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Adaptive hybrid coding of digital images

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Abstract---Existing and proposed algorithms for lossless encoding of arrays of non-principal coefficients of transforms formed as a result of discrete cosine transformation of 8x8 fragments corresponding to the brightness and chrominance components of digital color images are presented. The proposed algorithm involves efficient lossless encoding of a two-dimensional array of non-principal coefficients of transforms using zigzag - vertical scanning in addition to the existing zigzag-horizontal scanning, selecting the best one from them in terms of efficient encoding, and encoding the scanned one-dimensional data sequences with variable-length Huffman codes.

Keywords---linear transformation; transformant; zigzag scanning of coefficient arrays; efficient coding; hybrid coding.

1 Introduction

One of the main components of digital broadcasting systems is a device for reducing the transmission speed of digital images, which achieves this goal by reducing the psychophysiological and statistical redundancy in the brightness Y and chrominance C_r and C_b components of color images, i.e. by effectively coding digital images. For this purpose, the discrete cosine transform is used based on international standards. Based on it, a two-dimensional [(x,y)] composed of fragments of 8x8 size corresponding to the components of digital images is created.f Array transformation, formed by transformation [F(u,v)] Quantization of transform coefficients using matrices provided by standards and the resulting [F'(u,v)] Lossless encoding of arrays of principal and non-principal coefficients with variable-length Huffman codes [1 - 6].

2 The main part

The difference values of the main F'(0,0) coefficients of the quantized transforms formed by the transformation of each component of the color images into 8x8 fragments $f(x,y)$ (x, y,=1,2, …, 7) are encoded using variable-length unary codes. As for the sequence of zigzag - horizontally scanned non-

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primary F'(u,v) (u, v,=1,2, …, 7) coefficients , it is encoded using variable-length Huffman codes [2, 5, 6].

2 variants of calculating differences for an array of principal coefficients of a transformant and 5 variants of scanning them is known , in which two variants of calculating differences for a set of principal coefficients - horizontal (h) and vertical (v) - and the corresponding differences obtained in this way are considered. 5 options for scanning two-dimensional space - coding of differences without scanning, coding with zigzag-horizontal (ZH), zigzag-vertical (ZV), horizontal (H) and vertical (V) scans. Therefore, taking into account the options for calculating the differences, the number of coding options will be 10. Accordingly, taking into account all three components of the color image, the total number of options is 10^{3} =1000. Therefore, in order to determine the best in terms of efficiency from all possible combinations of options, it is necessary to take into account 10 additional binary symbols in the transmitted digital signal. However, as the results of the experiments showed, despite the transmission of additional symbols, the efficiency of adaptive coding was still Improved [1, 2, 5].

The efficiency of adaptive coding of digital images can be further increased by using the so-called hybrid algorithm, when in addition to zigzag-horizontal (ZH) scanning of a two-dimensional array of non-prime coefficients of the transforms corresponding to all three components of the images, zigzag-vertical (ZV) scanning is also used, which requires taking into account one binary symbol for each component of the image. As a result, in the case of combining (hybridization) with the algorithm discussed above, it will be necessary to include an additional 3 binary symbols (total 13) in the main digital stream.

Modeling of hybrid variants of adaptive coding in order to determine the effectiveness of each of them was carried out on different types of primary color images shown in Fig. 1: “Beyoncé” (pic. 1), “garniture” (pic. 2), and “lily” (pic. 3).

Pic. 1. Initial images “Beyoncé” (pic. 1), “garniture” (pic. 2) and “Lily” (pic. 3)

The dimensions of each component (luminance Y, and chromatic C_r and C_b) of the digital images used for testing are 256x256, which means that each of them contains 256x256=65536 discrete counts. It should be noted that according to international coding standards, the chromatic C_r and C_b components are decimated, which means omitting every second discrete element and every second line in the direction of the image expansion line [4].

As an example, let us consider the case when the matrix corresponding to the quantized transform formed as a result of the discrete cosine transformation of the brightness component Y of one of the fragments of the “ garniture ” image (pic. 2) has the following form [2].

$$[F'(u,v)] = \begin{bmatrix} 53 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}.$$

the zigzag-horizontal (ZH) scan of the formed [F'(u,v)] transform will have the form shown in pic. 2 [1].

$$53 \quad \underbrace{0 \quad -1} \quad \underbrace{0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0 \quad 0...0}$$

pic. 2. Zigzag-horizontally scanned sequence of the transform coefficient array

The main and non-main coefficients of the scanned sequence are encoded based on the following algorithm: In the considered [F'(u,v)] transform, the main coefficient is 53 . Based on the table of unary codes developed for its encoding, the corresponding row number R= 6 , and the column number C= 53 . Therefore, the unary 7-order code 1111110 corresponds to this coefficient, and the hexadecimal number corresponding to C is 1 1 01 0 1. As a result, the number of symbols required to encode the main coefficient is 1 3 . [1, 3, 5] .

As can be seen from pic. 2, in the sequence formed by scanning the coefficients of the [F'(u,v)] transformant in the horizontal direction, the coding of the first non-prime coefficient 0 and its next - 1 is performed jointly. For this set, Z=1 (the number of zeros in the set is 1) and R= 1 (the absolute value of the coefficient other than zero in the set is 1). Therefore, based on the table provided by the standard, the 4 -order number 110 0 is formed. The corresponding two-order code 1 0 (R=1, C= 0) corresponding to (- 1) is added to it . As a result, the 6 -order number 110 010 is obtained . Since all other coefficients of the sequence formed as a result of scanning are zero, according to the existing standard, a 4-digit number 1010 [1, 3, 5] is formed to mark the end of the sequence encoding.

Thus, the number of bits required for lossless encoding of the quantized [F'(u,v)] transform is m_1 =1 3 + 6 + 4 = 23 . For the initial [f(x,y)] fragment, in the case of 8-bit encoding of its elements, m=8x64=512 bits would be required, due to which the number of symbols in the considered case is reduced by m/m_1 ≈512/ 23 ≈ 22 , 26 times, which means that the effective encoding factor F≈ 22 , 26 .

When zigzag-vertical (ZV) scanning the formed [F'(u,v)] transformant (a proposed variant of lossless coding), the sequence of coefficients will have the form shown in pic. 3 [1].

53 -1 0 0 0 0 0 0 0 0 0...0

pic. 3. Zigzag-vertically scanned sequence of the transform coefficient array

As can be seen from Fig. 3, all other coefficients of the scanned sequence are zero. Therefore, according to the existing standard, a 4-digit number 1010 [1, 3, 5] is formed to mark the end of the sequence encoding.

Thus, the number of bits spent on encoding the quantized coefficients of the considered transform is $m_2 = 13+3+4=20$. As already shown, 512 bits are required for encoding the corresponding initial fragment. Therefore, in this case, the number of symbols will be reduced by $m/m_2 = 512/20 = 25.6$ times, which means that the effective encoding factor F=25.6.

In the case of an adaptive approach to the coding process of non-prime coefficients, i.e., when the array of non-prime coefficients is coded by either zigzag-horizontal (ZH) or zigzag-vertical (ZV) scanning (2 scanning options), an additional 1 bit is required to indicate the coding option. Therefore, in the considered transform, 24 bits will be spent instead of 23 bits during its zigzag-horizontal scanning, and 17 bits instead of 16 bits during its zigzag-vertical scanning. Therefore, in this case, the effective coding factors are $512/24 \approx 21.3$ and $512/21 \approx 24.38$, respectively. Therefore, in the considered case, when using zigzag-vertical scanning of the array of non-primary coefficients of the transformant, the effective coding factor increases by $24.38/21.3 \approx 1.15$ times compared to zigzag-horizontal scanning, which confirms the advantage of the adaptive approach to coding the array of non-primary coefficients over the non-adaptive option.

Adaptive coding In the case of the proposed hybrid algorithm, the number of encoding options will increase to 20 compared to the existing algorithm (10 options) . Therefore, the possible number of options for all three components of color images will be $20^3 = 8000$, which will require 13 characters for encoding, compared to the existing 10 characters.

In the case of the encoding variant, when adaptive encoding of the main coefficients of the transforms is performed based on the optimal direction of calculating their differences and zigzag-horizontal scans of the optimal and non-main coefficients of the corresponding two-dimensional array, the number of bits required for effective encoding for the full signals of the images is denoted by M_1, and in the case of the proposed encoding variant, when, along with the above-mentioned variants of adaptive encoding of the main coefficients, zigzag-vertical scanning of non-main coefficients is also used - by M_2, and the corresponding factors of effective encoding - by F_1 and F_2 (Table 1).

Table 1. Efficiency indicators of existing and proposed coding algorithms for full signals corresponding to color images

Complete (Total) signal Data				
Images	M_1, Bit	M_2, bit	F_1	F_2
"Beyoncé"	60525	**60499**	≈ 25,987	**≈25,998**
"Garnituri"	51295	**49787**	≈ 30,663	**≈31,592**
"Lily"	95088	**94863**	≈ 16,541	**≈16,580**

Note that in Table 1 , the best data in terms of coding efficiency is highlighted.

It is worth noting that the effective coding factor F is calculated taking into account that the Y, C_r and C_b components of the primary color images used for testing contain 256x256=65536 elements. Therefore, when encoding these elements in 8-bit format, 8x65536=524288 bits will be spent on each component of the image. Accordingly, the effective coding factors for the full signals of the images in the case of the existing (F_1) and proposed (F_2) encoding options will be:

$$F_1=3x524288/M_1=1572864/M_1; \qquad F_2=3x524288/M_2=1572864/M_2.$$

In addition, it is worth noting that in Table 1, when evaluating the efficiency of encoding images based on the adaptive hybrid algorithm, the additional 13 binary symbols required to determine the encoding option for the main and non-main coefficients of the information are also taken into account.

Table 1 clearly shows that using the adaptive hybrid coding algorithm made it possible to improve the efficiency of image coding.

3 Conclusion

Adaptive hybrid coding for efficient image coding, which involves combining the difference values of the principal coefficients of quantized transforms formed as a result of discrete cosine transformation of 8x8 fragments of brightness and color components of color images, and adaptive coding algorithms of the array of non-principal coefficients, provides the opportunity to increase the coding efficiency without deteriorating the quality indicators of the reconstructed images. In particular, as a result of hybrid coding, the number of binary symbols required for the full signal of the image "Beyoncé" decreased from 60525 to 60499, for the image "garniture" - from 51295 to 49787, and for the image "Lily" - from 95088 to 94863, i.e. the effective coding factor increased from 25,987 to 25,998, from 30,663 to 31,592, and from 16,541 to 16,580, respectively.

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