2019 Data Compression Conference (DCC)

The Bit Allocation Method Based on Inter-View Dependency for Multi-View Texture Video Coding

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Abstract: Multi-view texture video coding is very important, we propose a bit allocation method based on view layer and a bitrate decision method for P-frame of the dependent view (DV). First of all, considering that the distortion in the base view (BV) is directly transmitted to the DV by inter-view skip mode, the RD model of the DV is improved based on the inter view dependency. In this paper, a precise power model is derived based on our joint RD model to represent the target bitrates relationship between the BV and the DV. Then, since the P frame in the DV (P-DV) is mainly predicted from the corresponding I frame in the BV (I-BV) by inter-view prediction, the constant proportional relationship between the P-DV and the I-BV is discovered in this paper. Based on this discovery, a novel linear model is built to assign the target bitrates of the P-DV. Extensive experimental results exhibit that the proposed scheme provides a better RD performance than the state-of-the-art algorithms.

1. Introduction

In recent years, it is great challenge to transmit or store the large amount of 3D videos. 3D-HEVC has been developed based on the HEVC standard [1] to further improve the 3D video compress efficiency [2]. In practical video coding systems, the rate control (RC) scheme makes the encoder bit stream meet the requirements of channel bandwidth or storage space [3]. A typical RC process is composed of bit allocation and bitrate control. The bit allocation solves the limited bit resources issue at different coding levels, such as views, group of pictures (GOPs), frames and coding tree units (CTUs), which aims at getting the optimal rate-distortion (RD) performance. The purpose of the bitrate control is to achieve the assigned target bitrate as precisely as possible. To establish a more accurate RD model, a $R-\lambda$ model based rate control algorithm was proposed and adopted by HEVC [4] [5] [6]. Currently, the RC algorithm designed for single-view HEVC is used in 3D-HEVC, which achieves a good effect on the bit allocation within single view. However, for the view layer target bit allocation, only the empirically fixed ratio is considered [7]. Different allocation methods have different reconstructed qualities. How to determine the ratio between the views is still difficult. Hence, a reasonable view layer RC method can improve RD performance greatly for MVC.

Lots of researchers have focused on developing good inter-view bit allocation methods to improve the coding efficiency. Lim et al. [7] proposed the empirically optimal bit ratio 8:2 for 2 view case and 66:17:17 for 3 view case. A predefined fixed bit ratio

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DOI 10.1109/DCC.2019.00051

was used for inter-view bit allocation in [8] and [9]. The fixed bitrate ratio between left and right views was obtained by statistical analysis after pre-encoding in each view. Yuan et al. [10] proposed a frame level inter-view bit allocation method based on inter-view correlation to improve the coding efficiency for MV-HEVC. Firstly, a simplified Cauchy density based RD model was proposed to represent the RD characteristic for base view. Secondly, a RD model for dependent view was derived by considering the distortion propagation between base view and dependent view. Finally, the inter-view bit allocation problem was formulated as a convex optimization problem. Tao et al. [11] proposed a joint bit allocation and an inter-view dependency based RC algorithm for 3D-HEVC. Based on the proposed inter-view dependency distortion model, the objective optimization function was derived to obtain the ratio of the optimal target bitrates of the DV to the BV. An efficient bit allocation algorithm based on a novel view synthesis distortion model was proposed for MVD sequences in [12]. For inter-view bit allocation, the average ratio between the consumed bitrates of arbitrary view and the total bitrates is measured by pre-encoding the training sequences for four quantization parameters.

A novel bit allocation scheme based on inter view dependency and a P-frame target bitrate determination method of the DV are proposed in this paper. Two contributions of this paper are listed as follows:

(1) Based on our proposed multi-view RD model, the target bitrates relationship between the BV and the DV could be fitted accurately by the power model.

(2) The constant proportional relationship between the P-DV and the I-BV is discovered. Based on this discovery, a linear function model is built between the ratio of the consumed average bitrates of the P-DV to the corresponding I-BV and the ratio of the DV to the BV for the optimal target bitrates.

The remainder of this paper is organized as follows. Section II describes the proposed bit allocation algorithm. Experimental results are shown in Section III. Finally, the conclusions are presented in Section IV.

2. The proposed bit allocation algorithm

A typical three view prediction structure for MV-HEVC is illustrated in Figure 1. The hierarchical B picture (HBP) prediction structure is used to encode pictures in each view [1]. The BV is predicted with temporal motion compensated prediction (MCP). The left view and the right view are encoded with the temporal MCP and the disparity compensated prediction (DCP) by referring to the BV. Since the BV in multi-view bit stream shall be compatible to HEVC and be reference view for the DV, the BV needs to be allocated as much bitrates as possible to ensure higher visual quality under constant total rate constraints. At the same time, the DV also need to be assigned the reasonable target bitrates to obtain better coding performance. Considering these various cases, how to deal with the inter-view bit allocation problem is very necessary for improving the RD performance of the MVC.

A. Inter view bit allocation

MV-HEVC expands the HEVC-based RC technology from single-view video to multi-view. However, each view still uses the RC method based $R-\lambda$ model separately. The inter view correlation is not fully excavated. In the HEVC-based RC technology,

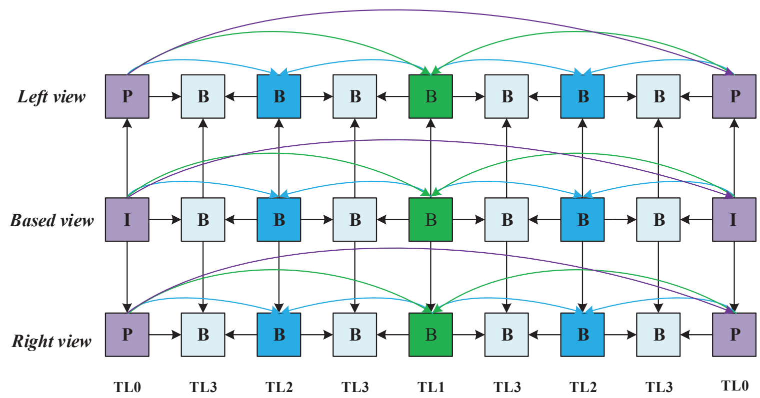


Figure 1: Typical prediction structure for MV-HEVC.

the hyperbolic model is used to represent the relationship between the bitrates R and the distortion D, the RD model is defined by

$$D(R) = \alpha R^{-\beta} \tag{1}$$

where α and β are model parameters dependent on the characteristics of the video content. D represents the distortion calculated from the mean square error (MSE), R represents the average number of bits consumed per pixel. Hence, The DR model of the base view is defined by

$$D_b = \alpha_b R_b^{-\beta_b} \tag{2}$$

For MVC, the prediction process of the DV refers to the information of the BV based on the DCP technique. Due to the inter-view prediction, the distortion of the DV is affected by the distortion of the BV seriously. When the current coding block in the DV picture uses the inter-view skip mode by referring to the BV, the distortion in the BV will be transmitted to the DV directly. Therefore, the distortion of the DV [10] using the inter-view skip mode can be expressed as

$$D_{d,skip} = \eta(D_b + \delta) \tag{3}$$

where D_b denotes the distortion of the base view, η indicates the proportion of the inter-view skip mode used in the dependent view. δ indicates the deviation due to erroneous DCP. The RD model of the coding unit predicted with other modes is defined by

$$D_{d,notskip} = \alpha_d R_d^{-\beta_d} \tag{4}$$

Hence, the distortion of the DV is divided into two parts, one is caused by the propagation of the distortion from the BV, and the other is caused by the quantization process of the DV itself. By further formula derivation, the distortion model of the DV can be obtained based on the theory proposed by Yuan' [10], which is defined by

$$D_d = D_{d,skip} + D_{d,notskip} = \eta(D_b + \delta) + \alpha_d R^{-\beta_d} = \eta(\alpha_b R_b^{-\beta_b} + \delta) + \alpha_d R_d^{-\beta_d} \tag{5}$$

The inter-view bit allocation problem can be expressed as the sum of the bitrates of the BV, and the DV is smaller than the total target bitrates with the minimum distortion, which is expressed as

$$\boldsymbol{min} \qquad J = D_b + D_d \qquad \boldsymbol{s.t} \quad R_b + R_d \leq R_T \tag{6}$$

where R_T represents the total target bitrates. Based on the above analysis, for two views case in MV-HEVC, by taking (2) and (5) into (6), (6) could be written as

$$\boldsymbol{min} \qquad J = (1+\eta)\alpha_b R_b^{-\beta_b} + \eta\delta + \alpha_d R_d^{-\beta_d} \qquad \boldsymbol{s.t} \quad R_b + R_d \leq R_T \tag{7}$$

Since the RD curves of the BV and the DV are hyperbolic functions, the convex functions are used to represent them. (7) can be converted into an unconstrained optimization problem based on the Lagrange Multiplier method, which is defined as

$$\boldsymbol{min} \qquad J = (1+\eta)\alpha_b R_b^{-\beta_b} + \eta\delta + \alpha_d R_d^{-\beta_d} + \lambda(R_b + R_d - R_T) \tag{8}$$

To get the optimal inter view bit allocation scheme, the partial derivative of J for R_b, R_d, and λ is obtained, respectively. Solving minimization problem in (8) is equivalent to setting the following derivative to zero.

$$\begin{cases} \dfrac{\partial J}{\partial R_b} = -(1+\eta)\alpha_b \beta_b R_b^{-\beta_b - 1} + \lambda = 0 \\ \dfrac{\partial J}{\partial R_d} = -\alpha_d \beta_d R_d^{-\beta_d - 1} + \lambda = 0 \\ \dfrac{\partial J}{\partial \lambda} = R_b + R_d - R_T = 0 \end{cases} \tag{9}$$

By solving the equation (9), the solution could be obtained as

$$(1+\eta)\alpha_b \beta_b R_b^{-\beta_b - 1} = \alpha_d \beta_d R_d^{-\beta_d - 1} \tag{10}$$

From the equation (10), the relationship between the optimal target bitrates of the BV and the DV could be derived as

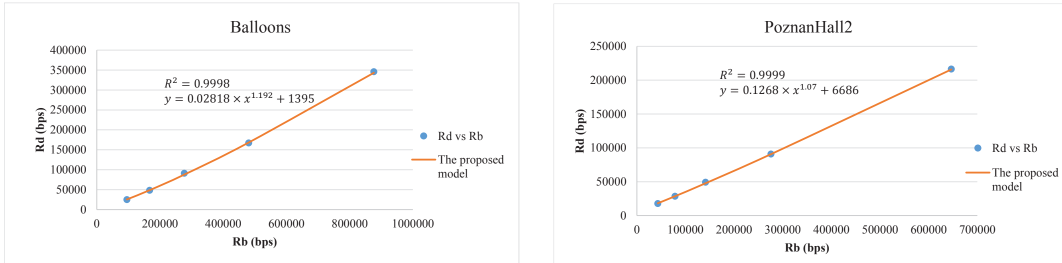
$$R_d = \frac{(1+\eta)\alpha_b \beta_b}{\alpha_d \beta_d} R_b^{\frac{\beta_b + 1}{\beta_d + 1}} \tag{11}$$

Therefore, the $R_d - R_b$ relationship can satisfy the power function, which is defined by

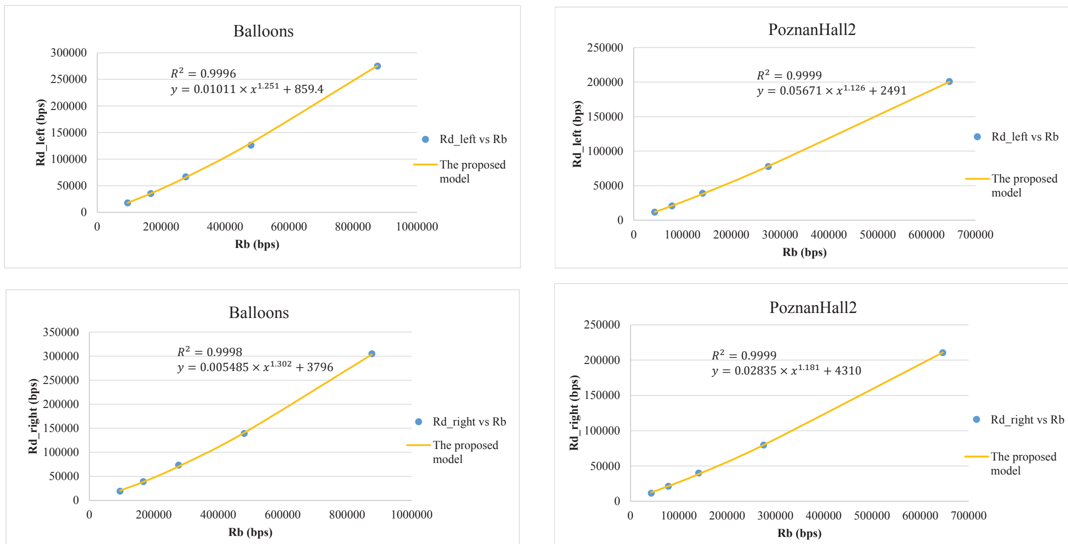
$$R_d = A R_b^B + C \tag{12}$$

where A and B are model parameters based on the texture content, C is the regulatory factor. In order to get the optimal target bitrates R_b and R_d, we utilize the bisection method to find the optimal root R_b^{opt} of the equation (13), which denotes the optimal target bitrates of the BV. Then, the R_b^{opt} is brought into equation (12) to obtain the optimal target bitrates R_d^{opt} of the DV.

$$R_b + A R_b^B + C - R_T = 0 \tag{13}$$



(a). Two views case



(b). Three views case

Figure 2: The relationship between target bit rate of the base view and the dependent view is fitted by the proposed model.

Similarly, for 3 view case, the inter-view bit allocation problem could be formulated as

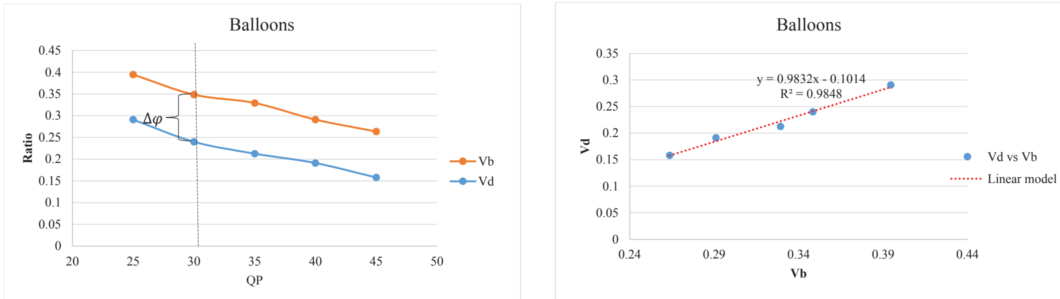
$$R_{d\_left} = A_1 R_b^{B_1} + C_1 \tag{14}$$

$$R_{d\_right} = A_2 R_b^{B_2} + C_2 \tag{15}$$

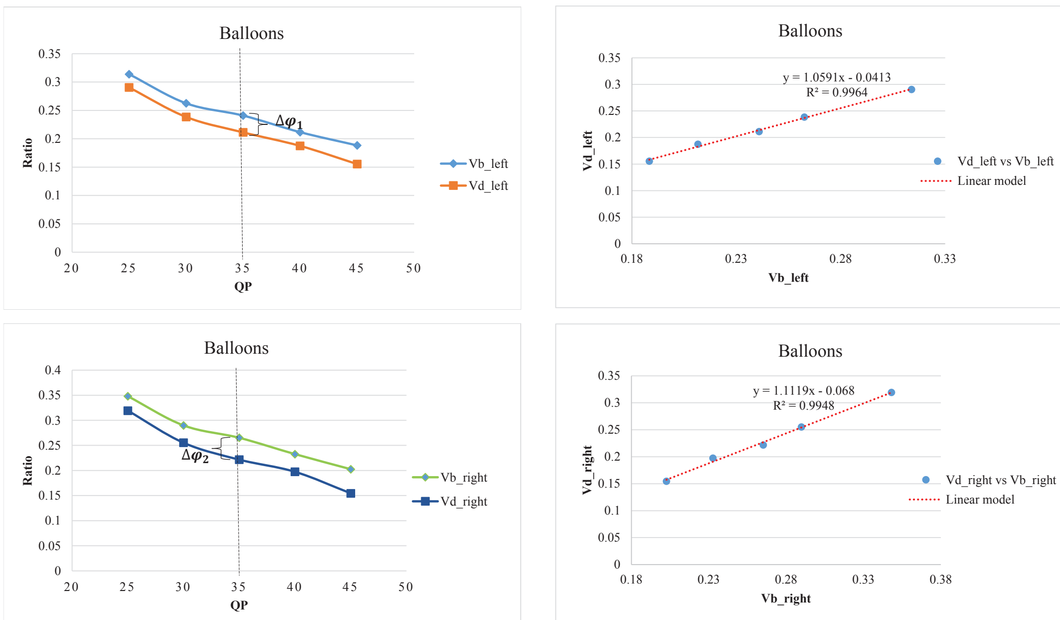
$$R_b + A_1 R_b^{B_1} + C_1 + A_2 R_b^{B_2} + C_2 - R_T = 0 \tag{16}$$

where R_{d_left} represents the target bitrates of the left view, R_{d_right} denotes the target bitrates of the right view and R_b represents the target bitrates of the base view.

In order to verify the accuracy of the derived $R_d - R_b$ relationship models, extensive experiments have been conducted on HTM 16.0 encoder. Two sequences with different spatial resolutions of 1024×768 ("Balloon") and 1920×1088("PoznanHall") are encoded with five different QPs (25, 30, 35, 40 and 45) under RA configuration. The above derived model is used to fit the relationship between the target bitrates of the BV and the DV for two-view and three-view case. As is shown in Figure 2, the above derived model fit the actual data well. We use the coefficient of determination (R^2) as a metric to evaluate the accuracy of the proposed model (12), (14) and (15). The closer the R^2 is to 1, the more correct the model is. It can be seen that the R^2 of both test sequences exceeds 0.999, which demonstrates the high accuracy of the proposed model.



(a). Two views case



(b). Three views case

Figure 3: The $V_d - V_b$ change trend under different QPs (left) and the corresponding $V_d - V_b$ linear fitting curve (right).

B. The target bitrates decision of the P frame for the dependent view

For the DV, the P frame mainly refers to the I-BV, and serves as the primary reference frame for subsequent B frames. Hence, the low visual quality of the predicted P frame can seriously damage the overall coding performance of the DV. A $R-\lambda$ model-based RC scheme for intra I frame is proposed in the BV [13], which provides more accurate target bitrates matching and preserves coding efficiency at the same time. However, for the DV, the ratio of the target bitrates of the P frame in the first GOP still uses the initial ratio set, and the ratio of the target bitrates of the subsequent P frames changes as the encoding parameters are updated. It is not necessarily meaningful for the target bit allocation of the P-DV. That is because the strong dependency between I-BV and P-DV is ignored. Therefore, a reasonable target bit allocation method for the P frame is necessary to improve the coding performance of the DV.

Since the P frame in the DV is mainly predicted from the corresponding I-BV utilizing the DCP technique, the coding performance of P frame depends greatly on the visual quality of I frame. Meanwhile, the target bitrates of I and P frames are also indirectly affected by the inter-view rate allocation. In order to investigate the target bitrates relationship of the P frame and the I frame, we carry out a series of experiments for Balloons and Kendo under the aforementioned test conditions in Section 2A. For two views case, V_b is used to represent the ratio of the actual consumed total bitrates of the DV to the BV, and V_d represents the ratio of the actual consumed average bitrates of the P-DV to the corresponding I-BV. V_b and V_d is defined by

$$V_b = \frac{R_d}{R_b}, \qquad V_d = \frac{\overline{R}_P}{\overline{R}_I} \tag{17}$$

As shown in Figure 3(a) (left), It can be observed that these two curves are approximately translational transformation under different QPs, the corresponding ratio difference $\Delta\varphi$ at each data point are almost equal. It can be concluded that V_d changes linearly with V_b. Hence, the $V_d - V_b$ relationship can be approximately formulated by the linear model as

$$V_d = kV_b + \varphi \tag{18}$$

where k and φ are model parameters.

To demonstrate the effectiveness of the linear relationship, the $V_d - V_b$ relationship curve is fit based on the least squares. As can be seen from Figure 3(a) (right), the R^2 of the linear model is over 0.98. It is very clearly indicated that the linear function can express the $V_d - V_b$ relationship under different QPs. After getting the actual bitrates consumption R_{I_actual} of the I-BV, the target bitrates R_P of the corresponding P frame for the DV are set as

$$R_P = V_d \times R_{I\_actual} \tag{19}$$

Similarly, for 3 view case, the target bitrate decision of the P frame for the DV could be formulated as

$$V_{b\_left} = \frac{R_{d\_left}}{R_b}, \qquad V_{d\_left} = \frac{\overline{R}_{P\_left}}{\overline{R}_I} \tag{20}$$

$$V_{b\_rigth} = \frac{R_{d\_right}}{R_b}, \qquad V_{d\_right} = \frac{\overline{R}_{P\_right}}{\overline{R}_I} \tag{21}$$

where V_{b_left} represents the ratio of the actual consumed bitrates of the left DV to the BV, V_{d_left} implies the ratio of actual consumed average bitrates of the P frame in the left DV to the corresponding I-BV. V_{b_rigth} denotes ratio of actual consumed bitrates of the right DV to the BV. V_{d_right} represents the ratio of the actual consumed average bitrates of the P frame in the right DV to the corresponding I-BV. As is illustrated in Figure 3(b) (right), the R^2 of the linear fitting function exceeds 0.99. The $V_{d\_left} - V_{b\_left}$ and $V_{d\_rigth} - V_{b\_right}$ relationship can be obtained by the above linear model, which is defined by

$$V_{d\_left} = k_1 V_{b\_left} + \varphi_1 \tag{22}$$

$$V_{d\_right} = k_2 V_{b\_right} + \varphi_2 \tag{23}$$

Table 1: Detailed RD values comparison

Test Sequence	Two view case		Our method vs Yuan's [10]	Three view case		Our method vs Yuan's [10]
	Total Rate	Avg.PSNR	BD-PSNR (**L/H**)	Total Rate	Avg.PSNR	BD-PSNR (**L/H**)
Kendo	502.54	40.91	0.667/0.445	502.10	39.83	0.849/0.563
	753.47	42.27		1004.57	42.11	
	999.48	43.26		1502.03	43.33	
	1502.03	44.24		2004.49	43.93	
	2002.95	44.79		2504.66	44.35	
	2501.20	45.30		3004.23	44.65	
Balloons	500.28	40.36	0.131/-0.026	500.40	39.22	0.401/0.075
	750.82	41.64		1001.45	41.50	
	998.75	42.55		1500.13	42.57	
	1501.20	43.46		2001.98	43.16	
	2001.35	43.97		2502.81	43.56	
	2501.00	44.47		3003.10	43.87	
Newspaper	501.30	38.50	0.155/0.115	500.92	37.85	0.825/0.586
	752.07	39.66		1002.64	39.87	
	1002.04	40.82		1502.80	40.97	
	1503.78	41.83		2003.89	41.64	
	2004.00	42.49		2504.37	42.13	
	2503.57	43.21		3004.32	42.67	
PoznanHall2	1000.71	41.60	0.112/0.016	1000.66	41.32	0.075/0.052
	1500.80	41.96		2000.90	41.90	
	2000.99	42.17		3001.18	42.27	
	3001.02	42.52		4001.52	42.43	
	4001.15	42.70		5001.67	42.57	
	5001.21	42.85		6001.75	42.68	
PoznanStreet	1000.42	37.39	0.660/0.413	997.90	36.60	0.646/0.451
	1501.83	38.18		1000.16	36.85	
	1999.87	38.89		2001.87	38.18	
	3000.58	39.53		2999.65	38.99	
	4001.82	39.94		4001.59	39.41	
	5001.29	40.24		5002.39	39.98	
Average			**0.345/0.195**			**0.559/0.345**

where k_1, k_2, φ_1 and φ_2 are model parameters. Hence, the target bitrates R_{P_i} of the every P frame for the left or right DV is defined as

$$R_{P\_i} = V_{d\_i} \times R_{I\_actual}, \qquad i = left\ or\ right \tag{24}$$

3. Experimental result

Compared with the fixed bit ratio and Shao's method [8], Yuan's [10] has more advantages in the coding performance recently. Our method also makes use of the theory of inter-view distortion transfer in Yuan's method. Therefore, Yuan's method is chosen as the anchor of our method. To evaluate the RD performance of the proposed algorithm, we test five 3D video sequences in HTM 9.2 platform. The experiments are conducted under common test conditions [14]. The view setting and the target rate setting of the 3D video sequences are the same as in [10]. Encoder parameters are set as the same with that of Table III in [10]. In this paper, it needs to be emphasized that the model parameters of the power model for the inter-view rate allocation and the linear model for the P-frame target bitrate decision are obtained by precoding each video sequence with five QP values (25, 30, 35, 40 and 45).

BD-PSNR is utilized to measure RD performance in the paper, which represents the PSNR-Y difference between the proposed method and the reference method at the same target rate. If the BD-PSNR is positive value, it means that the RD performance of the proposed method is superior to the reference method, vice versa. **H** denotes high bit rate (For two view, from 1000 kbps to 2500 kbps for 1024×768 resolution, from 2000 kbps to 5000 kbps for 1920×1088 resolution. For three view case, from 1500 kbps to 3000 kbps for 1024×768 resolution, from 3000 kbps to 6000 kbps for 1920×1088 resolution), **L** represents low bit rate (For two view case, from 500 kbps to 1500 kbps for 1024×768 resolution, from 1000 kbps to 3000 kbps for 1920×1088 resolution. For three view case, from 500 kbps to 2000 kbps for 1024×768 resolution, from 1000 kbps to 4000 kbps for 1920×1088 resolution). The experimental results are listed in Table 1. Compared with Yuan's [10], for two view case, the BD-PSNR gains are 0.195 dB for high bit rate and 0.345 dB for low bit rate. In particular, the sequence with the most BD-PSNR gains is Kendo. 0.667 dB BD-PSNR gain for low bit rate and 0.445dB BD-PSNR gain for high bit rate, respectively. For three view case, the advantages of our approach are more obvious, 0.345 dB BD-PSNR gain is achieved for high bit rate and 0.559 dB BD-PSNR gain is obtained for low bit rate. The most BD-PSNR gain is Kendo's 0.849 dB for low bit rate and Newspaper's 0.586dB for high bit rate. In summary, it can be obvious to see that our method is significantly better than [10].

4. Conclusion

In order to improve the coding efficiency of multi-view texture videos, a new inter-view level bit allocation and the P-frame target rate decision method of the DV was proposed in this paper. Due to the DV picture was predicted from the corresponding BV picture by DCP, the distortion of the BV could be propagated to the DV. Therefore, the RD model for the DV was derived by taking into account the inter-view dependency. Based on the joint RD model for multi-view, the mathematical relationship between the target bitrates of BV and DV was derived. The target bitrates of the BV and the DV could be obtained using the dichotomy to solve the mathematical model. Since the P-DV was mainly predicted by referring to the corresponding I-BV, a linear model was built based on the discovery of the constant proportional relationship between the ratio of the actual consumed bitrates of the P-DV to the corresponding I-BV and the ratio of the optimal target bitrate of the DV to the BV. According to the actual bitrates of the I-BV and the constant ratio solved by the linear model, the target bitrates of the P frame could be obtained without the complicated parameter update. Experiment results demonstrate that the proposed method is superior to other state of the art algorithms.

Acknowledgments

The authors would like to thank Xintong Yu for his great efforts during the revision period and the reviewers' valuable comments. This work was supported by the National Natural Science Foundation of China (NSFC) under grant No. 61871437 and No. 61702205.

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