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ANALYSIS AND MODIFICATION OF GRAPHIC DATA COMPRESSION ALGORITHMS

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АНАЛІЗ І МОДИФІКАЦІЯ АЛГОРИТМІВ СТИСНЕННЯ ГРАФІЧНОЇ ІНФОРМАЦІЇ

Abstract. The article examines the algorithms for JPEG and JPEG-2000 compression of various graphic images. The main steps of the operation of both algorithms are given, their advantages and disadvantages are noted. The main differences between JPEG and JPEG-2000 are analyzed. It is noted that the JPEG-2000 algorithm allows re-moving visually unpleasant effects. This makes it possible to highlight important areas of the image and improve the quality of their compression. The features of each step of the algorithms are considered and the difficulties of their implementation are compared. The effectiveness of each algorithm is demonstrated by the example of a full-color image of the BSU emblem. The obtained compression ratios were obtained and shown in the corresponding tables using both algorithms. Compression ratios are obtained for a wide range of quality values from 1 to ten. We studied various types of images: black and white, business graphics, indexed and full color. A modified LZW-Lempel-Ziv-Welch algorithm is presented, which is applicable to compress a variety of information from text to images. The modification is based on limiting the graphic file to 256 colors. This made it possible to index the color with one byte instead of three. The efficiency of this modification grows with increasing image sizes. The modified LZW-algorithm can be adapted to any image from single-color to full-color. The prepared tests were indexed to the required number of colors in the images using the FastStone Image Viewer program. For each image, seven copies were obtained, containing 4, 8, 16, 32, 64, 128 and 256 colors, respectively. Testing results showed that the modified version of the LZW algorithm allows for an average of twice the compression ratio. However, in a class of full-color images, both algorithms showed the same results. The developed modification of the LZW algorithm can be successfully applied in the field of site design, especially in the case of so-called flat design. The comparative characteristics of the basic and modified methods are presented.

Keywords: image compression algorithms lossless and lossy; jpeg; jpeg-2000; discrete cosine transform; discrete wavelet transform; modify lzw-algorithm.

Анотація. У статті досліджено алгоритми JPEG і JPEG-2000 стиснення різних графічних зображень. Наведено основні кроки роботи обох алгоритмів, відзначені їхні переваги й недоліки. Проаналізовано основні відмінності JPEG і JPEG-2000. Відзначено, що алгоритм JPEG-2000 дозволяє видаляти візуально неприємні ефекти. Це дає можливість виділити важливі області зображення й підвищити якість їх стиснення. Розглянуто особливості кожного кроку алгоритмів і порівняно складнощі їх виконання. Ефективність кожного алгоритму продемонстровано на прикладі кольорового зображення емблеми Білоруського державного університету. Наведено у відповідних таблицях отримані коефіцієнти стиснення за допомогою обох алгоритмів. Коефіцієнти стиснення отримано для широкого діапазону значень якості, від 1 до десяти. Досліджувалися зображення різних типів: чорно-білі, ділова графіка, індексовані й повнокольорові. Наведено модифікований алгоритм LZW-Lempel-Ziv-Welch, який можна застосувати для стиснення різноманітної інформації, від тексту до зображень. Модифікація базується на обмеженні графічного файлу 256-ма кольорами. Це дозволило проіндексувати колір одним байтом, замість трьох. Ефективність даної модифікації зростає зі збільшенням розмірів зображень. Модифікований алгоритм LZW можна адаптувати до будь-яких зображень, від однокольорових до повнокольорових. Підготовлені тести були проіндексовані до необхідної кількості кольорів у зображеннях за допомогою програми Fast Stone Image Viewer. Для кожного зображення було отримано сім копій, що містять відповідно 4, 8, 16, 32, 64, 128 і 256 кольорів. Результати тестування показали, що модифікована версія алгоритму LZW дозволяє, в середньому, в два рази збільшити коефіцієнт стиснення. Однак, на класі повнокольорових зображень обидва алгоритми показали однакові результати. Розроблена модифікація алгоритму LZW може бути з успіхом застосована в області дизайну сайтів, особливо у випадку, так званого, плоского дизайну. Наведено порівняльні характеристики базового й модифікованого методів.

Ключові слова: алгоритми стиснення зображень з втратами і без втрат; jpeg; jpeg-2000; дискретне косинусне перетворення; дискретне wavelet-перетворення; модифікований lzw-алгоритм.

Introduction

The current Information Age gives rise to huge amount of information, which requires large storage devices and high-speed communication channels. However, increasing the storage capacity and the speed of transmission is either technically impossible or not economically relevant. The task is to reduce the amount of information without changing it. This process is called archiving or data compression.

In fact, it is possible to compress almost any type of information, primarily because its "usual" representation is usually redundant. Redundancy is present in texts, since they necessarily contain repeating words, phrases, and even whole paragraphs. Redundancy of information is inherent in the speech, since it necessarily includes frequencies that are not perceived by human hearing. By removing redundancy, the need for information capacities required for storing information can be reduces, while retaining the ability to restore it to its original form. Thus, by removing the redundancy of information, the resources required to store and transmit data can be reduced.

Problem statement. Classification of compression algorithms

A number of the algorithms for graphic information compression are considered below. There is a comparative analysis, on the basis of which the most versatile and "efficient" algorithm will be chosen. The efficiency of a selected class of images compression will be examined according to the algorithm modification.

Compression of data that does not have the condition of redundancy (for example, a random signal or white noise, encrypted messages) is fundamentally impossible without loss [1]. Compression methods can be divided into two types:

1. Lossless compression techniques ensure that the decoded data is the same as the original.
2. Lossy compression techniques can distort the original data, for example, by removing an insignificant part of the data, after which full recovery is impossible.

The first type of compression is used when it is important to restore data after compression in an undistorted form, it is important for texts, numerical data, etc. Compression is achieved only due to a more economical presentation of data.

The second type of compression is used mainly for video images and sound. A higher compression ratio can be achieved due to losses [2, 3]. The main criteria for evaluating any data compression algorithm are:

- quality (a ratio or degree) of compression, i.e. the ratio of the length (in bits) of the compressed data representation to the length of the original representation;
- speed of encoding and decoding, determined by the time spent on encoding and decoding data;
- the amount of required memory.

There is no doubt that evaluating compression methods from a practical point of view depends on the intended field of application [4].

JPEG algorithm. JPEG is the standard for full color images. The algorithm operates with 8x8 areas where brightness and color change relatively smoothly. As a result, only the first coefficients are significant throughout the factorization of the matrix of such a range in the double cosine series. Thus, compression in JPEG is carried out at the expense of the smooth changes in colors of image.

The algorithm is based on a Discrete Cosine Transform (DCT) applied to the image matrix to obtain some new coefficient matrix. To obtain the original image, the inverse transformation is applied [4].

The Discrete Cosine Transform (DCT) decomposes the image into the amplitudes of certain frequencies. Thus, when transforming, we get a matrix in which many coefficients are either close or equal to zero. In addition, due to the imperfection of human vision, the coef-

ficients can be approximated more roughly without noticeable loss of image quality.

For this, quantization is used. In the simplest case, it is an arithmetic right circular shift. With this conversion, some information is lost, but a large compression ratio can be achieved.

Steps to realize the transformation algorithm:

- It is necessary to convert an image from RGB color space to YCrCb color space (sometimes called YUV). Y is the brightness component, and Cr, Cb are the components responsible for the color (chromatic red and chromatic blue).
- Divide the original image into 8x8 matrices. Three DCT matrices are formed from each – 8 bits separately for each component.
- Apply DCT to each matrix. In this case, we get a matrix in which the coefficients in the upper left corner correspond to the low-frequency component of the image, and in the lower right - to the high-frequency one.
- Quantization. Basically, the matrix is being divided into the quantization matrix element by element. For each component (Y, U and V), in the general case, its own quantization matrix is specified. At this stage, the compression ratio is controlled and the largest loss occurs.
- Convert the 8x8 matrix into a 64-element vector using "zigzag - scan", i.e. the elements with indices (0,0), (0,1), (1,0), (2,0)... are needed.
- Convolution of the vector using the group coding algorithm.
- Convolution of pairs by Huffman coding with a fixed table.
- The image restoration process in this algorithm is completely symmetric.

The method allows to compress some images without serious loss.

Advantages of the algorithm:

1. The compression ratio is set.
2. The color image can be 24 bits per point.

Disadvantages of the algorithm:

1. As the compression ratio increases, the image splits into separate squares (8x8), due to the fact that large losses occur at low frequencies during the quantization. It becomes impossible to restore the original data.
2. The Gibbs phenomenon manifests itself in halos along the borders of sharp color transitions.

JPEG algorithm characteristics:

- Compression ratio 2-200 (user-defined).
- Full-color 24-bit or grayscale images without sharp color transitions (photographs).
- Symmetry: 1.
- Special Features: In some cases, the algorithm creates a "halo" around sharp horizontal and vertical edges in the image (Gibbs phenomenon). In addition, when the compression ratio is high, the image splits into 8x8 pixel blocks.

JPEG-2000 algorithm. The main differences between the JPEG-2000 algorithm and the JPEG algorithm:

1. The best image quality with with the high compression. A higher compression ratio for the same quality.
2. Support for the encoding of specific areas with better quality. It is known that certain areas of an image are crucial for human perception (for example, the eyes in a photograph), while the quality of others can be sacrificed (for example, the back-ground). The main compression algorithm is replaced by wavelet transform. In addition to the specified increase in the compression ratio, it allows to get rid of the 8-pixel blocks that occurs when the compression ratio is increased. Moreover, smooth image development is now a standard feature.
3. To increase the compression ratio, the algorithm uses arithmetic compression.
4. Support of the compression without losses. Thus, it becomes possible to use JPEG in compression of medical images, in printing, in

text saving for recognition by OCR systems, etc.
5. Support of the single-bit (2-color) images compression.
6. Concerning the format, transparency is maintained. In addition, not only one bit of transparency (the pixel is transparent/opaque) is supported, but a separate channel, which will allow setting a smooth transition from an opaque image to a transparent background.

JPEG-2000 features:

1. Instead of a discrete cosine transform (DCT), a discrete wavelet transform (DWT) is used.
2. Arithmetic compression is used instead of Huffman coding.
3. The algorithm includes quality control of image areas.
4. The sampling of the U and V components after color space conversion is not used, because DWT can achieve the same result, but more accurately.

JPEG-2000 algorithm characteristics:

1. Compression ratio: 2-200 (user-defined). Lossless compression possible.
2. Full color 24-bit images. Grayscale images without abrupt color transitions (photos). 1-bit images.
3. Symmetry: 1-1.5.
4. Special Features: Allows to remove visually unpleasant effects, improving quality in specific areas. With strong compression, blockiness and large waves appear in the vertical and horizontal directions.

Comparative analysis of JPEG and JPEG-2000

Let us consider the algorithm of the simplest JPEG lossy codec. The whole process consists of the following steps, which are shown in Figure 1.

Fig. 1. Phases of the JPEG codec work

The sequences of processes for JPEG-2000 is similar, with the exception of using discrete wavelet transform (DWT) instead of discrete cosine in JPEG. Let us consider the features of each step and compare the complexity of the execution of each of the algorithms.

At the first stage of both algorithms, the image is converted from the RGB color space with the components responsible for the red, green (Green) and blue (Blue) components of the point color into the YCrCb color space (sometimes called YUV). All further work is done with this particular color space. Y is the brightness component, and Cr, Cb are the components responsible for color (chromatic red and chromatic blue) [5, 6].

The advantage of representing color through YCrCb, over RGB, is that it is the closest to the "natural" one, which is unconsciously performed by a person. The Y component or brightness is closely related to image quality.

The algorithms allow the subsampling of channels: each block of 4 pixels (2x2) of the Y luminance channel has the average value of Cb and Cr (subsampling scheme (4: 2: 0). Therefore, already at this stage, the size of the encoded information will decrease, and the size of the output file [7, 8].

At this point, the estimation of the running time of the algorithms is comparable.

Pixel grouping, transformation, quantization

At these steps, there is a fundamental difference between the two algorithms, which will determine the nature of the distortion of the images obtained after compression. This is how

JPEG splits each channel into 8x8 blocks. Each of the blocks is separately subjected to a discrete cosine transform. The JPEG-2000 algorithm does not require splitting the image into small square blocks, since the DWT (discrete wavelet transform) used in the algorithm works on fragments of any size.

Compression

The matrices obtained at the previous stage are compressed, but each of the algorithms does it in its own way. JPEG writes out the data of 8x8 blocks by zigzag scanning of the matrix, leaving most of the zero coefficients at the end of the chain, packs them using the RLE algorithm and then applies Huffman coding. The JPEG-2000 encoding process is more complex. According to the JPEG-2000 standard, immediately before encoding, fragments are divided into blocks (for example, 32x32 or 64x64) so that all blocks of one fragment are of the same size. In JPEG-2000, each block is encoded independently. The coding algorithm bypasses the matrix of roundoff coefficients of each block in lines [5].

Comparison of compressed images

Most images on the Internet go through lossy compression, so it is difficult to track the characteristic changes after recompression on them, only by considering rather large compression ratios, it will be possible to detect visible defects. For the experiment, take the image shown in Fig. 2. It has not been compressed, it contains areas with a single color fill and areas of smooth color transition.

Fig. 2. Original uncompressed image

Let us compress the image using the JPEG and JPEG-2000 algorithms. With different compression quality settings. Let us look at several pairs of images.

For the first pair, 2 compressed images were selected, which have approximately the same size ~ 45 kB, 4 times smaller than the original file. The pair is shown in Fig. 3.

Fig. 3. Comparison of images compressed with JPEG and JPEG-2000

It can be noted that the quality of image, which has been compressed using the JPEG-2000 algorithm, is better than the image, which has been compressed, compressed using JPEG.

Next, a pair of compressed images (Fig. 4), comparable in terms of the quality obtained after compression.

Fig. 4. Comparison of images compressed with JPEG and JPEG-2000

The images show defects of the used algorithms. For JPEG-2000, it is "blurring", "smoothing" of edges on contrasting transitions. For JPEG, it also adds "splitting" into 8x8 blocks. The two images can be called comparable in quality, but the size of the image compressed by the JPEG-2000 algorithm is 2.5 times less than the compressed JPEG: 15 kB versus 35 kB.

Therefore, JPEG-2000 can achieve better image quality at the same compression ratio, or achieve a higher compression ratio at the same quality, compared to JPEG.

Comparison of the results of the algorithms. Let us test the operation of two algorithms by two directions: by the compression ratio of the output images and by the operating time. We use the free library ImageMagick. It allows selecting the desired compression format, in that case JPEG and JPEG-2000, and setting the input quality parameter.

Tables 1 and 2 show the obtained compression ratios.

Table 1. JPEG compression ratios, taking into account different values of the quality parameter

quality	1	2	3	4	5	6	7	8	9	10
black and white	576	568	573	562	562	566	555	558	543	550
business graphics	72	64	59	55	52	48	45	40	36	30
indexed 128	83	67	56	48	42	37	31	25	20	15
indexed 256	92	74	62	53	47	40	34	27	21	15
full-color	54	46	40	36	33	30	27	23	20	16

Table 2. Compression ratios for JPEG-2000 taking into account different values of the quality parameter

quality	1	2	3	4	5	6	7	8	9	10
black and white	8554	7978	7572	7364	7231	7108	6980	6897	6815	6753
business graphics	479	240	141	91	65	48	38	273	26	23
indexed 128	2182	1226	489	68	15	8	5	4	3	3
indexed 256	2699	1556	668	113	19	9	5	4	3	3
full-color	203	99	55	34	21	14	9	6	5	4

Error! Select error. It can be seen from the test results, that the compression of black and white images with lossy algorithms also gives a huge benefit, as well as with lossless compression algorithms. However, in these images, the disadvantages of lossy algorithms are the most clearly visible.

As you can see, when setting the quality parameter close to one, we receive an advantage when using the JPEG-2000 algorithm. However, images compressed with this parameter at the output are of low quality - the boundaries of areas are blurred, contrasts and image details are lost, so compression with such a parameter is not required.

The JPEG algorithm is better for compression with a quality parameter close to 100 (to 10 at this scale). However, images compressed with a quality setting of 10 and a setting of, for instance, 5 are difficult to distinguish with a naked eye. With JPEG compression, the division into 8x8 blocks will be noticeable, but this is almost impossible to see in large photorealistic pictures. Therefore, when saving, the value of the quality parameter is used, equal to 30-50 (with a standard scale), or 3-5 in that particular case. Here, the JPEG-2000 algorithm is superior in compression ratio by 1.2 – 3 times.

Comparative analysis has shown that with the use of JPEG-2000 algorithm images can be

compressed 1.2-3 times more than using JPEG (when certain quality settings are selected). However, the JPEG-2000 algorithm requires more resources: memory and time.

The point of the LZW algorithm modification

The LZW (Lempel-Ziv-Welch) algorithm, based on replacing characters with some codes, is applicable to any kind of information, texts or images. This is done without any analysis of the input text. The classical model of the algorithm does not use the features of the graphical information storage format. A pixel is considered to be a unit of graphic information. For storing information about a pixel, most images are allocated 24 bits - 8 bits for each component of the RGB palette. The LZW algorithm operates with 8 bits as a character and initializes the dictionary with 256 characters (ASCII encoding).

Let us consider the content of a graphic file with the number of colors equal to 256. Width = w and height = h. Then the file containing this image will consist of w*h*3 (a pixel is represented by 3 channels) bytes, and all these bytes will sequentially go through the compression algorithm. Considering the number of colors, let us index 3 bytes with one. We will save the correlation between colors and their corresponding codes in the dictionary. Then we will just save this table into a compressed file. Thus, w*h*3 bytes that would be law encoded are converted to w*h, potentially reducing the size of the compressed file. However, as the size of the images increases, the memory required to store this additional information decreases to the number of bytes for compression. It is an advantage.

Obviously, this algorithm can be adapted to any image, be it one-color, 256-color, or even full-color. Let us analyze the stream of incoming symbols. Index 3 bytes (color) one and add this color to the dictionary if it is missing.

Files for analyzing

We will use BMP images as images for analyzing. A standard BMP file contains uncompressed image information.

Let us test several full-color images and use FastStone Image Viewer to index the number of colors in the images. As a result, we get 7 copies for each picture, which will contain 4, 8, 16, 32, 64, 128, 256 colors.

Figure 5 shows the test results – compression ratios for the standard version of the LZW algorithm on files with 16, 64, 256 colors.

The results of testing the modified version of LZW are shown in Figure 6. As you can see from the diagrams, the algorithms are similar. However, in the modified version this value increases to 13, while in the standard version there is a compression gain of up to 7.5 times.

Fig. 5. LZW compression ratio diagram

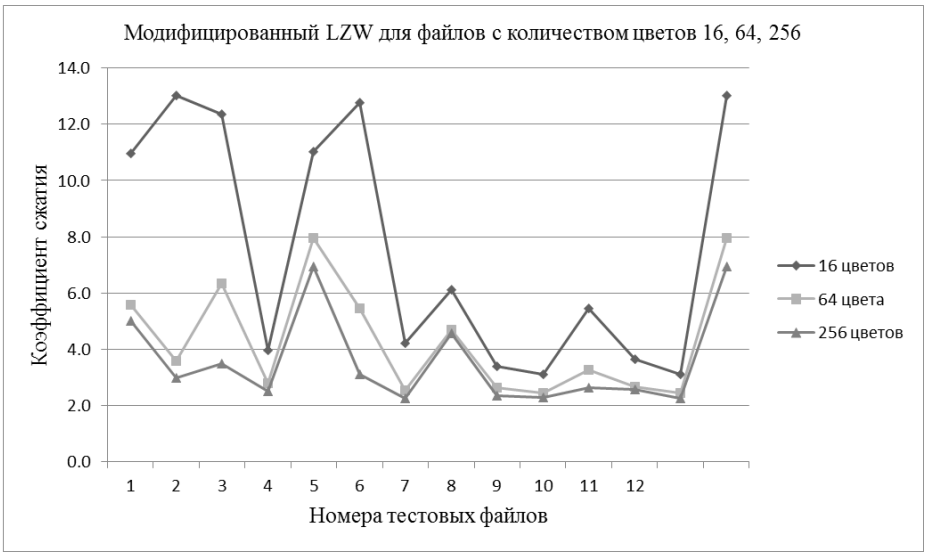

Fig. 6. Diagram of compression ratios of the LZW modification

Let us compare the average compression ratio for all classes of images (from 4 to full color). As it can be seen from Figures 5 and 6, the modification of the algorithm gives an advantage in 2 times compared to the usual version on images with an indexed palette. However, on the class of full-color images, the algorithms show the same result. The decompression speed of the algorithms is quite comparable. The modified algorithm turned out to be more efficient when considering images with no more than 256 colors.

Conclusion

As a result of a comparative analysis of lossy compression algorithms such as JPEG and JPEG-2000, the main approaches to transforming graphic information with minimal visual loss were formed. The features and advantages of each of the algorithms are clarified.

It is shown that the modified LZW algorithm allows obtaining a qualitative improvement in the compression ratio on image classes with a limited color palette.

The developed modification of the LZW algorithm can be applied in the areas of website design and program design, since the so-called "flat design" has become popular. In these areas, images are used with a limited color palette and large areas filled with one color. The test has shown that the developed modification gives good results for this class of images.

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