

Research Article

An Efficient Fractal Video Sequences Codec with Multiviews

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Multiview video consists of multiple views of the same scene. They require enormous amount of data to achieve high image quality, which makes it indispensable to compress multiview video. Therefore, data compression is a major issue for multiviews. In this paper, we explore an efficient fractal video codec to compress multiviews. The proposed scheme first compresses a view-dependent geometry of the base view using fractal video encoder with homogeneous region condition. With the extended fractional pel motion estimation algorithm and fast disparity estimation algorithm, it then generates prediction images of other views. The prediction image uses the image-based rendering techniques based on the decoded video. And the residual signals are obtained by the prediction image and the original image. Finally, it encodes residual signals by the fractal video encoder. The idea is also to exploit the statistical dependencies from both temporal and interview reference pictures for motion compensated prediction. Experimental results show that the proposed algorithm is consistently better than JMVC8.5, with 62.25% bit rate decrease and 0.37 dB PSNR increase based on the Bjontegaard metric, and the total encoding time (TET) of the proposed algorithm is reduced by 92%.

1. Introduction

There are several image/video compression methods, for example, JPEG, MPEG, and H.26X, which are all based on motion estimation/compensation (ME/MC) [1]. But fractal compression, which is based on the IFS (iterated function system) proposed by Mandelbrot [2], is a new approach to image coding. After Jacquin [3] proposed the first automatic algorithm for fractal coding of still images, much effort has been made in the area of the fractal still image coding techniques. For example, Fisher made use of quadtree to improve the method [4].

With the development of the fractal image compression, fractal coding method has been applied to video sequence compression [5]. Wang and Lai proposed a hybrid compression algorithm [6], which merged 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 was discussed. The adaptive partition and the hybrid compression algorithm exhibit relatively high

compression ratio for the sequence of motion images from a videoconference. But the computational complexity is high.

And with the advantages of high compression ratio and resolution-independent in the fractal coding, more researches were conducted. Distasi et al. tried to overcome the difficulty of such long consuming time [7]. Wu et al. proposed a schema genetic algorithm for fractal image compression to find the best self-similarity in fractal image compression [8]. Zhu et al. proposed an improved fractal compression method using more effective macroblock partition scheme instead of classical quadtree partition scheme to provide promising performances at low bit rate coding [9]. Giusto et al. used IFS and wavelet decomposition to achieve spatial zoom and slow motion replay of digital color video sequences [10]. Active scene detection, wavelet subband analysis, and color fractal coding based on earth mover's distance (EMD) measure were used to reduce computational load and to improve visual quality. The new classification scheme is useful for high speed and low power consumption [11]. The classification is devised with the intention of being hardware realizable. A scheme is

also laid out to store the classified domain and range data in order to accommodate easy hardware. Recently, Shipping Zhu improved the traditional fractal video coding based on a new hexagon block-matching motion estimation technology, which improves the compression efficiency [12].

Multiview video consists of multiple views of the same scene in which there are high degree of correlations between interviews and intraviews. Multiview video coding (MVC) is the key technology that serves the features and applications of three-dimensional television (3DTV). Alternatively, 3DTV displays can supply the 3D representation through the human brain to fuse the left and right views of the same scene, which are captured from slightly different viewing angles. Undoubtedly, it will be a very attractive and effective direction and technique to realize the 3D visual communication in the near future [13]. A novel intermediate view synthesis method based on disparity estimation was presented in [14]. The left and right parts of the image were divided into three kinds using strong and weak consistency constraints separately. Then different strategies are applied according to the characteristic of each region. Ryu et al. proposed an adaptive competition method in order to increase the accuracy of a motion vector (MV) prediction and save bit rate in multiview video coding (MVC) [15]. Motion vector predictors for INTER mode and SKIP (DIRECT) mode were optimally selected from a given adaptive set of predictors by a slightly modified rate distortion criterion. An interview motion model in terms of the global geometric transformation to represent the motion correlation between two adjacent views was proposed in [16]. Compared to the traditional single-channel video system, the original data of multiview video is much huge, which makes it indispensable to compress multiview video.

2. The Fractal Compression Theory and Mathematical Background

Let $I(x)$ be image luminance of a pixel at position $x = (u, v)$ and let $\{r_1, \dots, r_N\}$ be the set of N nonoverlapping range blocks (i.e., collections of pixel coordinates) partitioning the image. Similarly, let $\{d_1, \dots, d_M\}$ be the set of M , possibly overlapping, domain blocks covering the image. Finally, let $I_{r_i} = \{I(x) : x \in r_i\}$ and $I_{d_j} = \{I(x) : x \in d_j\}$.

For each range block r_i the goal is to find a domain block d_j and a contractive mapping w_i that jointly minimize a *dissimilarity* (distortion) criterion ε . The contractive affine mapping w_i consists of three submappings.

- (1) *Contraction*. $\sigma(I, x)$ is usually preceded by low-pass antialias filtering; for example, K -fold contraction with four neighbors averaging: $I(x) \xrightarrow{\sigma(I, x)} 1/4 \sum_{y \in \eta(Kx)} I(y)$, where $\eta(\cdot)$ is the first-order neighborhood (north-east-west-south).
- (2) *Photometric transformation* (accounts for different dynamic ranges of pixels in the range and domain blocks). $\gamma(I) \triangleq sI + o$, where s is a scaling factor (gain) and o is an offset.

- (3) *Geometric transformation* (inverse mapping: range \rightarrow domain). $\xi(x) \triangleq Ax + b$, where $x \in r_i$, A is a 2×2 matrix, and b is a translation vector (this mapping must be 1-to-1 between pixels of the range and domain blocks).

The overall transformation w_i that maps a domain-block pixel into the range-block pixel at x is defined by

$$w_i(I, x) \triangleq \gamma \circ \sigma(I, \xi(x)), \quad x \in r_i, \quad (1)$$

where \circ is the composition operator. The above general expression can be simplified by constraining the transformation A to eight cases: 4 rotations (0° , 90° , -90° , 180°) and four mirror reflections (mid-horizontal, mid-vertical, first diagonal, second diagonal). We denote the set of possible transformations A by $\{\zeta_i^P\}_{P=1}^8$. Furthermore, by expressing b_i implicitly as the index of the domain block, that is, j in d_j , we can write w_i as follows:

$$w_i(I_{d_j}, x) \triangleq s_i \cdot \sigma(I_{d_j}, \zeta_i^P(x)) + o_i, \quad x \in r_i, \quad P \in \{1, \dots, 8\}. \quad (2)$$

In order to encode range block r_i , a search for index j (domain block d_j) and for an isometric transformation ζ_i^P must be executed, jointly with the computation of photometric parameters s_i and o_i . This can be performed by minimizing the following mean-squared error:

$$\varepsilon(I_{r_i}, I_{d_j}, w_i) = \frac{1}{|r_i|} \sum_{x \in r_i} [I_{r_i}(x) - w_i(I_{d_j}, x)]^2. \quad (3)$$

$|r_i|$ denotes the number of range blocks. While the isometric transformation ζ_i^P and index j (equivalent to translation b) are usually found by exhaustive search, the scaling s_i and o_i offset are computed as follows:

$$s_i = \frac{\sum_{x \in r_i} [\sigma(I_{d_j}, \zeta_i^P(x)) - m_{d_j}] [I_{r_i}(x) - m_{r_i}]}{\sum_{x \in r_i} [\sigma(I_{d_j}, \zeta_i^P(x)) - m_{d_j}]^2}, \quad (4)$$

$$o_i = m_{r_i} - s_i \cdot m_{d_j},$$

where m_{r_i} and m_{d_j} represent the mean of the luminance values in the range and domain blocks, respectively. Instead of transmitting the photometric offset o_i (in addition to j , ζ_i^P , and s_i), mean value m_{r_i} of the range block r_i can be transmitted. This permits a precise representation of the mean local luminance but to assure convergence at the decoder, without a constraint on the luminance scaling coefficients, it requires a modification of the photometric transformation. This can be considered as orthogonalization with respect to the constant blocks and has been treated in detail in [17].

3. The Proposed Scheme

We encode the multiviews with the fractal codec method. Compared to the previous encoder, there is the homogeneous region condition and the improved motion estimation in monocular video codec, as shown in Figure 1. Fast disparity estimation algorithm and temporal-spatial prediction structure are also proposed in the paper.

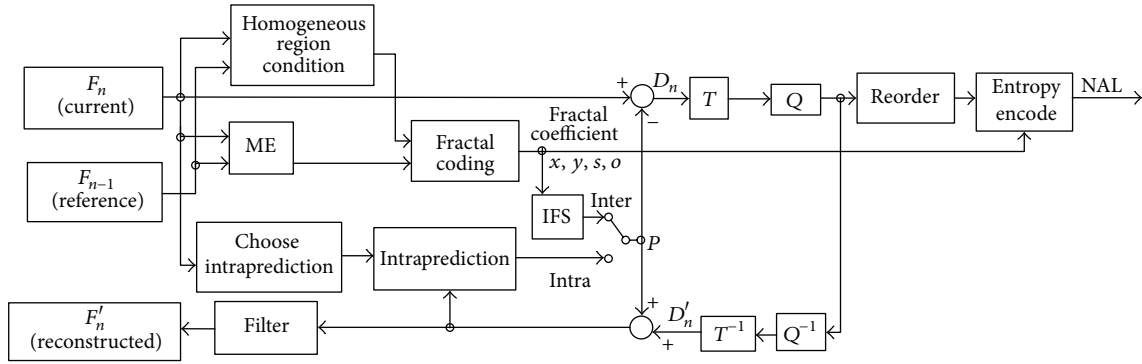


FIGURE 1: Fractal encoder for the video.

3.1. Extended Fractional Pel Motion Estimation Algorithm.

The traditional diamond pattern search uses large diamond search pattern (LDSP) and small diamond search pattern (SDSP). LDSP consists of nine checking points from which eight points surround the center one to compose a diamond shape. SDSP comprises five checking points which form a smaller diamond shape. Several specific features have been incorporated into motion estimation (ME) to improve its coding efficiency. However, they result in very high computational load. The difference between the integer pixel matching error surface and the fractional matching error surface is that in the searching window the former one is far from a unimodal surface, which will easily result in trapping in a local minimum. Because of the smaller search range of subpixel ME as well as the high correlation between fractional pels, we can predict the original search point precisely and fractional pel MV search can be terminated earlier. An extended fractional pel motion estimation algorithm employs SDSP and square pattern, which is based on motion vector. In the proposed scheme, the fractional candidate that is considered as starting MV of the current macroblock is predicted by taking fast motion vector prediction (FMVP) in neighbor block. We do not perform iteration of diamond pattern, instead we stop fractional pel search in $[-2, 2]$ of FMVP, which contains 50%–90% of the accurate MV and reduces the time of searching for best-matching block greatly. We employ the best and second best sum of absolute difference (SAD) from the four diamond points in fractional pel positions. If the first and second best matching points are at the opposite position, four surrounding points in the square pattern are compared. If the best matching point is next to the second best matching point, an additional point in the square pattern will be checked. For illustration, Figure 2 shows a simple search path example of extended diamond pattern search algorithm.

With acceptant PSNR and compression ratio, the proposed extended fractional pel motion estimation algorithm can speed up coding process greatly, which is very important for fractal video coding.

3.2. Homogeneous Region Condition. In general, decision of an optimum matching block for motion estimation depends on spatial and temporal homogeneity in video sequences. In

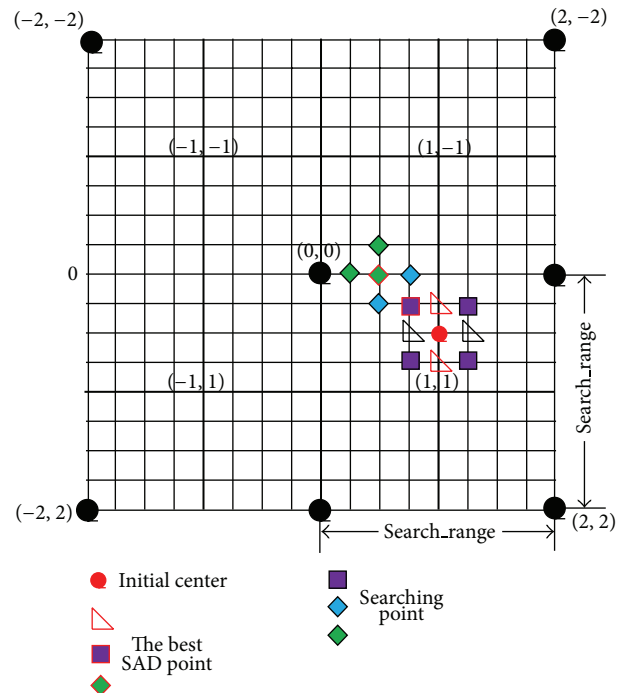


FIGURE 2: Extended diamond pattern search based on MVP.

fractal coding, root mean square (RMS) is used as matching error between D block and R block. Through two vectors, $a_1 \cdots a_n$ (from the D block D_i) and $b_1 \cdots b_n$ (from the R block R_i), and appropriate value s and o , the minimum matching error can be obtained as

$$\text{RMS} = \sum_{i=1}^n (s \cdot a_i + o - b_i)^2. \quad (5)$$

Setting the appropriate contrast factor s and brightness factor o , the value a_i after the affine transformation has the minimum square distance value from b_i . When partial derivatives of s and o are both 0, the minimum RMS can be obtained as

$$s = \frac{[n \sum_{i=1}^n a_i b_i - \sum_{i=1}^n a_i \sum_{i=1}^n b_i]}{[n \sum_{i=1}^n a_i^2 - (\sum_{i=1}^n a_i)^2]}, \quad (6)$$

$$o = \frac{1}{n} \left[\sum_{i=1}^n b_i - s \sum_{i=1}^n a_i \right], \quad (7)$$

where \bar{a} denotes the average value of the vectors $a_1 \cdots a_n$ and \bar{b} denotes the average value of the vectors $b_1 \cdots b_n$. Due to (6) and (7), (5) can be inferred as follows:

$$\begin{aligned} \text{RMS} &= \sum_{i=1}^n (s \cdot a_i + o - b_i)^2 \\ &= \sum_{i=1}^n \left(s \cdot a_i + \frac{1}{n} \left[\sum_{i=1}^n b_i - s \sum_{i=1}^n a_i \right] - b_i \right)^2 \\ &= \sum_{i=1}^n \left((a_i - \bar{a}) \cdot \frac{\sum_{i=1}^n (b_i - \bar{b})(a_i - \bar{a})}{\|a_i - \bar{a}\|^2} + \bar{b} - b_i \right)^2 \\ &= \|b_i - \bar{b}\|^2 \\ &\quad \times \sum_{i=1}^n \left(\frac{(a_i - \bar{a})}{\|a_i - \bar{a}\|} \cdot \frac{\sum_{i=1}^n (b_i - \bar{b})(a_i - \bar{a})}{\|b_i - \bar{b}\| \|a_i - \bar{a}\|} - \frac{b_i - \bar{b}}{\|b_i - \bar{b}\|} \right)^2. \end{aligned} \quad (8)$$

Let $\hat{a} = (a_i - \bar{a})/\|a_i - \bar{a}\|$, $\hat{b} = (b_i - \bar{b})/\|b_i - \bar{b}\|$ and, obviously, $\|\hat{a}\|^2 = 1$, $\|\hat{b}\|^2 = 1$; (8) can be inferred as follows:

$$\begin{aligned} \text{RMS} &= \|b_i - \bar{b}\|^2 \sum_{i=1}^n \left(\hat{a} \cdot \sum_{i=1}^n \hat{b} \hat{a} - \hat{b} \right)^2 \\ &= \|b_i - \bar{b}\|^2 \left(1 - \left(\sum_{i=1}^n \hat{b} \hat{a} \right)^2 \right). \end{aligned} \quad (9)$$

Let

$$\text{con} = \left(\sum_{i=1}^n \hat{b} \hat{a} \right)^2. \quad (10)$$

For each R block, $\|b_i - \bar{b}\|^2$ is already known, and the value con is considered in the rough optimum matching block decision when searching for the candidate blocks with least value of RMS.

For each R block in the matching process, if con is bigger than $\text{Threshold}_{\text{SCH}}$, the macroblock is classified into a spatially homogeneous region. And the further comparison is not necessary to determine the best error RMS. $\text{Threshold}_{\text{SCH}}$ is experimentally determined in advance and set to 0.1 in the experiment.

3.3. Fast Disparity Estimation Algorithm. Geometric constraints between neighboring frames in multiview video sequences can be used to eliminate space redundant. Using the joint motion estimation and disparity estimation predictable way, a minimum prediction error is chosen for the result. Parallax distribution constraint, which contains epipolar constraint, directional constraint, and spatial-time domain correlation, is used in this paper.

Epipolar constraint: the epipolar geometry is the intrinsic projective geometry between two views. Epipolar line can be found in the right image for a point of left image, on which the corresponding point can be searched. For parallel systems, only the search of x direction is needed just along the scan line.

Directional constraint: for the same scene, the left perspective projection image moves right relative to the right image. Therefore, searching only in one direction is necessary.

The spatial-time domain correlation: the disparity vector of the continuous variation disparity field has a strong correlation that exists in the same frame. For two adjacent frames, only a few pixels move and the positions of most pixels have not changed.

Therefore, corresponding disparity vector of the previous frame can be considered as the starting point for a small area search to find the actual disparity vector quickly. From the three constraints above, the best ME matching block of one block is mainly distributed in an area along the line. This characteristic is helpful to reduce the number of search candidates and further to decrease the ME time. Fast disparity estimation algorithm (FDEA) can greatly improve the coding efficiency, which makes full use of the correlation between left and right views, and can find the minimum matching error more quickly.

3.4. Temporal-Spatial Prediction Structure. Multiviewpoint video sequences are captured by several cameras at the same time and there is a high degree of correlation between interviews and intraviews. The prediction structure on spatial domain is different with temporal case. In temporal domain, it is known that data correlation is maximized when time separation is small. We use the next or previous frame as reference picture in temporal prediction of single video sequence. But for the multiviews, spatial correlation in interview domain may not be proportional with the distance between the cameras. For instance, if the two camera positions are far, it does not mean that this camera pair is less correlated than other pairs because other cameras may be rotated and the captured images are very different. Thus we should not only consider the position in interview prediction structure. The higher the interview similarity is, the greater its data redundancy is. So we proposed an algorithm for making the geometric prediction structure based on view center and view distance. When processing the multiview video signal, disparity prediction and motion prediction based on multi-references mode are combined to reduce the number of intraframe coded frames and improve the view compensation efficiency.

The proposed new prediction structure is shown in Figure 3 which contains 5 views and each view applies IPP prediction structure. The centre view channel is coded with homo-I-frame based on the discrete cosine transform (DCT) and other channels are coded based on disparity/motion compensation, in which the frames of P_0 , P_1 , P_3 , and P_4 are coded by our proposed disparity prediction named FDEA and P_2 is coded by the proposed fractal video coding.

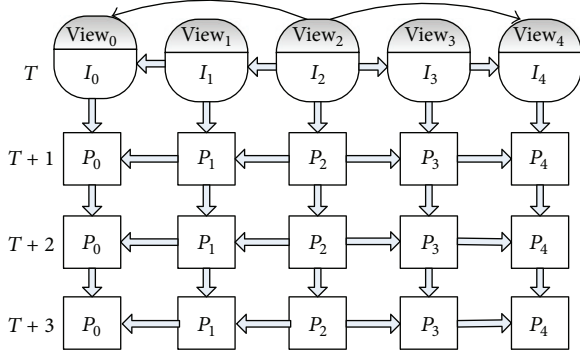


FIGURE 3: The proposed new prediction structure.

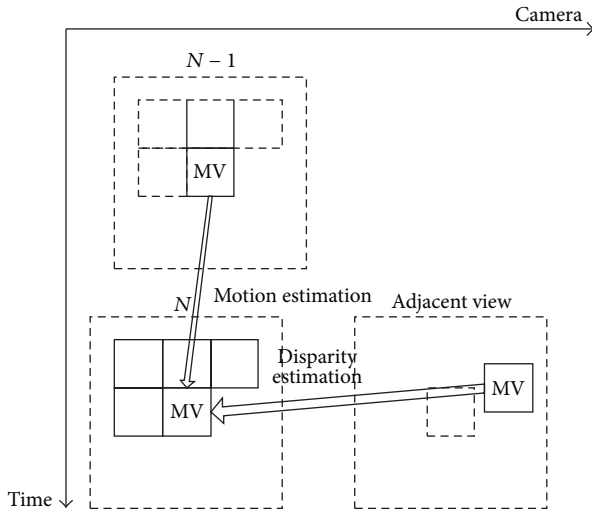


FIGURE 4: Disparity and motion search.

Figure 4 is the geometric schematic diagram of temporal-spatial prediction. Disparity and motion estimation are used for prediction to reduce data redundancy adequately.

4. Experimental Results

To verify the performance of the proposed method, Figures 5 and 6 illustrate the comparison of the average performances among the proposed method, JMVC8.5 and different methods in [18] with standard videos “Ballroom” (640×480 pixels,) and “Race” (640×480 pixels). First, segmentation is proposed in [18]. Each frame is divided into flat background region, complex background region, and foreground region by an adaptive threshold. Second, predictive modes are filtered further according to the texture direction of macroblocks, which can eliminate some unnecessary modes and improve the speed of mode searching [18]. Third, the prediction structure adjusts the selection of I-view and removes some interview predictions [18]. The maximum and minimum partition block sizes are 16×16 pixels and 4×4 pixels, respectively. The experiment is preceded in a PC (CPU: Inter Core2 E6300, 1.98 GHz, RAM: 2 G, DDR2). The test conditions are shown in Table 1.

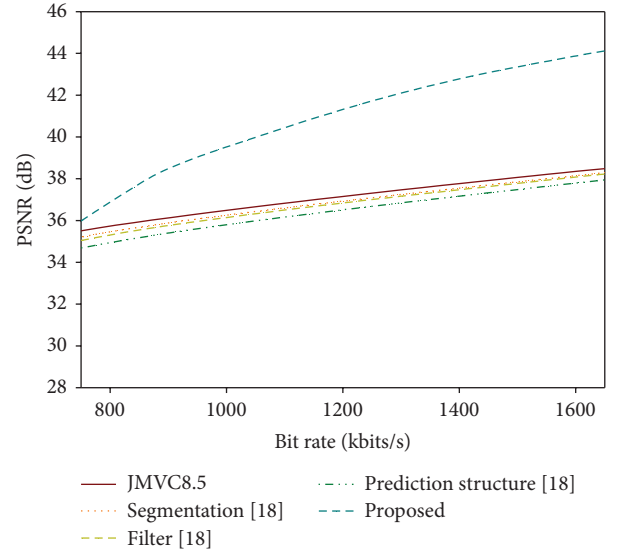


FIGURE 5: Comparisons of rate-distortion curves of “Ballroom.”

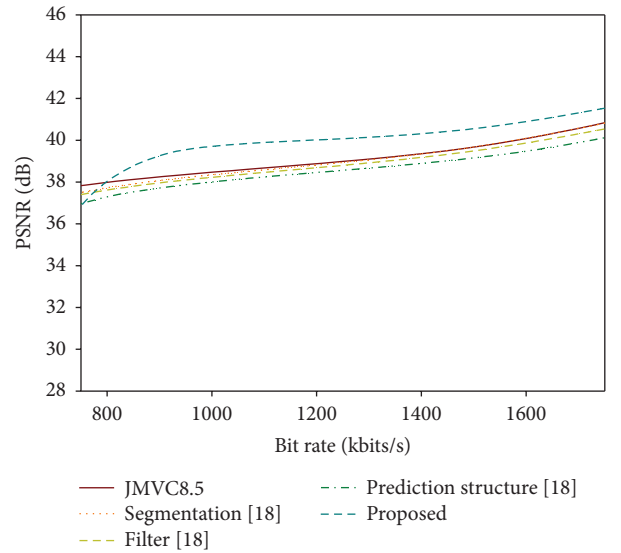


FIGURE 6: Comparisons of rate-distortion curves of “Race.”

TABLE 1: Coding parameters.

Number of frames	25
Bit rate/kbits/s	750–1750
Motion search mode	Fast Search
Motion search range	± 7 pixels with 1/4-pel accuracy
Prediction structure	Interview
Entropy coding method	CABAC

From Figures 5 and 6 and Table 2, one can see that the proposed fractal video sequences codec with multiviews reduces the encoding time and improves coding efficiency greatly, which leads to more real-time applications. With the QP decreasing, the performance of the proposed algorithm is superior to that of JMVC8.5 and the algorithms in [18] on

TABLE 2: Average compression time/s comparison of the proposed method with JMVC8.5 and the algorithms in [18].

Sequence	JMVC8.5	Segmentation [18]	Filter [18]	Prediction structure [18]
Ballroom	-87.07%	-0.43%	-0.85%	-0.85%
Race	-90.41%	-0.90%	-0.14%	-0.89%



FIGURE 7: The decoded image results of 3rd frame of “Ballroom.”

“Ballroom” and “Race.” The more data need to be compressed, the better performance will be got for the precise predictive estimation with fractional pel. And disparity and motion estimation reduce data redundancy fully. With the better decoding image quality, the proposed method uses lower bit rate and less coding time.

Figure 7 shows the original and decoded images of 3rd frame resulted from JMVC8.5 and the proposed method. The proposed fractal video sequences codec with multiviews reduces the encoding time and improves coding efficiency greatly, which leads to more real time applications.

To verify the performance of the small QP, it is compared with the state-of-the-art JMVC8.5 [19]. The configuration settings of the JMVC8.5 simulation environment are shown in Table 3. Public multiview sequences “Flamenco2” (640×480) and “Race” (640×480) are used for performance comparison.

Figure 8 illustrates that the coding efficiencies of the proposed algorithm improve a lot compared with JMVC8.5. The gain achieved is up to 33% bit rate saving for “flamenco2” and 35% bit rate saving for “race,” and the coding performance is about 0.49 dB higher for “flamenco2” and 0.38 dB higher for “race” than that of the JMVC8.5 coding, respectively. For comparison of the computational complexity, we use the total encoding time (TET). As shown in Figure 9, the TET of the proposed algorithm is reduced by 92%, on average. So, the proposed method is very effective.

In order to facilitate the comparison, the average performances computed with the Bjontegaard metric [20] are shown in Table 4. We note that the proposed method is consistently better than JMVC8.5, with 62.25% bit rate decrease and 0.37 dB PSNR increase.

The contents are organized as follows. The theory of fractal coding is summarized in Section 2. The proposed efficient fractal video sequences codec with multiviews

TABLE 3: Coding parameters.

Reference software	JMVC8.5
Number of frames	50
Frame rate	30
QP	26, 28, 30, 32
Motion search mode	Fast search
Motion search range	± 7 pixels with 1/4-pel accuracy
Entropy coding method	CAVLC

TABLE 4: Coding performance comparison of the proposed algorithm with JMVC8.5.

Sequence	BDBR (%)	BDPSNR (dB)
Race	-65.38	0.26
flamenco2	-59.13	0.48

is presented in Section 3. The experimental results are presented in Section 4. And finally the conclusions are outlined in Section 5.

5. Conclusion

In this paper, an efficient fractal video sequences codec with multiviews is presented to improve the encoding performance. We make full use of the characteristic of fractal video coding and the nature of video particularly. Compared to the JMVC8.5, better results are obtained with our proposed method.

We firstly improved the motion estimation and proposed the homogeneous region condition to get better performance of the based view. In addition, fast disparity estimation algorithm and temporal-spatial prediction structures are applied to further raise the compression efficiency.

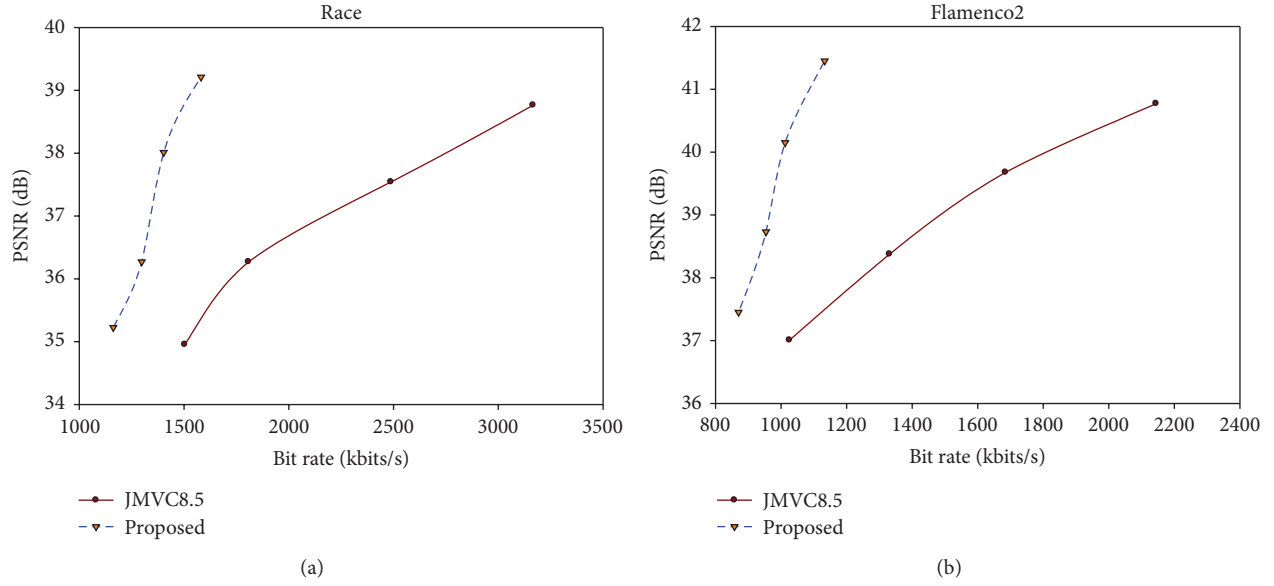


FIGURE 8: Rate distortion curve of (a) "Race" and (b) "flamenco2."

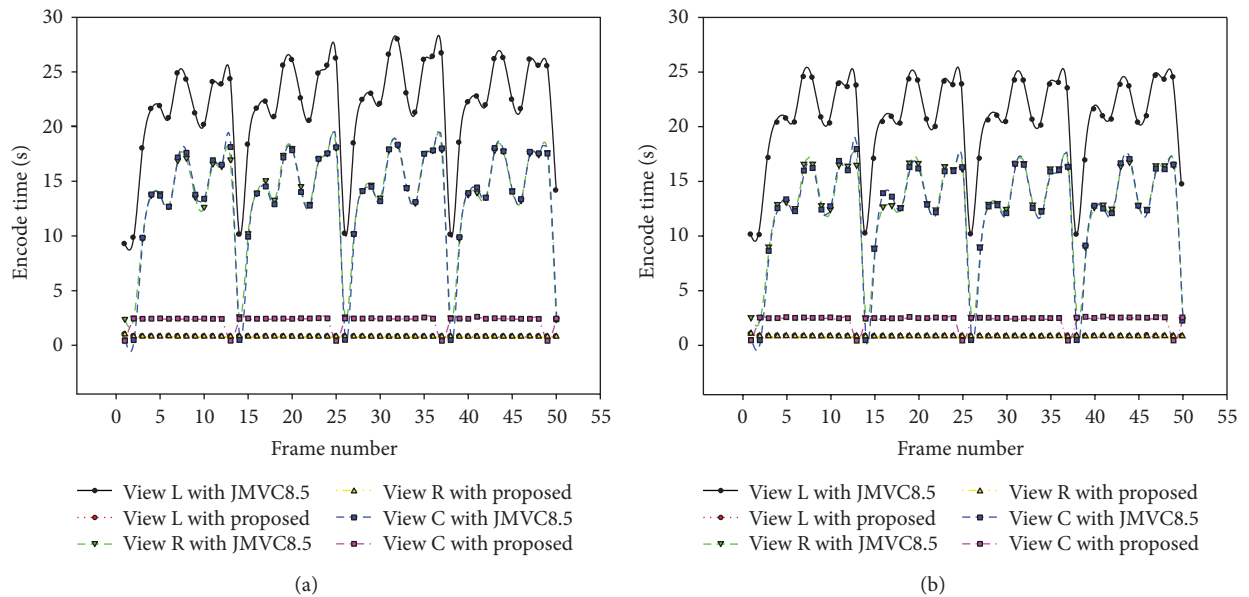


FIGURE 9: Comparison of encoding time with (a) "Race" and (b) "flamenco2."

The proposed algorithm spends less encoding time and achieves higher compression ratio with better decoding image quality. Experimental results show that the proposed algorithm is consistently better than JMVC8.5, with 62.25% bit rate decrease and 0.37 dB PSNR increase with the Bjontegaard metric. This method makes the best of various features of fractal coding and video motion and has done a great improvement and got considerably good results. Also, it has built a good foundation for the further research of multiview fractal video coding and other related coding methods.

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