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FRACTAL CODING OF VIDEO SEQUENCES BY GENETIC ALGORITHM

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Abstract. The results of application of the modified genetic algorithm of fractal coding to still images and video sequences are presented. The dependence of the compression coefficient on the size of the rank block is obtained. A comparison of fractal compression with standard MPEG-4 compression algorithms is performed and it is shown that it is possible to achieve double the compression coefficients at the same signal-to-noise ratio values. In the video sequence, both I-frames and predicted P, B frames were subjected to fractal compression. The simulation results showed what time in seconds is spent when encoding one frame. When the size of the rank block from 20 to 4 image elements was reduced, the encoding time increased by more than ten times for a still image, and for a video sequence less than twice, which indicates the perspectives of fractal compression of television images.

Key words: image, fractal coding, similarity, rank and domain blocks, compression ratio, signal to noise ratio.

Анотація. Надано результати застосування модифікованого генетичного алгоритму фрактального кодування до нерухомих зображень та відеопослідовностей. Отримано залежність коефіцієнта стиснення від розміру рангового блока. Здійснено порівняння фрактального стиснення зі стандартними алгоритмами стиснення MPEG-4 та показано, що можна досягти подвійного коефіцієнта стиснення за однакових значень співвідношення сигнал/шум. У відеосистемі обидва I-кадри та передбачувані кадри P, B піддавались фрактальному стисненню. Результати моделювання показують, який час у секундах витрачається при кодуванні одного кадру. При зменшенні розміру рангового блоку з 20 до 4 елементів зображення час кодування збільшився більш ніж у десять разів для нерухомого зображення, а для відеопослідовності менш ніж в два рази, що говорить про перспективність фрактального стиснення зображень.

Ключові слова: зображення, фрактальне кодування, самоподібність, рангові та доменні блоки, коефіцієнт стиснення, співвідношення сигнал/шум.

Аннотация. Представлены результаты применения модифицированного генетического алгоритма фрактального кодирования для неподвижных изображений и видеопоследовательностей. Получена зависимость коэффициента сжатия от размера ранга. Проведено сравнение фрактального сжатия со стандартными алгоритмами сжатия MPEG-4, и показано, что можно добиться удвоения коэффициентов сжатия при одинаковых значениях отношения сигнал/шум. В видеопоследовательности как I-кадры, так и предсказанные кадры P и B подвергались фрактальному сжатию. Результаты моделирования показали, какое время в секундах затрачивается при кодировании одного кадра. При уменьшении размера рангового блока с 20 до 4 элементов изображения время кодирования увеличилось более чем в десять раз для неподвижного изображения, а для видеопоследовательности менее чем в два раза, что говорит о перспективности фрактального сжатия телевизионных изображений.

Ключевые слова: изображение, фрактальное кодирование, самоподобие, ранговые и доменные блоки, коэффициент сжатия, отношение сигнал/шум.

In a fractal compression algorithm, as with other lossy compression algorithms, the mechanisms by which the compression ratio and the degree of loss can be adjusted are very important. By now, a sufficiently large set of such methods has been developed [1, 2, 3].

The purpose of this article is a comparative analysis of the obtained quality of reconstructed images after fractal compression by a modified parametric genetic algorithm of both still images and video sequences consisting of different frames. From the point of view of standard compression based on MPEG-4, it was carried out using the criterion of achievable compression ratio and speed.

Firstly, it is possible to limit the number of affine transformations, obviously providing a compression ratio of not less than a fixed value. Secondly, it can be demanded that in a situation where the difference between the processed fragment and its best approximation is higher than a certain threshold value, this fragment is necessarily crushed. Thirdly, you can prevent fractions of smaller sizes, for example, four points. By changing the threshold values and the priority of these conditions, we will be very flexible in controlling the image compression ratio in the range from bitwise matching to any compression ratio. Note that this flexibility will be much higher than the nearest "competitor" - the MPEG algorithm will be.

The Fractal Encoding of Still Images. The fractal transform algorithm operates with rectangular image areas of the same size – the size of the regions is fixed from the beginning of the algorithm to the end. The advantage of this algorithm is that, with the appropriate choice of dimensions of the processed areas, the uniform quality of the entire image encoding is ensured. With insufficient coding accuracy, the processed fragment is divided into four parts, each of which is processed in the same way as all others.

Let the luminance component of the still image be divided into N rank regions R_i, for each of which we find the corresponding domain D_i and the transformation W_i given by the coefficients (c_{i1}, c_{i2}, ..., c_{iK}) such that for each $r \in R_i$ there exists $d \in D$ such that $r = W_i(d)$. Moreover, the transformations W_i must be compressive, i.e. such that for all $d_l, d_k \in D_i$ the following holds [3].

The disadvantage of the basic algorithm of fractal compression is that for each rank block R the algorithm goes through all the domain blocks D and all variants of their orientations by carrying out per-pixel operations of changing the orientation and finding the transformation coefficients.

In this article, we consider a parametric algorithm for fractal image compression, in which statistical parameters are preliminarily calculated for rank blocks. The following statistical parameters were proposed:

Standard deviation in rank block (1)

$$\delta = \sqrt{\frac{\sum_{I} (P_{X,Y} - \mu)^2}{N_I}}. \tag{1}$$

Asymmetry in rank block (2)

$$a = \frac{\sum_{I} (P_{X,Y} - \mu)^3}{N_I \cdot \delta^3}. \tag{2}$$

Inter-pixel contrast difference within rank block (3)

$$c = \frac{\sum_{I} \left| P_{X,Y} - P_{X-d,Y} \right| + \left| P_{X,Y} - P_{X,Y-d} \right|}{N_I}. \tag{3}$$

The standard deviation β of the brightness of the pixel within rank block (4)

$$\beta = \frac{\sum_{x=1}^{Iw} \sum_{y=1}^{Iv} \left(\omega - \sqrt{\left(x - \frac{I_W}{2} \right)^2 + \left(y - \frac{I_V}{2} \right)^2} \right) \cdot \left(P_{X,Y} - \mu \right)}{\sum_{x=1}^{Iw} \sum_{y=1}^{Iv} \left(\omega - \sqrt{\left(x - \frac{I_W}{2} \right)^2 + \left(y - \frac{I_V}{2} \right)^2} \right)^2}, \tag{4}$$

where the parameter *w* is calculated by formula (5)

$$\omega = \frac{\sum_{x=1}^{Iw} \sum_{y=1}^{Iv} \left(\sqrt{\left(x - \frac{I_W}{2} \right)^2 + \left(y - \frac{I_V}{2} \right)^2} \right)}{N_I}. \tag{5}$$

The maximum of the horizontal (6) or vertical segment gradient (7)

$$h = \frac{\sum_{x=1}^{Iw} \sum_{y=1}^{Iv} \left(x - \frac{I_W}{2} \right) \cdot \left(P_{X,Y} - \mu \right)}{\sum_{x=1}^{Iw} \sum_{y=1}^{Iv} \left(x - \frac{I_W}{2} \right)^2}, \tag{6}$$

$$v = \frac{\sum_{x=1}^{Iw} \sum_{y=1}^{Iv} \left(y - \frac{I_V}{2} \right) \cdot \left(P_{X,Y} - \mu \right)}{\sum_{x=1}^{Iw} \sum_{y=1}^{Iv} \left(y - \frac{I_V}{2} \right)^2}, \tag{7}$$

The following conventions are used in the formulas: I – segment of the image;

N_I – number of pixels in the segment I;

$P_{X,\,Y}$ – pixel brightness value at the point (x, y);

μ – average pixel value in the segment I;

I_V, I_W – horizontal and vertical coordinates of a rank block in a domain block.

Initially, the comparison of domains and ranks is performed on these characteristics, which significantly reduces (in dozens of times) the subsequent amount of computation, in comparison with the basic algorithm of fractal compression. Next, the values of the vector of characteristics for each domain block are calculated and stored, and when processing the ranking block, its characteristic vector is first computed, then the distance between the vector of characteristics of a given rank and the vector of characteristics of each domain block is calculated. For the subsequent comparison, we select only the given *q*-percent of domains with the minimum distance *d* to this rank. Further, the search is performed with the only difference being that *q*% of domains having the characteristics are selected.

From transformations that transfer domains to rank areas, a mapping is created that takes the image to an image. In this case, the image code will be the location and dimensions of rank areas, as well as the coefficients of transformations describing the self-similarity inside the image. The number of bits required to describe the code will be substantially less than the number of bits required to describe the original image. The compression ratio is the ratio of the bit representation of the image to the bit representation of the code.

Five types of still images were subjected to fractal coding. The following test images were selected: a group of trees, a lone tree, a portrait of a girl, a mother with a child, a vase on the table.

The number of rank blocks, corresponding to their size, varied from twenty to two image elements. We used a parametric algorithm with an allowable incidence of the average brightness of rank-block descendant from the average brightness of the rank block-genome of no more than 5%. The procedure for selecting domains with closest distances from the vector of characteristics to rank provides selectivity, thereby limiting the number of domain blocks for enumeration, thereby reducing the number of operations and calculating the conversion coefficients. Parameters characterizing the time of encoding and decoding, as well as the average pixel error for a given permissible error for one type of image "a lone tree" (Fig.1) are given in Table 1.

Table 1 – Parameters for still image

PARAMETERS	Rank 20	Rank 12	Rank 8	Rank 4
Domain blocks	225	841	2977	4562
Rank blocks	1651	1504	1264	1228
Average pixel error, %	3,79	3,92	3,73	3,69
Compression ratio	4,35	4,68	5,38	5,51
Coding time, s	4,58	12,86	30,25	49,39
Decoding time, s	1,91	1,62	1,41	1,25

The image of a single tree, divided into rank blocks, 12 by 12 in size, is shown in Figure 1. The blockiness of the image is clearly visible.

The number of rank blocks varied from 1200 to 1700. The number of domain blocks varied from 225 to 4500. The time spent on coding ranged from 4 seconds to 50 seconds and grew with the number of domain blocks. The per-pixel error ranged from 3,7 to 3,9%, which indicates a practical independence from the number of blocks, and, primarily, from the chosen algorithm is fractal.

Figure 1 – The size of the rank block 12

Fig. 2 shows the dependence of the compression ratio on the size of the rank blocks. Fig. 3 shows the dependence of the signal-to-noise ratio on the size of the ranks. Fig. 4 shows the dependence of the average error of coding time.

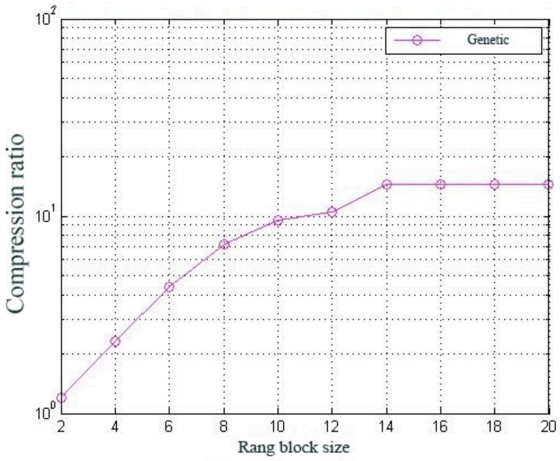

Figure 2 – The dependence of the compression ratio on the size of rank blocks

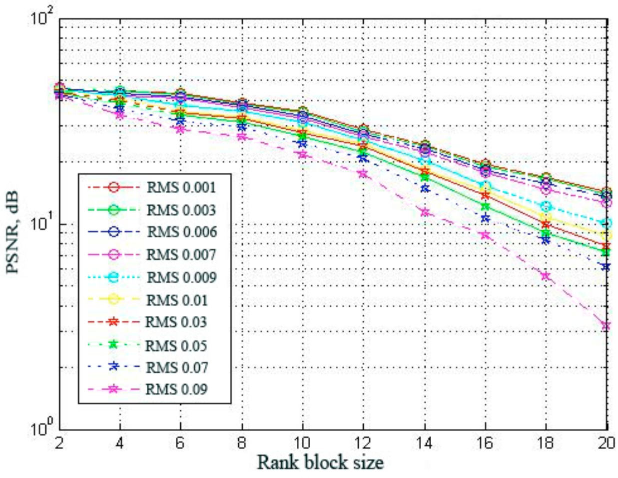

Figure 3 – The dependence of the signal/ noise ratio on the size of the ranks

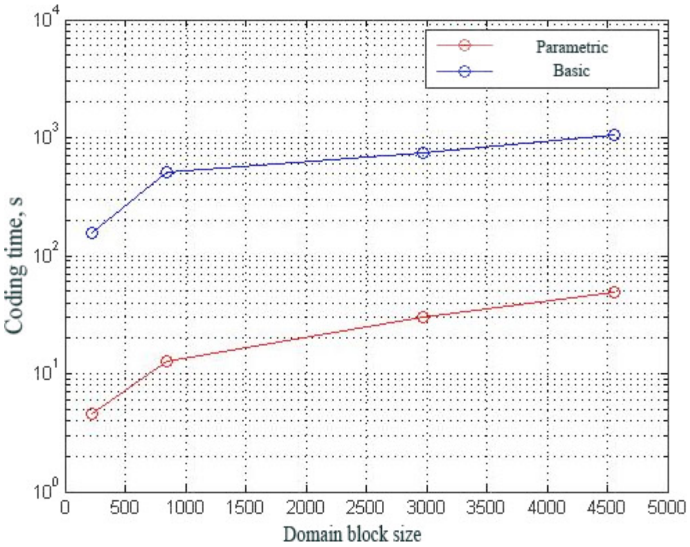

Figure 4 – The dependence of the average error of coding time

The Fractal Encoding of Movie Images. The video sequence can be compressed by two variants of fractal algorithms. More common is an algorithm in which each frame is treated as a separate two-dimensional image and encoded independently. Prediction on previous frames can speed up the encoding process. Moreover, you can use the already available set of rank and domain blocks. An interesting solution is to create a library of three-dimensional cubes - rank and domain blocks. Of course, storing all possible rank and domain blocks is perhaps desirable, makes it difficult to find the correct block. Already there is a solution that is close to the optimal solution for combining frames that are close in content to groups. This solution is used in MPEG-2, MPEG-4 compression standards. Frame groups contain different types of frames, known as *I*-frames, *P*-frames, *B*-frames. In standard MPEG encoder the main compression is provided by a discrete cosine transform and the selection of thresholds for the spectral coefficients.

However, not everything is as smooth as it may seem. If the image is uniform then the magnification results in an excellent outcome. However, if you compress the still life image, then it is very difficult to predict which new fractal structures will arise. You can increase almost any image two or three times, archiving each time with a small degree of loss.

Scaling is a unique feature inherent in fractal compression. Over time, it will probably be actively used in both special scaling algorithms and in many applications. Indeed, this requires the concept of "application in the window". It would be nice if the image shown in the window 100x100 had the same clarity and detail when zoomed to the full screen – 1024 × 768.

To study the efficiency of the modified genetic algorithm of fractal coding, a sequence of five difference frames was chosen. Table 2 shows the performance of the algorithm. Fig. 4 shows the sequence of five different frames from the video sequence.

Table 2 – Indicators of genetic compression algorithm

Indicators	Frame number				
	1	2	3	4	5
Domain blocks	571	447	311	278	361
Rank blocks	1838	1711	1352	1061	1115
Acceptable error	0,05	0,05	0,05	0,05	0,05
Average pixel error, %	2,61	2,12	1,61	2,51	2,83
Compression ratio	100,35	160	80,38	88,45	90,24
Coding time, s	1,73	2,18	1,25	1,39	2,06
Signal to noise ratio, dB	35,2	30,8	44,4	42,6	41,7

Attention is drawn to the increase in the compression ratio for the video sequence compared to the compression of a single image. The number of rank and domain blocks in this example is not an indicator for comparison because of different semantic content.

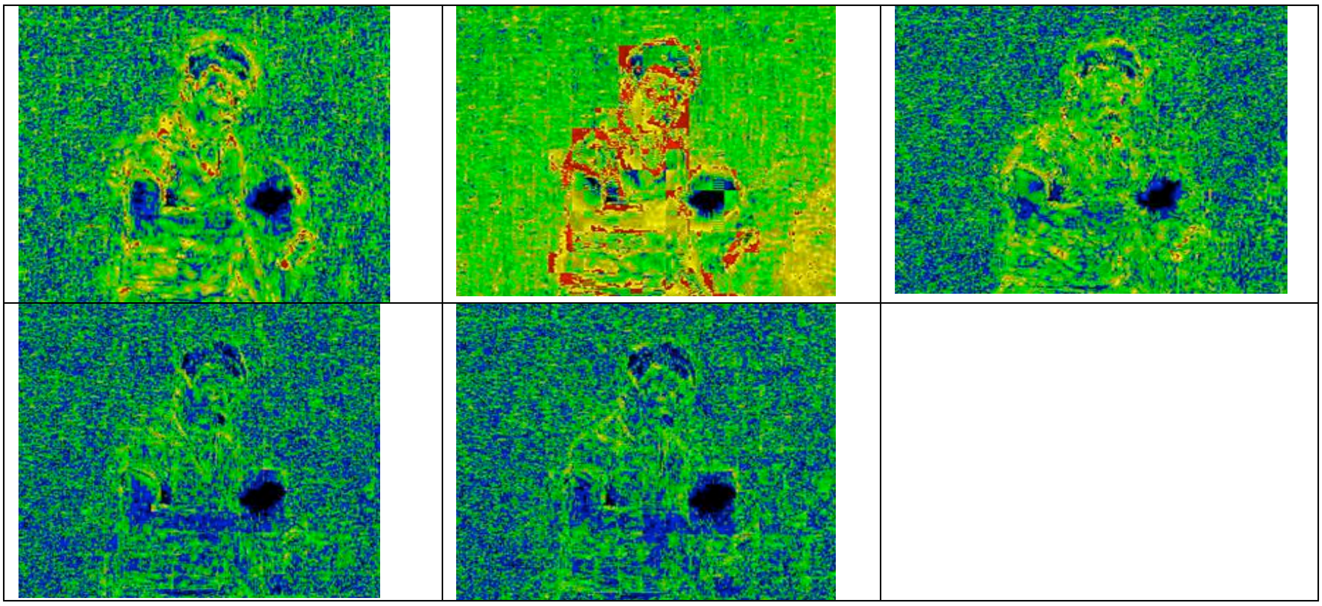

Figure 5 – The frames from the video sequence

The size of the rank block is one of the main decisive factors in determining the compression ratio. Obviously, the larger the size of the rank block, the higher the compression ratio, but the processing time increases and the mid-pixel error grows (see Fig. 6).

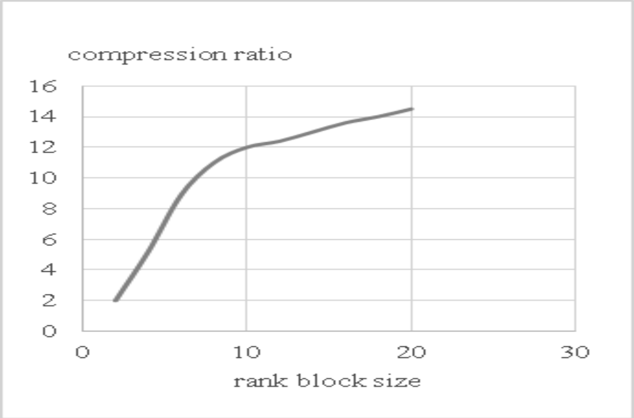

Figure 6 – The dependence of the compression ratio on the size of the rank block

With the use of the modified algorithm for four different semantics, the coding time varied from 4,8 to 49,39 p. For the same video sequences, the basic algorithm showed the coding time from 154,61 to 1068 p.

A comparison is also made with standard MPEG encoders (Fig.7).

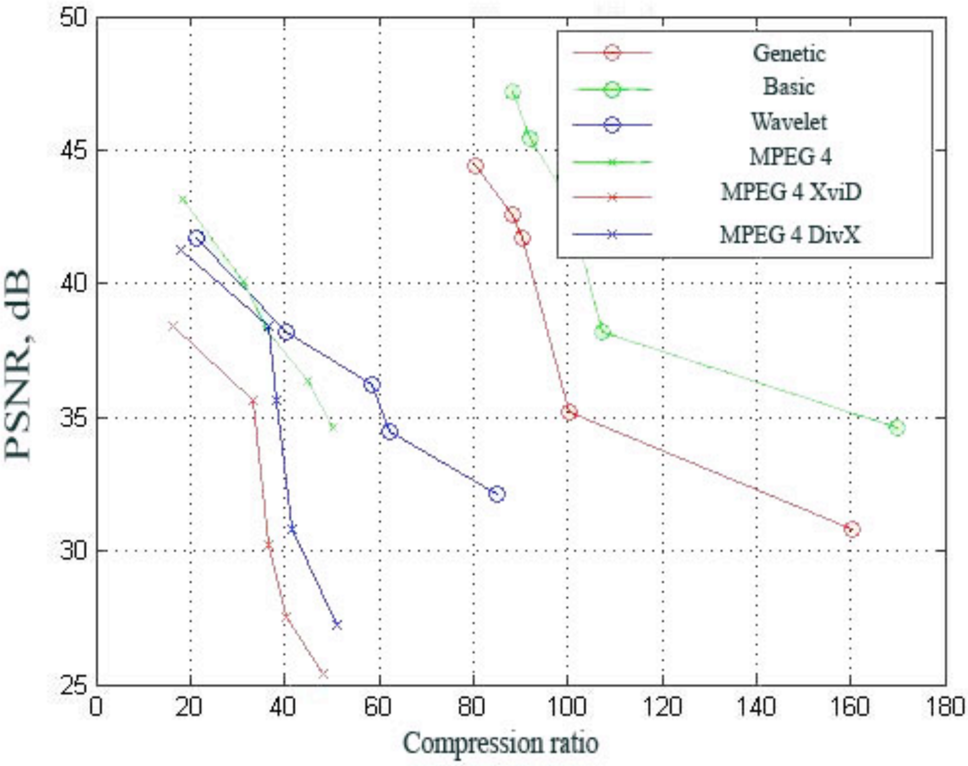

Figure 7 – Dependence of PSNR on the compression ratio

First, note that both algorithms operate with 8-bit (in grayscale) and 24-bit full-color images. Both are lossy compression algorithms and provide similar archiving factors. Both the fractal algorithm and MPEG have the ability to increase the compression ratio by increasing the loss. In addition, both algorithms are very well parallelized. Differences begin when we consider the time required for algorithms to archive/unzip. So, the fractal algorithm does compression hundreds and even thousands times longer than MPEG. Unpacking the image, on the contrary, will happen five to ten times faster. Therefore, if the image is compressed only once, but transmitted over the network and decompressed many times, then it is more profitable to use a fractal algorithm. MPEG uses image decomposition by cosine functions, so the loss in it (even at specified minimum losses) is manifested in waves and halos on the border of sharp color transitions. It is for this effect that they do not like to use it when compressing images that are prepared for high-quality printing: this effect can become very noticeable [4].

Fractal algorithm compression is spared this disadvantage. Moreover, when printing an image, each time, you must perform a zoom operation, since the raster (or a lineage) of the printing device does not coincide with the image raster. When converting, there can also be several unpleasant effects that can be combated or scaled by software (for low-cost printing devices such as conventional laser and inkjet printers) or by supplying a printing device with its processor, hard drive and a set of image processing programs (for expensive phototypesetting automata). As you might guess, when using a fractal algorithm such problems do not exist.

In this article, the comparative analysis of fractal coding of still and moving images is carried out. By time spent on encoding, the encoding of video sequences turns out to be faster. The final testing of the high-speed circuit showed that with photorealistic images, where the character of compression losses by the MPEG algorithm is less noticeable, the fractal compression is slightly behind. With raster images of geometric figures, fractal compression noticeably benefits MPEG, which is due to a higher degree of self-similarity of the images. The MPEG algorithm copes well with rectangles and lines arranged vertically or horizontally. On compression of text images, the algorithm works poorly (image text).

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