Fast ISP Coding Mode Optimization Algorithm Based on CU Texture Complexity for VVC

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Fast ISP Coding Mode Optimization Algorithm Based on CU Texture Complexity for VVC

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Abstract

In lately published video coding standard Versatile Video Coding (VVC/ H.266), the intra sub-partitions (ISP) coding mode is proposed. It is efficient for frames with rich texture, but less efficient for frames that are very flat or constant. In this paper, by comparing and analyzing the rate distortion cost (RD-cost) of coding unit (CU) with different texture features for using and not using ISP(No-ISP) coding mode, it is found that CUs with simple texture can get better coding performance in No-ISP coding mode. Based on this observations, a fast ISP coding mode optimization algorithm based on CU texture complexity is proposed, which aims to determine whether CU needs to use ISP coding mode in advance by calculating CU texture complexity, so as to reduce the computation complexity of ISP. The experimental results show that under All Intra (AI) configuration, the coding time can be reduced by 7%, while the BD-rate only increase by 0.09%.

Key words: ISP, VVC, H.266, Intra Prediction, Coding Unit (CU), Texture Complexity.

1. INTRODUCTION

Intra prediction has always been the main research field in video coding, which can take advantage of the spatial correlation of image to eliminate the spatial information redundancy and realize the compression of video data. In VVC, many new intra prediction techniques are proposed, including mode dependent intra smoothing (MDIS) , cross-component linear model(CCLM), position dependent intra prediction combination(PDPC), Multiple reference line (MRL) intra prediction, intra sub-partitions (ISP), matrix weighted intra prediction (MIP) and so on [1]. Intra prediction technology plays an important role in video coding technology. The improvement of intra prediction technology will have a great impact on the performance of video coding. Therefore, it is necessary to study the intra prediction technique to realize more efficient video coding.

In the process of intra prediction, the reference samples that can be used to create intra prediction signals are located only on the left and above of the current block. As the correlation between samples in the natural image will decrease with the increase of distance, the predicted quality of samples near the bottom-right corner of the block will be worse than those close to the top-left boundary of block [2]. In order to solve this problem, VVC proposes an intra sub-partitions coding mode, which divides the luminance intra prediction blocks horizontally or vertically into 4 or 2 equal size sub-partitions, which contain at least 16 samples. The minimum sub-partition size and the maximum block size that can use ISP coding mode are 4×8 (or 8×4) and 64×64 respectively.. If the size of block is greater than 4×8 (or 8×4), the corresponding block is divided into 4 sub-partitions. If the size of block is equal to 4×8 (or 8×4), the corresponding block is divided into 2 sub-partitions [3]. Given an input W×H block, the size of the sub-partition will be W×(H/K) for horizontal split and (W/K)×H for vertical split, where K is the number of sub-partitions, W and H represent the width and height of the block respectively. As shown in Fig, a 32×16 block can be divided into four 8×16 or four 32×4 sub-partitions, and a 8×4 block can only be divided into two 4×4 sub-partitions.

Fig. 1. Examples of division for blocks.

The processing method of each sub-partitions is similar to intra prediction block in VVC. Firstly, the intra prediction signal and residual signal are generated, and then the residual signal is transformed, quantized and entropy coding and sent to the decoder. After entropy decoding, inverse quantization, and inverse transformation, the reconstructed samples can be obtained by the residual signal plus the prediction signal. After a sub-partition has been processed, its reconstructed samples can be used to calculate the prediction signal of the next sub-partition, which will repeat the same steps until all sub-partitions have been coded [4]. As shown in Fig. 2, the block has been split horizontally into four sub-partitions. The first one was predicted using the neighboring samples of the CU. Now its reconstructed samples can be used to predict the next sub-partition. The procedure continues until the four sub-partitions have been processed. The advantage of the ISP coding mode is that each sub-partitions can be predicted using neighboring samples located at the shortest possible distance. ISP coding mode is efficient for video content with rich texture, but less efficient for video content that is very flat or constant. Therefore, this paper proposes a Fast ISP coding mode optimization algorithm based on CU texture complexity.

The remainder of this paper is organized as follows. In section 2 the relevant work of ISP and the video coding algorithm based on texture feature are introduced. In section 3，the existing problems of ISP coding mode are analyzed and an ISP coding optimization algorithm based on texture complexity is proposed. Experiment results are shown in section 4. Finally, in section 5 conclusions are drawn.

Fig. 2. An example of ISP coding mode.

2. RELATED WORKS

ISP coding mode is developed from the line-based Intra Prediction（LIP）coding mode. LIP coding mode was presented at the Kth meeting of JVET [5]. The main idea of LIP is to divide the luma intra prediction block into one-dimensional line. Each block needs to be partitioned using the LIP coding mode. In the AI configuration, the BD-rate can be reduced by 2.34% on average, while the encoder running time is changed to 293%. A 4×4 block can be divided into 4(4×1) lines, which can cause throughput problems. All blocks are 1×4(or 4×1), which can result in a worse bitstream. If the number of resulting lines for a block is large (for example, 64 rows), the encoder needs to do a lot of operation and memory access while checking the necessary rate-distortion (RD) tests. Column sub-partition (1×N) can be more difficult to implement because samples are allocated using raster scans, which makes memory access expensive. To solve the above problems, it was proposed at the Lth meeting of JVET that each block should be set into a certain number of partitions (each partition has at least 16 samples) and the final partition width should be at least 4 samples [6]. In AI configuration, the BD-rate can be reduced by 1.01% on average, while the encoder running time becomes 148%, which successfully reduces the complexity of encoder and is friendly to hardware implementation. After this meeting, LIP was officially renamed as ISP. Then, at the Mth meeting of JVET [7], the ISP algorithm was optimized to achieve a better balance between coding gain and encoder running time. The experimental results show that in the AI configuration, the BD-rate can be reduced by 0.59% on average. At the same time, the coding running time becomes 112%. Through the analysis of the experimental results of these proposals, it is found that ISP coding mode can significantly improve the BD-rate for videos with rich texture, but it is not efficient for videos with simple texture. Therefore, this paper proposes an Fast ISP coding mode optimization algorithm based on CU complexity to accelerate ISP coding mode.

According to the existing research results, many scholars use CU texture characteristics to optimize video coding. Shen et al. [8] proposed an effective CU size decision algorithm, which utilizes the texture characteristics and coding information of adjacent CUs. Experimental results show that the algorithm can significantly reduce the intra coding time and achieve consistent acceleration of all kinds of video sequences. In order to solve the problem of high computational complexity of QTBT, Peng et al. [9] proposed a multiple classifier-based fast QTBT partitioning algorithm for intra coding. The feature acquisition of classifier is mainly based on texture complexity and direction complexity. The algorithm can reduce the intra coding time by 64.54%, and the reduction of RD performance is negligible. Liu et al. [10] proposed an adaptive fast CU size decision algorithm based on CU complexity classification for HEVC intra prediction by using machine learning technology. Some image features are selected for training classifiers in this paper. Hou et al. [11] proposed a method based on texture complexity for CU partitioning, which uses the complexity of adjacent CU to judge the current CU texture features. On this basis, useless CU size an be filtered out to realize the encoding time reduction. A fast mode decision algorithm based on texture division and direction in HEVC frame coding was proposed in [12], which includes two sub-algorithms: CTU depth range prediction (CDRP) and internal prediction mode selection (IPMS). Under the AI configuration, the coding time of the proposed overall algorithm is reduced by 60% on average. In [13], the problem of the CU size decision and mode selection in the HEVC intra-encoder is solved by measuring the texture complexity and directional energy distribution of each CU, which accelerate the process of RDO. An effective algorithm based on homogeneity for reducing the complexity of HEVC intra coding was proposed in [14]. The scheme aims to terminate the CU partitioning of homogeneous regions in video frames in advance, or to skip the CU partitioning of complex texture regions. The decision result of split/non-split is based on a homogenous classification algorithm that avoids testing at all depths to determine the optimal CU size. In [15] a new fast intra frame coding algorithm is presented. Based on the analysis of the mode information obtained in the previous frame, a new feature is proposed to measure the complexity of video content. Then, the model is built according to the relationship between the feature and the depth range of the CU. According to the model, unnecessary operations of CU partitioning are skipped. In [16], a complexity reduction algorithm based on hierarchical classification for HEVC inter coding is proposed. At the beginning of the algorithm, the intra features and inter features describing texture and context properties of CUs are obtained from the training set, and then the classification model is generated by selecting features and designing classification criteria.

In general, the methods mentioned above are based on CU characteristics to optimize intra prediction or inter prediction, which can achieve significant time saving with negligible coding performance degradation. However, no one has yet used texture characteristics of CUs to optimize the ISP coding mode proposed in H. 266. To the best of our knowledge, the proposed solution in this paper is the first to be applied to optimize the ISP coding mode.

3. PROPOSED ALGORITHM

The ISP coding mode is not efficient for very flat or constant video content. In order to make the ISP coding mode more universal, a Fast ISP coding mode optimization scheme based on CU texture complexity is proposed. The proposed scheme can determine whether CU needs to use ISP coding mode based on CU texture complexity in advance, so as to achieve faster coding.

3.1. Observation and analysis

The key to improve the encoder performance is to select the best coding parameters. The search for the best coding parameter is traditionally performed in the rate distortion (RD) sense, which can be balanced between the number of bits used to encode an image block and the distortion generated by using that number of bits. The optimal R-D solution for blocks is to minimize the RD cost function. In the rate distortion optimization process of intra prediction, rate distortion cost (RD-cost) can measure the prediction performance very well. By comparing the RD-cost of different partition modes, the final partition mode will be determined. RD-Cost function J is calculated as follow [17]:

$$J = D + \lambda \times R \tag{1}$$

Where D is the distortion, R is the number of bits required to transmit the residual coefficient and signal parameter information, λ is the Lagrange multiplier factor.

In this paper, the RD-cost of CU in ISP coding mode and No-ISP coding mode was calculated respectively. The statistical sequences are BasketballDrill, RaceHorses, BasketballPass, BlowingBubbles, FourPeople and Kimono. The RD-cost of CU in ISP coding mode is denoted as J_{ISP}, and the RD-cost of CU in No-ISP coding mode is denoted as $J_{No\text{-}ISP}$. As shown in the Fig. 3, the percentage of CU that J_{ISP} is greater than $J_{No\text{-}ISP}$ is nearly 40%, which indicates that not all CUs are suitable for ISP coding mode. It is found in this paper that the CUs whose RD-cost in ISP coding mode is higher than that of in No-ISP coding mode have similar characteristics, which is that most of them have smooth texture. Therefore, for some CUs with simple texture, better prediction performance can be obtained in No-ISP coding mode. Fig.4 shows the first frame of FourPeople sequence. It can be seen that block A and block B have rich texture, while the texture of block C and D are very smooth. The comparison of RD-cost in ISP and No-ISP coding mode is shown in the Fig. 5. It is obvious that the RD-cost in ISP coding mode for block A and block B is significantly lower than that of in No-ISP coding mode. But the RD-cost in ISP coding mode for block C and block D is slightly higher than that of in No-ISP coding mode.

In summary, for some CUs with simple texture, better prediction results will be obtained in No-ISP coding mode. Therefore, CUs with simple textures can skip the ISP encoding mode in advance. In the next section, a method to measure the texture complexity of CU is presented to determine whether CU needs to use ISP coding mode.

Fig. 3. CU distribution.

Fig. 4. The first frame of FourPeople sequence.

Fig. 5. The comparison of RD-cost for ISP and No-ISP coding mode.

3.2. Method for measuring CU texture complexity

In order to classify each CU according to texture characteristics, a typical deviation value is used as a reference. MAD (mean absolute deviation) is the most representative deviation value, which is the average of the absolute deviation of a set of data, so it can be used as an indicator to measure the texture complexity of CU. MAD is calculated as follows:

$$MAD = \frac{1}{\text{height} \times \text{width}} \sum_{j=1}^{height} \sum_{i=1}^{width} | P(x, y) - mean | \tag{2}$$

Where *width* and *height* are respectively the width and height of CU, and *P(i,j)* is the luminance pixel value at *(i,j)*.

Fig. 6. Sampling interval of CU.

To further reduce the computational complexity, MAD is further simplified in this paper. Instead of calculating all pixel values, the interval sampling method is used to obtain pixel values. The sampling method is shown in the Fig. 6. Odd points are sampled from odd rows of pixel points, and even points are sampled from even rows of pixel points. This sampling method can not only reduce the computation by half, but also accurately measure the texture complexity. The calculation formula of texture complexity (*TC*) is shown in Formula (3).

$$TC = \frac{2}{height * width} \left(\sum_{j=2n-1}^{height} \sum_{i=2n-1}^{width} \left| P(i,j) - mean \right| + \sum_{j=2n}^{height} \sum_{i=2n}^{width} \left| P(i,j) - mean \right| \right) \quad \text{n=1,2......} \tag{3}$$

Where *width* and *height* are respectively the width and height of CU. *P(i,j)* is the luminance pixel value at *(i,j)*. And *mean* is the average of all sampled pixels.

According to the *TC*, CUs will be classified into two categories: simple texture, complex texture. When *TC* is less than ε, the current CU is classified as simple texture. When *TC* is greater than ε, the CU is classified as complex texture. ε is the threshold of CU texture complexity. Threshold setting plays a decisive role in this article. Better coding efficiency can be obtained by selecting the appropriate threshold. According to section 3.1, For some CUs with complex texture,whose RD-cost in ISP coding mode is usually lower than the RD-cost in No-ISP coding mode, are not suitable for using ISPcoding mode. For some CUs with complex texture, whose RD-cost in ISP coding mode is usually higher than that of in No-ISP coding mode,are suitable for using ISPcoding mode. Therefore, this paper makes a statistical analysis for the CU luminance samples in the video sequence, and *TC* is selected as the classification indicator of CU texture complexity. The *TC* value of CU in the statistical sequence is divided into two groups. The first group is the CUs that are not suitable for using ISPcoding mode.. The second group is the CUs that are suitable for using ISPcoding mode.The threshold value of CU texture complexity is determined by the probability density of *TC*. The probability density of *TC* is shown in Fig. 7. As can be seen from the figure, when the *TC* value is less than 20, the probability density of *TC* in the first group is always greater than that of in the second group. When *TC* is greater than 20, the probability density of *TC* in the first group is always smaller than that of in the second group. Therefore, in this paper, ε is set to 20. When the *TC* value of CU is less than 20, ISP coding mode can be skipped in advance.

Fig. 7. Probability density of TC.

In this paper, the texture complexity distribution of CUs whose RD-cost in ISP coding mode is greater than that of in No-ISP coding mode is calculated. As shown in Fig. 8, the proportion of CU with simple texture is 80%. This further proves that the proposed algorithm is reasonable.

Fig. 8. CU texture complexity distribution.

3.3. Flow of the proposed algorithm

According to the analysis in section 3.1, we have drawn the conclusion that the performance of ISP coding mode is closely related to CU texture complexity and a CU with simple texture can obtain better coding performance in No-ISP coding mode. Therefore, in section 3.2, this paper proposes a method to measure the CU complexity texture. By calculating the TC value of CUs, the decision result of CUs is divided into two cases: simple texture and complex texture. When the current CU has simple texture, the ISP coding mode will not be tested. If the current CU has complex texture, it will continue to use the ISP coding mode.

In this paper, a decision is added on the basis of the original algorithm. Before testing ISP, calculate *TC* value of CU. If *TC*<20, then the ISP flag is set to 0, CU will not test the ISP coding mode. If *TC*>20, continue to use the original ISP coding mode.

4. EXPERIMENTAL RESULTS AND DISCUSSION

In order to verify the performance of the proposed algorithm, the algorithm is implemented on the VVC reference software (VTM8.0). The proposed algorithm is to accelerate intra coding, so All Intra (AI) configuration is adopted and QPs are 22, 27, 32 and 37 respectively. In our work, standard test sequences of HEVC are selected, which involve different scenes and different resolutions. Bjøntegaard Delta rate (BD-rate) with piece-wise cubic interpolation method is used to assess the coding performance of the proposed algorithm. Time saving (TS) is used to measure the reduction of computational complexity and is defined as:

$$TS = \frac{1}{4} \sum_{QP_i \in \{22,27,32,37\}} \frac{Time_{VTM}(QP_i) - Time_{Pro}(QP_i)}{Time_{VTM}(QP_i)} \qquad (4)$$

The performance comparison between the VTM8.0 and the proposed algorithm are shown in Table 1. It presents the average BD-rate of six classes of video sequences. In the AI configuration, the proposed algorithm can achieve about 7% coding time saving with negligible loss of coding efficiency. It can be also observed that a consistent gain is obtained over all sequences. The largest gain comes from the sequence “BasketballDrill”, with up to 11% time saving. “BasketballDrill” contains a large number of flat or constant blocks that are considered as simple texture. Therefore, “BasketballDrill” can be compressed more efficiently by the proposed algorithm in this paper. Sequences with similar characteristics such as “BasketballDrive”, “Johnny” all show remarkable time saving. The proposed method does not perform well for sequences containing rich texture, such as “PartyScene”, “BQTerrace”. One of the main optimization goals of VVC is to improve the coding efficiency of ultra-high definition/high definition (UHD/HD) videos. It is noted that the proposed method generally performs better on UHD/HD sequences. This is because that the fast ISP coding mode optimization algorithm based on texture complexity has better performance on simple texture blocks and simple texture blocks often take a larger portion in UHD/HD sequences. It is a prominent advantage to favor high resolution sequences in future applications. Fig.9 illustrates the rate-distortion (RD) curves comparison results of our proposed algorithm compared with VTM8.0 for the BQMall (832× 480), BlowingBubbles (832×480), FourPeople (1280×720) and BasketballDrive (1920 ×1080) sequences respectively, which includes the best case (BlowingBubbles) and the worst case (BasketballDrill) in terms with the RD performance. The results show that the proposed algorithm is superior to VTM8.0 for most sequences, either in low bitrate or in high bitrate configuration. Even in the worst case, the proposed algorithm and the original VTM reference encoder can obtain very similar image quality under different QPs

Table 1. Performance comparison between the original VTM8.0 and the proposed algorithms

Class	***Sequence***	***BD-rate***			***TS***
		Y	***U***	***V***	
Class A	*Traffic*	0.12%	-0.24%	0.04%	7%
	PeopleOnStreet	0.04%	0.03%	-0.11%	7%
	Nebuta	-0.01%	-0.04%	-0.03%	6%
	SteamLocomotive	0.04%	-0.25%	-0.23%	6%
Class B	*Kimono*	0.05%	-0.10%	-0.07%	6%
	ParkScene	0.06%	-0.05%	0.35%	6%
	Cactus	0.14%	0.07%	-0.08%	6%
	BasketballDrive	0.24%	-0.41%	1.10%	9%
	BQTerrace	0.01%	-0.33%	-0.43%	4%
Class C	*BasketballDrill*	0.30%	0.45%	0.47%	11%
	BQMall	0.10%	-0.24%	0.37%	6%
	PartyScene	0.01%	0.46%	-0.33%	4%
	RaceHorsesC	-0.07%	-0.02%	0.09%	6%
Class D	*BasketballPass*	0.04%	1.47%	0.65%	8%
	BQSquare	0.18%	0.27%	0.61%	8%
	BlowingBubbles	0.00%	0.43%	0.65%	6%
	RaceHorses	0.12%	-0.12%	-0.53%	5%
Class E	*FourPeople*	0.17%	-0.51%	-0.71%	7%
	Johnny	0.22%	-0.33%	-0.26%	8%
	KristenAndSara	0.10%	0.22%	-0.40%	8%
	Average	0.09%	0.04%	0.06%	7%

Fig. 9. Rate-distortion (R-D) curves of several typical video sequences under different QPs (22, 27,

32, 37) between the original VTM8.0 and the proposed algorithm: (a) BQMall; (b) BlowingBubbles; (c) FourPeople; (d) BasketballDrive.

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5. CONCLUSION

The fast ISP coding mode optimization algorithm based on CU texture complexity is proposed in this paper to reduce the computation complexity of ISP. Firstly, it is concluded that the CUs with simple texture are not suitable for ISP coding mode by comparing the RD-cost of CU with different texture complexity in ISP coding mode and No-ISP coding mode. Then a method to measure the CU texture complexity is proposed. CU can be divided into simple texture and complex texture. Finally, the ISP coding mode will no longer be used for CUs with simple texture. The proposed method is tested on VVC reference software VTM8.0, the experimental results show that proposed algorithm can achieve about 7% coding time saving with negligible loss of coding efficiency.

Declarations

Abbreviations
VVC: Versatile Video Coding; HEVC: High Efficiency Video Coding; CU: Coding unit; VTM: VVC test model; RD-cost: rate distortion cost; No-ISP: not using ISP coding mode; AI: All Intra; MDIS: mode dependent intra smoothing; CCLM: cross-component linear model; PDPC: position dependent intra prediction combination; MRL: Multiple reference line intra prediction; MIP: matrix weighted intra prediction; LIP: line-based Intra Prediction; MAD: mean absolute deviation; TC:texture complexity ; TS: Time saving;

Availability of data and materials
The conclusion and comparison data of this article are included within the article.

Competing interests
The authors declare that they have no competing interests.

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Authors' contributions
ZL proposed the framework of this work, and MD carried out the whole experiments and drafted the manuscript. MZ, HZ and RW offered useful suggestions and helped to modify the manuscript. All authors read and approved the final manuscript.

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Figure legends

Fig. 1. Examples of division for blocks.
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Figures

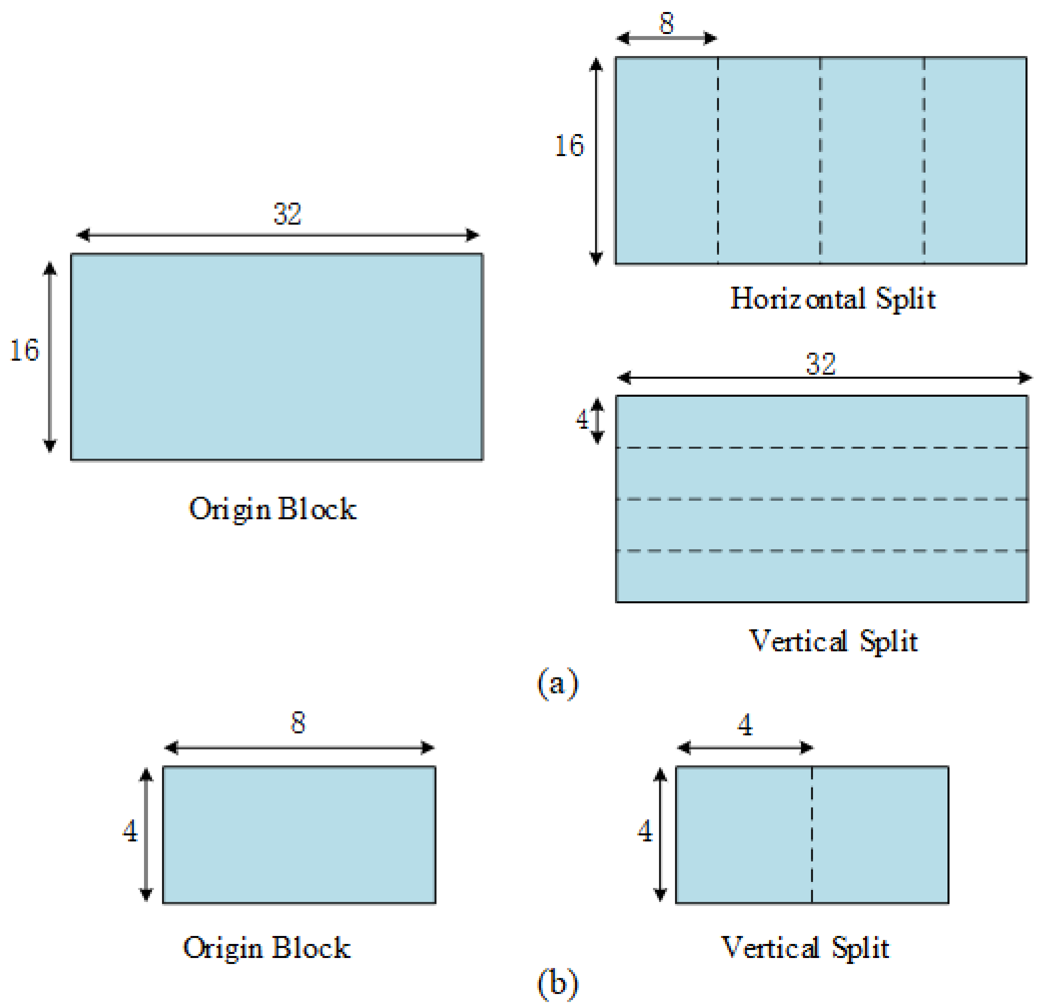

Figure 1

Examples of division for blocks.

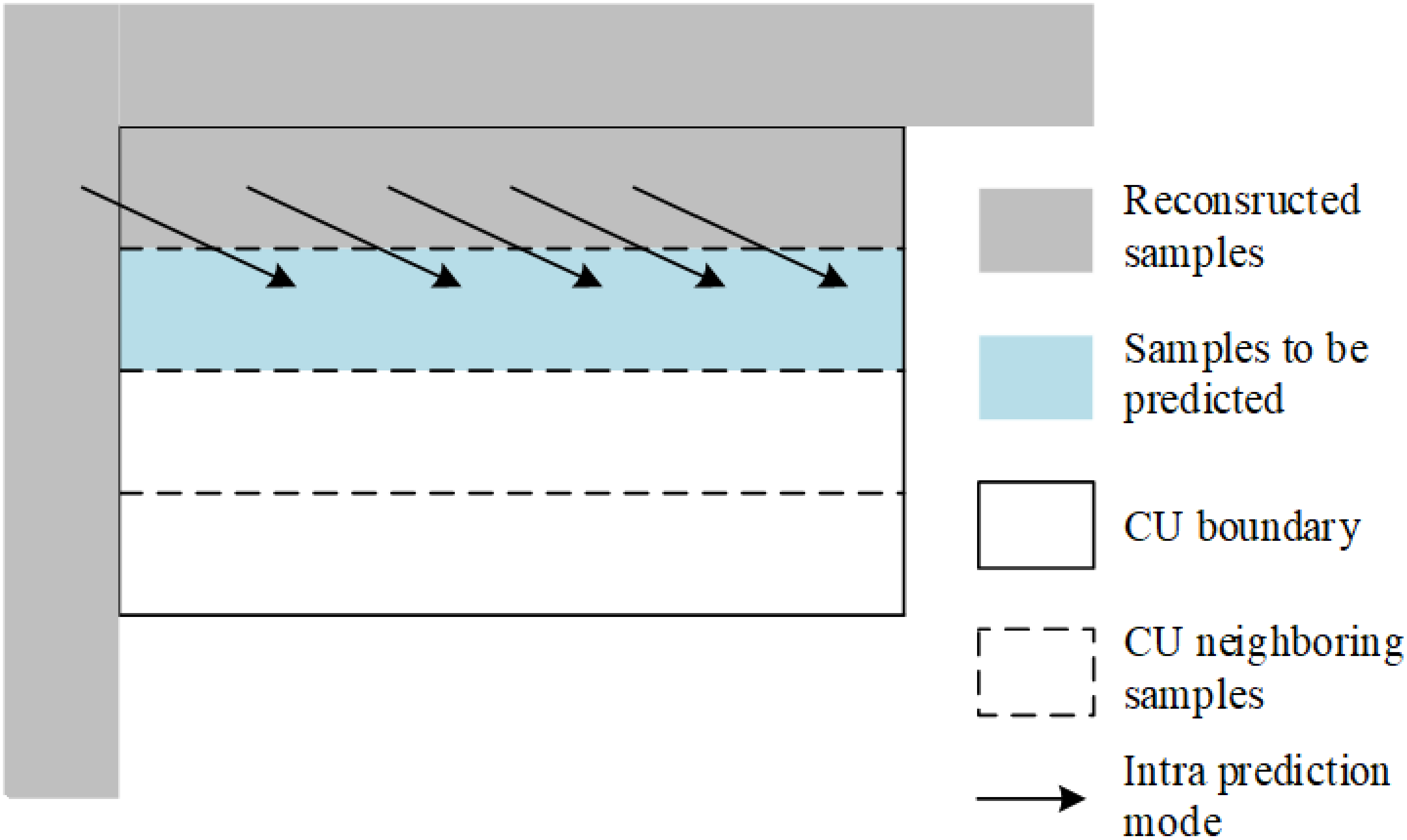

Figure 2

An example of ISP coding mode.

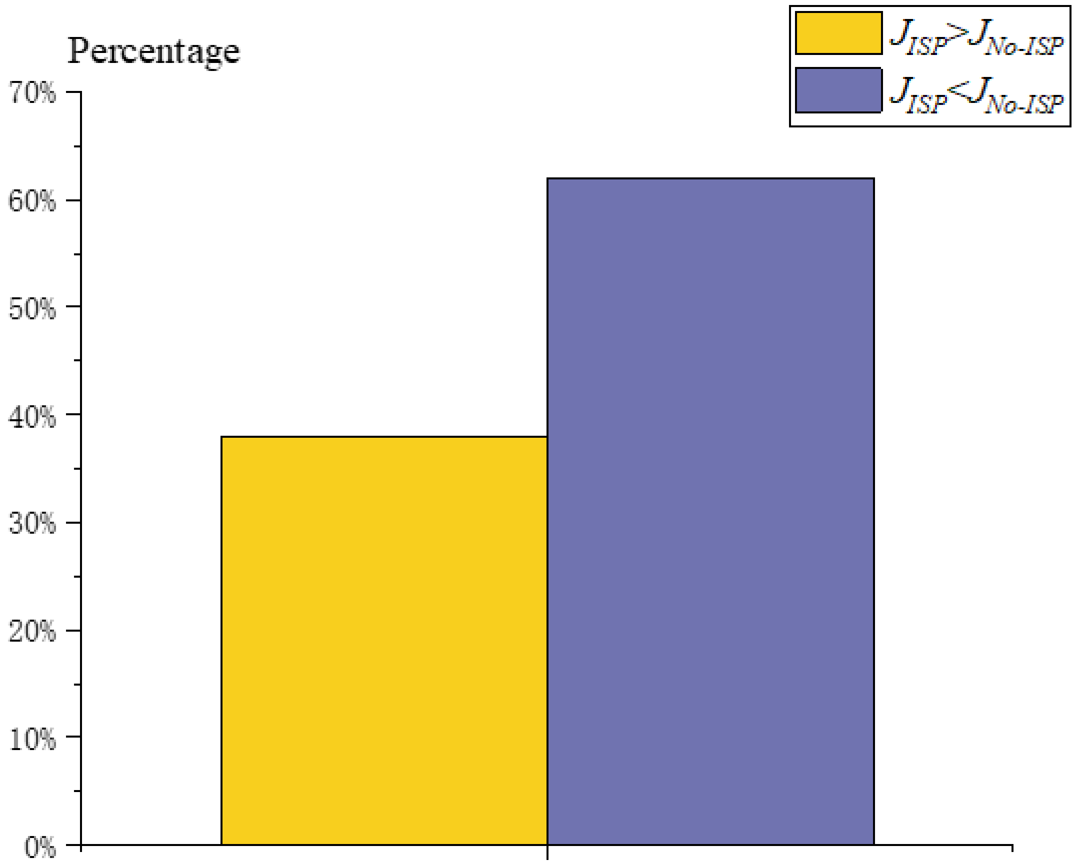

Figure 3

CU distribution.

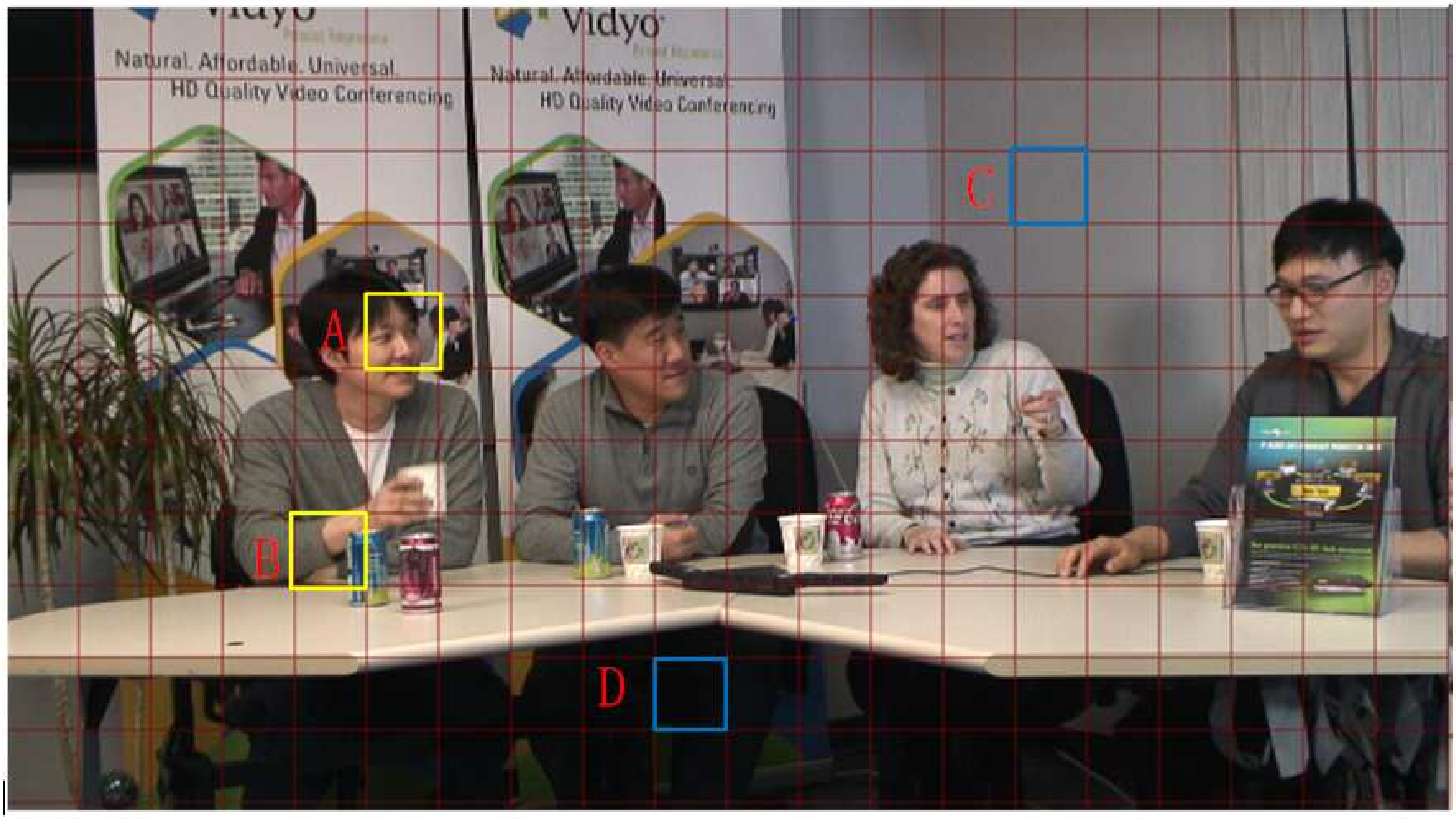

Figure 4

The first frame of FourPeople sequence

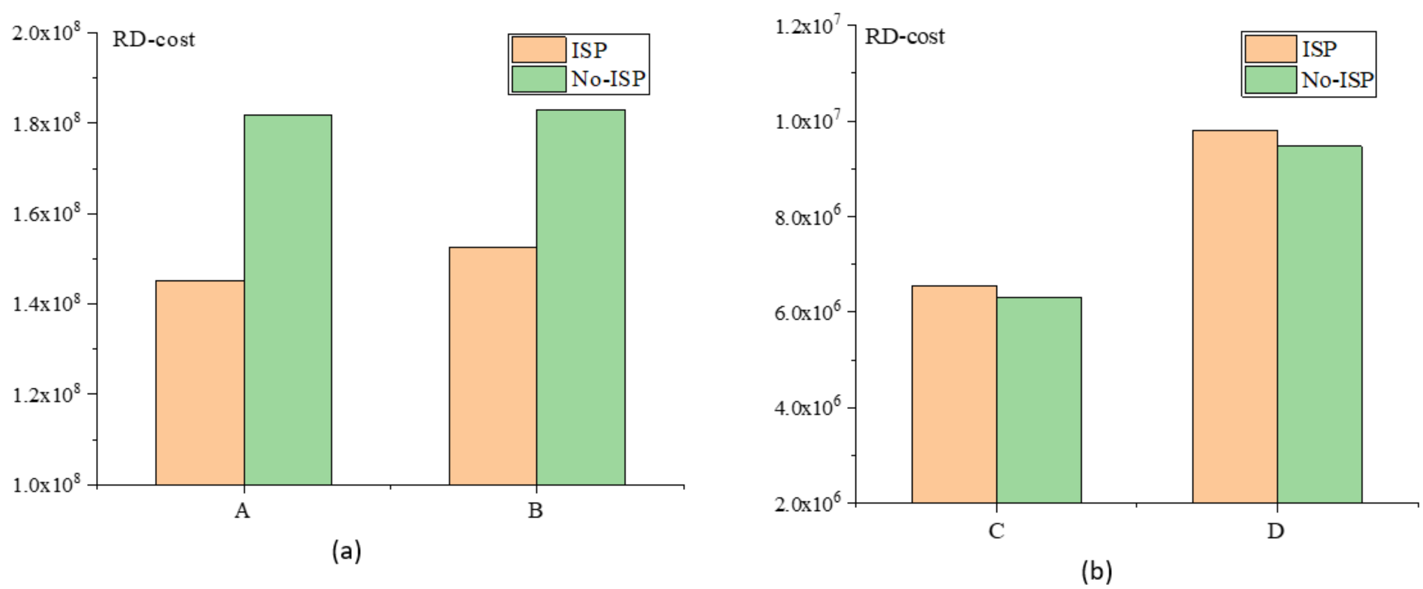

Figure 5

The comparison of RD-cost for ISP and No-ISP coding mode.

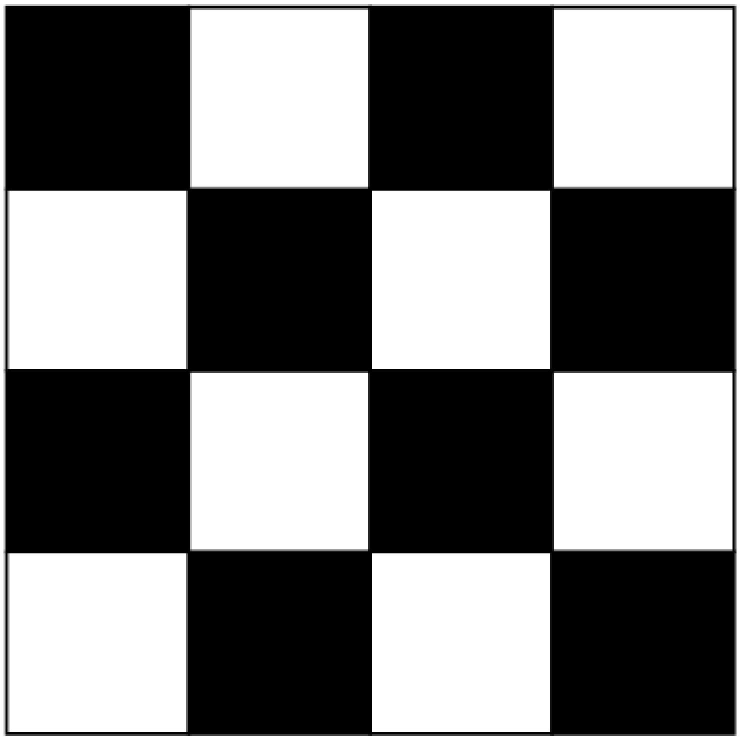

Figure 6

Sampling interval of CU

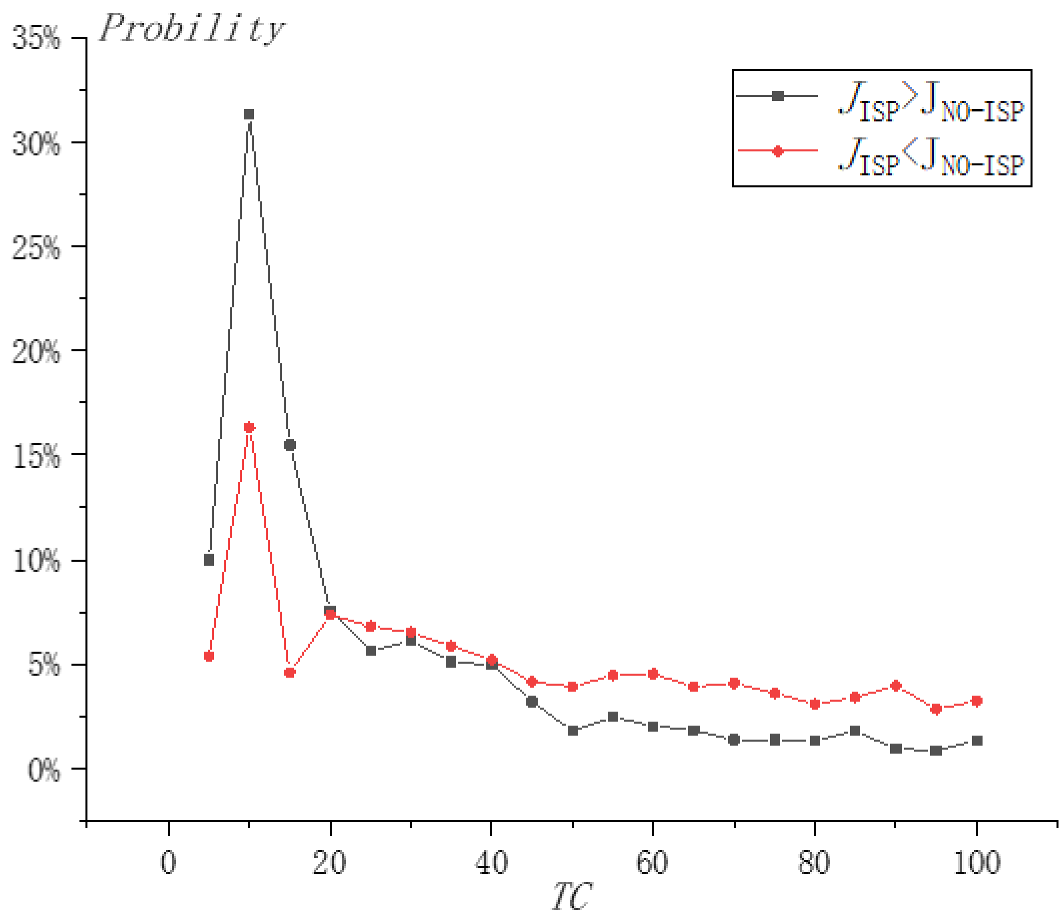

Figure 7

Probability density of TC

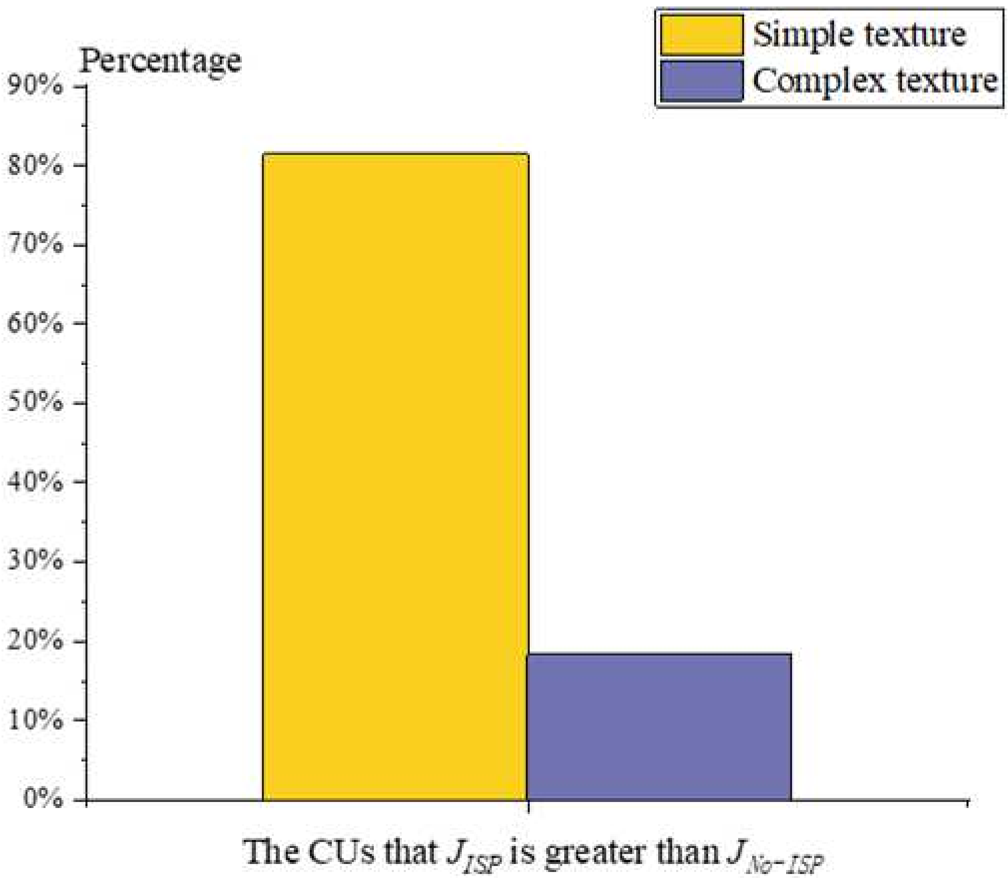

Figure 8

CU texture complexity distribution

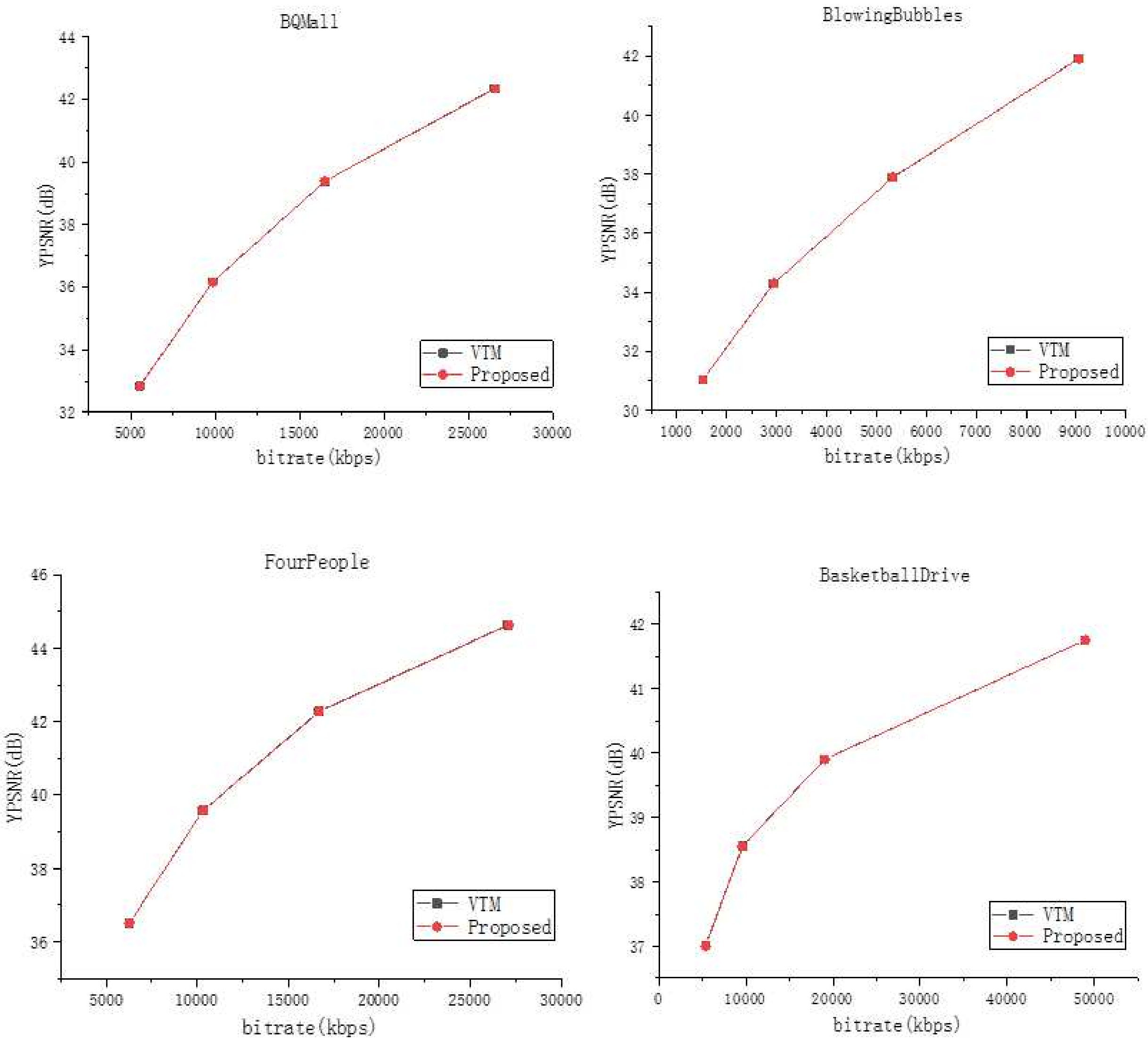

Figure 9

Rate-distortion (R-D) curves of several typical video sequences under different QPs (22, 27, 32, 37) between the original VTM8.0 and the proposed algorithm: (a) BQMall; (b) BlowingBubbles; (c) FourPeople; (d) BasketballDrive