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Comparative Analysis of Various Methods for Efficient Image Encoding

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ABSTRACT: Due to the problem of economical use of the bandwidth of digital telecommunication channels and the volume of devices storing the corresponding signals, the compact representation of digital signals is one of the current tasks. It is particularly problematic for high-information image signals, which is why they are distinguished from other types of signals by their broadband nature.

KEYWORDS: effective digital encoding, lossless encoding, Khafman code, discrete cosine transform (DCT), Walsh transform (WT) and etc.

I. INTRODUCTION

The political and economic activity of modern society depends significantly on reliable telecommunications and computing facilities that provide the processing and transmission (or storage) of sound and image signals.

The problem of efficient lossless encoding of images is relevant and actual task for modern society. In lossless encoding, the image reconstructed during decoding is identical to the original, making it suitable for applications such as defence sector, medical imaging, and other digital image archiving and transmission systems where even minimal loss is unacceptable. An example of lossless encoding includes the compact representation of text data in computer programs, where the loss or alteration of even a single bit is completely unacceptable. Lossless, compact representation of computer program text can be achieved by eliminating blank spaces and metadata related to the font used. Lossless image coding is typically based on the statistical properties of the corresponding signals, where compression is achieved solely through the reduction of statistical redundancy.

Digital imaging is playing an increasingly prominent role in the information landscape. The advancement of the Internet, coupled with technological progress in the development of high-performance computers, digital cameras, scanners, and printers, has driven the widespread adoption of digital imaging.

II. LITERATURE SURVEY

Back in 1948, Claude Shannon first accurately and clearly formulated the basic problem that must be solved in the development and implementation of any telecommunications system. The essence of this problem is that any telecommunications system must ensure, at a given point or moment in space or time, the exact or approximate recovery of a message selected at another point (moment). According to Shannon's information theory, any message has a certain meaning, although this is not necessarily the main point for solving the engineering problem. The most important thing is that the message sent is selected from a certain family of possible messages. Therefore, Shannon argues that reliable telecommunications must be digital. At the same time, the scientist divided the task of reliable telecommunications into subtasks of encoding the message source and channel.

The task of encoding various types of signal sources (text files, digital images, digitally represented music, television programs, etc.) is to create an encoder that provides a compact (compressed) description of the original signal.

III. METHODOLOGY

The effectiveness of a particular encoding method is determined by the compression achieved and the degree of identity between the encoded and original images. In the case of maximally achievable compression for image signals, the

initial and decoded images should be absolutely identical. For example, lossless coding should be implemented in medical diagnostics and military target detection systems.

There are various image encoding methods of signals, that we can review.

Entropic coding is not distinguished by a high compression ratio, which is why it is used in combination with other methods (DPCM, linear transformations), which increases the efficiency of the main coding method. For example, entropy coding is used in systems for encoding 8x8 image fragments with DCT (Discrete Cosine Transform) to compactly encode the set of all coefficients of the transform (except the first one), since many of them are equal to zero or slightly different from zero. Each non-zero coefficient is represented as a pair of numbers, the first of which shows the number of zero symbols (bits) before the given coefficient, and the second - the value of the given coefficient. In entropic coding, the Khafman code is more often used, which involves constructing a variable-length code, due to which symbols with high probability are assigned short codewords, and symbols with low probability are assigned relatively long codewords, thereby achieving an additional increase in compression obtained by linear transformation. Entropic coding does not cause additional information loss, which is why it is used as an independent method in lossless coding systems.

Differential Pulse Code Modulation (DPCM) is an elementary coding method, which is why it takes into account the correlation between only the closest elements of the image. Therefore, it is impossible to achieve high compression ratios when directly encoding image signals using this method. It, like entropic encoding, is used in hybrid (combined) systems of efficient encoding. For example, using DPCM, an encoding algorithm is implemented by predicting the 1st ("main") coefficients of the DCT of 8x8 image fragments (blocks) (interfragmentary DPCM), thereby reducing the average number of symbols required for their encoding of transforms.

In vector image quantization, an N-dimensional vector composed of N counts (elements) of a digital signal is simultaneously quantized (encoded). A vector can consist of elements taken only along the row direction of the image (one-dimensional quantization) or elements from neighboring rows (two-dimensional quantization). The set of all n-dimensional vectors in the signal is divided into a subset of n_l vectors that differ slightly from each other. In each subset, one reference vector is selected that is "representative" of all vectors in the subset. All reference vectors of the image thus obtained are recorded in a so-called codebook, and each of them is assigned a specific code group. The codebook can be changed according to the structure of the signal to be processed. The construction of the codebook is part of the encoding process and therefore must be transmitted to the receiver. Vector quantization is a lossy encoding method. The advantage of this method is the simplicity of the decoder, although searching for the reference vector in the transmitter requires a large number of calculations.

The fractal encoding method of images is close in essence to the vector quantization method. The only difference is that in this case the codebook is performed by blocks cut from the original image. Fractals are images that have the property of self-similarity, which means that part of the image is similar to the whole image, this part is similar to a smaller part of it, etc. Fractal coding uses the property of similarity of details of different scales in real images.

Vector quantization and fractal coding methods provide significant information compression and can be used to encode audio and video signals. However, the large number of calculations performed during encoding prevents their use in digital television.

Pyramid coding of image signals is sometimes called a method based on local operators. In pyramid coding, instead of the original image, its low-frequency approximation is calculated and the prediction error and the calculated predicted value are encoded. Since the prediction error is inherently of high-frequency, and the human eye is less sensitive to high-frequency image components, in this case, image elements can be transmitted over a telecommunications line with a reduced number of symbols compared to the number of symbols required for the original image elements, thereby achieving compression. In the literature, pyramidal constructions of Laplace and orthogonal types are discussed.

The latter is based on the construction of a pyramid using the so-called wavelet transform. The levels of the wavelet pyramid are independent of each other, which ensures independent coding of each level and, consequently, increases the efficiency of pyramid coding. Wavelet transform image coding is based on the decomposition of signals into either frequency subbands or resolution-based subbands. The division of signals into frequency subbands is used to solve many problems in television, in particular, when transmitting audio signals or recording them in a storage device.

One of the prominent methods of digital image processing and coding is the motion estimation and compensation method. Obviously, it is an interframe coding method and is used in conjunction with other coding methods (in particular, linear transforms). When using this method, an image frame is divided into rectangular macroblocks, and for each of them, a similar macroblock is found in another frame. Once the direction of motion (vector) is determined, it can be compensated for. This encoding method is one of the foundations of the MPEG-1 and MPEG-2 standards. Dividing an image into fixed-size rectangular macroblocks often does not allow for accurate description and compensation of moving objects. Currently, much attention is being paid to the development of more advanced methods that use macroblocks of variable sizes and shapes and gradient methods for motion estimation, which allow determining the motion vector of each element of the image. Of the linear transformations listed above, the Karunen-Loev transformation (KLT) is theoretically the most optimal, since it fully takes into account the statistical characteristics of image signals. However, it has not found practical application because it does not have a fast calculation algorithm compared to other conversions.

The singular transform (ST) is efficient in terms of the root-mean-square error (RMSE) of the reconstructed signal. However, its implementation requires a larger number of operations than that of a CGL, which is why it is considered useful only in memory systems.

The literature also discusses the skew transformation (STR), which is useful only for a small group of images, since it is only applicable to fragments with monotonically and slightly varying brightness. Among the practically feasible transforms for efficient encoding of image signals, the discrete cosine transform (DCT) is considered to be the closest to optimal, followed by the Walsh transform (WT), Fourier transform (FT), and Haar transform.

The Fourier transform (FT) is effective in terms of recovery of the root-mean-square error, and there is a fast algorithm for its implementation, but it is still not used in practice due to the operations performed on complex numbers for calculating the coefficients of the transform.

Of the existing transforms, the simplest in terms of practical implementation is the Haar transform (HT), whose functions are also used in the wavelet transform method. It decorrelates the original signal less than other transforms, which is why it is considered a less efficient method.

The discrete cosine transform (DCT) is considered the closest approximation to the root-mean-square error in terms of the reconstruction algorithm. It also has a fast transformation algorithm and requires fewer operations than the root-mean-square error. It is precisely because of this advantage that it has become one of the components of the JPEG and MPEG standards. But it should also be noted that the basis matrix corresponding to this transformation contains elements expressed as fractional numbers, and therefore, when calculating the coefficients of the transformant, we are already dealing with irreversible errors. Because of this, its use for lossless image encoding is unacceptable.

The Walsh transform (WT) and its variants - Pell (PT), Hadamard (HT) and X-transforms - are free from the aforementioned shortcomings of the DCT. Among them, the structure of the rows of the basic matrix of the WT almost coincides with the structure of the rows of the basic matrix of the DCT, which is why a similar arrangement of coefficients is obtained in both cases. Although it is less efficient than DCT in terms of monotonically decreasing coefficient energy in the transform, it should still be used in efficient digital image coding systems, especially in cases of lossless coding. We can also assume that this small "advantage" of the DCT over the WT can be offset by the fact that when calculating the coefficients of the transform, the DCT makes the same amount of errors (and irreversible errors) due to the fractional elements of its basis matrix, as there is a difference in the monotonically decreasing energy of the coefficients in the corresponding transforms of these transformations. In addition, it is also acceptable to take into account the fact that a fast transformation algorithm can also be used for the WT, the implementation of which is simple compared to the implementation of the fast algorithm for the DCT, since in the first case it is necessary to perform only the operations of addition and subtraction of integers (the elements of both the initial image and the basic matrix of the WT are integers), and in the second case - both the operations of addition and subtraction, as well as multiplication and rounding of fractional numbers (the elements of the basic matrix of the DCT are fractional numbers). If we also take into account the regularities of symbol placement in Walsh transforms, whose consideration increases the coding efficiency without additional losses, then the WTs can be recommended for use in both lossless and partial lossy image coding systems.

IV. EXPERIMENTAL RESULTS

Based on several experiments I conducted and the materials I collected, it has been determined that Extremely good results in lossless encoding of images by linear transformations can be carried out in the case of using the Walsh transform, It has been shown that even in partial lossy image coding systems, the parameters of which are regulated by the JPEG and MPEG standards for encoding static and dynamic images, the use of the Walsh transform is more effective than the discrete cosine transform, firstly, due to the possibility of easily adapting the table of quantization of the discrete cosine transform coefficients to the Walsh transform coefficients.

The efficiency of Walsh transform matrix redundancy compression in the case of both lossless and partial lossy encoding of images depends on the size of the transform fragments. In particular, it is shown that for almost all test images the efficiency increases when the fragment size increases to 4x4, and then decreases, which is why the option of encoding fragments of size 4x4 should be considered optimal for the corresponding encoding systems.

In the case of converting the test images "Lena", into 4x4 fragments, $K_d=64$ and providing fairly high parameters for evaluating the reconstructed images using objective and subjective criteria, the number of bits required for each image element can be reduced from:

8 bits/e to 1.19 (nxn=4x4; $K_d=64$; $m_2=1,19$ bits/e; $F=6,66$) (rmse =5.83; nrmse=0.05; snr=25.65; psnr=32.86) bits/element, with an additional 4 bits per element compared to lossless coding. (See:Table @Image „Lena”)

Table:

Image "Lena" (4x4, n (fr)=4096)								
K (d)	M_2	m_2 , bits/e	C	F	RMSE	PNRMSE	SNR, db	PSNR, db
1	340193	5,19	0,65	1,54	0	0		
2	336097	5,12	0,64	1,56	0,5	0,004	46,98	54,19
4	315617	4,82	0,60	1,67	0,72	0,006	43,81	51,02
8	270561	4,13	0,52	1,92	1,11	0,01	40,06	47,26
16	209121	3,19	0,4	2,50	1,97	0,02	35,08	42,28
32	143585	2,19	0,27	3,70	3,48	0,03	30,13	37,34
64	78049	1,19	0,15	6,66	5,83	0,05	25,65	32,86
128	12513	0,19	0,02	50	9,47	0,09	21,43	28,64

IMAGE: „LENA”



V. CONCLUSION

The case of simultaneous use of different coding methods is called a hybrid coding method (for example, MPEG standards provide for a combination of linear transformation with differential pulse-code modulation and motion estimation and compensation methods) and in this way increases the coding efficiency.

The JPEG and MPEG standards for dynamic image compression, integrate a combination of discrete cosine transform, motion prediction, and entropy coding techniques. Therefore, among the above-mentioned coding methods, the method using linear transformations occupies a prominent place due to its high efficiency.

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