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# THE METHOD OF ADAPTIVE STATISTICAL CODING TAKING INTO ACCOUNT THE STRUCTURAL FEATURES OF VIDEO IMAGES

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***Abstract.*** *The paper proposes a method of improved adaptive integral arithmetic coding. This method is advisable to use in the technology of multi-level processing of video data based on the JPEG method. The technology is based on the detection of key information at several stages of video data processing. To reduce the output volume, the RLE algorithm and integral arithmetic coding are adapted to the new structure of the input data. Thus, the method of linearization of two-dimensional transformants based on zig-zag scanning was further developed. The differences of the method consist in carrying out vector intertransformation zig-zag linearization taking into account the selection of spectral components defined as complementary. The linearized decomposition approach was developed for the first time transformants based on entry into control ranges. In connection with the presence of different types of transformants in the group, the threshold is adapted according to the criterion of the total uneven number of non-equilibrium complementary components. On the basis of taking into account the probability of occurrence of dictionary elements, integrated arithmetic coding (two-dictionary integrated arithmetic coding) has been improved. Determination of current code components according to the decomposed working interval depending on the power of the dictionaries of significant elements and the number of repetitions. This allows you to additionally take into account the statistical features of the components of the RLE-structured linearized transformants and reduce the length of the arithmetic code; for the first time, a transformant compression method was created based on the reduction of various types of redundancy in groups of transformants. Comparative experimental analysis with known methods indicated that the developed technology has a higher compression ratio with reduced processing time. This makes it possible to ensure the necessary level of access and reliability in the conditions of the growth of the original volume of data.*

**Keywords**: method of multilevel selective processing, RLE, arithmetic coding

## METODA ADAPTACYJNEGO KODOWANIA STATYSTYCZNEGO Z UWZGLĘDNIENIEM CECHY STRUKTURALNE OBRAZÓW WIDEO

***Streszczenie.*** *W artykule zaproponowano metodę ulepszonego adaptacyjnego całkowego kodowania arytmetycznego. Metodę tę zaleca się stosować w technologii wielopoziomowego przetwarzania danych wideo w oparciu o metodę JPEG. Technologia opiera się na wykrywaniu kluczowych informacji na kilku etapach przetwarzania danych wideo. Aby zmniejszyć głośność wyjściową, algorytm RLE i całkowe kodowanie arytmetyczne są dostosowywane do nowej struktury danych wejściowych. Tym samym rozwinięto metodę linearyzacji dwuwymiarowych transformantów w oparciu o skanowanie zygzakowate. Różnice metody polegają na przeprowadzeniu zygzakowatej linearyzacji międzytransformacyjnej wektorów z uwzględnieniem doboru składowych widmowych określonych jako komplementarne. Po raz pierwszy opracowano podejście do rozkładu linearyzowanego transformantów w oparciu o wejście w zakresy kontrolne. W związku z obecnością w grupie różnych typów transformantów próg dobierany jest według kryterium całkowitej nieparzystej liczby nierównowagowych składników dopełniających. Na podstawie uwzględnienia prawdopodobieństwa wystąpienia elementów słownikowych udoskonalono zintegrowane kodowanie arytmetyczne (zintegrowane kodowanie arytmetyczne dwusłownikowe). Wyznaczanie bieżących składowych kodu według rozłożonego interwału roboczego w zależności od mocy słowników elementów znaczących i liczby powtórzeń. Pozwala to dodatkowo uwzględnić cechy statystyczne składników linearyzowanych transformantów o strukturze RLE i zmniejszyć długość kodu arytmetycznego; po raz pierwszy stworzono metodę kompresji transformantów, polegającą na redukcji różnego rodzaju redundancji w grupach transformantów. Porównawcza analiza eksperymentalna ze znanymi metodami wykazała, że opracowana technologia charakteryzuje się wyższym stopniem sprężania przy skróconym czasie przetwarzania. Pozwala to zapewnić niezbędny poziom dostępu i niezawodności w warunkach wzrostu pierwotnego wolumenu danych.*

**Słowa kluczowe**: metoda wielopoziomowego przetwarzania selektywnego, RLE, kodowanie arytmetyczne

## Introduction

Air monitoring systems are widely used in the monitoring system of critical infrastructure facilities. They create conditions for forming and transmitting video information on a scale close to real time with a sufficient level of reliability [7, 23, 31]. At the same time, it is necessary to increase the level of reliability by ensuring the required resolution of the video frame [6, 14, 24, 28]. This allows the user to accumulate enough data to make an informed decision. However, such requirements lead to an increase in the volume of initial video data [2, 6, 15, 20, 26]. At the same time, the bandwidth of the existing communication channels is not enough to process and transmit the required volumes of video data in real time. Thus, there is a scientific and applied problem of ensuring the necessary level of availability and reliability of video data in conditions of growth in their volume [3, 8, 11].

One of the ways to ensure the necessary level of accessibility is the use of coding technologies. These technologies are aimed at reducing the output volume. Methods based on integral arithmetic coding are widely popular. Publications [16, 17, 30] proved the perspective of using integral arithmetic coding to increase the level of accessibility. These methods are used as separate elements in the JPEG, JPEG-2000 methods.

The essence of the method is that [1, 5, 21, 23, 27, 28, 29]:

- each element is processed in the stream separately [9, 12];
- the code is formed by determining which control interval the element fell into during coding [18];
- scaling of the working interval to reduce the code length of an individual element. What happens with the use of elementary arithmetic operations [13, 14].

But the use of only arithmetic coding technologies does not allow to fulfil the condition of availability of video data in full. The disadvantage of arithmetic coding technologies is [4]:

- the need to use a significant number of arithmetic operations for coding [4, 19];
- do not take into account the structural features of intermediate data that are formed in the process of processing by the JPEG method.

To eliminate the shortcomings, it is suggested:

- to form a multi-level technology. It consists in the fact that during the selective processing of significant data at several stages of the JPEG, JPEG-2000 processes.
- carry out a modification of the integral arithmetic coding in the direction of taking into account the structural feature of the data after processing by the RLE method.

Publications propose a multi-level video data processing technology approach. The basis of which includes the process of identifying and processing significant data in the spatio-temporal and spectral domains. As a result, two types of components remain:

- significant, that carry the main information load;
- complementary, what may contain artifacts of information blocks.

At the last stage of multi-level technology, it is proposed to process only complementary components. Which is aimed at reducing processing time while maintaining the level of reliability.

Therefore, the purpose of the article is to develop an improved method of integral arithmetic coding based on taking into account the frequency of dictionary elements after processing by the RLE algorithm in the technology of multi-level data processing.

## 1. Justification of the data processing method

The multi-level technology consists in the detection and processing of significant and complementary data in three stages JPEG, JPEG-2000.

The first stage consists in the detection and processing of supplementary data in the space-time domain based on the threshold method [2]. This stage is aimed at the primary selection of significant and complementary data in the minimum time. Additional data needs to be reduced in volume and is transferred to the third stage of processing. Key data needs clarification and is transferred at the second stage of processing.

The second stage consists in identifying and processing significant data in the spectral domain [11]. This stage is aimed at partial processing of significant data. The share is chosen depending on the saturation level of the transformant. The level of saturation is determined by taking into account the number of units in bit planes. This stage is aimed at increasing the reliability of data due to qualitative identification of key information. Key data require processing aimed at maintaining the required level of reliability. Additional data require further volume reduction in the third stage of processing.

At the third stage, it is proposed to process the data obtained from the first and second stages. It will consist in coding of supplementary data to reduce the original volume of data. Coding is done using RLE methods and integral arithmetic coding.

At the beginning of the third stage, it is proposed to divide the image into groups of 2x2 transformants shown in Fig. 1. The coordinates of the group of transformants in the image have the form, where the coordinate of the group along the lines, a by columns [3, 8].

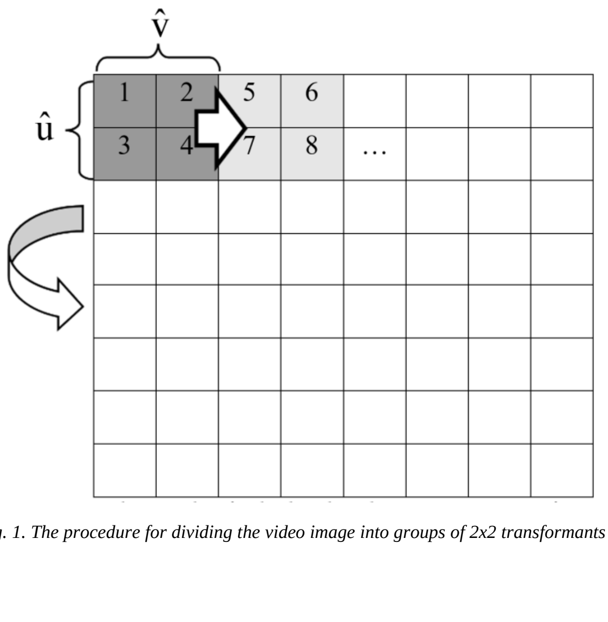


*Fig. 1. The procedure for dividing the video image into groups of 2x2 transformants*

To determine the size of the initial data when processed by the RLE algorithm, it is suggested to analyze the service information of the second stage, namely, the type of transformant by saturation.

Knowing the type of combination, it is possible to calculate the amount complementary components in the transformant group. This, in turn, allows you to determine up to what point arithmetic coding and decoding should be carried out. Also, this feature allows you to divide the set of complementary components into parts in accordance with needs (requirements). For this purpose, we suggest using the linearized decomposition method transformants. The basis of which is the determination of the threshold for splitting the data stream received after RLE. Which is aimed at reducing the power of the dictionary and providing conditions for increasing the amount of redundancy. That will have a positive effect in the process of arithmetic coding. For this purpose, the following is proposed: finding the threshold for dividing the linearized flow into two parts. This is done taking into account the presence of different types of transformants in the group. At the same time, the general unevenness of the number of non-equilibrium complementary components is taken into account. This will have a positive effect aimed at reducing the source code of a single coded symbol at the stage of adaptive integral arithmetic coding. It is proposed to divide the flow of supplementary components into 40% and 60% with the number of components from 180 to 217. After all, for these types of combinations, the capacity of the dictionary of element values will be greater than for other types in which the stream is transmitted completely.

Thus, when dividing the transformant group into two parts. Total amount complementary component is determined by the expression:

$$\eta_{dop}^{(trg)} = \eta_{40\%dop}^{(trg)} + \eta_{60\%dop}^{(trg)} \quad (1)$$

where $\eta_{40\%dop}^{(trg)}$ – the number of complementary components of the first part of the linearized flow for the group of transformants; $\eta_{60\%dop}^{(trg)}$ is the number of complementary components of the second part of the linearized flow for the group of transformants.

In the case of transmission of a linearized stream without splitting into two parts, expression (1) takes the form:

$$\eta_{dop}^{(trg)} = \eta_{100\%dop}^{(trg)} \quad (2)$$

where $\eta_{100\%dop}^{(trg)}$ is the number of complementary components of the entire linearized flow for the group of transformants.

After dividing the linearized stream, the corresponding number of components is fed to the RLE processing algorithm. As a result of RLE processing, we get a pair of element values, the number of elements for the quantized components of the transformant group.

## 2. Development of a data processing method

To reduce the volume of the video frame, it is suggested to take into account the structural feature of the data obtained after RLE. For this, it is necessary to improve the method of adaptive integral arithmetic coding. Features include the presence of two types of data. The first data type contains dictionary elements element values. The second type of data contains dictionary elements of the number of repetitions.

To reduce the power of the general dictionary, it is suggested to make modifications, namely if:

- on the transmitting side, the value of the number of repetitions is equal to one (c = 1), then this value is neglected (not coded) due to the fact that it occurs most often. The quality of recovery of the encoded sequence is ensured by the fact that the user knows to which dictionary the encoded element belongs. If the decoder receives two items from the dictionary in row values of the elements, a unit is added between them as the elements of the dictionaries alternate;

- after the quantization stage, there will always be an element whose value is equal to zero (c = 0), so it should be placed on the left side in the first interval (6). After all, the probability of the appearance of this element is the greatest. This manipulation is aimed at reducing the code of the zero element, which will have a positive effect on the compression level as a whole;
- the largest value of the number of repetitions is in the last pair after processing by the RLE algorithm, then the coding of the pair is redundant. After all, the value of the element of the last pair is equal to zero c = 0. So, for high-quality decoding, it is enough to transmit only the number of repetitions of the last pair to the receiving side.

In order to unambiguously determine whether an element belongs to a dictionary, it is suggested to place the dictionary components separately in the working interval. Namely, components from the dictionary of element values are located on the left. Components from the dictionary of the number of repetitions (right) (Fig. 2).

This will make it clear which dictionary the decoded element belongs to. After all, the limit of dictionaries is known both on the transmitting and receiving side. Also, it allows saving the data structure for RLE decoding.

The coding process, taking into account the proposed modifications, is proposed to be carried out:

- for the first of the two parts of the linearized flow using the expression:

$$\eta_{40\%}(\hat{v},\hat{u}) = \eta^{(trg)}_{40\%dop} \tag{3}$$

where $\eta_{40\%}(\hat{v},\hat{u})$ is the quantity coded complementary component of the first parts of the linearized flow for the group of transforms;

- in the case of encoding the second of two parts or the whole linearized flow using the expression:

$$\eta_{60\%}(\hat{v},\hat{u}) = \eta^{(trg)}_{60\%dop} \tag{4}$$

where $\eta_{60\%}(\hat{v},\hat{u})$ – quantity coded complementary components of the second part of the linearized flow for the group of transforms.

The element code is generated using the following control intervals (Fig. 3):

1. The first control interval. Its limits are determined by the formula:

$$\eta_{60\%}(\hat{v},\hat{u}) = \eta^{(trg)}_{60\%dop} - 2 \tag{5}$$

where $\eta^{(trg)}_{60\%dop}$ is the beginning of the working interval at the i-th step.

2. The second control interval. The limits of which are in the range:

$$\left[l_i; \tfrac{1}{2}(h_i - l_i)\right] \tag{6}$$

3. The third control interval. Its boundaries correspond to the expression:

$$\left[\tfrac{1}{4}(h_i - l_i); \tfrac{3}{4}(h_i - l_i)\right] \tag{7}$$

The scaling process includes the process of doubling the spacing of an element. It occurs when the interval of the element falls into the control intervals (5–7).

At the same time, during coding, the interval $\left[l_i^{(\beta)}(\hat{v},\hat{u});\ h_i^{(\beta)}(\hat{v},\hat{u})\right)$ of the element may fall into the control interval (5 - 7) several times. Based on this, the scaled interval of the element is proposed to be marked $\left[\hat{l}_i^{(\beta)}(\hat{v},\hat{u});\ \hat{h}_i^{(\beta)}(\hat{v},\hat{u})\right)$ for the transformant group with coordinates $(\hat{v},\hat{u})$.

Checking the compliance of the interval of the coded element with the control interval (5) is performed by analyzing only the upper limit of the interval of the element. After that, it is possible to issue a zero (part of the code) and scale the interval twice to the right according to the following rule:

- the code element is equal to zero (c = 0) if the condition is met:

$$h_i^{(\beta)}(\hat{v},\hat{u}) < \tfrac{1}{2}(h_i - l_i) \tag{8}$$

$$\text{then } \begin{cases} \hat{l}_i^{(\beta)}(\hat{v},\hat{u}) = 2 * l_i^{(\beta)}(\hat{v},\hat{u}) \\ \hat{h}_i^{(\beta)}(\hat{v},\hat{u}) = 2 * h_i^{(\beta)}(\hat{v},\hat{u}) \end{cases}$$

where $h_i^{(\beta)}(\hat{v},\hat{u})$ is the upper boundary of the coded element at the i-th step of the group of transformants with coordinates $(\hat{v},\hat{u})$; $\hat{h}_i^{(\beta)}(\hat{v},\hat{u})$ is the scaled upper boundary of the coded element at the i-th step of the group of transformants with coordinates $(\hat{v},\hat{u})$; $\hat{l}_i^{(\beta)}(\hat{v},\hat{u})$ is the scaled lower boundary of the coded element at the i-th step of the group of transformants with coordinates $(\hat{v},\hat{u})$.

Checking the compliance of the interval of the element with the control interval (6) is performed by analyzing only its lower boundary. After that, it is possible to issue a unit (part of the code) and scale the interval twice to the left according to the following rule:

- the code element is equal to one (c = 1) if the condition is fulfilled:

$$l_i^{(\beta)}(\hat{v},\hat{u}) > \tfrac{1}{2}(h_i - l_i) \tag{9}$$

$$\text{then } \begin{cases} \hat{l}_i^{(\beta)}(\hat{v},\hat{u}) = h_i^{(\beta)}(\hat{v},\hat{u}) - 2(h_i - l_i^{(\beta)}(\hat{v},\hat{u})) \\ \hat{h}_i^{(\beta)}(\hat{v},\hat{u}) = h_i^{(\beta)}(\hat{v},\hat{u}) - 2(h_i - h_i^{(\beta)}(\hat{v},\hat{u})) \end{cases}$$

where $l_i^{(\beta)}(\hat{v},\hat{u})$ the lower boundary of the coded element at the i-th step of the group of transformants with coordinates $(\hat{v},\hat{u})$.

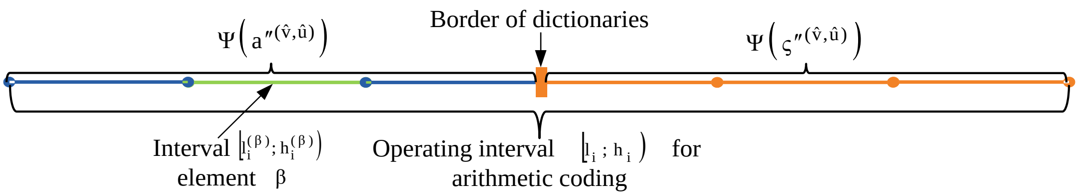


*Fig. 2. An example of constructing a working interval for arithmetic coding*

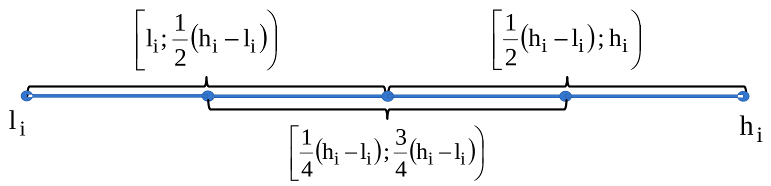


*Fig. 3. Graphic representation of control intervals*

In the case of hitting an element interval which is coded into the control interval (7), the counter s is increased by one and scaling from the middle of the working interval according to the following rule:

$$s = s+1,\ \text{if} \begin{cases} \frac{1}{4} \le l_i^{(\beta)}(\hat{v},\hat{u}) < \frac{1}{2} \\ \frac{1}{2} \le h_i^{(\beta)}(\hat{v},\hat{u}) < \frac{3}{4} \end{cases} \tag{10}$$

Then the new interval boundaries will take the form:

$$\begin{cases} \hat{l}_i^{(\beta)}(\hat{v},\hat{u}) = 2\left(l_i^{(\beta)}(\hat{v},\hat{u}) - \left(\frac{1}{4}(h_i - l_i)\right)\right) \\ \hat{h}_i^{(\beta)}(\hat{v},\hat{u}) = 2\left(h_i^{(\beta)}(\hat{v},\hat{u}) - \left(\frac{1}{4}(h_i - l_i)\right)\right) \end{cases}$$

The counter is reset to zero if $\left[\hat{l}_i^{(\beta)}(\hat{v},\hat{u}),\ \hat{h}_i^{(\beta)}(\hat{v},\hat{u})\right)$ the element interval falls within the control interval (5) or (6). At the same time, the number of units in case of falling into the control interval (5) corresponds to the value of the counter before reset. In the case of falling into the control interval (6), the value of the counter before reset indicates the number of zeros.

- assignment of new boundaries $[l_i, h_i)$ of the general working range for the i-th step. Which corresponds to the scaled boundaries of the interval of the element coded in the previous step and is found according to the formulas:

$$l_i = \hat{l}_{i-1}^{(\beta)}(\hat{v},\hat{u}),\ h_i = \hat{h}_{i-1}^{(\beta)}(\hat{v},\hat{u}) \tag{11}$$

On the receiving side, taking into account the assumptions, the decoding process is proposed to be stopped in the event of:

- decoding the first of the two parts of the linearized stream when the requirements of the expression are met:

$$\eta_{40\%}(\hat{v},\hat{u}) = \eta_{40\%dop}^{(trg)} \tag{12}$$

- decoding the second of two parts or the whole of the linearized flow when meeting the requirements of the expression:

$$\eta'^{(trg)}_{60\%dop}(\hat{v},\hat{u}) = \eta^{(trg)}_{60\%dop} - \max\left(\Psi\left(\varsigma''^{(\hat{v},\hat{u})}\right)\right) \tag{13}$$

where $\max\left(\Psi\left(\varsigma''^{(\hat{v},\hat{u})}\right)\right)$ is the maximum value of the number of repetitions.

## 3. Comparative experimental evaluation

To assess the level of efficiency of the developed technology, it is suggested to compare it with known technologies according to the speed criterion (Fig. 4) and the value of the compression ratio (Fig. 5). For qualitative assessment, the closest similar methods were chosen, namely:

- classical arithmetic coding;
- integral arithmetic coding;
- RLE.

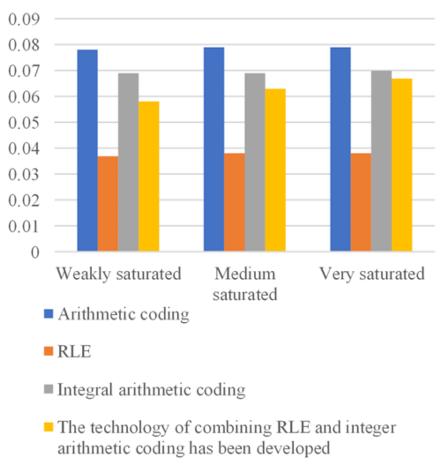


*Fig. 4. Comparative characteristics of known technologies with the one developed according to the performance indicator*

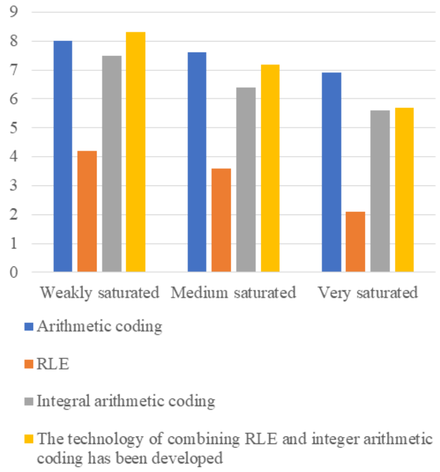


*Fig. 5. Comparative characteristics of known technologies with the developed one based on the value of the compression ratio*

Analysis of Fig. 4 and Fig. 5 indicated:

- the developed technology of advanced integral arithmetic coding has advantages in speed. In comparison with the classic integral arithmetic coding by 2–9% for blocks corresponding to saturation. Compared to classical arithmetic coding by 13–25% for blocks corresponding to saturation;
- the developed technology of advanced integral arithmetic coding has advantages in the level of compression. In comparison with the classic integral arithmetic coding by 4–12% for blocks corresponding to saturation. Compared to classical arithmetic coding by 5% for weakly saturated blocks.

Therefore, the developed technology has a higher compression ratio with reduced processing time compared to known compression technologies. This makes it possible to ensure the necessary level of access and reliability in the conditions of the growth of the original volume of data.

These transformations make it possible to reduce the power of the dictionary, which has a positive effect on the subsequent stages of processing. As a result, two dictionaries combined on one working interval for complete arithmetic coding are formed. This allows the elements on the receiving side to be decoded unambiguously.

Integrated arithmetic coding based on taking into account the frequency of dictionary elements (two-dictionary integrated arithmetic coding) has been improved. The differences of the method consist in determining the current code components according to the decomposed working interval depending on the power of the dictionaries of significant elements and the number of repetitions. This allows you to additionally take into account the statistical features of the components of the RLE-structured linearized transformants and reduce the length of the arithmetic code.

## 4. Conclusions

The article improves the method of integral arithmetic coding in combination with the RLE method. This concept is based on the detection of key information at several stages of processing, adaptation of the RLE algorithm and integral arithmetic coding to the new structure of input data. The comparative analysis indicated that the developed technology has a higher compression ratio with reduced processing time in comparison with known compression technologies. This makes it possible to ensure the necessary level of access and reliability in the conditions of the growth of the original volume of data.

The developed technology of advanced integral arithmetic coding has advantages in:

- quick action. In comparison with the classic integral arithmetic coding by 2–9% for blocks corresponding to saturation.

Compared to classical arithmetic coding by 13–25% for blocks corresponding to saturation;

- compression levels. In comparison with the classic integral arithmetic coding by 4–12% for blocks corresponding to saturation. Compared to classical arithmetic coding by 5% for weakly saturated blocks.

Therefore, the developed technology has a higher compression ratio with reduced processing time compared to known compression technologies. This makes it possible to ensure the necessary level of access and reliability in the conditions of the growth of the original volume of data.

Transformants based on zig-zag scanning was further developed. The differences of the method consist in carrying out vector intertransformation zig-zag linearization taking into account the selection of spectral components defined as complementary. This ensures consideration of structural features in the middle and in the stream of transformants and creates conditions for increasing the efficiency of RLE-transformation.

Linearized decomposition method was developed transformants based on thresholding. The differences of the method consist in finding the threshold taking into account the presence of different types of transformants in the group by determining the total uneven number of non-equilibrium complementary components. This allows:

- reduce the power of dictionaries of elements of the RLE-structured sequence;
- provide conditions for increasing the amount of redundancy that is reduced in the process of arithmetic coding.

These transformations make it possible to reduce the power of the dictionary, which has a positive effect on the subsequent stages of processing. As a result, two dictionaries combined on one working interval for complete arithmetic coding are formed. This allows the elements on the receiving side to be decoded unambiguously.

In perfectly integral arithmetic coding based on taking into account the frequency of dictionary elements (two-dictionary integral arithmetic coding). The differences of the method consist in determining the current code components according to the decomposed working interval depending on the power of the dictionaries of significant elements and the number of repetitions. This allows you to additionally take into account the statistical features of the components of the RLE-structured linearized transformants and reduce the length of the arithmetic code.

So, the task of the article, which was to improve integral arithmetic coding based on taking into account the frequency of dictionary elements after processing by the RLE algorithm, has been achieved.

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