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Research on graphic data formats for compact representation and comparison of images

This article investigates common methods of lossy and lossless compression of graphic information. The advantages and disadvantages of compression methods are identified as a result of the research. A comparative analysis of the main capabilities of graphic information compression methods is conducted. The relevance lies in the efficient transmission, processing, and storage of graphic information, as large data volumes require increased network bandwidth and significant resources for data storage. The practical significance lies in solving the task of effectively reducing data sizes by applying well-known compression methods. Based on the study of graphic data formats, the development of algorithms for the computational scheme of "precise" processing of halftone images for pattern recognition is presented. Such a scheme rewrites a multigradient image into a three-level representation and implements a balancing procedure, which allows forming image features in a more compact form and computing the correlation function faster. The effectiveness of using developed methods of compact image representation with correlation comparison of balancing curves is demonstrated compared to traditional correlation comparison of images.

Keywords*: image, compression, lossy, lossless, three-level representation, balancing, correlation function.*

Introduction. The problem of transmitting large volumes of graphic information via communication channels continues to be topical. The existing methods of coding graphic information begin to be replaced by more complex and effective methods based on analyzing the content side of information about objects and phenomena in images. In contrast to formal description, which weakly takes into account their specificity. Such methods of information representation better reproduce the semantics of objects of the corresponding subject area.

Images such as maps, diagrams, blueprints, etc., which are structured, are not processed too efficiently by existing image coding methods. Since they are characterized by internal correlations which are strongly and selectively related to their ordered and organized structure. Therefore, the lack of taking into account this structure leads to a decrease in the compression performance of graphic information, which determines the effective bandwidth of communication channels, as well as to a decrease in the performance of coding and decoding procedures.

In this connection the problem of development of computer methods of representation and coding of graphic information, which would take into account the specificity of graphic images, as well as increase the level of efficiency of their representation in telecommunication systems, becomes urgent.

Currently, there are quite a few methods for compact representation of graphic information. The basis of any data compression methods lies in utilizing the inherent redundancy of the original information. Compression methods for graphic information are developed to reduce the volume of the original information using either lossless or lossy transformations. Thus, such methods are divided into lossy compression and lossless compression [1]. Common standard methods and their combinations do not give clear answers about which of them are the best. Everything depends on the specific requirements for the reconstructed post-compression image, the available hardware and software support [2].

Lossy compression is the transformation of input data into output data that reproduce the external characteristics of the input data with a difference in volume. The degree of similarity between input and output data is determined by the degree of correspondence of certain properties of the image represented by a given information stream. Lossy compression methods allow for significantly higher compression ratios. However, this leads to distortion of the output image and deterioration in its quality. Therefore, when comparing different compression methods, the quality of image reconstruction must be taken into account. Lossy compression is most commonly used for multimedia data, especially for streaming data transmission and telephony. Lossy methods are typically applied to compress images and audio [1, 3].

Lossless compression is the transformation of input data into output data where the encoded information can be recovered with bit accuracy. Lossless compression methods are used to reduce data size. By employing these methods, it is possible to accurately reconstruct the original data. For each type of digital information, there are typically specific lossless compression methods. The result of lossless compression is always a reduction in the volume of the output information stream without altering its informativeness, i.e., without loss of information structure. Lossless compression methods are used in areas where data accuracy and transmission speed between system nodes are crucial. For instance, in scientific and medical applications where information loss is unacceptable or where image noise itself is the primary information. Its practical significance lies precisely in its hardware implementation. Such encoders are used in security systems, data collection systems, satellite, underwater, and other surveillance systems, as well as in astronomical instruments and telescopes [4].

Analysis of recent research and problem statement. Initially, conventional methods used in backup systems and in the creation of distributions were first applied for image compression. These algorithms compressed information without alteration. Large companies utilized compression methods for storing vast amounts of data. With the advent of the internet, there arose a need to improve existing compression methods, as channel bandwidth was extremely narrow [1]. Therefore, formats such as ZIP, GIF, and PNG were developed. The first successful archiver, ARC, allowed compressing multiple files into an archive, and its outputs were open. ARC used a modified LZW method. With the advancement of computer technology, the DEFLATE method replaced the LZW method. Among the new features was the ability to split the archive into volumes. This version is still widely used despite its venerable age. The GIF (Graphics Interchange Format) image format supports lossless image compression and is limited to a palette of 256 colors. It remains popular, especially due to its support for animation. Currently, DEFLATE is the most popular compression algorithm. As new classes of images are increasingly used, old methods no longer meet compression requirements. This led to the creation of a new type of algorithms - lossy compression algorithms [5]. Typically, the compression ratio, and thus the level of quality loss, can be specified in them. This achieves a compromise between image size and quality. One of the significant problems of image compression is the lack of adequate criteria for evaluating quality loss because the quality may deteriorate at any stage of processing (during digitization, when converting to a limited color palette, when converting to another color representation system for printing, during lossy compression).

It is known that almost all graphic information subjected to compression is intended for further analysis by humans. It is best to assess image quality loss visually, using sight. Compression is considered excellent when it is visually impossible to distinguish between the original image and the one restored after compression. It is considered normal when the original and the restored image after compression can only be distinguished by comparing the two images.

In practice, even with excellent preservation of quality, regular specific changes may be introduced into the images. Therefore, lossy compression methods are not recommended for compressing images that will subsequently need to be printed with high quality or processed by image recognition programs [6]. Unpleasant effects with such images may arise even with simple scaling [7-9].

Aims and Objectives of the Research. Today, an important task in communication systems is the effective transmission and preservation of images due to the large sizes of graphic images requiring significant storage resources. The application of image compression methods, which involve reducing the file size, addresses this issue. There are many developed methods for compressing graphic information, including methods focused on compression and decompression, as well as methods focused on the degree of compression. Typically, such methods are developed for specific types of graphic information. Therefore, to analyze different image compression methods, it is necessary to know which class of images to focus on (monochromatic, halftone, color, images with continuous tone, discrete-tone images, images with large areas of one color). Thus, it is difficult to delineate and compile a universal description of known methods. This can only be done for typical methods under the condition of using typical methods on typical platforms [9].

The scientific novelty lies in the development of a method of generalized spatially connected dissection of image parts. On the basis of which comparison functions are calculated, including correlation, which allows the implementation of the method of image segmentation and compact representation. The considered methods of image representation make it possible to determine the list of quality parameters of the system functioning, to create evaluation criteria adapted to the complex nature of quality parameters; to estimate the computing power required to implement the optimal structure of a computer network.

Materials and Research Methods. Among the main lossless compression methods are the RLE method, the LZW method, the Huffman method, the JBIG method, the Lossless JPEG method, and the DEFLATE method. Let's consider them in more detail.

1. RLE Method (Run Length Encoding) - is one of the oldest and simplest compression methods. This method is easy to implement as it does not require additional memory during compression /decompression. The method is oriented towards images with a small number of colors or images with larger color areas that are repeated. RLE has high speed and does not require additional memory during compression. However, RLE has a low compression ratio. This method is effective for compressing raster tonal images (BMP, PCX, TIFF) as they contain long series of repeated byte sequences [1, 3, 9]. The main advantage of RLE is its lower computational complexity with simpler encoding and decoding stages, facilitating faster implementation compared to other encoding methods for better distortion-free compression [10].

2. LZW Method (Lempel-Ziv-Welch) - is a universal lossless compression method aimed at 8-bit images. Compression is achieved by identical byte subsequences in the stream. The compression process is relatively simple: characters in the input stream are read sequentially, and it is checked whether such a string exists in the created string table. If the string exists, the next character is read, and if the string is absent, the code for the previous found string is entered into the stream, the string is entered into the table, and the search begins again. LZW is universal, as its variants are used in common archivers. It is implemented in GIF, TIFF, and TGA formats. The main drawback of this method is its low compression ratio compared to two-stage coding schemes [1, 3, 9].

3. Huffman Method - is a classic method for compressing information, applicable to text files, where text symbols are replaced by strings of bits of different lengths, ensuring a unique construction of a code with the lowest average number of symbols per letter for a given distribution of probabilities among the characters. The Huffman method is practically not applied to images in their pure form but is usually used as one of the compression stages in more complex schemes. It is the only method that does not increase the size of the output data in the worst case (if we do not consider the need to store the recoding table along with the file) [1, 3, 9].

4. DEFLATE Method based on a combination of LZW (Lempel-Ziv-Welch) and Huffman algorithms. The DEFLATE method is quite simple to implement, fast, and widely used in software. The disadvantage of the method is the low coding efficiency of small data volumes. Compared to RLE, LZW, and Huffman methods, the DEFLATE method is optimal in terms of loss quality ratio. Therefore, it is advisable to develop a new approach to image compression based on the DEFLATE method using a preprocessing stage. At this stage, data should be prepared, firstly, with repeated fragments and, secondly, with a large number of identical pixels in the image. The preprocessing stage may include the following main algorithms: background color determination; determination of image presence; analysis of the possibility of separating image fragments; bringing fragments to a rectangular form; direct processing of image fragments. Additionally, increasing the compression ratio is possible by selecting a color model. Since the DEFLATE algorithm compresses by the frequency of pixel appearance in the image, it is advisable to use a color-difference model, in which two color components have a reduced dynamic range of data for image fragments with homogeneous rows [3].

Table 1. **Comparison of the main characteristics of lossless graphic information compression methods**

Method name	Main characteristics of the method	Advantages and disadvantages of the method
RLE Method (Run Length Encoding)	The essence lies in encoding repetitive color values.	*Advantages:* simple to implement, useful for redundant data such as images with a large number of pixels.
		Disadvantages: compression leads to an increase in file size.
LZW (Lempel-Ziv-Welch method)	Repetition of homogeneous color sequences	*Advantages*: simple to implement, high compression speed, does not require additional memory.
		Disadvantages: low compression ratio
Huffman Method	Differing color occurrence frequencies	*Advantages:* high compression speed, relevant for text files, ensures unambiguous construction of a code with the smallest average number of symbols per letter for a given distribution.
		Disadvantages: practically not applicable to images in their pure form
DEFLATE	Compression occurs due to the sharp frequency of appearance of pixels in the image and their homogeneous rows.	*Advantages:* simple to implement, fast, widely used in software.
		Disadvantages: low efficiency of encoding small data volumes
JBIG	Compression of one-bit black-and-white images	*Advantages:* allows control over the order of splitting the image into bit planes, the width of the strips in the image, and scaling levels (enabling viewing of the image through reduced copies).
JBIG	Compression of one-bit black-and-white images	*Disadvantages:* reduction in compression ratio with increased levels of noise in the input data
Lossless JPEG	Targeted at full-color 24-bit and 8-bit images without a palette	*Advantages:* universal
		Disadvantages: low compression ratio (when compressing lossless images)

5. *JBIG Method (Joint Bi-level Experts)* was developed by the ISO Joint Bi-level Experts Group specifically for compressing one-bit black-and-white images (e.g., for faxes or scanned documents) and can be applied to both 2-bit and 4-bit images, dividing them into separate bit planes. Like the Huffman method, the JBIG method uses short chains for common symbols and long chains for rare ones. However, unlike it, the JBIG method uses sequences of symbols. JBIG allows controlling the order of breaking the image into bit planes, the width of strips in the image, and scaling levels. The latter allows for easy orientation in a database of large-sized images by first viewing their reduced copies. Adjusting these parameters allows for gradually unpacking the image on the screen when receiving the image over the network or any other channel with a bandwidth significantly lower than the processor's capabilities,

enabling the operator to analyze the picture long before the decompression process is completed. A characteristic feature of JBIG is a sharp decrease in compression ratio with increasing noise levels in the input image [1, 3, 9].

6. Lossless JPEG Method was developed by a group of photography experts (Joint Photographic Expert Group). JPEG-LS is based on the LOCO-I compression method. It significantly differs from the JPEG and JPEG2000 methods, although the name is similar. Unlike JBIG, Lossless JPEG is oriented towards full-color 24-bit and 8-bit images without a palette (in grayscale). It represents a special implementation of JPEG without loss. JPEG includes two compression methods - lossless and lossy. This method is recommended for use in systems with fairly limited resources, such as space stations or web cameras. The JPEG-LS method consists of three main execution stages: modeling, prediction, and encoding. Its main difference from other algorithms is the prediction module and context work [1, 3, 4, 9]. To compare lossless graphic compression methods, let's consider Table 1.

Therefore, the aforementioned lossless information compression methods are universal and cover all types of images, but they have too small compression ratios. Using one of the lossless compression methods can provide approximately a two-fold image compression, although this largely depends on the characteristics of the image. Lossy compression methods are the most effective, but they also require evaluation based on the criteria mentioned above, as reproduction methods are crucial for ensuring rational reproduction of the original (analog or digital) with a full set of color and tone characteristics [3, 9].

Therefore, let's analyze the main lossy graphic information compression methods. Among the main lossy compression methods are the JPEG method, the JPEG 2000 method, the fractal method, and the Wavelet (recursive method). Let's consider them in more detail.

1. JPEG Algorithm - one of the most widespread and powerful methods. Today, it is the standard for full-color images. It operates on 8x8 blocks where brightness and color change relatively smoothly.

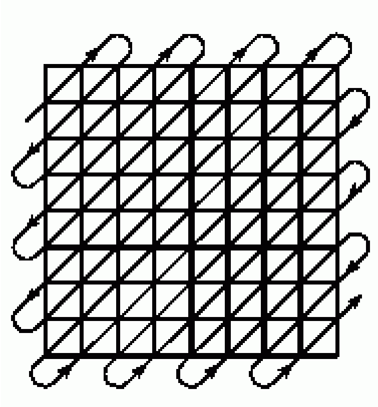


Fig. 1. **Image area 8x8**

As a result, when decomposing the matrix of such a region into a double row by cosine, only the first coefficients turn out to be significant. Compression in JPEG is achieved due to the smoothness of color changes in the image [3, 8, 9].

The method covers full-color 24-bit images (24 bits per pixel) or grayscale images without sharp color transitions (photographs). Symmetry: 1 [3, 9].

The compression algorithm scheme according to the JPEG standard is shown in Fig. 2.

Compression of images according to the JPEG standard involves the following sequence of steps:

1) The color image is converted from the RGB space to the YCrCb space.

In images of the RGB format, there is a significant correlation between the color components. The components R, G, and B are transformed into the Y component and two chrominance components U and V, in the YUV format, where Y is the luminance signal, and U and V are the chrominance difference signals.

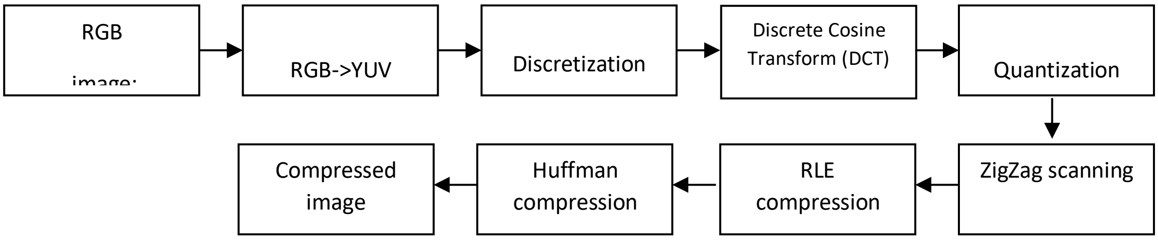


Fig. 2. **Scheme of the JPEG image compression algorithm**

The transformation is performed from pixel to pixel using the following formulas:

$$Y = 0.3 \cdot R + 0.59 \cdot G + 0.11 \cdot B; \tag{1}$$

$$U = -0.15 \cdot R - 0.29 \cdot G + 0.44 \cdot B; \tag{2}$$

$$V = 0.62 \cdot R - 0.52 \cdot G - 0.1 \cdot B, \tag{3}$$

where *R*, *G*, *B* are the color signals of the image (red, green, and blue respectively).

Representation of a color image in the *YUV* system allows exploiting the characteristics of human visual perception, which has low sensitivity to color accuracy [1, 8].

2) The color image is divided into large pixels. Pixels of each color component are assembled into 8 × 8 blocks, called data units;

3) Discrete cosine transformation (DCT) is applied to each data unit, resulting in 8 × 8 blocks of frequency data units (to reduce data redundancy in the image);

4) Quantization of each DCT block coefficient: each of the 64 frequency components of the data units is divided by a special number called the quantization coefficient (QC), which is rounded to an integer. Implementing DCT is the most challenging aspect. The encoding process using DCT involves dividing the image into 8x8 blocks (for encoding color images, each component is processed independently).

Within each block, a two-dimensional DCT is performed according to the expression:

$$F(u,v) = \frac{1}{4} \cdot C(u) \cdot C(v) \cdot \sum_{i=0}^{7} \sum_{j=0}^{7} cos\left(\frac{(2 \cdot i + 1) \cdot u \cdot \pi}{16}\right) cos\left(\frac{(2 \cdot j + 1) \cdot v \cdot \pi}{16}\right), \tag{4}$$

where $C(x) = \begin{cases} \frac{1}{\sqrt{2}} & x = 0 \\ 1 & x <> 0 \end{cases}, x = 0,...,u,v - 0,1,2,...,7.$

When decoding, the inverse discrete cosine transform (IDCT) is computed:

$$F(i,j) = \frac{1}{4} \cdot \sum_{i=0}^{7} \sum_{j=0}^{7} C(u) \cdot C(v) \cdot F(u,v) \cdot cos\left(\frac{(2 \cdot i + 1) \cdot u \cdot \pi}{16}\right) cos\left(\frac{(2 \cdot j + 1) \cdot v \cdot \pi}{16}\right), \tag{5}$$

where i, j – 0,1,2 … 7.

5) Encoding the resulting coefficients using static Huffman coding: all 64 quantized frequency coefficients of each data unit are encoded using a combination of RLE and the Huffman algorithm. At the static encoding stage, besides the Huffman algorithm, the JPEG specification allows the use of other methods to reduce information volume, such as arithmetic coding QM.

6) In the final step, a header with the JPEG parameters used is added, and the results are output to a compact file. The compression ratio is set by the user from 2 to 200, although in practice, the compression ratio does not exceed 20-25 [3, 8, 9].

JPEG has its peculiarities. The most well-known are the "Gibbs effect" and the division of the image into 8x8 squares. The former manifests itself at the sharp boundaries of objects, creating a kind of "halo." Dividing into squares occurs when too high a compression percentage is specified for a particular image. A drawback of the JPEG method is also that horizontal and vertical stripes on the display are often not visible and may only appear as moiré when printed. For this reason, JPEG is not recommended for use in printing at high compression ratios. However, when rational compression limits and dithering algorithms are applied, it can be considered as a compression option to reduce the file size of full-color images in original layouts for publications that will be printed [1].

2. JPEG 2000 Method. Developed by the same group of experts in the field of photography as JPEG. The scheme of compressing images according to the JPEG2000 standard is presented in Fig. 3.

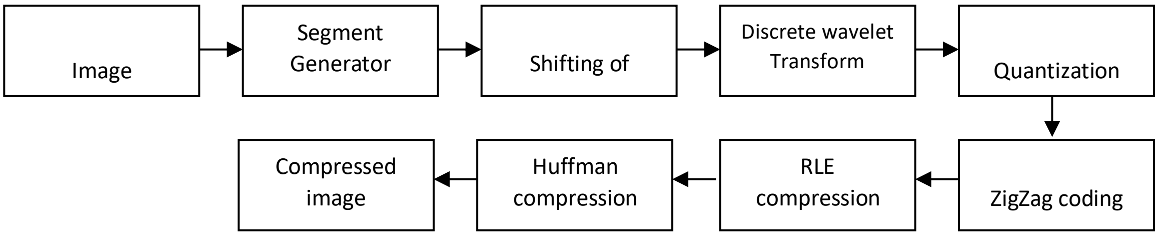


Fig. 3. **Compression scheme for JPEG2000 images**

The scheme of the JPEG 2000 algorithm is very similar to the basic JPEG scheme. The differences are as follows:

- instead of discrete cosine transform (DCT), discrete wavelet transform (DWT) is used;
- arithmetic compression is used instead of Huffman coding;
- the algorithm includes quality management for image regions from the beginning;
- explicit sampling of the U and V components after color space transformation is not used because DWT can achieve the same result, but slightly better.

Thus, when implementing the JPEG 2000 algorithm, unlike the JPEG algorithm, we obtain:

- improved image quality with significant compression;
- support for lossless compression. This allows the use of JPEG for compressing medical images, in printing;
- support for compression of one-bit (2-color) images. In JPEG, when compressing a 1-bit image, it increased by 8 times. Then an attempt was made to compress, often less than 8 times. Now JPEG 2000 can be recommended as a universal method;
- at the JPEG 2000 format level, transparency is supported. When creating web pages, now you can apply a transparent background not only in GIF but also in JPEG 2000. In addition, not only 1-bit transparency (transparent / opaque pixel) is supported, but also a separate channel, allowing for a smooth transition from an opaque image to a transparent background [8, 9].

3. The fractal method is a mathematical process of encoding rasters containing real images into a set of mathematical data describing the fractal properties of the image. The method is based on the fact that all natural and most artificial objects contain redundant information in the form of repeating patterns (fractals) [11]. The method relies on representing the image in a compact form using coefficients of iterated function systems (IFS). IFS translates one image into another. The transformation applies to points in three-dimensional space (x-coordinate, y-coordinate, brightness) [3, 8, 9, 11]. In other words, it involves searching for self-similar areas in the image. The method utilizes systems of domain and range blocks of the image, square-shaped blocks covering the entire image [12]. According to this method, the image is divided into numerous non-overlapping range sub-images, and numerous non-overlapping domain sub-images are determined. For each range block, the encoding algorithm finds the most suitable domain block and an affine transformation that maps this domain block to the given range block. The structure of the image is reflected in the system of range blocks, domain blocks, and transformations [3, 8, 9].

The process of fractal compression begins with taking two identical instances of the image – A and B, one of which is divided into non-overlapping blocks (range areas), while the other is provided with a set of domains that may overlap.

After this, the most appropriate domain is selected for each rank region. The numbers of domains used for encoding each rank region are recorded in a file. The compressed image file contains a header with information about the location of rank regions and domains.

Fractal compression is an asymmetric process. Compression takes much longer than decompression. This characteristic makes it effective for images that are continuously decompressed but rarely compressed. Therefore, the fractal method is suitable for use in image databases. There is a significant amount of research by foreign scientists dedicated to optimization issues of digital image fractal compression. One notable work discusses the method of fractal image compression using spatially sensitive hashing. However, little attention has been paid to optimization methods of fractal compression that would have equally high characteristics of compression ratio and quality of the restored image. The question of constructing fast fractal compression methods remains particularly relevant today [11].

Thus, after analyzing the features of the fractal compression method, it has been determined that it is capable of providing the best balance between compression ratio and quality of the restored image. The method has good prospects for further development. During the transformation of ordinary raster images into fractal ones, there is the possibility of scaling the fractal image without introducing artifacts or losing details, as is typical for raster images [11]. The advantages of the fractal method lie in its high compression ratios, speed of inverse transformation, and the possibility of further structural analysis of the image. However, the compression results depend on the principles of selecting basic elements and domains, and the compression ratio depends on the repetitiveness of the basic elements. The algorithm is oriented towards full-color images and grayscale gradations. Fractal compression is implemented in the FIF format [1].

The main drawback of the fractal method is its low compression speed. This is because to obtain high-quality images, each rank region requires iterating through all domain blocks, and for each domain block, at least eight affine transformations are required. This problem is only partially solved. Due to the noted drawbacks, this method is relatively rarely applied in practice.

The process of fractal transformation is asymmetric. That is, image reconstruction occurs much faster than compression. Therefore, researchers have opportunities to improve efficiency and search for other optimization methods for fractal encoding [11].

4. Wavelet-Recursive Method. Wavelet compression involves the utilization of wavelets, which are defined only in a portion of the argument domain and can be considered as replicas of a single basic function that differ in scale and position. The method's concept lies in storing in a file the difference between the average values of neighboring blocks in the image, which typically tend to be close to 0 [1, 9]. This method is oriented towards compressing color and grayscale images with smooth transitions, making it ideal for images like X-ray snapshots. Today, experts identify several advantages of wavelet compression compared to methods based on discrete cosine Fourier transformation, which is used in JPEG. In modern image compression methods, wavelet compression allows for a significant increase (up to two times) in the compression ratio of grayscale and color images while maintaining visual quality compared to previous-generation methods [1, 3, 8].

Wavelet transformation has found wide application in image processing tasks (language, satellite images, X-rays), pattern recognition, and the study of crystal and nano-object surface properties [13]. Wavelet transformations are used in medical diagnostics to compress images with minimal information loss required for diagnosis. Wavelet transformations are more sophisticated compared to Fourier transformation. The goal of new methods for analyzing medical signals is to automatically establish a correct diagnosis in the absence of a doctor or in cases of insufficient qualification, thereby increasing the likelihood of diagnosing diseases at early stages [14].

The coefficients of continuous wavelet transforms contain information about the energy of individual components of the electrocardiography signal and the time of their appearance. This allows for simultaneous investigation of the slow and fast dynamics of changes in the cardiac signal over time.

One advantage of this method is its ability to easily implement the gradual "unveiling" of an image when transmitting it over a network. Additionally, since we essentially store a reduced copy of the image at the beginning, it simplifies its display in the header. Unlike JPEG and fractal algorithms, this method does not operate in blocks, such as 8x8 pixels. More precisely, we operate in blocks of 2x2, 4x4, 8x8, and so on. However, because we store coefficients for these blocks independently, it is relatively easy to avoid splitting the image into mosaic squares [8].

In recent years, wavelet transformation has become known as a powerful tool for image compression. Various approaches related to wavelet-based encoding are well-known. The effectiveness of transformation encoding essentially depends on compressing energy with two-level wavelet transforms [13, 15]. The creation of a new system of "wavelet" functions has revolutionized the theory of signal processing and storage, allowing information to be compressed by 100-150 times without significant loss of quality. This is the main purpose and achievement of using wavelet transforms.

Therefore, by analyzing the main characteristics of lossy compression methods for graphic information [16, 17], we present the comparison results in Table 2.

Table 2. **Comparison of the main characteristics of lossy compression methods for graphic information**

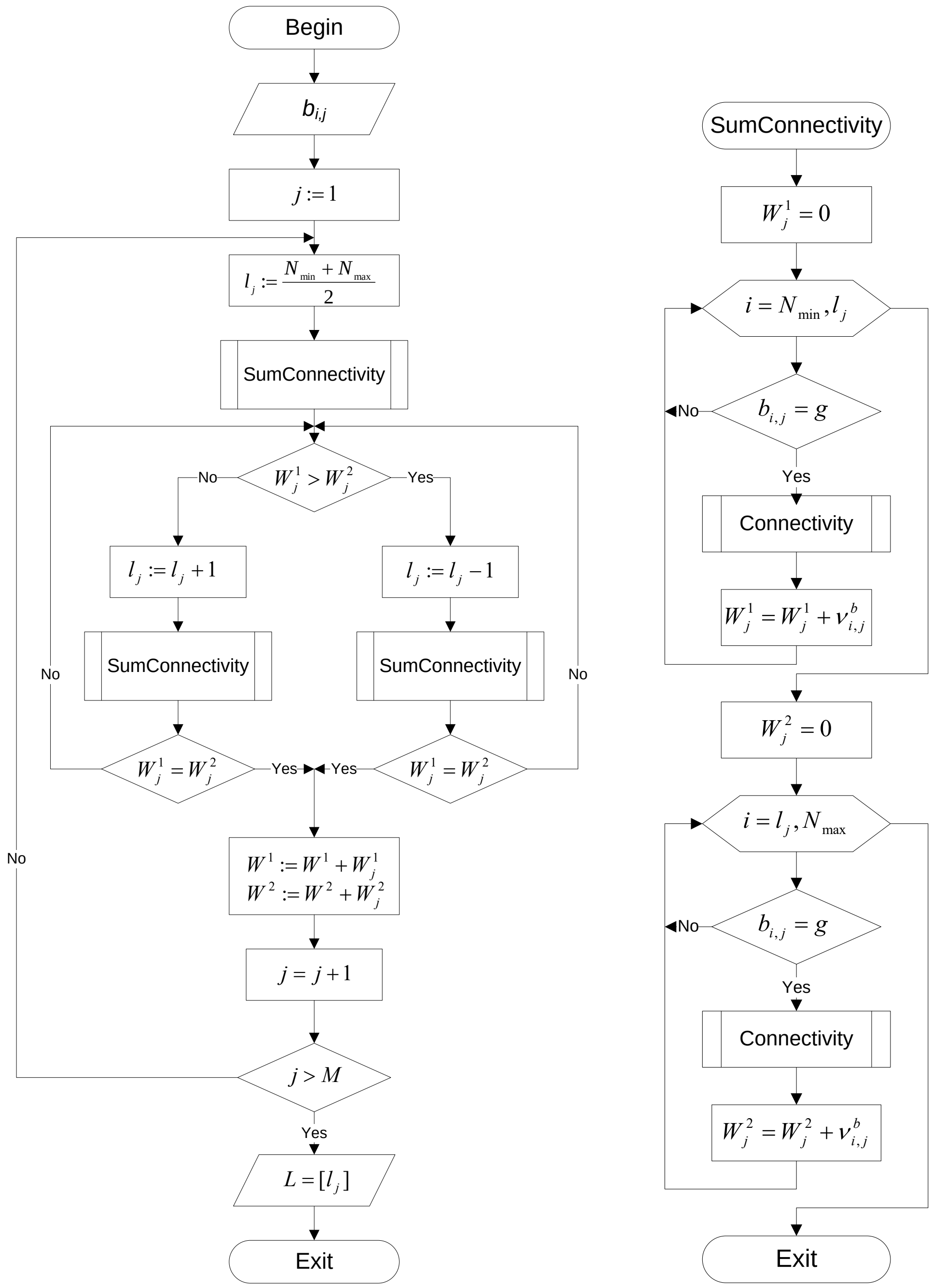
Method name	The main characteristics of the method	Advantages and disadvantages of the method
JPEG	Absence of sharp boundaries	*Advantages:* Good quality of the restored image
		Disadvantages: Gibbs effect. Lack of automatic conversion for multiple cases
JPEG 2000	Absence of sharp boundaries	*Advantages:* Improved image quality with significant compression, support for lossless compression, support for compression of binary (2-color) images
JPEG 2000	Absence of sharp boundaries	*Disadvantages:* Absence of automatic conversion for multiple cases
Fractal method	Full-color images and grayscale gradations	*Advantages:* High compression ratio, high speed of inverse transformation, possibility of further structural analysis of the image, smaller size of physical data used to record fractal codes compared to the initial raster data.
		Disadvantages: Low compression speed, which makes the method relatively rare in application
Wawelet (recursive compression)	Compression of color and grayscale images with smooth transitions	*Advantages:* Ability to compress information without significant loss of quality
		Disadvantages: Their relative complexity

Development of algorithms for compact image representation. Based on the developed preprocessing model [18, 19], let's create an algorithm. The images to be processed are provided as files in PCX or BMP graphic formats. To represent the image as a matrix of pixel brightness values, we will create a procedure for reading the file and decoding data from the PCX format. Information about the image size and the number of brightness levels is also extracted from the image file. After decoding the data, we obtain a brightness matrix. $A = [a_{i,j}]$. Next, the image is prepared. We find the average brightness value of all elements in matrix A of the image.

$$\bar{a} = \frac{1}{N \cdot M} \cdot \sum_{i,j} a_{ij}. \tag{6}$$

Next, we determine the array of differences between each element and the average value of the image.

$$r_{ij} = a_{ij} - \bar{a}. \tag{7}$$



a) b)

Fig. 4. **The algorithm for equalization block diagram**

Threshold δ, satisfying the condition $N_t^{(1)} = N_t^{(-1)} = N_t^{(1)}$ is found in this way. A search is conducted for brightness values t, and it is assumed that $\delta=t$, $t=\epsilon(0\ldots t_{max})$, where t_{max} - is the maximum value of brightness levels for the given image. Next, all elements of the array $R=\lfloor r_{ij} \rfloor$ are compared with the threshold δ. This takes into account the number of elements classified as $N_t^{(1)}, N_t^{(-1)}, N_t^{(0)}$ and calculates the value of the variable $maxP_t = N_t^{(1)} \cdot N_t^{(-1)} \cdot N_t^{(0)}$ for every value t. So the value of t for which the variable $MaxP$ takes the maximum value is chosen as the threshold δ.

To find the elements of the prepared image, we will use the obtained threshold δ. Then,

$$\begin{cases} \text{If } R_{i,j} > \delta, \text{ то } b_{i,j} = 1; \\ \text{If } R_{i,j} < -\delta, \text{ то } b_{i,j} = -1; \\ \text{If } R_{i,j} \le |\delta|, \text{ то } b_{i,j} = 0; \end{cases} \tag{8}$$

Thus, a matrix of elements $B=[b_{i,j}]$ is formed.

According to the mathematical model [18], we will develop an algorithm for the formal description of image parts (Fig. 4).

Let's compose a procedure for reading the preprocessed image represented by a matrix. $B=[b_{i,j}]$. Balancing by connectivity is carried out as follows. The balancing curve point is set in the middle of the column section where balancing occurs.

$$l_j := \frac{N_{min} + N_{max}}{2}. \tag{9}$$

Next, the SumConnectivity procedure is called (Fig. 4, b), in which the total connectivity values in the column are calculated from the beginning to the dividing point W_j^1 and from the dividing point to the end of the column W_j^2.

$$W_j^1 = \sum_{i=N_{min}}^{l_i} v_{i,j}^b, \quad W_j^2 = \sum_{i=l_i}^{N_{min}} v_{i,j}^b. \tag{10}$$

The connectivity values of the preparations are separately determined for zero, unitary, and minus unitary preparations g=(-1, 0, +1). The connectivity of individual preparations is computed as follows: adjacent elements of the preparation under consideration are iterated over, and the connectivity of this preparation is taken as equal to the number of elements that are also preparations for them, the connectivity value is found $b_{i,j}=g$.

Total connectivity values obtained W_j^1 and W_j^2 are being compared: if $W_j^1 > W_j^2$, then the point of the balancing curve is lowered by one step. At the same time, if the element $b_{i,j}$, is equal to g, then its connectivity $v_{i,j}^b$ is found and $W_j^1 = W_j^1 - v_{i,j}^b$, $W_j^2 = W_j^2 + v_{i,j}^b$. This operation is performed until equality is achieved $W_j^1 < W_j^2$.

If $W_j^1 = W_j^2$, then the described procedure takes place in reverse order. Similar operations are performed for the following columns. After that, the obtained connectivity values are added up. $W_\Sigma^1 = \sum_{j=1}^{M} W_j^1$, $W_\Sigma^2 = \sum_{j=1}^{M} W_j^2$.

In addition to the values of connectivity W_j^1 and W_j^2 the coordinates of each point of the balancing curve are also recorded.

Next, the balancing of the area of the image below the dividing curve takes place. Here, the lower boundary is the initial row of the prepared image, and the upper boundary is the array with the coordinates of the curve points from the previous balancing. Afterward, balancing occurs, according to the provided algorithm, for the area above the dividing curve. In this case, the lower boundary is the array with the coordinates of the dividing curve points, and the upper boundary is the last row of the prepared image.

Following the described algorithm, the prepared image is divided both vertically and horizontally. During implementation on the computer, image processing was done sequentially – first, the processing of the initial image occurred, and its balancing curves were saved in the array $arsi_{i,j}$. The correlation coefficients were found after finding the balancing curves for the second image.

In the table 3, the estimation of the execution time of the "exact" scheme of image processing with the correlation comparison of the balancing curves and the estimation of the time for the traditional correlation comparison of images are given [20].

Table 3. **Execution time of the "exact" image processing scheme with correlation comparison of balancing curves**

Image size	Computation time, msec				
	Balancing horizontally for 1 field of preparations	Balancing vertically and horizontally for 1 field of preparations	Balancing vertically and horizontally for 3 fields of preparations	Three steps of balancing vertically and horizontally for 3 fields of preparations	Evaluation of traditional image correlation comparison time
100×100	5	20	110	220	770
128×128	10	110	220	390	1320
200×200	110	110	500	880	3130
256×256	110	220	660	1320	4730

Comparative analysis of Table 3 shows that: if one equalizing curve is used for image recognition, the time savings of the developed method compared to the traditional one will be 43 times. If two equalizing curves are used for image recognition, the time savings of the developed method compared to the traditional one will be 22 times. If six equalizing curves are used for image recognition, the time savings of the developed method compared to the traditional one will be 7,2 times. If eighteen equalizing curves are used for image recognition, the time savings of the developed method compared to the traditional one will be 3,6 times. This algorithm allows you to process images in real time, like similar methods [21-23].

According to the presented algorithms, a program was developed and used to evaluate the performance of the compact image representation and comparison method. The conventional correlation comparison of images was done pixel by pixel. Therefore, as the dimensionality of the images increases, the correlation comparison time increases significantly (Fig. 5).

The results given in the table have relative values. Since the absolute values depend on the performance of computer systems on which the given algorithms will be realized. And also the results depend on the software implementation, which can be optimized for a particular hardware structure.

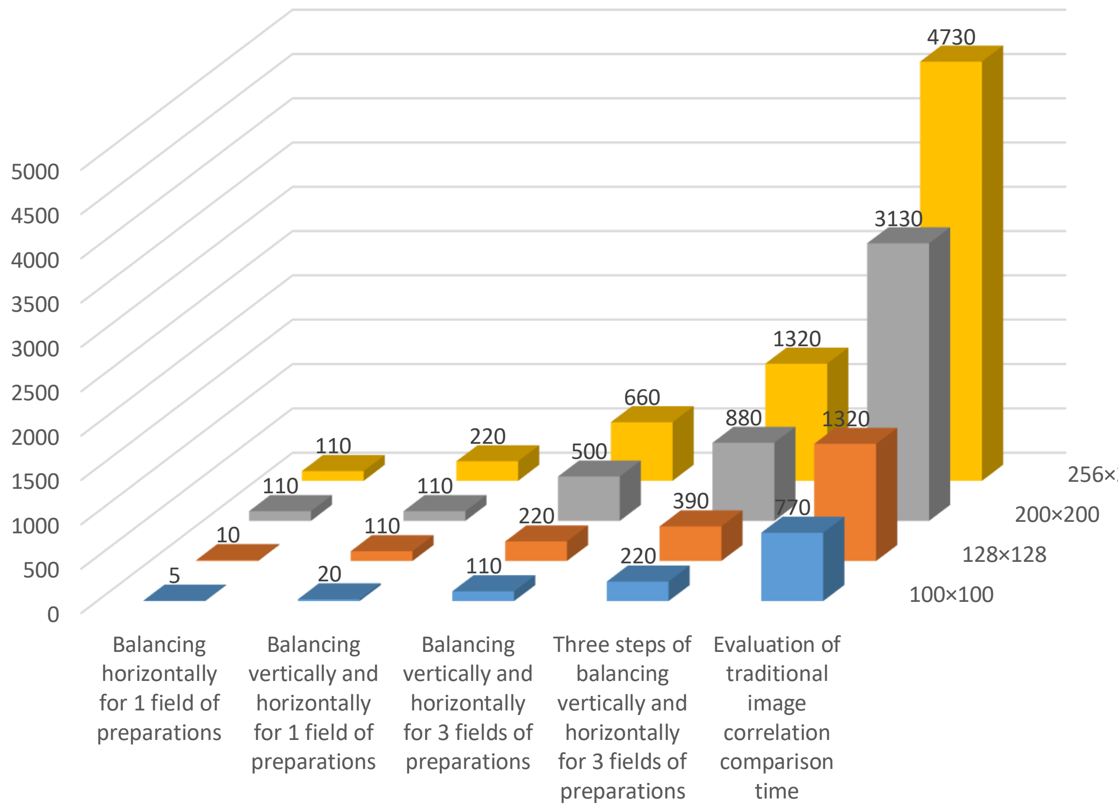


Fig. 5. **A comparison chart of the execution time of an "exact" image processing scheme with a correlation comparison**

Conclusions. The research has shown that the main requirements for universal methods of compact image representation include high compression ratio, quality of compressed images, compression/ decompression speed, and consideration of individual image characteristics.

We believe that among the researched methods, the fractal method of lossy compression is the most promising for further development, improvement, and practical application in computer technologies. It has several unique features and advantages: image reconstruction is much faster, noticeable artifacts at color transitions are reduced, the method can be used for compressing images intended for high-quality printing, and image scaling is possible.

Algorithms have been developed that implement an "accurate" image processing scheme, within which a multi-level image representation is carried out, and an equalization procedure is implemented, allowing for a more compact representation of image features and faster computation of the correlation function. It has been shown that the method of equalization of halftone images within the "accurate" processing scheme and excessive equalization in four directions, compared to the traditional method of correlation image processing, allows reducing the image recognition time for different numbers of equalizing curves from 3.6 to 43 times.

The algorithms for describing the information fields of an image in the form of a spectrum of spatial connectivity of its constituent elements are presented. Based on this concept, a method of generalized spatially connected dissection is proposed, on the basis of which comparison functions are calculated, including the correlation function, which allows the implementation of the method of image segmentation and their compact representation.

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Дослідження графічних форматів даних для компактного представлення і порівняння зображень

В статті проводиться дослідження поширених методів стиснення графічної інформації із втратами та без втрат. В результаті дослідження виділено переваги та недоліки методів стиснення. Здійснено порівняльний аналіз основних можливостей методів стиснення графічної інформації. Актуальність полягає в ефективній передачі, обробці та збереженні графічної інформації, оскільки великій обсяг даних вимагає збільшення пропускної здатності мереж і значних ресурсів для зберігання даних. Практичне значення полягає у вирішенні завдання ефективного зменшення розмірів даних шляхом застосування відомих методів стиснення.
На основі дослідження графічних форматів даних приводиться розробка алгоритмів обчислювальної схеми «точної» обробки напівтонових зображень для розпізнавання образів. Така схема здійснює переопис багатоградаційного зображення в трирівневе подання і реалізує процедуру урівноваження, що дозволяє в більш компактному виді формувати ознаки зображення і швидше обчисляти кореляційну функцію. Показано ефективність використання розроблених методів компактного подання зображень із кореляційним порівнянням урівноважуючих кривих перед традиційним кореляційним порівнянням зображень.

Ключові слова: зображення, стиснення з втратами, перетворення, трирівневе подання, урівноваження, кореляційна функція.