic aspects associated with the presence of errors occurring in data transmission channels [14-19]. This leads to significant shortcomings arising in the process of video data reconstruction, from the point of view of ensuring the appropriate level of reliability. The main ones are the following [20-23, 25]: loss of relevance due to time delays arising in the process of video data delivery; partial or complete destruction of video data, which makes it impossible to identify key elements.

Thus, the use of statistical coding technologies, which are implemented in modern algorithms for coding video information, allows compact presentation of coded data, but does not provide the required level of reliability under the conditions of errors occurring in communication channels.

II. RELATED WORK

The papers [24-30] analyzed the shortcomings of modern video data coding methods from the point of view of ensuring the required level of reliability. Thus, the main disadvantage of existing compression coding methods is the avalanche effect of errors occurring in data transmission channels [32-35]. Fig. 1 shows the results of experimental studies of video image reconstruction (options a) in Fig. 1) under the conditions of errors in the communication channel.

The test image airplane.bmp was used as initial data [31] encoded using an algorithm JPEG. Modeling of the data transmission channel was carried out at the following error levels: $P(\varepsilon) = 10^{-4}$ (options b) in Fig. 1); $P(\varepsilon) = 10^{-5}$ (options c) in Fig. 1).

Analysis of the results shown in Fig. 1 indicates that:

- when the level of errors in the data transmission channel is equal to $P(\varepsilon) = 10^{-4}$, in the process of reconstruction, the video image is destroyed (options b) in Fig. 1). This is due to the avalanche effect of the action of errors;

- when the level of errors in the data transmission channel is equal to $P(\varepsilon) = 10^{-5}$, in the process of reconstruction, a partial destruction of the video image occurs (options c) in

Fig. 1). However, even partial destruction leads to the loss of key elements of the video image.

Thus, the analysis of the results of experimental studies shows that the use of existing technologies of compression coding does not allow ensuring the required level of reliability of video information for information communication systems of the air segment under the conditions of errors in the communication channel.

In turn, existing approaches to solving the specified problem are based on the use of noise-resistant coding methods. But the use of these methods leads to a significant increase in the size of coded data due to the use of additional correction bits in accordance with the level of errors that occur in the process of video data delivery. This, in turn, leads to the fact that in the conditions of bandwidth limitations of data transmission channels, there are time delays that lead to the loss of relevance of the received video data. That is, along with improving the level of reliability, there are significant problems with the efficiency of delivery of video information resources.

Therefore, increasing the level of reliability of video images for information communication systems of the air segment in the conditions of errors in communication channels is an urgent scientific and applied task.

The purpose of the article is to develop a method of compression coding using the internal restructuring of the information space to increase the level of reliability under the conditions of errors in the data transmission channel.

a) test image b) $P(\varepsilon) = 10^{-4}$ c) $P(\varepsilon) = 10^{-5}$

Figure 1. The results of the reconstruction of images with different degrees of saturation at a given level of errors in a discrete symmetric transmission channel without memory: a) weakly saturated; b) moderately saturated; c) highly saturated

III. DEVELOPMENT OF A COMPRESSION CODING METHOD USING INTERNAL RESTRUCTURING OF INFORMATION SPACE

To develop a method of encoding video data in order to increase the level of reliability in the event of errors in the communication channel, it is necessary to formulate a number of requirements, the fulfillment of which must ensure:

1) localization of the action of errors to reduce their impact on the destructive action in the process of video data reconstruction;

2) additional reduction of structural redundancy of coded video data.

Therefore, the video data processing process is proposed to be carried out in two stages:

1st stage: restructuring of the information space by counting the regularities found in the binary representation of coded data;

2nd stage: coding information resource data using the structural decomposition of the statistical space.

The structural and functional scheme of codegram formation for the message element using the specified approach is shown in Fig. 2.

It is proposed to consider in more detail each of the stages of the codegram formation assigned to the message element, according to the proposed approach.

Thus, at the first stage, it is proposed to carry out the restructuring of the information space by taking into account the regularities found in the binary representation of coded data. An internal binary structure means the sequence of binary digits, which specifies the element u_ξ in the message $U(\theta)$. Binary representation of the element u_ξ consists of a sequence $[u_\xi]_2$ of binary digits $q_{\xi,\alpha}$, $\alpha = \overline{1, |u_\xi|_2}$: This is set as follows:

$$[u_\xi]_2 = \{q_{\xi,1};\ ...;\ q_{\xi,\alpha};\ ...;\ q_{\xi,|u_\xi|_2}\}, \quad (1)$$

where $q_{\xi,\alpha}$ is α-th digit of the element u_ξ.

In turn, a set of signs λ for video sequence $U(\theta)$ is described by the following expression:

$$\Lambda(U(\theta)) = \{\lambda_1, ..., \lambda_i, ..., \lambda_{|\Lambda(U(\theta))|}\}, \lambda = \overline{\lambda_1; \lambda_{|\Lambda(U(\theta))|}}, \quad (2)$$

where $\Lambda(U(\theta))$ is a set of signs λ, which is found in the internal binary structure $[u_\xi]_2$ of elements u_ξ in the message $U(\theta)$;

$|\Lambda(U(\theta))|$ is the feature set power λ for video sequence $U(\theta)$;

λ_i is i-th value of the sign λ.

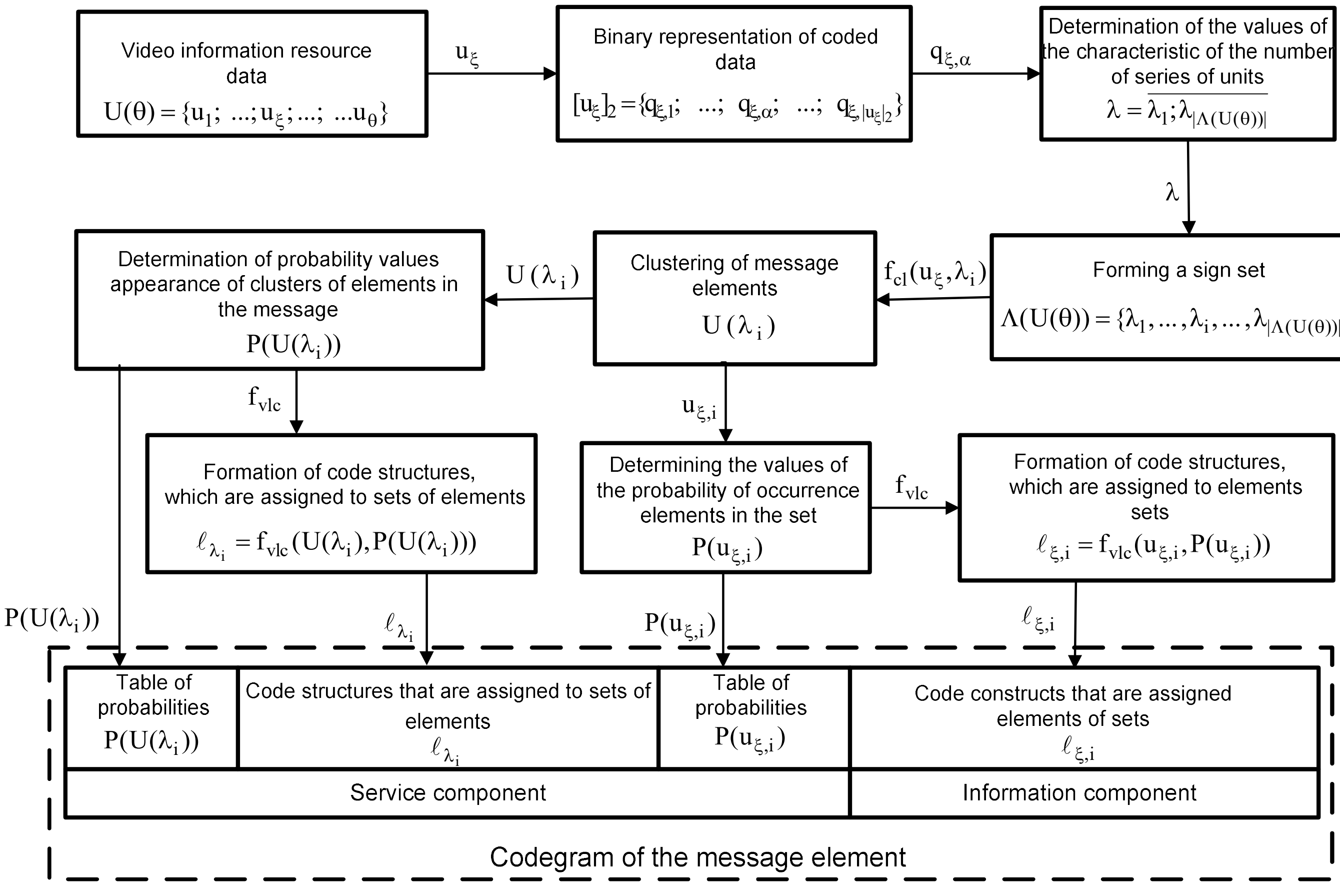


Figure 2. The structural and functional diagram of the formation of the message element codegram

To increase the efficiency of statistical coding from the standpoint of improving the reliability of video information and further reducing code redundancy, it is proposed to develop a technology for clustering video sequence data $U(\theta)$ on a quantitative sign λ.

Video sequence clustering $U(\theta)$ on a quantitative basis λ is given by the following expression:

$$U(\theta)\xrightarrow{f_{cl}}\{U(\lambda_1),...,U(\lambda_i),...,U(\lambda_{|\Lambda(U(\theta))|})\}, \quad (3)$$

where f_{cl} is the message clustering functionality $U(\theta)$ of the set $U(\lambda_i)$ on the sign of λ, $\lambda=\overline{\lambda_1,\lambda_{|\Lambda(U(\theta))|}}$;

$U(\lambda_i)$ is a set (cluster) of elements u_ξ, the binary representation of which has the same value of the sign λ, i.e., $\lambda=\lambda_i$.

For internal data restructuring, it is proposed to use quantity as a quantitative sign λ series of units (SU) in the binary representation of elements u_ξ.

Clustering of elements u_ξ of video sequences $U(\theta)$ with the same amount of SU is given by the following expression:

$$f_{cl}(u_\xi,\lambda_i): U(\theta)\xrightarrow{f_{cl}}\{U(\lambda_1);...;U(\lambda_i);...;U(\lambda_{|\Lambda(U(\theta))|})\}, \quad (4)$$

where $f_{cl}(u_\xi,\lambda_i)$ is the element clustering functionality u_ξ of video sequences $U(\theta)$ with the same amount λ_i SU.

The advantage of using this quantitative feature is the simplicity of algorithmic implementation (the process of forming a quantitative feature involves the use of only arithmetic and logical operations).

In turn, power $|U(\lambda_i)|$ cluster $U(\lambda_i)$ alphabet, elements u_ξ which have the value of the sign λ SU, equal to $\lambda=\lambda_i$, is defined by the following expression:

$$|U(\lambda_i)|=\frac{(|u_\xi|_2+1)!}{(2\lambda_i)!\ (|u_\xi|_2+1-2\lambda_i)!}. \quad (5)$$

In turn, the alphabet $\Lambda(U(\vartheta))$ signs of quantity λ SU for the alphabet $U(\vartheta)$ elements of the video sequence $U(\theta)$ depends on the length $|u_\xi|_2$ of binary representation $[u_\xi]_2$ of the element u_ξ. So, for the case where the length $|u_\xi|_2$ of binary representation $[u_\xi]_2$ of the element u_ξ has an even value, i.e.:

$$|u_\xi|_2=2\times Z^{\geq},$$

where $Z^{\geq}$ is the set of positive integers.

The alphabet $\Lambda(\mathrm{U}(\vartheta))$ of the sign λ of the amount of SU will be as follows:

$$\Lambda(U(\vartheta)) = \overline{0, \frac{|u_{\xi}|_2}{2}}. \quad (6)$$

As a result of clustering the alphabet $\mathrm{U}(\vartheta)$ of video sequences $\mathrm{U}(\theta)$ on the basis of quantity λ SU will form sets $\mathrm{U}(\lambda_{\mathrm{i}})$, the number of which is set by the power $|\Lambda(\mathrm{U}(\vartheta))|$ alphabet $\Lambda(\mathrm{U}(\vartheta))$ signs:

$$|\Lambda(U(\vartheta))| = \frac{|u_{\xi}|_2}{2} + 1. \quad (7)$$

Next, it is proposed to investigate the second stage - data coding of the video information resource using the structural decomposition of the statistical space, which was performed at the previous stage.

For this purpose, it is proposed to use a two-hierarchical scheme of statistical coding with clustering (TSCC). Fig. 2 presents the structural and functional scheme of the formation of the codegram of the message element using a probabilistic-statistical approach to the formation of the informational and service parts of the codegram – a two-hierarchical coding scheme.

The essence of the two-hierarchical scheme of statistical coding with clustering is as follows:

– at the first stage, statistical coding of the elements u_{ξ} of the message $U(\theta)$ in the statistical space of sets $U(\lambda_{\mathrm{i}})$, that is, an informational component is formed $\ell_{\xi,i}$ codegram ℓ'_{ξ} (Fig. 2);

– at the second stage, statistical coding of clusters is proposed $U(\lambda_{\mathrm{i}})$ elements u_{ξ} with the same values of the quantity sign λ_{i} SU in the statistical space of the message $U(\theta)$. As a result, code constructions (CC) $\ell_{\lambda_{\mathrm{i}}}$ will be formed, which are identifiers for non-uniform code structures $\ell_{\xi,i}$, formed at the first stage of coding - the code part of the service component of the codegram.

The service part of the codegram, except for information about the distribution of probability values $P(u_{\xi,i})$ appearance of elements $u_{\xi,i}$ in the cluster $U(\lambda_{\mathrm{i}})$, includes a table of cluster occurrence probabilities $U(\lambda_{\mathrm{i}})$ of elements $u_{\xi,i}$ in the message $U(\theta)$ (Fig. 2).

Statistical coding of elements $u_{\xi,i}$ of a set $U(\lambda_{\mathrm{i}})$, which consists of κ - elements ($\xi = \overline{1,\kappa}$), is given by the following expression:

$$U(u_{\xi,i}) \xrightarrow{f_{vlc}} L'(\kappa), \xi = \overline{1,\kappa}, \quad (8)$$

where $f_{vlc}(u_{\xi,i}, P(u_{\xi,i}))$ is the function of forming uneven code structures $\ell_{\xi,i}$ for elements $u_{\xi,i}$ of the set $U(\lambda_{\mathrm{i}})$.

Information about the distribution of probability values is used here $P(u_{\xi,i})$ appearance of elements $u_{\xi,i}$ in sets $U(\lambda_{\mathrm{i}})$ (Fig. 2), taking into account which is based on the function $f_{vlc}(u_{\xi,i}, P(u_{\xi,i}))$ a code structure is formed $\ell_{\xi,i}$. This function is described by the following expression:

$$\ell_{\xi,i} = f_{vlc}(u_{\xi,i}, \mathrm{P}(u_{\xi,i})), \quad (9)$$

where $\ell_{\xi,i}$ is uneven CC assigned to cluster $U(\lambda_{\mathrm{i}})$ element $u_{\xi,i}$;

$P(u_{\xi,i})$ is probability of appearance of elements $u_{\xi,i}$ in the cluster $U(\lambda_{\mathrm{i}})$.

As a result of statistical coding of elements $u_{\xi,i}$ plural $U(\lambda_{\mathrm{i}})$ a set $L'(\kappa)$ of code constructions $\ell_{\xi,i}$ is formed, which has the following form:

$$L'(\kappa) = \{\ell_{1,i};\ \ldots;\ \ell_{\xi,i};\ \ldots;\ \ell_{k,i}\}, \quad (10)$$

where κ is the number of non-uniform code constructions in the set of codes $L'(\kappa)$.

Internal binary structure of uneven code structures $\ell_{\xi,i}$, which are assigned to the elements $u_{\xi,i}$ clusters $U(\lambda_{\mathrm{i}})$ consists of a sequence $[\ell_{\xi,i}]_2$ of binary digits $q_{\xi,\alpha}$, $\alpha = \overline{1, |\ell_{\xi,i}|_2}$. This is given as follows:

$$[\ell_{\xi,i}]_2 = \{q_{\xi,1};\ \ldots;\ q_{\xi,\alpha};\ \ldots;\ q_{\xi,|\ell_{\xi,i}|_2}\}, \quad (11)$$

where $q_{\xi,\alpha}$ is α-th digit of the code structure $\ell_{\xi,i}$;

$|\ell_{\xi,i}|_2$ is the length of the uneven code structure $\ell_{\xi,i}$, which is assigned to the element $u_{\xi,i}$ cluster $U(\lambda_{\mathrm{i}})$.

Accordingly, a set of code constructions that will be formed in the process of coding elements u_{ξ} of message $U(\theta)$ in the statistical space of sets $U(\lambda_{\mathrm{i}})$ will appear as the following expression:

$$L'(\theta) = \{\ell_{\xi,1};\ \ldots;\ \ell_{\xi,i};\ \ldots;\ \ell_{\xi,|\Lambda(U(\theta))|}\}, \xi = \overline{1,\theta},$$
$$i = \overline{1, |\Lambda(U(\theta))|}, \quad (12)$$

where θ is the number of elements in the set of codes $L'(\theta)$.

Statistical coding of sets into which elements are combined in the process of clustering u_{ξ} message $U(\theta)$ with the same values of the quantity sign λ SU is given by the following ratio:

$$U(\lambda_i) \xrightarrow{f_{vlc}} L(\lambda_i), \qquad (13)$$

where $f_{vlc}(U(\lambda_i), P(U(\lambda_i))$ is the function of forming uneven code constructions ℓ_{λ_i} for sets $U(\lambda_i)$ of elements $u_{\xi,i}$, $i = \overline{1, |\Lambda(U(\theta))|}, \xi = \overline{1, \theta}$.

Information about the probability distribution of the occurrence of sets is used here $U(\lambda_i)$ elements $u_{\xi,i}$ in the initial message $U(\theta)$. Given this information based on the function $f_{vlc}(U(\lambda_i), P(U(\lambda_i))$ a code structure ℓ_{λ_i} is formed. This function is described by the following formula:

$$\ell_{\lambda i} = f_{vlc}(U(\lambda_i), P(U(\lambda_i)), \qquad (14)$$

where $P(U(\lambda_i))$ is the probability of the appearance of a set $U(\lambda_i)$ in the message $U(\theta)$.

As a result of encoding sets $U(\lambda_i)$ of elements $u_{\xi,i}$ in the statistical space of the message $U(\theta)$ a set $L(\lambda_i)$ of codes ℓ_{λ_i} is formed, which is as follows:

$$L(\lambda_i) = \{\ell_{\lambda_1}; \ ...; \ \ell_{\lambda_i}; \ ...; \ \ell_{\lambda_{|\Lambda(U(\theta))|}}\}. \qquad (15)$$

Code ℓ_{λ_i} is an uneven length code $|\ell_{\lambda_i}|_2$ consisting of the sequence $[\ell_{\lambda_i}]_2$ of binary digits $q_{\lambda_i,\alpha}$, $\alpha = \overline{1, |\ell_{\lambda_i}|_2}$. This is given as follows:

$$[\ell_{\lambda_i}]_2 = \{q_{\lambda_i,1}; \ ...; \ q_{\lambda_i,\alpha} \ ...; \ q_{\ell_{\lambda_i},|\ell_{\lambda_i}|_2}\}, \qquad (16)$$

where $q_{\lambda_i,\alpha}$, is α-th digit of the code structure ℓ_{λ_i}.

Thus, as a result of using the proposed coding scheme (TSCC), a codegram ℓ'_ξ will be formed in length $|\ell'_\xi|_2$, the internal binary structure $[\ell'_\xi]_2$ which is given by the following expression:

$$[\ell'_\xi]_2 = [\ell_{\lambda_i}]_2 \cup [\ell_{\xi,i}]_2. \qquad (17)$$

IV. RESULTS

The effectiveness of the developed method of encoding data of video information resource using the internal restructuring of the information space from the point of view of ensuring an increase in the level of reliability is estimated.

It should be noted that the method of encoding data of a video information resource using the internal restructuring of the information space allows creating conditions for localization of action of errors in the course of reconstruction of video information resources.

Fig. 3 shows a possible option for decoding the source code sequence $L(\theta)$ in terms of errors ε in the data channel.

The fragment of the source code sequence is shown in Fig. 3, which demonstrates a typical example of an error ε occurring in the senior categories code design $\ell_{\xi-1}(\lambda_i)$ that leads to the following consequences:

1. The decoder erroneously identifies the code constructs $\ell_{\xi-1}(\lambda_i)$ and $\ell_\xi(\lambda_i)$ assigned in the process of statistical coding to the elements that are combined in the process of restructuring the video sequence data $U(\theta)$ in one cluster (i.e., $u_{\xi-1}, u_\xi \in U(\lambda_i)$):

$$\ell'_{\xi-1}(\lambda_i) \neq \ell_{\xi-1}(\lambda_i), \ell'_\xi(\lambda_i) \neq \ell_\xi(\lambda_i), \qquad (18)$$

where $\ell'_{\xi-1}(\lambda_i)$, $\ell'_\xi(\lambda_i)$ are code constructions that are formed due to the errors in the data channel.

The considered variant of avalanche effect of action of errors (Fig. 3) is connected with the fact that for sequence of code designs which are appropriated in the course of statistical coding to the elements belonging to one cluster, property of prefixity will be carried out.

2. In conditions when it is known which of the clusters belongs to the following code structure $\ell_{\xi+1}(\lambda_j)$, the decoder identifies it without errors. Therefore, if there are no errors in the decoding process, then the following code constructions (code constructions $\ell_{\theta-1}(\lambda_j)$ and $\ell_\theta(\lambda_j)$) are decoded without an error. That is, the effect of errors is localized within the sequence of code constructions $\ell'_{\xi-1}(\lambda_i)$ and $\ell'_\xi(\lambda_i)$ (Fig. 3), assigned to the elements of one set $U(\lambda_i)$.

Fig. 4 shows the results of the reconstruction of the test video image for the developed method. Experimental studies are conducted for the case when the probability of errors in the data channel has the following values: $P(\varepsilon) = 10^{-4}$, $P(\varepsilon) = 10^{-5}$. A discrete symmetric channel without memory was used as a data transmission channel.

Comparative assessment of quantity K'_{dm} of distorted pixels that affect the quality of visual perception of video images, in terms of errors in the data channels for the developed method of compression encoding and the existing method (JPEG) is shown in Figs. 5-6.

Analysis of the data in Figs. 5-6 shows that the use of the developed method allows you to increase the level of reliability of video data at a given level of errors in the reconstruction process. So, for the case when the error in the discrete symmetric data channel without memory is set to a value equal to $P(\varepsilon) = 10^{-5}$, the use of the developed method allows us to reduce the number K'_{dm} of distorted pixels that affect the quality of visual perception of video images, compared to the existing method on average 10-17 times.

Accordingly, for the second case under study (when $P(\varepsilon) = 10^{-4}$) the number K'_{dm} of distorted pixels, which affects the quality of visual perception of video images, is reduced by an average of 16-18 times compared to the existing method.

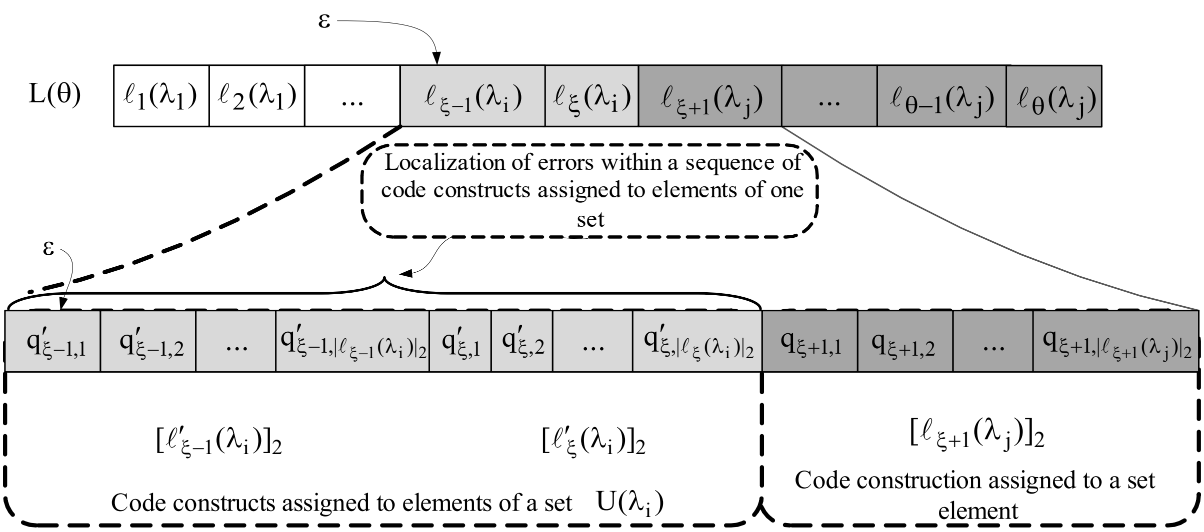
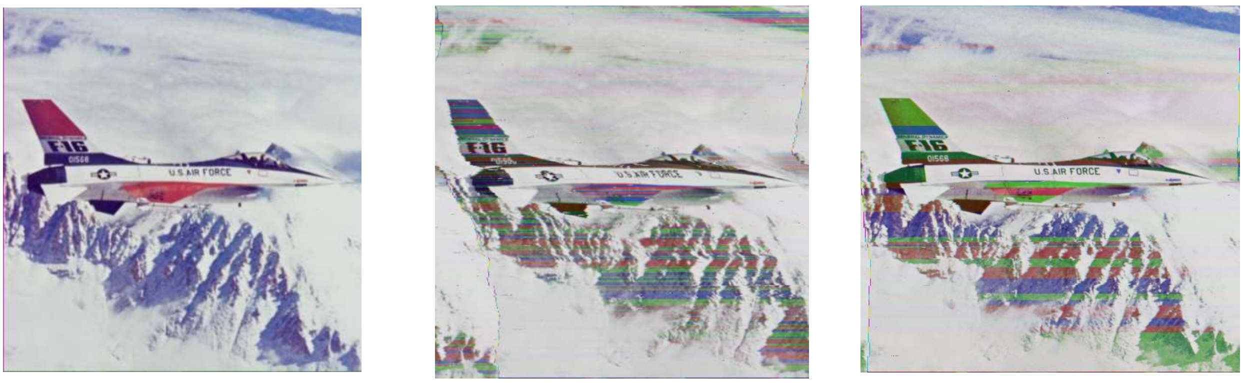


Figure 3. Scheme of localization of errors in the process of decoding a fragment of the source code sequence using the developed method of restructuring video sequence data



a) b) c)

Figure 4. The results of the reconstruction of the test video image for the developed method: a) $P(\varepsilon)=0$; b) $P(\varepsilon)=10^{-4}$; c) $P(\varepsilon)=10^{-5}$

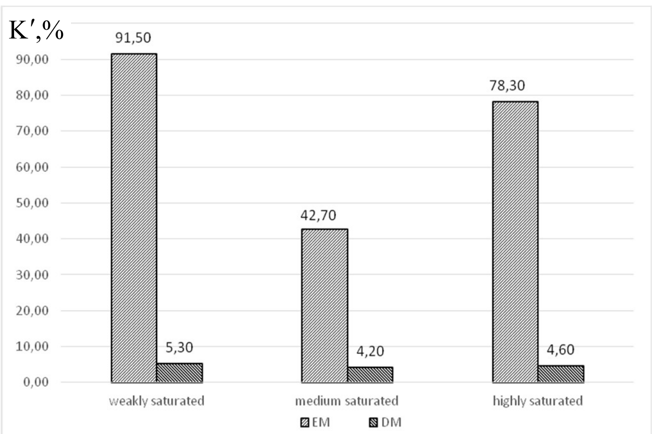


Figure 5. Diagram of the dependence of quantity K'_{dm} of distorted pixels at a given error rate from the degree of image saturation for the developed and existing methods, $P(\varepsilon)=10^{-5}$.

Application of the developed method of encoding data of a video information resource using the internal restructuring of the information space in the process of codegram formation ℓ'_{ξ} , which is assigned to the element u_{ξ} of the message $U(\theta)$, allows us to increase the efficiency of statistical coding from the position of additional reduction of code redundancy of the service part ℓ_{λ_i} of the codegram ℓ'_{ξ} and the code sequence $L'(\theta)$ in general.

In turn, the transformation of the positioning strategy of individual CC in the general code sequence $L'(\theta)$ creates conditions for localization of the action of errors that occur in the process of data reconstruction of the video information resource.

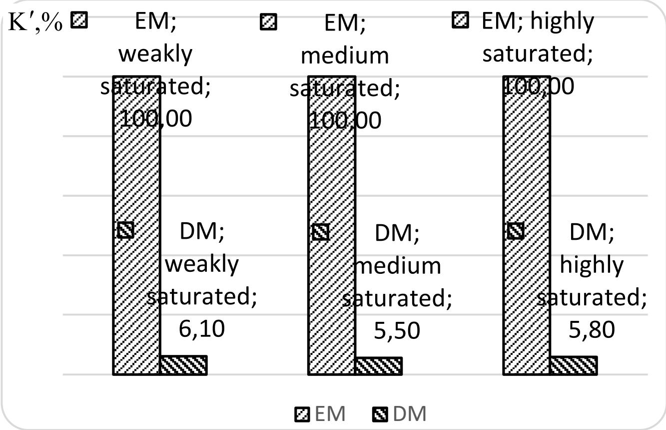


Figure 6. Diagram of the dependence of quantity K'_{dm} of the distorted pixels at the given error rate from the degree of image saturation for the developed and existing methods, $P(\varepsilon)=10^{-4}$

This is ensured by entering into the structure of the codegram identifiers of code structures assigned to the elements of the message in the process of statistical coding in the information space of sets. This means that the decoder knows which of the clusters this or that code structure belongs to, and error localization occurs within the element's codegram.

V. CONCLUSIONS

For the first time, a method of compression coding using internal restructuring of the information space is developed. Distinctive characteristics of the method are that at the stage of preparing video data for coding, the restructuring of the information space is used without loss of integrity by forming clusters based on the structural feature by the number of binary series. The essence of the specified direction is to identify regularities in the binary structure of the message elements based on a quantitative feature. In turn, at the stage of coding, a two-hierarchical scheme of statistical coding is used, which involves the use of a statistical approach to form the informational and service component of the codegram.

This allows:

- performing the restructuring of the information space without loss of integrity based on the number of series of units;

- providing conditions for an additional reduction of the structural redundancy of code representation of information by reducing the capacity of the information space;

- ensuring the localization of the action of errors in the process of data reconstruction of video information resources by taking into account the transformation of the positioning strategy of individual code structures in the general code sequence;

- increasing the level of reliability of video information using compression coding technologies in the conditions of ensuring the necessary level of operational efficiency by adding identifiers (markers) of code constructions assigned to message elements in the process of statistical coding in the information space of sets to the structure of the codegram.

At the same time, the following results are achieved:

- as a result of the use of internal restructuring of the video sequence data based on the number of series of units, conditions are created for additional reduction of the structural redundancy of the code representation of information due to a significant reduction in the power of the information space (to the level of clusters), within which the data is coded;

- localization of the action of errors in the process of reconstruction of video information resources is ensured by entering into the codegram an element of the service component - identifiers (markers) of code constructions. So, for the case when an error in a discrete symmetric data transmission channel without memory is given by a value equal to $P(\varepsilon)=10^{-5}$, the use of the developed method allows us to reduce the amount K'_{DM} of distorted pixels, which affect the quality of visual perception of video images, compared to the existing method by an average of 10-17 times. Accordingly, for the case when $P(\varepsilon)=10^{-4}$ a number K'_{DM} of distorted pixels is reduced by an average of 16-18 times compared to the existing method.

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