Multiple Description Image Coding Based on Fast Fractal Coding

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Abstract—**Multiple description coding (MDC) is an effective method for robust transmission of image and video over unreliable networks. In this paper, a new multiple description image coding scheme based on fractal coding is proposed, which can satisfy the robust transmission in case of channel failure. In view of computation complexity of fractal image coding, Fine granularity successive elimination (FGSE) is applied to speed up the encoding process. Compared with the conventional scheme, the experimental results show that the proposed scheme can improve rate distortion performance efficiently and reduce the coding complexity simultaneously.**

Keywords- fractal image coding, multiple description coding, multiple description scalar quantization

I. INTRODUCTION

Multiple description coding (MDC) is an effective method for robust transmission over unreliable networks. As shown in Fig.1 [1], the typical structure of MDC has two coded streams (called descriptions) and each stream is transmitted over independent channel. It can avoid packet loss efficiently without retransmission, satisfy the demands of real-time services and relieve the network congestion [2]. If only one channel works, the source can be reconstructed by the side decoder with certain acceptable distortion, called side distortion. When both channels work, the reconstructed quality can be achieved with the smallest central distortion upon the reception of all descriptions. Generally, in the typical MDC, the more descriptions are received, the better decoding quality will be reconstructed.

Since 1988's, the second generation method named fractal image coding (FIC) has been widely studied [3]. The FIC is based on Iterated Function System (IFS), which has many advantages, such as resolution independence, high compression ratio, high reconstructed image quality and fast decoding process. So FIC is a promising technique that has great potential to improve the efficiency of image storage and image transmission. In 1989, the first practical fractal image compression scheme was presented [4]. The scheme is based on the representation of an image by a set of iterated contractive transformations for which the reconstructed image closed to the original image is an approximate fixed point. But it suffers from a long coding time, which and limits its practical application. Many accelerated algorithms were proposed to speed up the coding process over the past two decades. However, most of them reduced the computation complexity effectively at the cost of the drop of decoded quality.

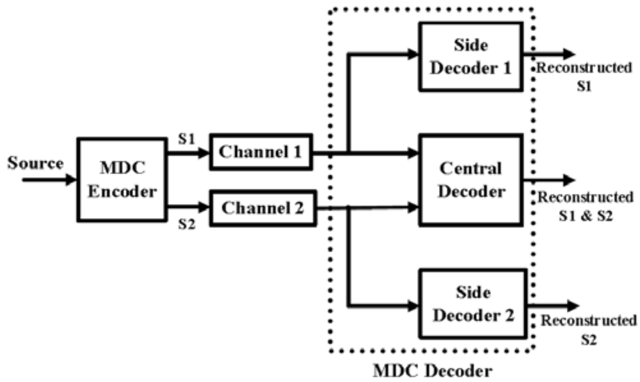

Figure 1. Structure of MDC with two channels and three receives

In view of the characteristics of fractal image coding, small change of the fractal parameters may generate great impact on the reconstructed quality, so the fractal parameters are too sensitive to transmit over the unreliable channels. In [5], multiple description coding scheme based on fractal image coding (MDFIC) was proposed by handling the fractal parameters to accommodate the transmitted over two channels. In order to adapt to the process of multiple description coding, the parameters of fractal image coding should be quantized by MDSQ (Multiple Description Scalar Quantization) and MDLVQ (multiple description lattice vector quantization) in order to adapt to the process of multiple description coding. However, this method may lead to lower rate distortion performance and higher computation complexity. In this paper, a novel scheme is proposed to improve MDFIC on reconstructed image quality. Furthermore, a fast fractal image coding algorithm based on FGSE [6] is applied to speed up the coding process.

The remainder of the paper is organized as follows. Firstly, basic fractal image coding scheme and MDFIC are briefly reviewed in Section Ⅱ. The proposed scheme is introduced in Section Ⅲ, which is followed by the experimental results and conclusion.

II. REVIEW OF FIC AND MDFIC

A. The basic fractal image coding scheme

The process of Jacquin's fractal image coding scheme, derivation of most improved scheme, is shown in Fig.2[7] and will be introduced briefly as follows.

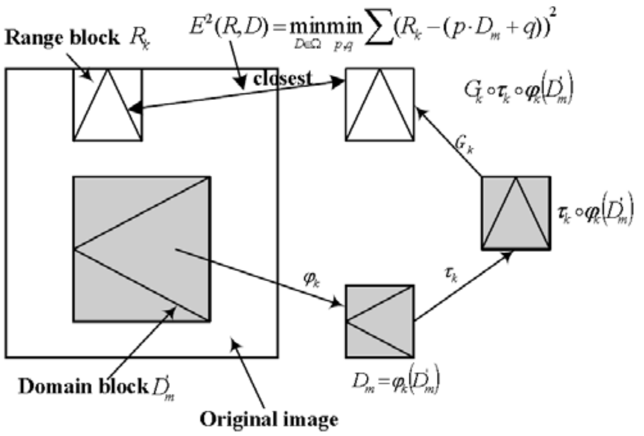

Figure 2. Process of Jacquin's fractal image coding scheme

Firstly, the original image I_{org} (size L*L) is divided into non-overlapping range blocks $R_1, R_2, \cdots, R_k, \cdots R_N$, whose size is B*B, $\bigcup_{k=1}^{N} R_k = I_{org}$ and domain blocks $D_1^{'}, D_2^{'}, \cdots D_m^{'}, \cdots D_M^{'}$ whose size is 2B*2B.

Secondly, find the best transformation ω_k consists of a spatial contraction map φ_k followed by isometry transformation τ_k (four rotations and four flips) and massic transformation G_k that is the composition of a contrast scaling p and a luminance shift q, viz. $\omega_k = G_k \circ \tau_k \circ \varphi_k$, $G_k(x) = p * x + q$. For convenience, we can create a domain pool Ω by contracting the domain blocks to the same size as range blocks, viz. $\Omega = \{D = \varphi(D^{'})\}$.

Thus, for the sake of finding the best range-domain match blocks, the square error distortion of the range block R and the transformed domain block D should be minimal,

$$E^2(R,D) = \min_{D\in\Omega}\min_{p,q}\sum(R_{i,j}^{(k)} - (p\cdot D_{i,j}^{(m)} + q))^2 = \sum_i\sum_j (R_{i,j}^{(k)} - (s\cdot D_{i,j}^{(m)} + o))^2 \quad (1)$$

where $R_{i,j}^{(k)}$ and $D_{i,j}^{(m)}$ are pixel intensity of optimal matching blocks R_k and contracted domain block D_m at (i,j) respectively; I is a matrix whose elements are all ones.

Thirdly, store the transformation parameters. The optimal contrast scaling s and luminance shift o can be achieved by equation (2).

$$s = \frac{\left\langle R - \bar{R}\cdot I, D - \bar{D}\cdot I \right\rangle}{\left\| D - \bar{D}\cdot I \right\|^2}, \quad o = \bar{R} - s\cdot\bar{D} \quad (2)$$

Where $\bar{R}$, $\bar{D}$ are the average intensity of range block R and the contracted domain block D, respectively.

In decoding end, the original image is recovered from several iterations with arbitrary image on condition of iterated contractive affine transformations.

B. MDFIC

As mentioned above, the reconstructed image is obtained by some iteration with arbitrary initial image. The fractal parameters are so important that if they change a little, the reconstructed image may vary greatly. Thus they are not suitable to transfer over harsh environments. MDFIC [5] has solved the problem by modifying the parameters based on the characteristic of them to meet the needs of multiplex transmission—correlation of fractal parameters within each range block and adjacent range blocks.

The optimal contrast scaling s and luminance shift o of the same range block are correlative strongly and almost close to 1, while the average pixel intensity and optimal contrast scaling s of one range block are correlative weakly[8,9]. The decoded image can also be reconstructed using the contrast scaling, average pixel intensity and the position of the optimal domain bock by orthogonal decoding [9]. Thus the fractal parameters in MDFIC convert to contrast scaling s, average pixel intensity $\bar{R}$ and the position of the optimal domain bock p. s is quantized by MDLVQ [10] and $\bar{R}$ is quantized by MDSQ.

III. THE PROPOSED SCHEME

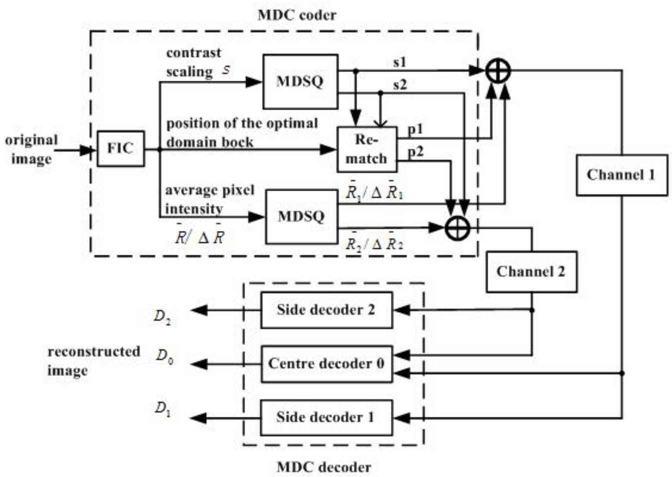

Figure 3. The framework of the proposed scheme

The framework of multiple description coding based on FIC and MDSQ is illustrated in Fig. 3. Each model is introduced in detail as follows. The differences between

MDFIC and the proposed scheme are substitute MDLVQ for MDSQ, application with fast fractal image coding based on FGSE and handling the difference of average intensity between adjacent range blocks.

A. FIC

As mentioned in section Ⅱ, Jacquin's scheme achieved automatically for fractal image coding, but it suffers from a long coding time and limits its practical application. For example, for an $N \times N$ image, the number of arbitrarily sized square sub-regions is of order $O(N^3)$ and the exhaustive search for finding the optimal mappings is of order $O(N^4)$. In reference [6], a fast fractal image coding algorithm based on FGSE [11] is proposed. FGSE, a fast optimal block matching in motion estimation, is featured by providing a sequence of fine grained boundary levels in an aim to reject a checking candidate as early as possible, thus it can reduce the computational complexity. Fig.4 illustrates the successive elimination process with as many as 85 increasing boundary values for N=16. One candidate is evaluated sequentially from the lowest level to the highest level. Many non-matched candidates can be eliminated in each level. And only a small number of candidates will be left for matching-error calculations in the highest level.

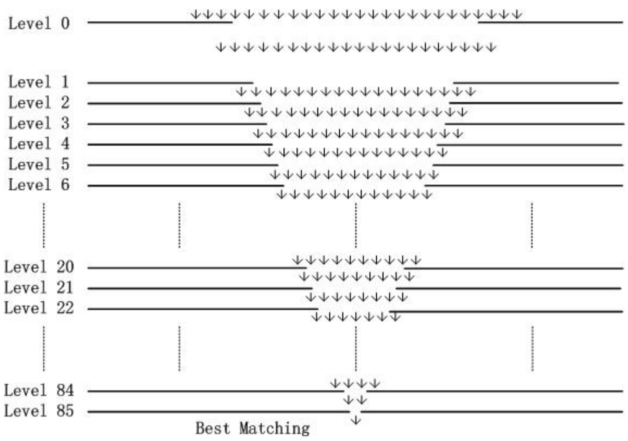

Figure 4. sequential elimination process from Level 0 to Level 85

Reference [6] established the relationship between $E^2(R,D)$ and SAD shown below by deducing formulas.

$$\frac{2 \cdot E(R,D)}{\left\| R - \bar{R} \cdot I \right\|} \geq SAD = BV_L \geq \cdots \geq BV_l \geq \cdots BV_0 \qquad (3)$$

where $E(R,D)$ denotes the minimum mean square error of a range and domain block, the evaluated criterion of FIC, SAD indicates the sum of absolute difference, the cost function of FGSE, totally boundary level $L = (N \times N - 1)/3$, $BV_l = \sum_{i=0}^{S_l - 1} \left| a^{(k)}_{n(k,l)\times n(k,l)} - b^{(k)}_{n(k,l)\times n(k,l)} \right|$, $(l = 0,1,2,3,4,5)$, $a^{(k)}_{n(k,l)\times n(k,l)}$, $b^{(k)}_{n(k,l)\times n(k,l)}$ denote the square sum of the k^{th} sub-block at l^{th} level in $\phi(R)$ and $\phi(D)$ ($\phi(R)$ and $\phi(D)$ is the normalized range block R and domain block D), respectively. $n(k,l) \times n(k,l)$ is the size of the k^{th} sub-block at level l.

From equation (3), for any range block R and any domain block D, we notice that, if $E(R,D)$ is small enough, and then SAD is small enough. Whereas if they differ greatly, then $E(R,D)$ might be too large for R and D to constitute a close match. In other words, equation (3) implies that the range block R and the domain block D cannot be closely matched unless SAD is as close as possible. Each candidate domain block is evaluated sequentially from the lowest Level 0 to the highest Level 85 for N=16. If the candidate domain block cannot be eliminated at any level between Level 0 and 84, its matching error will be calculated at Level 85. Each level contributes to eliminate a part of non-matched candidate domain blocks, just a small number of candidate domain blocks will remain for matching-error calculations.

B. MDSQ

As a practical system to complete the process of MDC, MDSQ is carried out two steps, named quantization step and index assignment step. Each input sample is mapped onto two reconstruction levels.

	000	001	010	011	100	101	110	111
000	0							
001	1	2						
010		3	4					
011			5	6				
100				7	8			
101					9	10		
110						11	12	
111							13	14

(a)

	000	001	010	011	100	101
000	0	1				
001	2	3	5			
010		4	6	7		
011			8	9	11	
100				10	12	13
101					14	15

(b)

	00	01	10	11
00	0	1	5	6
01	2	4	7	12
10	3	8	11	13
11	9	10	14	15

(c)

Figure 5. Index assignment in MDSQ

Vaishampayan developed MDSQ theory [12] by combining the scalar quantization with coding. Thus MDSQ is divided into two steps: one is the scalar quantization and the other is the index allocation; it is expressed as $\alpha_0 = \ell \circ \alpha$, where α is carried out by ordinary scalar quantizer of fixed rate and ℓ is the index allocation process to each example x. Obviously, it is a mapping process of one-dimension to two-dimension, $I : N \to N \times N$ and described as index allocation matrix shown in Fig.5. Each quantized coefficient corresponds to the point of the matrix. Its indexes (i_1, i_2) are composed of label to row and column. Meanwhile, ℓ must be reversible in order to reconstruct the signals, expressed as ℓ^{-1}. In the decoder, reconstructed signal is obtained from (i_1, i_2), i_1 and i_2 by the three decoder β_0, β_1, β_2 respectively. If both descriptions are received, the central decoder β_0 is used to reconstruct signal precisely by indexes (i_1, i_2); If only one description is obtained, the side decoder β_1 or β_2 will be used to constructed signal approximately by row index i_1 or column index i_2. Index allocation process follows the basic rules: the quantized units is coded from 0 to $x-1$ from upper left to lower right and began filling with the main diagonal; the distribution range of quantization coefficient is indicated by the number of occupied diagonal.

The simplest quantization matrix is A(2) whose diagonal number is 2, as shown in Fig.5(a). The 15 quantized values, coded from 0 to 14, are assigned to index matrix of 8×8. If the central decoder works, accurate reconstruction signal can be achieved from the index (i_1, i_2); if the side decoder works, reconstruction signal is achieved only from the row index i_1 or column index i_2 and will produce side distortion of difference 1 (e.g. by constructing from row index 101, the possible coefficient may be 9 or 10 and the range is 1). There are only 15 quantized coefficients in the index matrix with 64 units, redundancy of this index assignment is very high. Index matrix A(3), whose diagonal number is 3, is shown in Fig.5(b). 16 quantization coefficients are assigned to index matrix of 6×6 and it is relatively low redundancy of index assignment. If the side decoder works, the maximum distortion is 3 (e.g. by constructing from column index 100, the possible coefficient may be 11, 12 or 14 and the range is 3). Index assignment matrix shown in Fig.5(c) is full. Although there is no redundancy in this matrix, the distortion is very big and the maximum is up to 9. References [13] and [14] are improvements on MDSQ.

In MDFIC, the contrast scaling s is quantized by MDLVQ. In MDLVQ, since the lattice A2 is the space which can be spanned by two vectors (1,0) and (-1/2, $\sqrt{3}/2$), the area of the hexagonal lattice is determined by the two vectors[10]. Although the algorithm outperforms the tradition, it is weaker than algorithm in [13]. Above all, s is quantized to two descriptions s_1 and s_2 to accommodate to transfer independently in two channels.

In MDFIC, the average intensity of range block is quantized by 7 bits unthinking of the correlation between average pixel intensity of adjacent range blocks. In practical, the correlation between average intensity of adjacent range blocks is very strong, and the number differs a little. If the difference between them is quantized by MDSQ, the correlation between the range block can be further removed. Meanwhile, number of bits is descending to further improve compression ratio for small dynamic range of difference. Here, the average intensity of range blocks is firstly coded by predictive coding and then quantized into two descriptions by MDSQ coding to accommodate to transfer in two channels.

C. *Re-match*

In order to create two descriptions for the position of domain block, re-match scheme is also used in the scheme. If only one description is received, reconstructed image cannot be achieved by traditional fractal image decoding with contrast scaling s and position of domain block p. Thus the position parameters should adjust to different channels (denote by p_1 and p_2 separately) so as to reconstruct correct decoding image. Re-match scheme is the same as that in MDFIC. It is no longer to explain here.

D. *Central decoder and side decoder*

Here the decoder, similar to that in MDFIC, is adopted to reconstruct image in accordance with the received descriptions.

IV. EXPERIMENTAL RESULTS

Simulations which evaluate the efficiency of the proposed algorithm are performed on a PC with Pentium(R) D 2.80GHz CPU. The standard images "Lena", "Peppers" and "Girl" $(512\times 512\times 8)$ are used to compare the performance of MDFIC and the proposed scheme.

The fast fractal image coding based on FGSE [6] is used for FIC. The depth of Quadtree, the method of segmenting image, is 5, 6, 7. The domain step is the same as the size of range blocks. Since MDSQ in [13] outperforms MDLVQ in [10], different from MDFIC, scaling factor is quantized with 3bits by MDSQ. The quantization method with average intensity of range block and difference of average pixel intensity between adjacent range blocks is the same as that of MDFIC. The bit numbers is 7 bits and 4 bits respectively.

The experimental results shown in Table Ⅰ indicate that the proposed scheme outperforms MDFIC in reconstructed image quality, bit rate per channel and coding speed. The possible reasons may lie in some aspects explained in following sections.

①Table Ⅰ shows the performance of reconstructed image quality evaluated by PSNR compared the proposed scheme against MDFIC. Almost all the reconstructed quality of central decoder and side decoder are a little better than that of MDFIC, but it should be much better in principle by using advanced MDSQ [13]. It is because that difference of average pixel intensity between adjacent rang blocks is handled simultaneously to improve the bit rate at the expense of inferior quality. So the quality only increases with about 0.2dB, where S_0 represents decoded quality of central decoder, S_1/S_2 represents the higher quality between side decoder S_1 and S_2.

② Transmission of $\Delta\bar{R}$ (difference of average pixel intensity of adjacent range blocks) instead of $\bar{R}$ (average pixel intensity of range blocks) contributes to the better performances on bit rate per channel increased by about 0.07bpp shown in Table Ⅰ.

③When compared with coding speed, the proposed scheme is faster than MDFIC and improves about 40% for available fast fractal image coding and advanced MDSQ against MDLVQ. Simulations in [6] represent that only half domain blocks are left to compute matching distortions. However, the coding speed just increased 40% because of normalized process in practice.

In addition, Fig.6 shows reconstructed image quality of central and side decoder for "Lena"(bpp = 0.5). The figure 6(b) and 6(c) can satisfy the human visual characteristics.

TABLE I. PERFORMANCE OF MDFIC VERSUS PROPOSED SCHEME

Original Image	MDFIC			Proposed scheme			
	PSNR(dB)		***bpp***	***PSNR(dB)***		***bpp***	***Speed up***
	S_0	S_1/S_2		S_0	S_1/S_2		
Lena	34.55	32.78	0.48	34.55	32.97	0.40	40%
Girl	35.99	34.28	0.30	35.99	34.47	0.24	42%
Pepper	33.82	32.21	0.49	33.82	32.42	0.44	44%

(a) original image (Lena)

(b) reconstructed image by central decoder（PSNR=34.55dB）

(c) reconstructed image by side decoder（PSNR=34.77dB）

Figure 6. Reconstructed quality of central and side decoder for "Lena"(0.5bpp)

V. CONCLUSION

In this paper, a new multiple description image coding scheme based on fast fractal image coding is proposed to improve the conventional MDFIC. By handling the scale factor and average pixel intensity, the proposed scheme can improve side and central rate distortion performance. Furthermore, the algorithm of fast fractal coding based on FGSE is applied to speed up the encoding process. Experimental results show the better performance compared with the conventional MDFIC, which may be a good choice in practical applications.

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