Fractal image coding using sub-block luminance level shifting

サブブロック輝度シフトを用いたフラクタル画像符号化

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Abstract This paper presents an improved fractal block coding scheme for still images. The proposed scheme employs a new technique which we call "*sub-block luminance level shifting.*" In fractal block coding, an input image is first partitioned into range blocks. Each range block is encoded by a set of contractive affine transformations of its corresponding domain block. One of the coded data for each range block is an average pixel value of the range block, which is used for luminance level shifting between the range block and the contracted domain block. In our proposed method, a range block is further partitioned into sub-blocks in some cases and an average value of each sub-block instead of the range block is used for luminance level shifting. We have proposed an improved fractal block coding scheme applying this sub-block luminance level shifting adaptively block-by-block basis and also combining this method with adaptive range block size fractal coding. The computer simulation results show that the proposed fractal coding scheme gives higher SNR (Signal-to-Noise Ratio) values and better image qualities compared to the conventional fractal block coding scheme.

1. INTRODUCTION

Since Barnsley[1] first presented the idea of fractal image coding, it has received considerable attention as a new image compression concept and various coding approaches[2-8] have been studied. Jacquin[2-3] has successfully developed a fractal block coding scheme, where an input image is represented by a set of contractive affine transformations. The parameters which describe the transformations are determined by extracting self similarities in the image.

In the fractal block coding method proposed by Jacquin, an input image is first partitioned into non-overlapping range blocks. Each range block is encoded by a set of contractive affine transformations of its corresponding domain block. The coded data for each range block consist of 1) an average pixel value of the range block, 2) domain block position coordinate values, 3) a contrast scaling factor value, and 4) indexes of the domain block isometric transformations. The range block average pixel value is used for luminance level shifting between the range block and the corresponding contracted domain block.

In order to improve the fractal block coding performance, we have studied a new method which we call "*sub-block luminance level shifting.*" In our proposed method, a range block is further partitioned into 4 sub-blocks and an average value of each sub-block instead of the range block is used for luminance level shifting between the range block and the contracted domain block. The other coded data such as 2), 3), 4) are given for the range block not for the sub-block. We have proposed an improved fractal block coding scheme applying this sub-block luminance level shifting adaptively block-by-block basis and also combining this method with adaptive range block size fractal coding.

This paper describes the proposed coding scheme and its experimental results. Section 2 briefly reviews the conventional fractal block coding method. Section 3 describes "*sub-block luminance level shifting.*" Section 4 proposes an improved fractal coding scheme using the sub-block luminance level shifting. Computer simulation results are shown in both Sections 3 and 4. Finally, Section 5 gives conclusions.

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2. REVIEW OF FRACTAL BLOCK CODING

In this Section, we briefly review the fractal block coding scheme presented by Jacquin.[2,3] Figure 1 shows an outline of fractal block coding. An input image is first partitioned into non-overlapping blocks called range blocks. Each range block R of size $B X B$ is approximated by other regions of the image called the domain block D of size $2B X 2B$. This approximation process employs domain block search in a domain pool and a set of contractive affine transformations of the domain block. The transformation is composed of a spatial contraction (from $2B X 2B$ to $B X B$), pixel value transformations (contrast scaling and luminance level shifting), and isometric transformations (reflections and rotations). The fractal block coding process consists of finding the most suitable domain block and its transformation parameters for each range block in such a way that the transformation of the domain block D is a good approximation of the range block R.

Equation (1) gives the approximation for the range block R by a set of contractive affine transformations of the domain block D'.

$$R'(k,l) = aD'(k,l) + (\overline{R} - a\overline{D'}) \qquad (1)$$

where $R'(k,l)$ is an approximated pixel value for the range block, $\overline{R}$ the average pixel value of the range block, $D'(k,l)$ the pixel value of the contracted and transformed domain block, $\overline{D'}$ the average pixel value of the domain block, and a a contrast scaling factor. The term $(\overline{R} - a\overline{D'})$ means average luminance level shifting between the range block and the contracted and transformed domain block. The approximation is evaluated based on a distortion value e^2 given by the Eq. (2).

$$e^2 = \sum_{k=1}^{B}\sum_{l=1}^{B}[R(k,l) - R'(k,l)]^2 = \sum_{k=1}^{B}\sum_{l=1}^{B}[\{R(k,l) - aD'(k,l)\} - (\overline{R} - a\overline{D'})]^2 \qquad (2)$$

where $R(k,l)$ is the pixel value of the range block. We search the best approximation which gives the least value of e^2 in Eq.(2). The coded data for each range block are given by the followings: 1) range block average pixel value, 2) domain block position coordinate values, 3) contrast scaling factor value, and 4) index value for identifying one of the 8 isometric transformations of the contracted domain block.

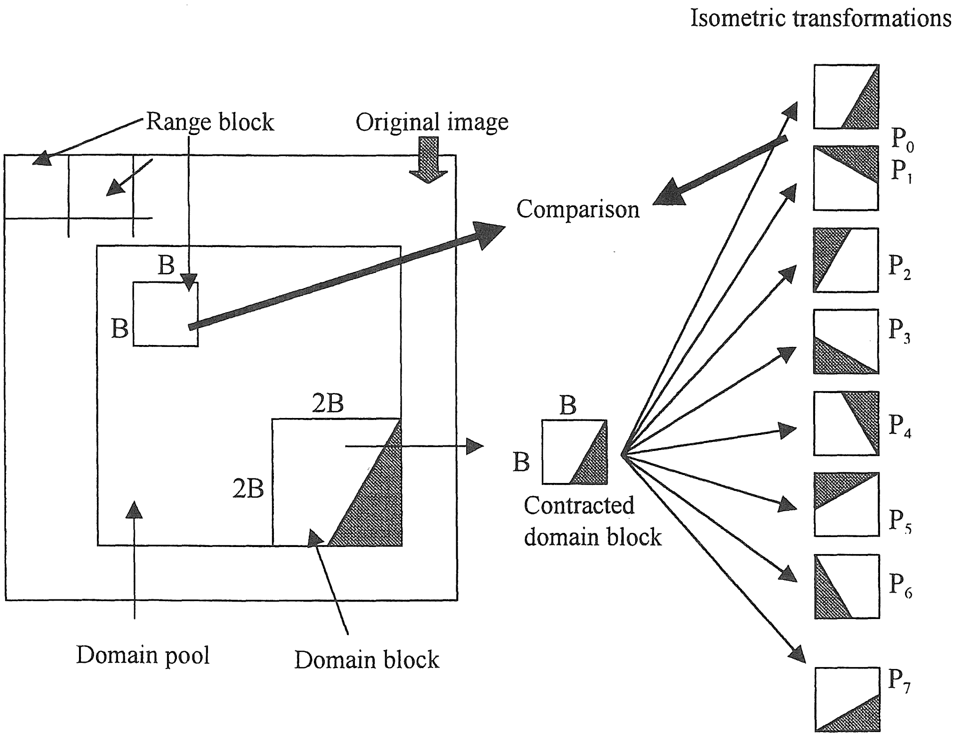


Fig.1 Outline of the fractal block coding

The fractal decoding process consists of iterating the same contractive transformations based on the coded data, starting from any initial image until a stable decoded image is obtained.

3. SUB-BLOCK LUMINANCE SHIFTING

3.1. Sub-block luminance shifting

As shown in Eq.(1) and Eq.(2), conventional fractal block coding employs only single luminance level shifting for each range block. In order to improve its approximation accuracy, we have modified the luminance level shifting method. Each range block and its corresponding contracted domain block are further partitioned into 4 sub-blocks of size *B/2 X B/2*, respectively, as shown in Fig.2. Luminance level shifting is performed for each *B/2 X B/2* sub-block instead of *B X B* block. In this case, the range block approximation is evaluated based on a distortion value e^2 given by the Eq.(3).

$$e^2 = \sum_{k=1}^{B/2}\sum_{l=1}^{B/2}[\{R(k,l) - aD'(k,l)\} - (\overline{R_1} - a\overline{D_1'})]^2 + \sum_{k=1}^{B/2}\sum_{l=B/2+1}^{B}[\{R(k,l) - aD'(k,l)\} - (\overline{R_2} - a\overline{D_2'})]^2 + \sum_{k=B/2+1}^{B}\sum_{l=1}^{B/2}[\{R(k,l) - aD'(k,l)\} - (\overline{R_3} - a\overline{D_3'})]^2 + \sum_{k=B/2+1}^{B}\sum_{l=B/2+1}^{B}[\{R(k,l) - aD'(k,l)\} - (\overline{R_4} - a\overline{D_4'})]^2 \quad (3)$$

The term $(R_i - aD_i')$ shows luminance shifting for each sub-block, where $i = 1,2,3$ *or* 4. This method uses 4 sub-block average values for each range block. The other processes such as domain block search, spatial contractions, contrast scaling, and isometric transformations are the same as the above-mentioned conventional method, that is, they are carried out for a *B X B* range block.

3.2. Experiments of sub-block luminance level shifting

(1) Experimental conditions

In order to estimate the proposed sub-block luminance level shifting method, we carried out computer simulation experiments of fractal block coding using this method. Experimental conditions are as follows:

(1) The test image is "Lenna" with *512 X 512* pixels and *8* bit/pixel.
(2) The range block size is *8 X 8* pixels.
(3) The domain block size is *16 X 6* pixels (twice the range block size).
(4) The domain block search area (domain pool) is *31 X 31* pixels.
(5) The domain block search accuracy is *2* pixels.
(6) The quantization accuracy of average pixel value is *6* [bit/pixel].
(7) A set of scaling factor values are: $a = 0.7, 0.8, 0.9$ and 1.0.
(8) The isometric transformation consists of *8* patterns of rotations and reflections.

Decoded image quality is evaluated by both examining decoded images visually and calculating their SNR (Signal to Noise Ratio) values given by Eq.(4)

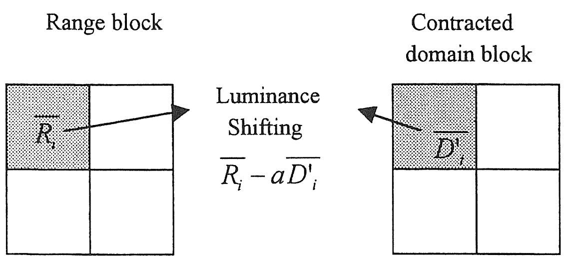


Fig. 2 Sub-block luminance shifting

$$SNR = 20\log_{10}(S_{pp} / N_{rms}) \quad [\text{dB}] \qquad (4)$$

where S_{pp} (= *255* for *8* bit/pixel) is the peak-to-peak value of an input image and N_{rms} is the root mean square of the pixel value difference between the input original and decoded images. Coding bit rates r_1 [bit/pixel] for the conventional luminance level shifting method and r_2 [bit/pixel] for the proposed sub-block luminance level shifting method are calculated by Eq.(5) and Eq.(6), respectively,

$$r_1 = (X + Y + Z + A) / N_R \qquad (5)$$

$$r_2 = (4X + Y + Z + A) / N_R \qquad (6)$$

where X(= *6* [bit/block]) is the number of bits used for a range block (or sub-block) average pixel value, Y (= *8* [bit/block]) for domain block position coordinate values, Z (=*3* [bit/block]) for identifying one of the 8 isometric transformations, A (= *2* [bit/block]) for the scaling factor value, and N_R (= *8 X 8* [pixels]) the total number of pixels of a range block.

(2) Experimental results

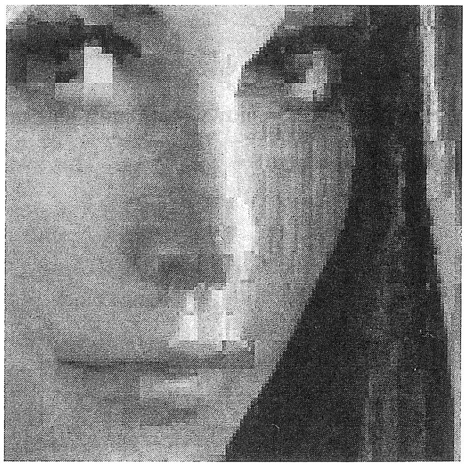
Figure 3 shows a comparison of decoded images between the proposed and the conventional luminance level shifting methods. The proposed method gives higher SNR values and better image quality especially in the edge area compared to the conventional method. However, in spite of the higher bit rate of the proposed method than the conventional one, their quality difference is not obvious in smooth areas such as "the cheeks." Hence, in terms of compression efficiency, executing this sub-block luminance level shifting for the entire image is found to be inappropriate. We also have to point out that even if we apply the sub-block luminance level shifting method, using the range block of fixed size *8 X 8* for the entire image cannot attain sufficient image quality as shown in Fig.3.

4. PRPPOSED FRACTAL BLOCK CODING SCHEME

4.1. Proposed fractal coding scheme

In order to solve the above-mentioned problems and realize a highly efficient fractal coding scheme, we apply the sub-block luminance level shifting adaptively block-by-block basis according to the approximated range block distortion. We also combine this sub-block luminance shifting with adaptive range block size fractal coding. Figure 4 shows a flowchart of the proposed coding scheme. The coding procedure for each range block is as follows:

Sub-block luminance level shifting
SNR: 29.7 [dB]
Bit rate: 0.58 [bit/pixel]



Conventional luminance level shifting
SNR: 27.9 [dB]
Bit rate: 0.30 [bit/pixel]

Fig. 3 Decoded image comparison between sub-block and conventional luminance level shifting methods

(1) Fractal block coding with the range block size of *B X B* is carried out. Conventional luminance shifting is performed for each *B X B* block. If the distortion of the approximated range block is larger than a threshold *T*, go to step (2). Otherwise, the coding of the range block is completed.
(2) Fractal block coding with the range block size of *B X B* is carried out. The proposed sub-block luminance level shifting is performed for *B/2 X B/2* sub-block. If the distortion of the approximated range block is larger than the threshold *T*, go to next step (3). Otherwise, the coding of the range block is completed.
(3) Fractal block coding with the range block size of *B/2 X B/2* is carried out. Conventional luminance level shifting is performed for each *B/2 X B/2* block.

4.2. Experiments of the proposed fractal coding scheme

(1) Experimental conditions

We carried out computer simulation experiments in order to evaluate the proposed coding scheme. The experimental conditions are as follows:

(1) The range block sizes are *8 X 8* and *4 X 4* which are employed adaptively based on the distortion of the approximated range block.
(2) The domain block sizes are *16 X 16* and *8 X 8* (twice the each range block size).
(3) Sub-block luminance level shifting is employed adaptively based on the distortion of the approximated range block.

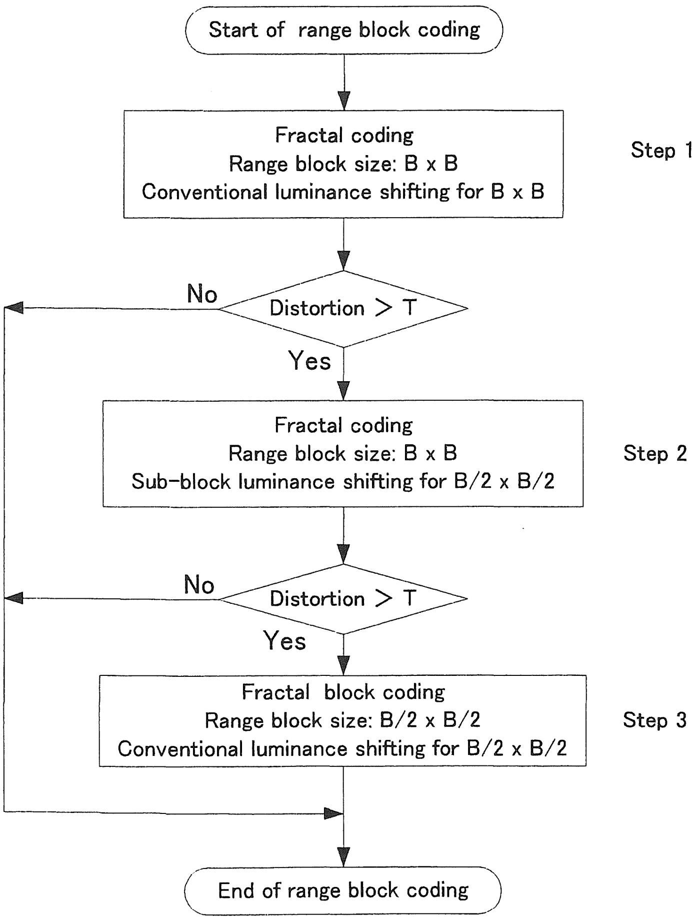


Fig. 4 Flowchart of the proposed fractal coding scheme

The other conditions, such as a test image, domain block search, the search accuracy, quantization accuracy of an average value, scaling factors and isometric transformations, are the same as mentioned in **3.2**.

The coding bit rate r [bit/pixel] required for this scheme is calculated by Eq. (7).

$$\begin{aligned} r = [&(X+Y+Z+A+S)\times B_1 \\ &+(4X+Y+Z+A+S)\times B_2 \\ &+\{4(X+Y+Z+A)+S\}\times B_3]/N_T \end{aligned} \tag{7}$$

where S (= *2* [bit/block]) is the number of bits used for identifying luminance level shifting methods and range block sizes, B_k [blocks] the number of range blocks processed by coding step k (= *1, 2 or 3*) in Fig. 4, and N_T (=*512 X 512* [pixels]) the total number of pixels of an input image. The following conditions, such as $X = 6$ [bit/block], $Y = 8$ [bit/block], $Z=3$ [bit/block] and $A=2$ [bit/block], are the same as defined in **3.2**. For comparison purposes, we have also experimented the conventional fractal block coding scheme which employs only the adaptive range block sizes of *8 X 8* and *4 X 4*, but does not employ sub-block luminance level shifting. The procedure of this case is given by removing step 2 from Fig.4. The total bit rate r_3 [bit/pixel] required for this case is calculated by Eq. (8).

$$\begin{aligned} r_3 = [&(X+Y+Z+A+S)\times B_1 \\ &+\{4(X+Y+Z+A)+S\}\times B_3]/N_T \end{aligned} \tag{8}$$

Coding bit rates are varied by the threshold value T.

(2) Experimental results

Figure 5 shows a comparison of the performance (SNR vs. bit rate) between the proposed and conventional schemes. The proposed scheme shows higher SNR values than the conventional scheme especially in low bit rates less than about 1.0 [bit/pixel]. An SNR gain of about 2 dB is obtained at 0.5 bit/pixel. Figure 6 shows a comparison of decoded images between the proposed and the conventional schemes. We can see the qualitative difference around the "nose" and the "lips" of Lenna. Clearly the proposed scheme provides better picture qualities.

5. CONCLUSIONS

This paper has described an improved fractal block coding scheme for still images. The scheme employs a new technique which we call "*sub-block luminance level shifting.*" In fractal block coding, each range block is encoded by a set of contractive affine transformations of its corresponding domain block. A range block average pixel value is used for luminance level shifting between the range block and the contracted corresponding domain block. In the proposed method, a range block is further partitioned into 4 sub-blocks in some cases and an average value of each sub-block is used instead of the range block. In order to realize a highly efficient fractal coding scheme, we have applied this sub-block luminance level shifting adaptively

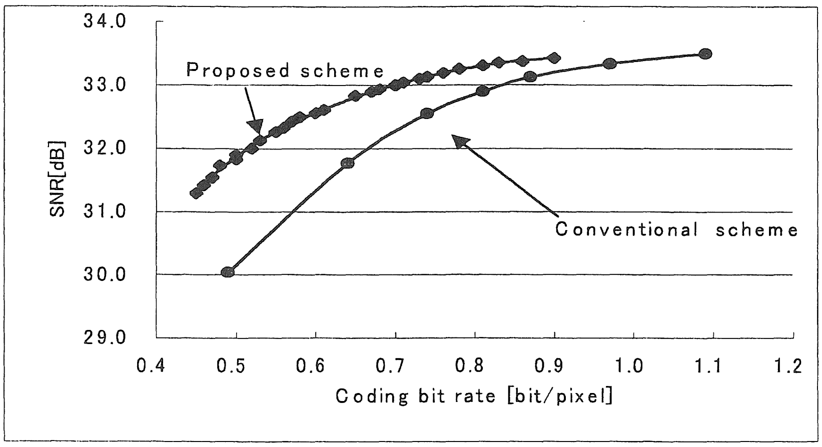


Fig. 5 Comparison of SNR - bit rate performance between the proposed and conventional schemes

Proposed coding scheme
Bit rate : 0.61 [bit/pixel]
SNR = 32.61 [dB]

Conventional ccoding scheme
Bit rate : 0.64 [bit/pixel]
SNR = 31.77 [dB]

Fig. 6 Comparison of decoded images between the proposed and conventional schemes

block-by-block basis according to the range block distortion. We have also combined this sub-block luminance level shifting with adaptive range block size fractal coding. The computer simulation results have shown that the proposed fractal coding scheme gives higher SNR values and better image qualities compared to the conventional scheme.

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