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Fractal video sequences coding with region-based functionality

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ABSTRACT

In this paper, we explore the fractal video sequences coding in the context of region-based functionality. Since the main drawback of fractal coding is the high computational complexity, some schemes are proposed to speed up the encoding process. As fractal encoding essentially spends most time on the search for the best-matching block in a large domain pool, this paper firstly ameliorates the conventional CPM/NCIM method and then applies a new hexagon block-matching motion estimation technology into the fractal video coding. The images in the video sequences are encoded region by region according to a previously-computed segmentation map. Experimental results indicate that the proposed algorithm spends less encoding time and achieves higher compression ratio and compression quality compared with the conventional CPM/NCIM method.

1. Introduction

Region-based video sequences coding has been intensely investigated in the last few years and is one of the more appealing features of MPEG-4 standard [1]. Compared with the block-based coding, it allows manipulation of image regions without complete decoding of the stream, and then improves the coding quality and reduces the bit rate. The region-based approach has been considered as a very promising alternative to the block-based approach. It permits new functionalities at the receiver, such as advanced region-based queries, selective region transmission. Also, for a given rate, region-based coding often achieves better image quality than standard coding since region boundaries usually coincide with the intensity edges that are difficult to encode. In such a scheme, a prior segmentation map (*alpha* plane) of the image, which segments the image into regions, is known in advance [2].

Fractal compression, which is based on iterated function system original proposed by Barnsley and his coworkers in 1988 [3], is a potential image compression method. He and his students successfully applied it into image compression. Fractal image compression reduces the redundancy of images by using self-similarity properties and seems to be a favorable method for the image compression due to its advantages of high compression ratio, fast decompression and resolution independence. This is particularly suitable for the situation of one encoding and many decoding [4]. Fractal coding is thought to be one of the three most prominent codec methods. However, its major drawback is that fractal encoding is complex and time-consuming to search for the best-matching block in a big pool of domain blocks, and this seriously embarrasses the fractal image coding method's application into the practice.

Fisher classified the image blocks (range block and domain block) [5–7]. An image block is divided into four quadrants. The average and the variance are computed for each quadrant, so for the four quadrants, 72 classes are constructed. The

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range block found matches only in the domain pool which is the same class with it. This reduced the searching space efficiently. However it needs large amount of computations in the classifying process and maybe some range blocks cannot find the matching blocks in the same class in the domain pool.

As the developing of the fractal image compression, fractal coding method has been applied on video sequence compression, for instance, the famous hybrid circular prediction mapping (CPM) and non-contractive inter-frame mapping (NCIM) [8]. The CPM/NCIM combines fractal video coding with the well-known motion estimation and compensation (ME/MC) algorithm that exploits the high temporal correlations between adjacent frames. In CPM and NCIM, each range block is motion compensated by a domain block in the previous frame, which is of the same size as the range block even though the domain block is always larger than the range block in conventional fractal image codec. The main difference between CPM and NCIM is that CPM should be contractive for the iterative decoding process to converge, while NCIM need not be contractive since the decoding depends on the already decoded frames and is non-iterative. Recently, Wang proposed a hybrid compression algorithm, which merges the advantages of a cube-based fractal compression method and a frame-based fractal compression method, and an adaptive partition instead of fixed-size partition is discussed. The adaptive partition and the hybrid compression algorithm exhibit relatively high compression ratio for the sequence of motion images from a videoconference [9]. Selim used the spiral architecture instead of the square block decomposition in fractal compression. The experiments show that the using of spiral searching or decomposition and decoding produces better visual quality images than that produced by conventional systems at the same compression ratio but with a longer time consumed [10]. Jyh-Horng Jeng proposed a Huber fractal image compression method. The simulation results show that this method is robust against outliers in the image. However the main disadvantage of this method is the high computational cost [11]. Distasi tried to overcome the difficulty of the large time consumed [12]. Ming-Sheng Wu proposed a schema genetic algorithm for fractal image compression to find the best self-similarity in fractal image compression [13,14].

In conclusion, a fractal image codec performs better in terms of very fast decoding process as well as the promise of potentially good compression quality. But at present, fractal codec is not standardized because of its huge calculation amount, slow coding speed and the poor decoding image quality when compressing corrupted images.

In order to alleviate the above difficulties, a novel fractal video coding algorithm with region-based functionality is proposed in this paper to improve the encoding speed and the compression quality, meanwhile, it makes fractal video coding more flexible and functional. The contents are organized as follows: The theory of fractal coding is summarized in Section 2. The proposed novel methods for region-based fractal video sequence coding are presented in Section 3. The experimental results are presented in Section 4. And finally the conclusions are outlined in Section 5.

2. The fractal compression theory and mathematical background

The idea of fractal image compression is based on the Iteration Function System in which the governing theorem is the Contractive Mapping Fixed-Point Theorem. We define this theorem as follows:

2.1. Contractive maps

Let X be a metric space with metric d.

A map $\omega : X \to X$ is Lipschitz with Lipschitz factor s if there exists a positive real value s such that

$$d(\omega(x), \omega(y)) \leqslant s d(x, y) \tag{1}$$

for every x, $y \in X$. If the Lipschitz constant satisfies $s < 1$, then ω is said to be contractive with contractivity s.

The Contractive Mapping Fixed-Point Theorem: let X be a complete metric space and $f : X \to X$ be a contractive mapping. Then there exists a unique point $x_f \in X$ such that for any point $x \in X$

$$x_f = f(x_f) = \lim_{n\to\infty} f^{on}(x) \tag{2}$$

Such a point is called a fixed point or the attractor of the mapping f.

2.2. Generalized Collage Theorem

Let f be eventually contractive with exponent n, then there exists a unique fixed point $x_f \in X$ such that for any $x \in X$

$$x_f = f(x_f) = \lim_{k\to\infty} f^{ok}(x) \tag{3}$$

In that case,

$$d(x, x_f) \leqslant \frac{1}{1-s}\frac{1-\delta^n}{1-\delta} d(x, f(x)) \tag{4}$$

where s is the contractivity factor of f^{on} and δ is the Lipschitz factor of f.

Let X be a complete metric space. An iterated function system is a collection of contractive maps $\omega_i : X \to X$ for $i = 1,\ldots,n$. By the Contractive Mapping Fixed-Point Theorem, iterated function system is just a collection of maps that defines a unique attractor. As the attractor is unique, it is completely specified by the map ω and initial value independent [4].

The fractal image and video encoding is an inverse problem that we need to find an IFS which has the whole image as its attractor. However, no completely general solution to this problem exists to the date as only local self-similarities exist in natural images. Therefore, the IFS is extended to form the Partitioned Iterated Function System (PIFS) which is a collection of contractive maps $\omega_i : D_i \to X$, for $i = 1,\ldots,n$ where X is a complete metric space and $D_i \subset X$, for $i = 1,\ldots,n$. PIFS makes it possible to encode more general and non-self-similar sets and by using collage coding method, a similar part of the region can always be found for every small part of a region.

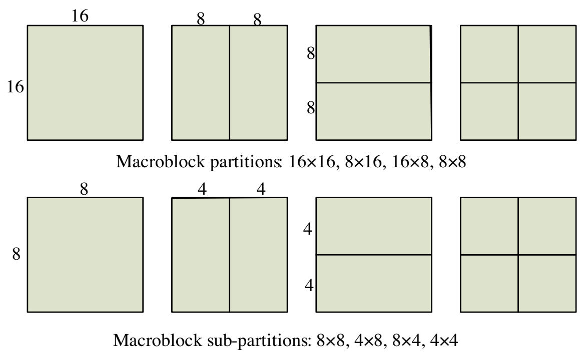
3. The proposed region-based fractal video coding scheme

3.1. Macroblock partition

Partitioning images is the first step in a practical fractal encoding scheme and it determines the complexity of searching for the best-matching block in a large domain pool. Quadtree partition, HV partition and triangular partition have been used in the fractal encoding. But the drawback of these methods is that the matching process is very complex. In this paper, the tree structured partition is explored to the application into the fractal encoding. The image is firstly partitioned into non-overlapped macroblocks size of 16×16 as shown in Fig. 1(a), and each macroblock can be split up in 4 ways: 16×16, 16×8, 8×16 or 8×8. If the 8×8 mode is chosen, each of the four 8×8 macroblock partition within the macroblock may be split in a further 4 ways: 8×8, 8×4, 4×8 or 4×4. These partitions give rise to a large number of possible combinations within each macroblock. An example is shown in Fig. 1(b).

The best matching domain block for range block is determined by evaluating the RMS (Root Mean Square). The minimum RMS means the best matching. It is determined by

$$RMS = \frac{1}{N}\left[\sum_{i=1}^{N} r_i^2 + s\left(s\sum_{i=1}^{N} d_i^2 - 2\sum_{i=1}^{N} r_i d_i + 2o\sum_{i=1}^{N} d_i^2\right) + o\left(N \cdot o - 2\sum_{i=1}^{N} r_i\right)\right] \tag{5}$$



(a) Tree structured partition modes.

(b) An example of the tree structured partition.

Fig. 1. Illustration of the tree structured partition modes.

where the contrast factor s is

$$s = \frac{N\sum_{i=1}^{N} r_i d_i - \sum_{i=1}^{N} r_i \sum_{i=1}^{N} d_i}{N\sum_{i=1}^{N} d_i^2 - (\sum_{i=1}^{N} d_i)^2} \tag{6}$$

and the offset factor o is

$$o = \frac{1}{N}\left[\sum_{i=1}^{N} r_i - s\sum_{i=1}^{N} d_i\right] \tag{7}$$

r_i is pixel value of Range block (R), d_i is pixel value of Domain block (D), N is the number of pixels in the block.

3.2. DCT-based encoding method in I frame

In CPM/NCIM [6], the original four reference frames are encoded as a coding group. Each range block R_i is approximated by a domain block $D_{a(i)}$ in $F_{[k-1]_4}$ in the kth frame F_k, where $[k]_4$ denotes (k modulo 4), is defined as follows:

$$R_i \cong s_i \cdot \vartheta[D_{a(i)}] + o_i \cdot C \tag{8}$$

where s_i, o_i are the contrast factor and the brightness offset respectively, $a(i)$ denotes the location of the optimal domain block, C is a contrast block and ϑ is the orthogonalization operator.

In CPM, the coding involves complex block-classifying, block-overturning and iteration which result in the poor compression performances. Then the method based on DCT is proposed to treat the original frame in this paper.Assume f be a $N \times N$ pixels image block, the DCT transformation of f is denoted as

$$F(m,n) = \frac{2}{N} C_m C_n \sum_{i=0}^{N-1}\sum_{j=0}^{N-1} f(i,j)\cos\left(\frac{(2i+1)m\pi}{2N}\right) \times \cos\left(\frac{(2j+1)m\pi}{2N}\right) \tag{9}$$

where m, $n = 0, 1, \ldots, N-1$, and

$$C_k = \begin{cases} 1/\sqrt{2}, & \mathrm{k} = 0 \\ 1, & \text{others} \end{cases}$$

In this paper, the original frame is firstly partitioned into blocks of size of 8×8, and then the following steps are performed to each block: DCT transformation, quantization of the DCT coefficients with a given quantization step QS and Huffman coding the DCT coefficients.

The comparison of the compression performance between CPM and the proposed method is shown in Table 1.

Table 1 is the comparison of original frame of the video sequence "mother–daughter" (352×288 pixels) coding results using CPM and the proposed method respectively. Compared with CPM method, PSNR improves by 10.21 dB and the encoding speed is 292 times faster when using the proposed method. Meanwhile the compression ratio increases a little. The improvement of the original frame coding quality is helpful to the latter frames coding of the video sequence.

3.3. The reduction of the computational complexity

For a given fractal resolution in image encoding, (χ, φ), there are: χ^2 range blocks R_k, $k = 1, 2, \ldots, \chi^2$, φ^2 domain blocks D_i, $i = 1, 2, \ldots, \varphi^2$ and 8 geometric maps $\omega^{(m)}$. Each R_k needs to search all of the collection of D_i to find the optimal matching in 8 ways. In total, $\chi^2 \times \varphi^2 \times 8$ matching tests are needed to finish the encoding. Clearly, it is a hard working. In real world video sequences, more than 80% of the blocks can be regarded as stationary ($MV = (0,0)$) or quasi-stationary ($MV = (\pm 1, 0)$ or $(0, \pm 1)$) blocks and most of the motion vectors are enclosed in the central 5×5 pixels area for search window [15]. Since the motion image sequences exhibit high temporal correlations, the domain-range mapping becomes more effective if the size of the domain block is the same as that of the range block. And the search region for the motion vectors in the domain is localized in the area near the location of the range block in this paper.

Table 1
The comparison of original frame coding results between CPM/NCIM and the proposed method.

	PSNR/dB	Compression ratio	Compression time/s
Proposed	40.79	15.33	0.031
CPM/NCIM	30.58	14.98	9.062

3.4. A new hexagon search algorithm

Fractal image compression is time consuming in the encoding process as it spends a lot of time on the search for the best-matching block in a large domain pool. So research on efficient and fast motion estimation algorithm is significant to reduce the encoding time. Hexagon-based search employs a hexagon-shaped pattern and results in fewer search points with similar distortion. In this paper, a novel fast block-matching called cross-hexagon search algorithm (NHEXS) is proposed. The new Hexagon search consists of two patterns: cross-based and hexagon-based patterns. As the motion vectors distribution possesses cross-center biased characteristics (74.16%) in the central 4×4 pixels area, two cross-shaped patterns: small-cross-shaped (SCSP) and large-cross-shaped (LCSP), as shown in Fig. 2(a), are proposed as the first two initial steps to the hexagon-based search.

There are two different sizes of hexagon search patterns: large and small hexagon patterns. The large hexagon pattern used in this paper consists of not only the 7 check points in classic large hexagon pattern, but also the two edge points (up and down), as shown in Fig. 2(b). Therefore, the new large hexagon pattern consists of 9 search points which realizes a distinct search speed gain without increasing computational complexity of large hexagon search algorithm.

From the simulation results on the video sequences, we found that nearly 70% blocks that can be regarded as stationary or quasi-stationary blocks. By having this highly cross-based property in most of the real world sequences, we take the small cross-shaped patterns as the first two steps in NHEXS, which will save the number of search points for stationary or quasi-stationary blocks. Then, search the rest points of LCSP and square-center-biased (SCB) within ±2 pixels which is guiding a much more precise direction for the subsequent HEXS as shown in Fig. 2(c).

3.5. Region-based fractal video sequences coding

In this paper, a novel region-based fractal coding scheme is proposed. The regions can be defined by a prior segmentation map (*alpha* plane) and are encoded independently of each other. Segmentation map associates a label with each image point as shown in Fig. 3(a).

The range and domain blocks remain rectangular. We restrict the distortion RMS to a segment which is a subset of pixel location in the range block that is associated with one region. Let $I(x, y)$ be the image intensity of a pixel at position (x, y), $S^n_{d_j}$ be the nth segment in the domain block d_j and $S^m_{r_j}$ be the mth segment in the range block r_j. There are four cases regarding the locations of r_j and d_j with respect to the region R_0 as shown in Fig. 3(b):

(1) r_i and d_j are both interior blocks;
(2) r_i and d_j are both boundary blocks;
(3) r_i is an interior block whereas d_j is a boundary block;
(4) r_i is a boundary block whereas d_j is an interior block.

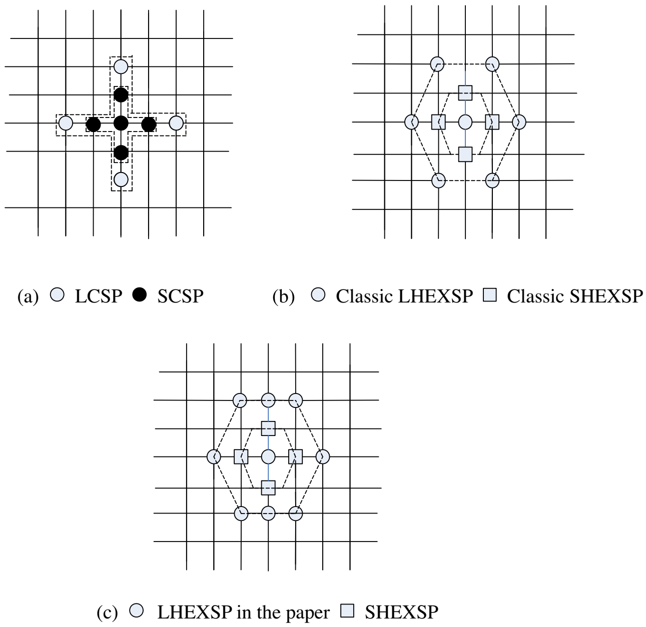
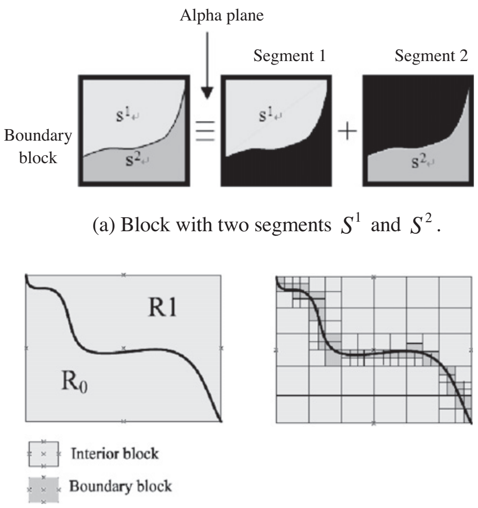


Fig. 2. Search patterns in the proposed NHEXS algorithm.



(a) Block with two segments S^1 and S^2.

(b) Illustration of the tree structured partition for the interior and boundary blocks, the same partition is used for the range and domain blocks.

Fig. 3. The definition of region and its tree structured partition.

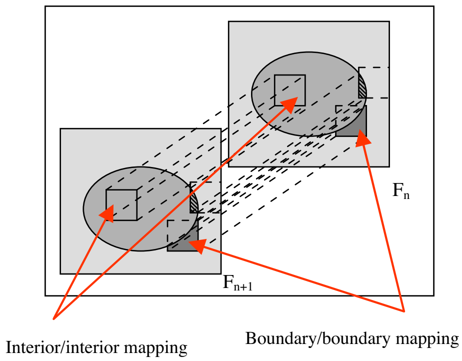


Fig. 4. Illustration of the region-based video frames mapping for the interior and boundary blocks.

In case of (1), standard full block search is executed among some region interior blocks. In case of (2), let $\widetilde{I}_{d_j}$ be a padded version of I_{d_j} defined as

$$\widetilde{I}_{d_j} = \begin{cases} I_{d_j}(x,y) & if\,(x,y) \in S^n_{d_j} \\ v & \text{others} \end{cases} \tag{10}$$

where v is a padding value, typically mean local intensity in $S^n_{d_j}$. Since only partial matching is performed, a new distortion measure RMS is defined as follows,

$$RMS(I_{r_i}, \widetilde{I}_{d_j}, \omega^m_i) = \frac{1}{|S^m_{r_i}|} \sum_{(x,y)\in S^m_{r_i}} [I_{r_i}(x,y) - \omega^m_i \widetilde{I}_{d_j}(x,y)]^2 \tag{11}$$

where ω^m_i denotes an affine transformation for segment $S^m_{r_i}$. The distortion is evaluated only at pixel positions within a single range block segment $S^m_{r_i}$. In case of (3), intensity extrapolation (10) of the domain block is always needed and in case of (4), no padding is needed. Illustration of the tree structured partition for the interior and boundary blocks are shown in Fig. 3(b). Illustration of the region-based video frames mapping for the interior and boundary blocks is shown in Fig. 4.

4. Experimental results

To evaluate the performance of the proposed fractal codec, a simulation has been conducted. Five video sequences: "foreman", "highway", "paris", "bus" and "flower" (352 × 288 pixels, 15 frames) are encoded without region-based functionality firstly. The maximum and minimum partition block sizes are 16 × 16 pixels and 4 × 4 pixels respectively. To compare the performances with the proposed method, CPM/NCIM in which the CPM frames is set for 4 and H.264 (Baseline profile, JM15.0 [16]) are performed. The experiment is proceeded in a PC (CPU: Intel® Core™ 2 Duo E6300, 1.86 GHz, RAM: 2 G, DDR2).

The distortion between the original video image t and retrieved image $\hat{t}$ caused by lossy compression is measured in peak signal to noise ratio (PSNR) and defined by

$$PSNR(t,\hat{t}) = 10 \cdot \log_{10}\left(\frac{255^2}{MSE(t,\hat{t})}\right) \tag{12}$$

MSE (Mean Squared Error) which is the measurement of the similarity between two image blocks u and v of the same size $L \times L$ is defined as follows:

$$MSE(u,v) = \frac{1}{L^2}\sum_{i,j=0}^{L-1}[u(i,j) - v(i,j)]^2 \tag{13}$$

The comparison of average coding results is shown in Table 3. The proposed method can raise compression ratio 1.8–4.5 times, speed up compression time 13–42 times, and improve the decompression image quality 1.8–4 dB in comparison with CPM/NCIM. Although the PSNR and compression ratio are lower compared to H.264, the encoding speed is better than H.264.

To evaluate the performance of the proposed region-based codec, we encode the video sequence "foreman" (352×288 pixels, 15 frames) region-by-region by using the proposed region-based coding scheme. The compression results are shown in Table 2. The compression ratio and PSNR of region 1 and region 2 are both prior to the full frame coding.

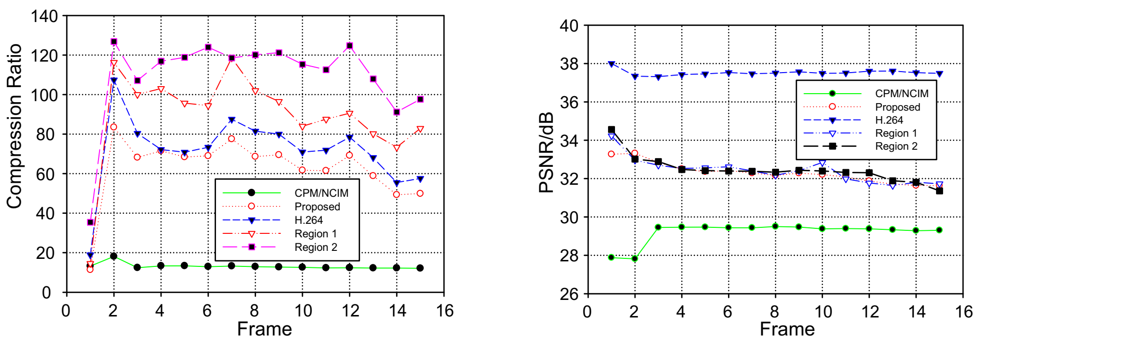
The compression ratio and PSNR curves are shown in Fig. 5 for the fifteen frames of "foreman". Compared with H.264, our region-based fractal video codec has better performances in the compression ratio. And this method has a comparative performance in PSNR comparing with full frame coding.

Table 2
The compression results of "foreman".

Average value	Region 1	Region 2	Full frame
PSNR (dB)	32.426	32.464	32.307
Compression ratio	89.285	109.200	62.526
Bit per pixel	0.089	0.073	0.128

Table 3
The comparison of the average coding results of five video sequences.

	PSNR (dB)			Compression ratio			Compression time (s)		
	CPM/NCIM	Proposed	H.264	CPM/NCIM	Proposed	H.264	CPM/NCIM	Proposed	H.264
Foreman	29.10	32.307	37.52	13.719	62.526	71.614	8.6	0.202	4.659
Paris	31.21	33.744	36.21	10.58	45.83	39.925	8.9	0.312	3.85
Flower	22.18	26.12	36.36	8.87	19.77	18.085	24.2	0.756	4.86
Bus	27.71	29.56	35.87	8.39	15.22	22.153	11.18	0.845	6.933
Highway	31.29	35.38	38.86	25.72	82.76	122.51	7.6	0.178	3.322



(a) The compression ratio. (b) PSNR curves for the region-based scheme for the video sequence of "foreman".

Fig. 5. The comparison results of proposed algorithm with CPM/NCIM and H.264.

Full frame, 32.120db, 0.133bpp | Region1,32.821, 0.097bpp | Region2,32.352db,0.069bpp | *alpha plane*

Fig. 6. The decoded full frame, region 1, 2 and *alpha* plane of third frame of "foreman".

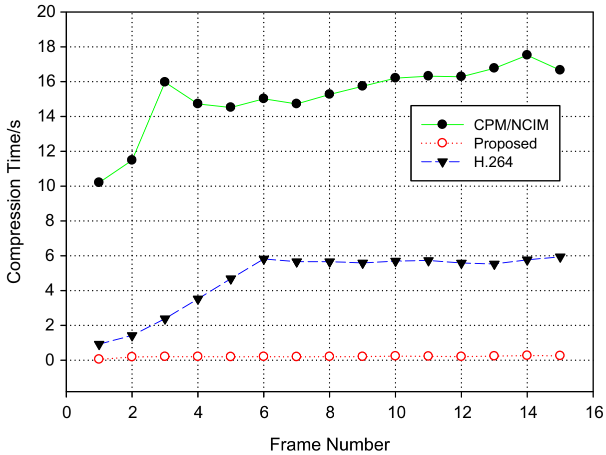


Fig. 7. The compression time curve for the video sequence of "foreman".

The compression time curve for the fifteen frames of the video sequences of "foreman" is shown in Fig. 7. The result indicates that the coding speed of the proposed method is 75.034 times and 23.059 times respectively compared with CPM/NCIM and H.264 scheme. The decoded images of the third frame in the video sequences "foreman" are shown in Fig. 6.

5. Conclusion

In this paper, a novel fractal video coding method with region-based functionality is presented to reduce the encoding time and improve the encoding quality. We firstly improve the conventional CPM/NCIM method. In addition, a new hexagon motion estimation technology is applied to further raise the compression efficiency as the encoding time is essentially spent on the search for the best-matching block in a large domain pool. Meanwhile, this method is with true region-based independent coding/decoding functionalities. The experimental results indicate its efficiency and correctness. In comparison to the CPM/NCIM method, the proposed algorithm spends less encoding time and achieves higher compression ratio and the compression quality.

Acknowledgments

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