FRACTAL CODING OF IMAGE SEQUENCE USING EXTENDED CIRCULAR PREDICTION MAPPING

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ABSTRACT

This paper proposes a novel algorithm for fractal coding of color image sequence, based on the extended CPM (Circular Prediction Mapping). In the extended CPM, each range block is approximated by a domain block in the adjacent frame, which is of the same size as the range block. Therefore the proposed domain-range mapping is similar to the block matching algorithm in the motion compensation techniques, and we can exploit the temporal correlation in moving image sequence effectively. Also we show that fast decoding is possible, since the decoder requires about 1 multiplication and 3 additions per pixel for each Y, U, V components. The computer simulation results on real image sequences demonstrate that the proposed algorithm provides very promising performance at low bit-rate.

1 INTRODUCTION

After Jacquin first proposed an automatic algorithm for fractal coding of still images[1], much effort has been reported on the fractal still image coding techniques[2]. However, little work has been done on the fractal image sequence coding techniques. Lazar extended Jacquin's algorithm straightforwardly to the video sequence coding, by employing 3-D domain blocks and range blocks[4]. But the 3-D block approach generates severe 3-D blocking artifacts in the reconstructed images in many cases. Another approach, which encodes only the blocks most different from previous frame, is proposed by Monro[5]. In other words, a simple motion compensation with zero motion vector is performed in Monro's algorithm.

In this paper, attempts have been made to propose a novel algorithm for fractal coding of color image sequence, which fully exploits the temporal correlation between the frames. The CPM (Circular Prediction Mapping) is a suitable contraction mapping for encoding and decoding of image sequence, in which each range block is motion-compensated by a domain block in the circularly previous frame[3]. We shall show that the CPM can be combined with NCIM (Non-Contractive Inter-frame Mapping), to further exploit the temporal correlation between the frames, without affecting the convergence behavior of the decoding process. Moreover, the NCIM-coded frames can be decoded very fast, since the decoder requires only 1 multiplication and 3 additions per pixel. Also a color coding scheme, which exploits the component similarity between the luminance (Y) component and the color (U, V) components, as well as the temporal correlation, is provided. The computer simulation results on the real image sequences demonstrate that the proposed algorithm provides very promising performance, at low bit-rate below 256 Kbps.

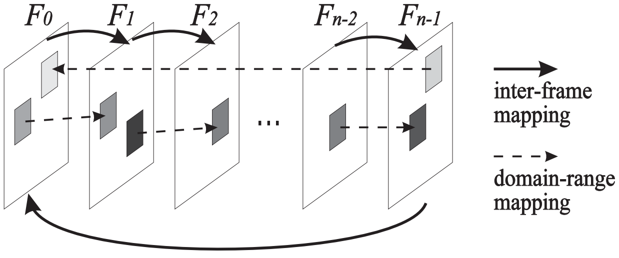

Figure 1: The structure of the CPM

2 THE EXTENDED CPM

The extended CPM is a hybrid mapping of CPM and NCIM. In this section, we describe the extended CPM, and propose two methods for color components coding.

2.1 CPM

In the CPM, n frames are encoded as a coding group, and each frame is predicted blockwise from the n-circularly previous frame, as shown in Figure 1. In other words, each range block R_i in the k-th frame F_k is approximated by a domain block $D_{a(i)}$ in the circularly previous frame $F_{[k-1]_n}$, where $[k]_n$ denotes (k modulo n). The size of the domain block is chosen to be same as that of the range block, so as to exploit high temporal correlation between frames efficiently. Then, the approximation of R_i is given by

$$R_i \cong \widetilde{R_i} = s_i \cdot \mathcal{O}(D_{a(i)}) + o_i \cdot C, \qquad (1)$$

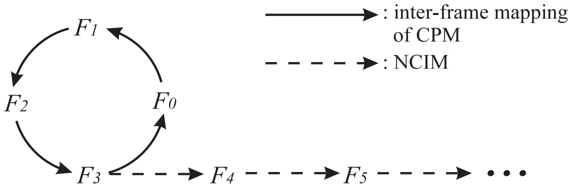

Figure 2: The hybrid structure of CPM and NCIM

where $a(i)$ denotes the location of the optimal domain block, and s_i, o_i are real coefficients, respectively. The C is a constant block whose all pixel values are 1, and $\mathcal{O}$ is the orthogonalization operator, proposed by Øien[2] for fractal still image coder.

The proposed domain-range mapping can be interpreted as a kind of motion compensation techniques. The $a(i)$ describes the translational motion of block, *i.e.*, the $a(i)$ is the motion vector. Besides the translational motion, the changes in contrast and overall brightness of block are compensated by the s_i and o_i coefficients, respectively. By constraining the contrast scaling coefficients s_i to be quantized between -1 and 1, the CPM becomes a contraction mapping. In the decoder, the CPM is applied iteratively to arbitrary n frames to reconstruct the attractor frames. More detailed discussion of the CPM can be found in earlier work[3].

2.2 NCIM

The n inter-frame mappings, which compose the CPM, should be contractive for the decoding process to converge, and the increased contrast between frames cannot be depicted by the CPM. Therefore, instead of encoding all the frames by the CPM, the hybrid mapping of CPM and NCIM can be employed as shown in Figure 2.

In Figure 2, the first four frames F_k $(0 \leq k < 4)$ are encoded by employing the CPM, and the following frames F_k $(k \geq 4)$ are encoded by employing the NCIM's, respectively. The NCIM's are same as the 4 inter-frame mappings which compose the CPM, except that there is no constraint on the contrast scaling coefficients s_i, *i.e.*, the absolute value of s_i could be larger than 1. Therefore, we can exploit the temporal correlation further with the NCIM's, obtaining more coding gain.

From the view point of graph theory[6], the first four frames encoded with the CPM are the *minimal decodable set* of frames, in that they can be decodable without reference to the other frames, and the following frames encoded with the NCIM's depend sequentially on the minimal decodable set in the *dependence graph*. Therefore, only the CPM affects the convergence of the extended CPM (CPM+NCIM's), and the NCIM's need not be contractive. In addition, the frames encoded with the NCIM's can be reconstructed very fast in a non-iterative way, after the iterative reconstruction of the minimal decodable set of frames.

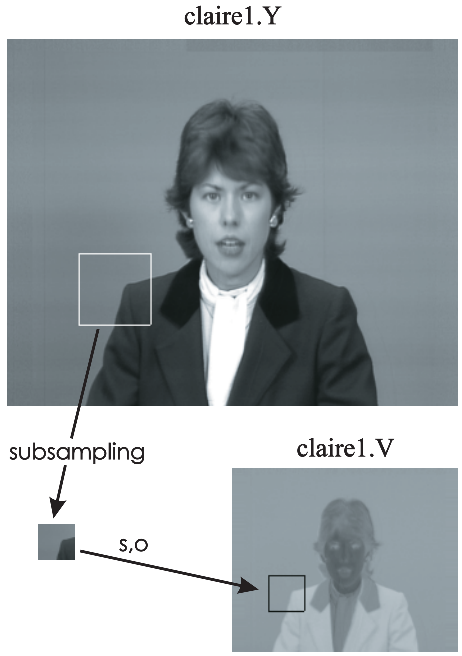

Figure 3: Illustration of color range block coding

However, the CPM should be employed at the start of a sequence or after scene changes, in order to encode frames without depending on the previous frames. Moreover, the CPM-coded frames provide access points for the decoding process to begin, and they should be inserted in some frequency, according to the requirement of random access.

2.3 Coding of Color Components

2.3.1 Method 1 - sharing motion vector

The extended CPM can be employed independently for encoding of the color (U,V) components of image sequence, as well as the luminance (Y) component. But, by sharing the information of the motion vectors $a(i)$ in Eq.(1), further compression can be achieved. More specifically, if we find a motion vector $a(i)$ for encoding of a luminance range block, the $a(i)$ can be used as the common motion vector for encoding of the color range blocks at the same location.

2.3.2 Method 2 - exploiting component similarity

Besides the motion vector sharing, we can employ alternative approach for encoding of color range block, which exploit the high similarity between the luminance component and the color components. This is illustrated in Figure 3. It can be seen that there is much similarity between the luminance frame and the color frame. Therefore the range block in the color frame can be efficiently approximated by the domain block in the luminance frame at the same location, after subsampling. As in Eq.(1), the s coefficient describes the contrast change, and the o coefficient represents the DC value of the range block, respectively.

2.4 Decoding Complexity

Fast decoding of images is an essential requirement for many applications of image compression. Let us briefly describe the complexity of the proposed decoder. The domain-range mapping in Eq.(1) can be rewritten as

$$\begin{aligned} R_i \cong \widetilde{R_i} &= s_i \cdot (D_{a(i)} - d \cdot C) + o_i \cdot C \\ &= s_i \cdot D_{a(i)} + (o_i - s_i d) \cdot C, \end{aligned} \tag{2}$$

where d denotes the DC value of the domain block $D_{a(i)}$. Let the size of the range block be $r \times r$. Then it can be easily shown that the above domain-range mapping requires $(r^2 + 2)/r^2 \cong 1$ multiplication and $2r^2/r^2 = 2$ additions per pixel.

If the CPM is employed to encode some frames, it should be iteratively applied at the decoder to reconstruct the frames. Since 3 iterations are sufficient for the CPM to converge in most cases, the decoder can reconstruct the attractor frames fast, requiring 3 multiplications and 6 additions per pixel. Moreover, the NCIM-coded frames can be reconstructed very fast in a non-iterative way, requiring only 1 multiplication and 2 additions per pixel.

3 SIMULATION RESULTS

The proposed algorithm is implemented as shown in Figure 2, *i.e.*, the first four frames are encoded with the CPM, and the following frames are encoded with the NCIM till the next scene change, respectively. And each luminance frame is spatially partitioned into the range blocks of maximum size 32 × 32 and minimum size 4 × 4, using a quadtree structure. Since the color frames are half the size of the luminance frame, they are partitioned into the range blocks of maximum size 16 × 16 and minimum size 2 × 2, according to the same quadtree structure. The color range blocks, larger than 2 × 2, are encoded with the *Method 1* by sharing the motion vector with the luminance range block at the same location. But, for coding efficiency, four adjacent 2 × 2 color range blocks are jointly encoded with the *Method 2* by exploiting the component similarity.

The tested image sequences are the standard CIF (352 × 288) image sequences, whose frame rates are originally 25 frames/s. But the frame rates are reduced to 8.33 frames/s to demonstrate the performances at low bit-rate, below 256 Kbps. In other words, every third frame is encoded and the other two frames are skipped.

Figure 4 shows the bit-rate and PSNR performances of the proposed algorithm on the "Claire" sequence. The average bit-rate is 0.073 bpp, which amounts to 65.3 Kbps in bits per second. Since this sequence contains no scene change in the 1st ~ 80th frames (originally, 1st ~ 238th frames), the first four frames are encoded with the CPM and the following frames are encoded with the NCIM's, respectively. It is seen that the performances for the NCIM-coded frames are better than those for the CPM-coded frames. This is due to that the NCIM's can exploit the temporal correlation more effectively than the CPM, since there is no constraint on the contrast scaling coefficients s_i. However, the CPM should be employed at the start of a sequence or after scene changes, in order to encode the first four frames without depending on the previous frames. Figure 5.(a) shows the 8th reconstructed frame of "Claire" Sequence. It can be seen that the proposed algorithm reconstructs the image very faithfully, considering the low bit-rate of 65.3 Kbps.

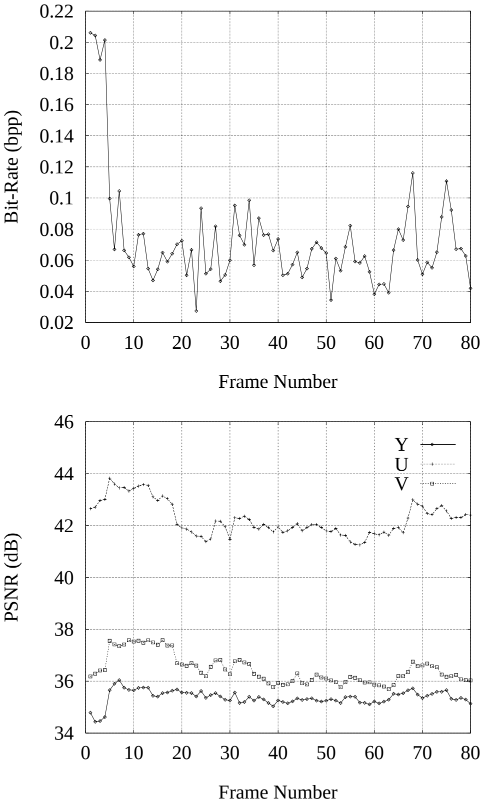

Figure 4: The bit-rate and PSNR performances of the proposed algorithm on the 'Claire" sequence

Table 1 presents the performances of the proposed algorithm on various CIF image sequences. The provided PSNR and bit-rate values are averaged over 1st ~ 80th frames. About 23 % of the total bits are allo-

Table 1: The performance of the proposed algorithm

	Bit-Rate (Kbps)	PSNR (dB)		
		Y	U	V
Carphone	116.8	29.6	37.8	37.3
	211.8	32.1	39.3	38.7
Foreman	119.8	28.9	38.2	35.8
	208.3	30.8	39.4	36.5
Claire	49.5	34.9	41.8	36.1
	80.8	36.0	42.6	36.6

cated for coding of the color components. Figure 5.(b) and (c) show the samples of the reconstructed frames of the "Carphone" and "Foreman" sequences, respectively. It is observed that the tree outside the window in the "Carphone" sequence and the sharp edge of the background structure in the "Foreman" sequence are reconstructed very faithfully, without exhibiting any severe blocking artifacts. In the 3-D block approaches[4], the domain-range mapping often fails, and the quality of the reconstructed frames is poor in such finely detailed and fast moving regions. These simulation results indicate that the proposed algorithm provides much better performance than the conventional 3-D block approaches.

4 CONCLUSION

We proposed a novel algorithm for fractal coding of moving image sequence, based on the extended CPM, in which each range block is motion-compensated by a domain block in the adjacent frame. Also a color coding scheme, which exploits the component similarity as well as the temporal correlation, was provided.

It was demonstrated that the proposed algorithm provides very good image quality, at low bit-rate below 256 Kbps, without observing any severe blocking artifacts. Moreover, the proposed algorithm is very fast in decoding, since it requires about 1 multiplication and 3 additions per pixel. A further parameter optimization will make the proposed algorithm a strong candidate for low bit-rate coding techniques.

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(a) "Claire" 8 th (65.3 Kbps)

(b) "Carphone" 66th (211.8 Kbps)

(c) "Foreman" 10th (119.8 Kbps)

Figure 5: Samples of the reconstructed frames