A New Rate Control Algorithm based on Statistical Analysis for MVC

Qiaoyan Zheng, Mei Yu*, Gangyi Jiang, Feng Shao, Zongju Peng
Faculty of Information Science and Engineering, Ningbo University, Ningbo, China
Email: yumei2@126.com, qiaoyan817724@163.com

Abstract—**Rate control is one of important tools in multi-view video coding (MVC). This paper presents a new rate control algorithm for MVC by analyzing the rate allocation proportion among different types of views. The proposed algorithm is performed on three levels, that is, view level, group-of-picture (GOP) level and frame level. Firstly, we reasonably allocate bit-rate among views based on the statistical analysis in the view level. Then, in the GOP level, the initial quantization parameter (QP) of each GOP is set according to the QP values of B frames. Finally, the frame complexity is used to regulate the target bit for each frame. Experimental results show that the proposed algorithm can accurately control bit-rate to satisfy the requirements of multi-view video systems.**

Index Terms—**multi-view video coding, rate control, bit allocation, statistical analysis, frame complexity**

I. INTRODUCTION

In order to meet the increasing diversity requirements of video quality and content, multi-view video technologies with three dimensional (3D) visualization capabilities become a research hotspot in recent years[1], 3D video contents has become the major driving force governing today's dynamics of the consumer electronic market [2-3]. Moreover, mobile 3D video services are also becoming reality [4, 5, 11] along with the popularization of mobile phone supporting stereoscopic display. Multi-view video is a new technique in which a scene is recorded by using several synchronous cameras from different positions [22]. In multi-view video coding (MVC) standard, disparity-compensated prediction together with motion-compensated prediction are exploited to reduce redundancies for obtaining high coding efficiency [6]. Rate control (RC) problem has been widely studied in mono-view video coding standards, such as MPEG-2 TM5 [7], H.263 TMN8 [8], MPEG-4 VM8 [9] and H.264 RC algorithm [10]. However, there is still no a RC solution in the current joint multiview video coding test model (JMVC). It is necessary to study the efficient and relevant algorithm of bit allocation and RC for MVC, which should allocate bits between inter-views to keep the quality of each view consistently.

Most current RC algorithms concentrate on 2D video communications [12, 22], which are not fit well to MVC that adopts the hierarchical B pictures (HBP) coding structure. RC algorithm [13-14] for MVC is recently being preliminarily developed in 3D video research areas. In [15], a RC algorithm for MVC was proposed to reasonably allocate bit-rate among views based on correlation analysis. In [16], some characteristics of MVC was used to allocate proper bit rates for B frames and the quantization parameters (QP) of B frames in MVC were taken into account when deciding the initial QP of GOP. In [17-18], bit allocation and RC algorithm for multi-view video plus depth were presented. However, the existing rate control algorithms cannot efficiently work for HBP based MVC. One reason is that the rate allocation of B frames is not carefully considered in the rate control algorithms. Another reason is that in P-view and B-view of MVC, the key frames are not I frames, they are inter-view predicted B frames or P frames.

In this paper, we propose a novel frame level MVC rate control algorithm, which is performed on three levels, the view level, GOP level and frame level. At the view level, we first get the rate allocation proportion among views according to different types of views with statistical analysis and the rates are discriminatorily allocated according to the special characteristics of MVC. At the GOP level, the QP values of B frames are used to compute the initial QP of each GOP. At the frame level, we propose a multi-view video oriented frame level RC algorithm based on frame complexity. Experimental results show that multi-view video oriented bit allocation and RC algorithm can accurately control the bit-rate.

II. THE PROPOSED RATE CONTROL ALGORITHM

MVC makes use of redundancies between adjacent views for high coding efficiency. To control bit rate for MVC and the corresponding bit-stream transmission, we propose a new MVC rate control algorithm. The diagram of the proposed algorithm is shown in Fig. 1. It consists of three stages: 1) view level rate allocation; 2) GOP level rate control; 3) frame level rate control. In the proposed algorithm, statistical analysis about rate allocation proportion among views in the first stage is processed.

A. Statistical Analysis about Rate Allocation Proportion among Views

Fig. 2 shows HBP coding structure in MVC, in which eight views are encoded. It is seen that there is no inter-view predication in view S0, thus it is called I-view here. P-views, such as the views S2, S4, S6 and S7, are

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encoded with unidirectional inter-view prediction from the reconstructed I-view and the previous reconstructed P-view. Likewise, the views S1, S3 and S5, called as B-view, are encoded with bidirectional interview prediction from the reconstructed I-view and P-view. Therefore, all views are divided into three types, I-view, P-view and B-view, in the view level of the proposed algorithm.

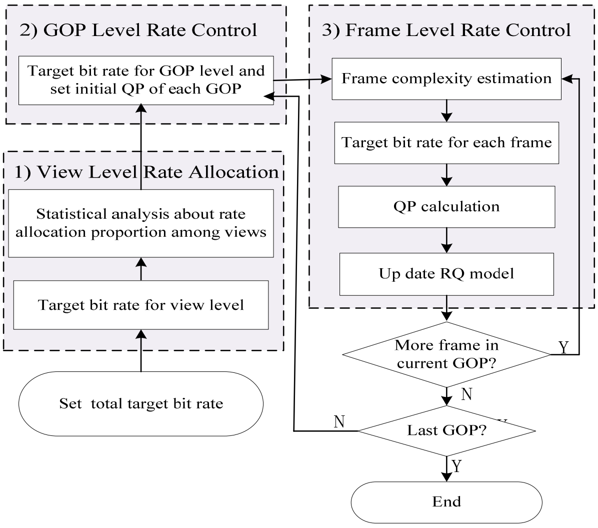


Figure 1 Block diagram of the proposed MVC rate control algorithm

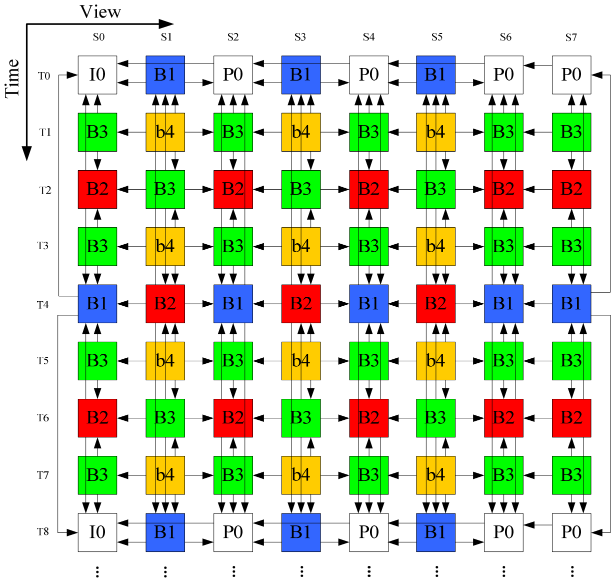
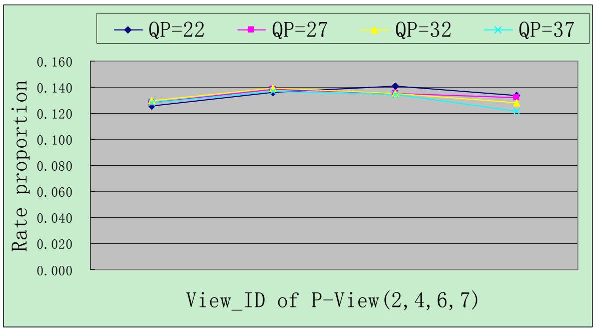
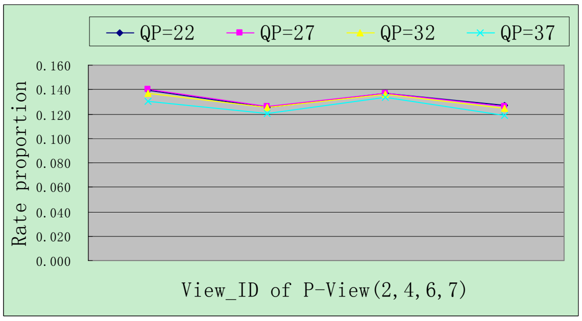


Figure 2. MVC coding structure with HBP.

In order to analyze the rate proportion among views in MVC method, the basis-QPs in the fixed QP MVC scheme are set to 22, 27, 32 and 37. Fig. 3 shows the rate allocation proportion of each P-view with respect to Ballroom and Ballet sequence, respectively. The proportion of single P-view is almost the same, from 0.12 to 0.14 under different fixed QP coding, and the average proportion is 0.13.



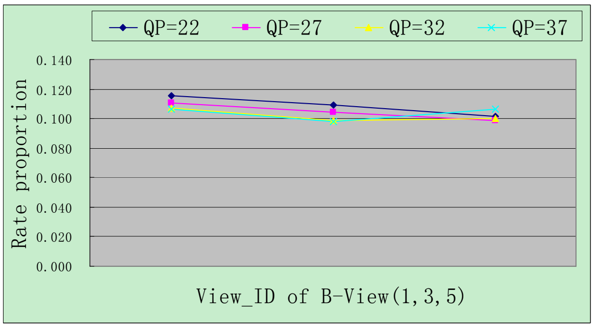
(a) Ballroom



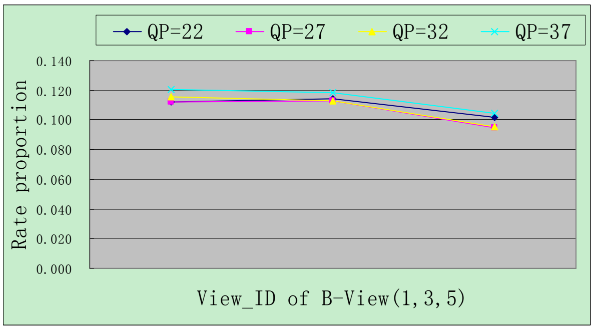
(b) Ballet

Figure 3. Rate allocation proportion of each view in P-view.

Likewise, Fig. 4 shows the rate allocation proportion of each B-view for Ballroom and Ballet sequence, respectively. The proportion of single B-view is about from 0.1 to 0.12 under different fixed QP coding, and the average proportion is 0.11. It can be seen that, the rate allocation proportion for each view in different types of views, the P-view and the B-view, is almost equal.



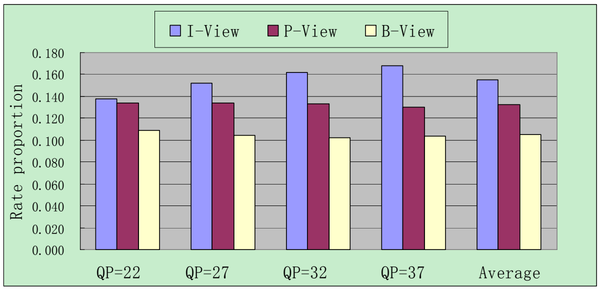
(a) Ballroom



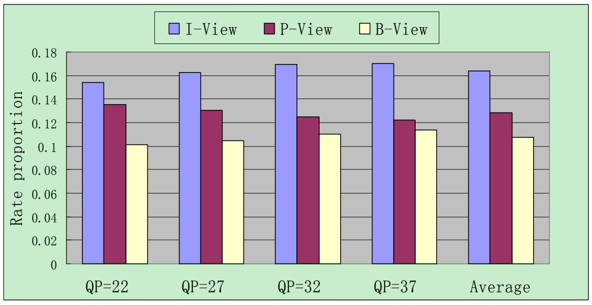
(b) Ballet

Figure 4. Rate allocation proportion of each view in B-view.

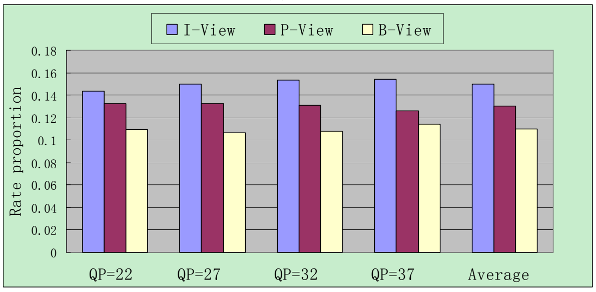
Next Fig. 5 shows the statistical average rate allocation proportion among the I-view, each B-view and each P-view, for Ballroom, Rena, Breakdancers, and Ballet. In the figure, the proportion among three types of views is approximately equal to 0.155: 0.133: 0.105 for Ballroom, 0.164: 0.128: 0.108 for Rena, 0.160: 0.126: 0.112 for Breakdancers, and 0.150: 0.130: 0.110 for Ballet. According to the statistical observation, the rate allocation proportions among three types of views for different sequences are approximately equal.



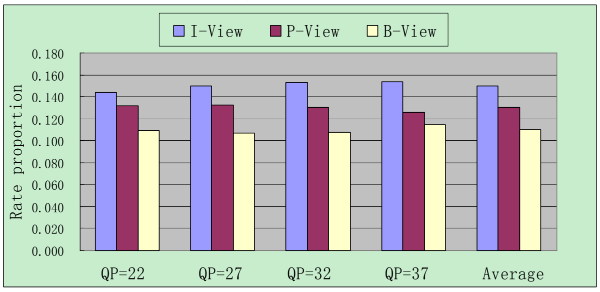
(a) Ballroom



(b) Rena



(c) Breakdancers



(d) Ballet

Figure 5. Average rate allocation proportion among different types of views for different sequences.

Finally, the statistical rate proportion among the I-view, all B-views and all P-views are shown in Fig. 6. It is clear that, the proportions among three types of views between different sequences have some slight difference, especially the proportion of I-view which is encoded with intra-view coding technique. The average rate proportion is approximately equal to 0.157: 0.517: 0.326 for the four sequences, Ballroom, Rena, Breakdancers, and Ballet. Under the total rate constraint, the view level rate allocation is needed to be offline performed before the actual encoding.

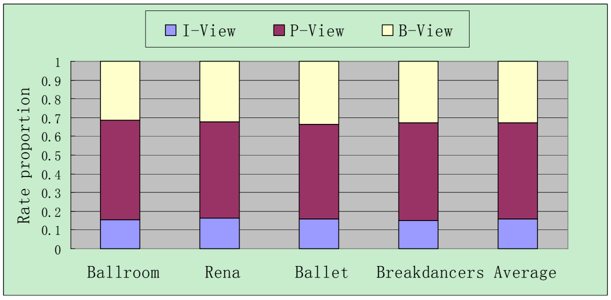


Figure 6. Rate allocation proportion among the three types of views for different sequences.

B. Multi-view Video Rate Control

1) Target Bit Rate for View Level

We allocate the bits rationally based on above statistical analysis about rate allocation proportion among views in different sequences. In the proposed method, the target bit for each view is computed by:

$$T_{view}(k) = T_{total} \times w(k) \tag{1}$$

where T_{total} and k denote the total bit rate for all views and the coding order index of view point, respectively. w (k) is rate allocation proportion for each view, which depends on statistical analysis. T_{view} (k) is target bit for the k-th view.

2) Target Bit Rate for GOP Level and Setting Initial QP of Each GOP:

In the GOP level, the total number of bits allocated to each GOP is computed and the initial QP of each GOP is set. At the beginning of encoding the i-th GOP, the total number of bits allocated for the i-th GOP is computed by

$$T_r(i,0) = \frac{u(i,1)}{F_r} \times N_{GOP} - (\frac{B_s}{8} - B_c(i-1, N_{GOP})) \tag{2}$$

where N_{GOP} denotes total number of frames in the current GOP, u (i, 1) is available channel bandwidth, F_r is frame rate, and B_c (i-1, N_{GOP}) is actual buffer occupancy after coding the (i-1)th GOP. The buffer occupancy should be kept at B_s/8 after coding each GOP. Since the channel bandwidth may vary at any time, T_r is updated frame by frame as follows

$$T_r(i,j)=T_r(i,j-1)+\frac{u(i,j)-u(i,j-1)}{F_r}\times(N_{GOP}-j)-A(i,j-1) \tag{3}$$

where A (i, j-1) denotes the actual encoded bit-rate for the (i-1)-th frame.

In the case of the constant bit rate (CBR), i.e. $u(i,j) = u(i,j-1)$, equation (3) is simplified as

$$T_r(i,j) = T_r(i,j-1) - A(i,j-1) \tag{4}$$

In other words, Equation (2) is also applicable to the CBR case.

As shown in Fig. 2, MVC predicting structure has a large number of B pictures. Hence, the QP values of B frames are taken into account when deciding the initial QP of GOP. The initial QP is computed by

$$\hat{Q}_{st\_c} = \frac{Sum_{BQP}}{N_b} - 1 - \frac{8T_r(i-1, N_{GOP})}{T_r(i,0)} \tag{5}$$

where N_b is total number of B frame in a GOP and Sum_{BQP} is the sum of QPs for all B frames in the previous GOP. The I-frame, the P frame in P-view and the first B frame in B-view in each GOP are coded using $\hat{Q}_{st\_c}$.

To maintain the smoothness of visual quality among successive frames, the QP $\tilde{Q}_{st\_c}$ is adjusted by

$$\tilde{Q}_{st\_c} = \min\{Q_{st\_p} + 2, \max\{Q_{st\_p} - 2, \hat{Q}_{st\_c}\}\} \tag{6}$$

where Q_{st_p} is the QP of the previous B frame.

The final QP is further bounded by

$$Q_{st\_c} = \min\{51, \max\{\tilde{Q}_{st\_c}, 1\}\} \tag{7}$$

3) Rate Control Scheme for Frame Level

H.264 could only control the bit rate of I-frame and P-frame which cannot be directly used in MVC that contains a large number of B frames. The QP of the first B frame is given at the GOP level; we only need to predefine target buffer levels for other B frames in each GOP. The function of target buffer level is to compute a target bit for each B frame, which is used to compute QP.

The bit allocation is implemented by predefining a target buffer level for each B picture. The function of target buffer level is to compute a target bit for each B frame, which is then used to compute the QP. After coding the first B frame in the *i*-th GOP, we reset the initial value of target buffer level as

$$Tbl(i,2) = B_c(i,2) \tag{8}$$

where B_c (*i*, 2) is the actual buffer occupancy after coding the first B frame in the *i*-th GOP.

In rate control of JVT-G012, The target buffer level for the subsequent P frames is determined by

$$\begin{aligned} Tbl(i,j) &= Tbl(i,j-1) - \frac{Tbl(i,2) - Bs/8}{N_p - 1} \\ &+ \frac{\tilde{W}(i,j-1)(L+1)u(i,j-1)}{F_r(\tilde{W}_p(i,j-1) + \tilde{W}_b(i,j-1)L)} - \frac{u(i,j-1)}{F_r} \end{aligned} \tag{9}$$

where $\tilde{W}_p(i,j)$ is the average complexity weight of P pictures, $\tilde{W}_b(i,j)$ is the average complexity weight of B pictures, and $Tbl(i,j)$ is the target buffer level. $\tilde{W}_p$ and $\tilde{W}_b$ are computed by

$$\tilde{W}_p(i,j) = \frac{W_p(i,j)}{8} + \frac{7 * \tilde{W}_p(i,j-1)}{8} \tag{10}$$

$$\tilde{W}_b(i,j) = \frac{W_b(i,j)}{8} + \frac{7 * \tilde{W}_b(i,j-1)}{8} \tag{11}$$

In MVC, the B frames are treated as P frames, so the target buffer level for the subsequent B frames is determined by

$$Tbl(i,j) = Tbl(i,j-1) - \frac{Tbl(i,2)}{N_b - 1} \tag{12}$$

where *Tbl* (*i*, *j*) is the target buffer level, in which frame complexity is not considered, as a result, the above scheme generally occurs skipped frame and quality degradation. Considering the frame complexity for B frames is adjusted by

$$Tbl(i,j) = Tbl(i,j-1) - \frac{Tbl(i,2)}{N_b - 1} \times \frac{W_b(i,j-1)}{AW_b(i,j-1)} \tag{13}$$

where W_b (*i*, *j*-1) is the complexity weight of the (*j*-1)-th B pictures, AW_b (*i*, *j*-1) is the average complexity weight of the coded B pictures, and the frame complexity W_b (*i*, *j*) is computed by

$$W_b(i,j) = QP(i,j) \times bits(i,j) \tag{14}$$

where *QP* (*i*, *j*) and *bits* (*i*, *j*) denote the QP and encoded bits, respectively.

In rate control of JVT-G012, the rate distortion optimization (RDO) model and the mean absolute difference (MAD) prediction model are not accurate; there usually exists a difference between the actual buffer fullness and the target buffer level. Therefore, the target bits need to be compute for each frame to reduce the difference between the actual buffer fullness and the target buffer level. This is achieved by the following microscopic control.

Then, $\tilde{f}(i,j)$ for the current frame is computed by adopting a leaky bucket model and linear tracking theory according to the predefined frame rate, the current buffer occupancy, the target buffer level and the available channel bandwidth as follows

$$\tilde{f}(i,j) = \frac{u(i,j)}{F_r} + \gamma(Tbl(i,j) - B_c(i,j)) \tag{15}$$

where γ is a constant and its value is 0.75 when there is no B frame and is 0.25 otherwise in JVT-G012. Here, because the B frames are treated as P frames, γ is set to 0.75. B_c (*i*, *j*) denotes the current buffer fullness.

Meanwhile, the number of remaining bits should also be considered when the target bit is computed. In rate control of JVT-G012, $\hat{f}(i,j)$ for the P frame is determined according to the number of remaining bits, the average complexity weight of the remaining P and B frames in the *i*-th GOP.

$$\hat{f}(i,j) = \frac{W_p(i,j-1)T_r(i,j)}{W_p(i,j-1)N_{p,r}(j-1) + W_b(i,j-1)N_{b,r}(j-1)} \tag{16}$$

In MVC, the B frames are treated as P frames, so equation (16) is simplified as

$$\hat{f}(i,j) = \frac{T_r(i,j)}{N_{b,r}(j-1)} \tag{17}$$

Above the equation, the remaining bits are evenly disturbed to the remaining B frames. We propose an optimal bit allocation scheme based on frame complexity as follows

$$\hat{f}(i,j) = \frac{T_r(i,j)}{N_{b,r}(j-1)} \times \frac{W_b(i,j-1)}{AW_b(i,j-1)} \tag{18}$$

where $N_{b,r}$ (j-1) is the number of the remaining B frames in the i-th GOP.

In terms of the frame level rate control of JVT-G012, the target bit rate for the j-th frame is a weighted combination of $\hat{f}(i,j)$ and $\tilde{f}(i,j)$

$$f(i,j) = \beta \times \hat{f}(i,j) + (1-\beta) \times \tilde{f}(i,j) \tag{19}$$

where β is a constant and its value is 0.5 when there is no B frame and is 0.9 otherwise in JVT-G012. Here, because the B frames are treated as P frames, β is set to 0.5.

Based on the allocated target bits, the quantization step-size can be computed by the quadratic RQ model

$$f(i,j) - H(i,j) = \left(\frac{X_1}{Q_s^2} + \frac{X_2}{Q_s}\right) \times MAD(i,j) \tag{20}$$

where X_1 and X_2 are the model coefficients, $f(i,j)$ denotes the total number of bits needed to code the current frame, $H(i,j)$ is the sum of header bits and motion bits, $MAD(i,j)$ is a prediction of the MAD of residue of the lamination motion compensation.

In MVC, the QPs are used in both rate control algorithm and RDO, which resulted in the following chicken and egg dilemma when the rate control is studied: to perform RDO for the current frame, a QP should be first determined by using the MAD of current frame. However, the MAD of current frame is only available after the RDO. So a linear model is introduced to predict the MADs of the current frame by that the previous frame, which results in a chicken and egg dilemma. Suppose that the predicted MAD of the current frame and the actual MAD of the previous frame are denoted by MAD_{cb} and MAD_{pb} , respectively. The linear prediction model is then given by

$$MAD_{cb} = a_1 \times MAD_{pb} + a_2 \tag{21}$$

where a_1 and a_2 are two coefficients of prediction model. The initial value of a_1 and a_2 are set to 1 and 0, respectively. They are updated after coding each frame.

To accurately characterize the RD relationship, the model coefficients X_1 and X_2 in (20), and a_1 and a_2 in (21) need to be updated once every other frame using a linear regressive technique.

The MAD of current B frame is predicted by model using the actual MAD of previous B frame. The QP $\hat{Q}_{bc}$ corresponding to the target bit is then computed by using the quadratic model in (20). To maintain the smoothness of visual quality among successive frames, the QP $\tilde{Q}_{bc}$ is adjusted by

$$\tilde{Q}_{bc} = \min\{Q_{bp}+2, \max\{Q_{bp}-2, \hat{Q}_{bc}\}\} \tag{22}$$

where Q_{bp} is the quantization parameter of the previous B frame. The final quantization parameter Q_{bc} is further bounded by

$$Q_{bc} = \min\{51, \max\{\tilde{Q}_{bc}, 1\}\} \tag{23}$$

III. EXPERIMENT RESULTS

In order to demonstrate the effectiveness of the proposed MVC rate control algorithm, experiments are performed with Ballroom[19], Rena[20], Ballet[21], and Breakdancers[21]. The test arguments of four sequences are shown in Table I.

In the experiments, we use the revised MVC software JMVC6.0 to implement the rate control algorithm. Two schemes, JMVC with the proposed rate control and without rate control, are tested, respectively. The test conditions of the four sequences are shown in Table II.

TABLE I.
TEST SEQUENCES

Sequence	Picture Resolution	Views
Ballroom	640×480	0~7
Rena	640×480	0~7
Breakdancers	1024×768	0~7
Ballet	1024×768	38~45

TABLE II.
TEST CONDITIONS

Frame Rate	15	Channel Type	CBR
GOP Length	8	Search Mode	Fast Search
Search Range	32	Frame's No.	81
Frame Rate	15	Channel Type	CBR

A. Rate Control Accuracy

We first confirm the accuracy of the proposed multi-view video rate control algorithm. Table III summarizes the matching accuracy between the controlled bit-rate and the target ones. In Table III, the target bit-rate and the actually controlled bit-rate are with respect to all of the eight views. The rate control error (RCE) is used to measure the accuracy of the bitrate estimation

$$RCE = \frac{|R_{target} - R_{actual}|}{R_{target}} \times 100\% \tag{24}$$

where R_{target} and R_{actual} denote the target bit-rate and the actual coding bit-rate, respectively.

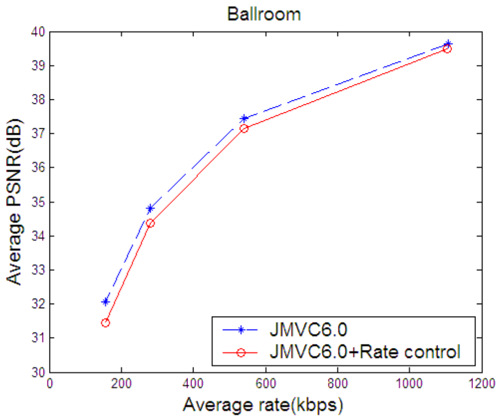
Table II indicates that the absolute inaccuracy of the proposed multi-view video rate control algorithm is within 0.42%. Through the simple pre-statistical rate allocation proportion method, the rate allocation can approximately adapt to the different types of views and the proposed method can provide a certain degree of rate control accuracy for MVC.

TABLE III.
SIMULATION RESULTS OF MVC RC

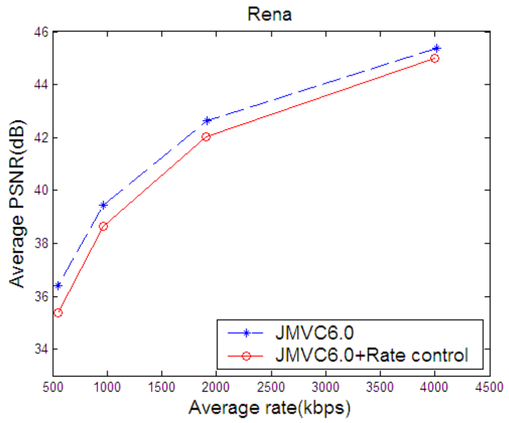
Sequences	Target bit rate (kbps)	Actual bit rate (kbps)	RCE (%)
Ballroom	8852.496	8839.686	0.14
	4334.225	4327.584	0.15
	2243.433	2246.327	0.13
	1248.575	1249.886	0.11
Rena	4012.802	4001.086	0.29
	1917.638	1909.649	0.42
	969.455	967.689	0.18
	547.194	546.862	0.06
Breakdancers	15233.820	15236.180	0.02
	5427.114	5428.452	0.02
	2580.990	2581.440	0.02
	1463.913	1464.4815	0.04
Ballet	6346.296	6349.655	0.05
	2848.064	2846.938	0.04
	1577.990	1579.274	0.08
	957.215	958.9229	0.18

B. Multi-view Video Quality Comparison

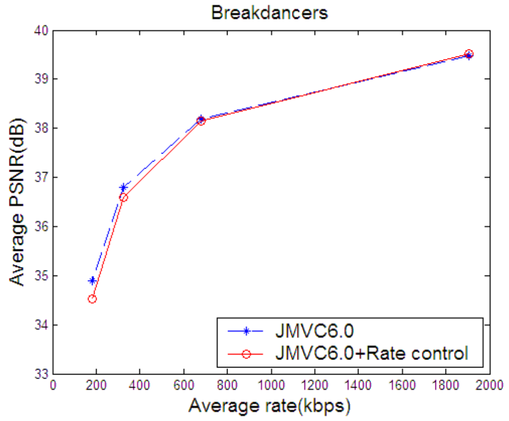
In order to objectively evaluate performance of rate control algorithms, the rate-distortion (RD) performance comparison results between the proposed multi-view video rate control coding and fixed cascading QP coding are shown in Fig. 7. In Fig. 7, the average bit-rate is the average value of eight views, and the PSNR value is also the average value of eight views. It can be seen that, compared with the fixed QP coding, the proposed rate control method can almost achieve the comparable RD performance at high bit-rate, a slightly inferior RD performance at low bit-rate. The RD performance of rate control method holds a lesser effect on multi-view video quality than the fixed QP coding because that MVC adopts the hierarchical B-frame prediction structure, which notably promotes the coding efficiency. In addition, the predefined rate allocation ratio is average value, which is not very suitable for all sequences.



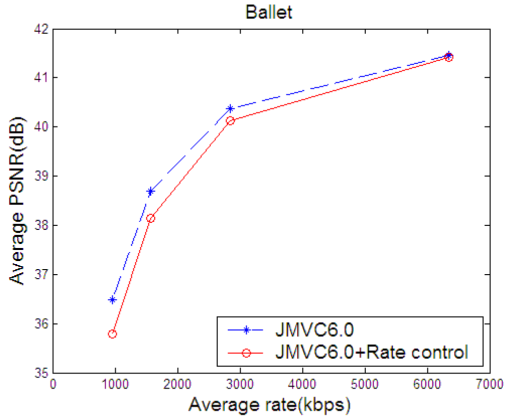
(a) RD performance comparison for Ballroom



(b) RD performance comparison for Rena



(c) RD performance comparison for Breakdancers



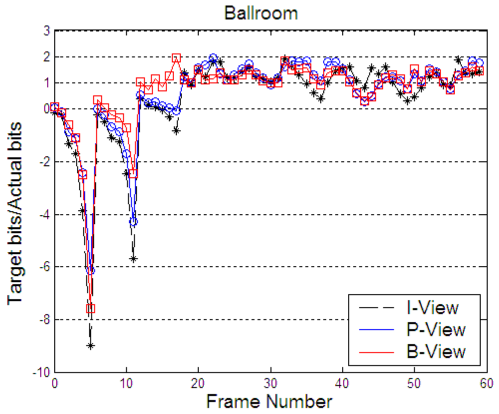
(d) RD performance comparison for Ballet

Figure 7. RD performance comparison between the fixed cascading QP coding and the proposed rate control coding.

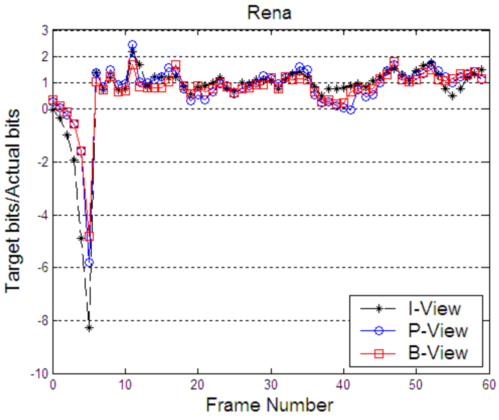
C. The Fluctuations of Rate Controlling Accuracy

Besides the whole rate controlling accuracy and RD performance, the fluctuations of rate controlling accuracy between the consecutive frames are also taken into account. Fig. 8 shows the ratio between target bits and actual bits in three types of views, where the I-view is S0, the P-view is S2 and the B-view is S1. In Fig. 8, the I frame and the first B frame does not carry out rate controlling in each GOP, so the number of rate control frame is 60. The value of ratio between target bits and actual bits is closer to 1, the rate controlling accuracy is higher.

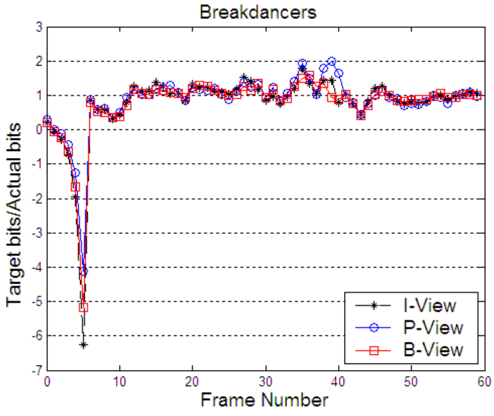
Fig. 8 shows that the target bits are inadequate and the actual coding bits of the encoding frame are possibly higher than the target allocated bits in short frames because of the rate-quantization model is not stable enough in short time. However, this phenomenon will disappear after about two GOPs are encoded, and the value of the ratio between the target bits and actual bits is fluctuated around 1 for the subsequent frames. The proposed rate control algorithm allocates the target bits for one encoding frame with considering the current buffer status. It can be seen that the rate-quantization model is gradually updated and the proposed rate control can maintain suitable rate controlling accuracy in a short time even if the frame is easy or complex to be coded.



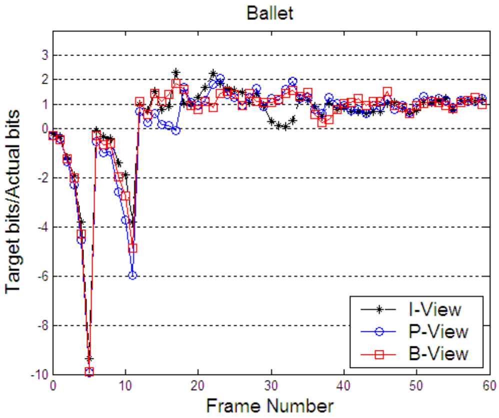
(a) the ratio between target bits and actual bits for Ballroom



(b the ratio between target bits and actual bits for Rena



(c) the ratio between target bits and actual bits for Breakdancers



(d) the ratio between target bits and actual bits for Ballet

Figure 8. The ratio between target bits and actual bits in three types of views for the proposed RC.

IV. CONCLUSIONS

This paper presents a novel rate control technique for multi-view video coding, which is performed on three levels, namely view level, GOP level and frame level. At the view level, the rates are discriminatorily allocated according to the special characteristics of MVC. At the GOP level, the bits and the initial QP considering the QP values of B frames of each GOP are computed. In the frame level, the target bits are allocated according to the frame complexity. Experimental results show that the proposed rate control technique can accurately control the bit-rate. In the proposed rate control method, rate allocation proportion is off-line processed in view level, so we will further study the bit allocation relation among the views in order to achieve online processing. Due to the huge amount of data in 3D video applications, the decoder must prevent the resource buffer from overflow or underflow. Hence, the multi-view video rate control must take into account the buffer requirement, which not only considering outputting one single view, but also multiple views. In addition, We could investigate just noticeable distortion (JND) as a perceptual criterion in rate control process, so as to keep low bits consumption in each scalable level while maintain optimal encoding results.

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Qiaoyan Zheng received the B.S. degree in electronic and information engineering from Hebei Institute of Architectural Engineering, Zhangjiakou, China, in 2009. She is currently working toward the M.S. degree at Ningbo University, Ningbo, China. Her current research interests include image/video processing and rate control.

Mei Yu received her M.S. degree from Hangzhou Institute of Electronics Engineering, China, in 1993, and Ph.D. degree form Ajou University, Korea, in 2000. She is now a professor in Faculty of Information Science and Engineering, Ningbo University, China. Her research interests include image/video coding and video perception.

Gangyi Jiang received his M.S. degree from Hangzhou University in 1992, and received his Ph.D. degree from Ajou University, Korea, in 2000. He is now a professor in Faculty of Information Science and Engineering, Ningbo University, China. He is a member of the IEEE. His research interests mainly include digital video compression and communications, multi-view video coding, etc.

Feng Shao received his B.S. and Ph.D degrees from Zhejiang University, Hangzhou, China, in 2002 and 2007, respectively, all in Electronic Science and Technology. He is currently an associate professor in Faculty of Information Science and Engineering, Ningbo University, China. His research interests include image/video coding, image processing, and image perception, etc.

Zongju Peng received his B.S. degree in computer science from Sichuan University, Chengdu, China, in 1998, and Ph.D. degree from Institute of Computing Technology, Chinese Academy of Science in 2010. He is currently an associate professor in Faculty of Information Science and Engineering, Ningbo University, China. His research concentrates on image/video compression.