Novel United Buffer Rate Control Methods for Stereoscopic Video

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Abstract—**To investigate the impact of buffer on stereoscopic video coding, three rate control (RC) methods were presented. In the separate buffer RC method (SBRC), left and right views achieved rate controlling using respective buffer in their own given target bitrates. The united buffer RC (UBRC) and its improved united buffer RC (I-UBRC) methods were both in a given total bandwidth and the united buffer, they were performed on three levels, namely stereoscopic group of pictures (SGOP) level, stereoscopic frame (SFrame) level and frame level. The united buffer RC method adopted asymmetric-quality bits allocation based on the mean absolute difference (MAD) of left and right images in frame level. The improved united buffer RC method took relative complexity and importance into account to allocate bits rationally in SFrame level. Experimental results show that the proposed three methods can accurately control the rate to satisfy the requirements of stereoscopic video coding, and the coding efficiency of the improved united buffer RC method is the highest.**

Index Terms—**rate control, stereoscopic video, united buffer, frame complexity, asymmetric**

I. Introduction

Three-dimensional (3D) video has gone a step beyond conventional two-dimensional (2D) video by viewers with a totally new stereoscopic video and interactive viewing experience. With more and more 3D cinemas and 3D movies being available, 3D multimedia contents has become the major driving force governing today's dynamics of the consumer electronic market [1, 2]. Moreover, with the popularization of mobile phone supporting the switchable 2D/3D stereoscopic display, 3D video services being brought into mobile is also becoming a reality [3]. Inline with these market dynamics, the demand for more effective technologies such as bandwidth and memory space are going to be very important in the future.

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Rate control (RC) plays an essential role in adjusting the 3D video quality to satisfy the channel bandwidth constraint and the decoder buffer constraint, RC algorithms has been widely studied this years. For 2D video, RC algorithms mainly research on rate distortion model [4, 5], visual attention [6, 7] and frame complexity [8, 9]. Recently a number of projects have begun work on RC in 3D video research areas, such as guiding by visual attention [10] or visual sensitivity perceptual characteristics [11]. In [12], a multi-view video coding (MVC) RC algorithm is proposed to reasonably allocate bit-rate among views based on statistical analysis. In [13], a joint buffer-related RC algorithm considering the special characteristics of multi-view hypothetical reference decoder for MVD is presented. In [14], video quality metric (VQM) with an evolution strategy algorithm is used to identify the best possible QP for both color and depth map videos. In [15], a distortion-quantization relationship of left and right views is characterized as to control the rate in asymmetric-quality stereoscopic video.

In this paper, we propose three RC methods to allocate target bits for stereoscopic video. In the separate buffer RC (SBRC) method, left and right views control the rate with respective buffer. The united buffer RC (UBRC) and the improved united buffer RC (I-UBRC) methods control the rate based on the united buffer, they are both performed on three levels, namely stereoscopic group of pictures (SGOP) level, stereoscopic frame (SFrame) level and frame level. The UBRC method reasonably allocate bits based on the mean absolute difference (MAD) of left and right images in frame level, then carry out rate controlling and achieve a good weighted PSNR. However, in the UBRC method, the equal allocation strategy is used in SFrame level, and the bit allocation is determined only by current MAD in the frame level. The MAD only reflects one frame coding information, we should have the information to measure the complexity of the sequence, so the I-UBRC method adopts uneven allocation strategy base on image characteristics in SFrame level, and the MAD of the coded frames is also used to reasonably allocate bitrates in the frame level.

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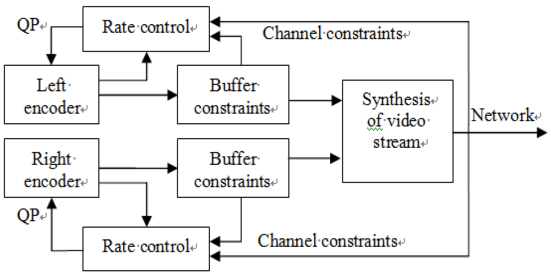
This paper is organized as follows: In Section II, we briefly describe the characteristics about buffer and assessment for stereoscopic video. The three efficient RC methods that regulated the generated bits to achieve the target bits for stereoscopic video coding are proposed in Section III. Then, the experimental results are analyzed in Section IV. Finally, the conclusions are given in Section V.

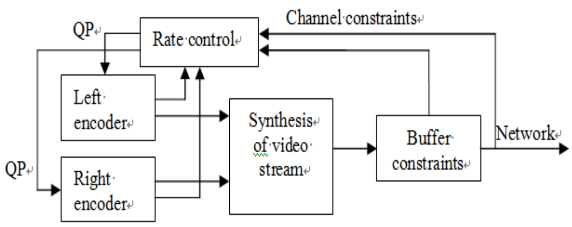
II. RELATED WORKS

How to allocate bandwidth resources to get the best stereoscopic visual effects is the essential problem in video stereoscopic video transmission. Meanwhile, we should make full use of given bandwidth, the actual bit rate cannot be much lower than the target bandwidth, neither nor exceed it. If the rate allocation and controlling problems are not solved, the good and stable decoded video quality cannot be achieved in a given bandwidth.

The inherent characteristics of the stereoscopic video: Compared with the monocular video, two views, and the reference relation in stereoscopic video are more complicated. The two natural ideas about bit allocation are thought because there are two views in stereo video. First, the target bits are allocated for left and right views with their own buffer, as shown in Fig.1(a), QP is determined according to their own bandwidth and residual information. It is worth noting: the residual of right view is obtained based on disparity estimation and motion estimation. Second, left and right views share the same buffer in the total bandwidth, as shown in Fig.1(b), and determine the QP in the given total bandwidth and the same buffer constraints.



(a) Separate buffer



(b) United buffer

Figure 1. Block diagram of the separate buffer and the united buffer

For the separate buffer method, its technical difficulty is the realization of variable exchange mechanism and a simple interpolation for the B frame in single channel is not suitable for the right channel which has a large number of B frames. The problem of the united buffer method is to determine the target bit numbers of stereoscopic image pair, then how to carry out reasonable bit allocation between left and right views.

Strategy about B frame based on buffer for monocular video [16] is of reference value to the design of the separate buffer method, but it does not consider the difference of B frame in the right channel: Some B frame are used as reference frame while others are not. Relative to the unified buffer method, an effective bit allocation method that assigns the target number of bits to pictures is proposed and improves the overall quality of images encoded by a hierarchical-based encoder [17].

In the stereoscopic video, stereoscopic effect in the form of stereo image pairs is presented to the audience. Distortion measures of video quality are based on subjective or objective. The research about subjective assessment for a single channel is not very mature, but even less for stereoscopic video. The certain poor quality is allowed between left and right views at the same stereo video subjective quality [18]: the value is 2dB will be a safe bound. In addition, the average PSNR is applied in many stereoscopic video methods [19, 20]. Therefore, the average PSNR is used to measure the stereo video quality while considering the poor quality in this paper. The rate-distortion model of stereoscopic video coding is described as

$$\begin{aligned} &\text{Maximize} \quad PSNR_{LR} = \frac{PSNR_L + PSNR_R}{2} \\ &\text{Subject to} \quad \begin{cases} |PSNR_L - PSNR_R| \le \delta \\ R_L + R_R \le R_{LR} \end{cases} \end{aligned} \tag{1}$$

where $PSNR_L$ and $PSNR_R$ denote the coding distortion of the left and right views, respectively, and δ is the maximum value of the poor quality. R_L and R_R denote the coding bits of the left and right views, respectively, and R_{LR} denotes the target bits for the stereoscopic video.

III. THE PROPOSED RATE CONTROL ALGORITHM

After the above discussion about the buffer and evaluation, we propose three RC methods for stereoscopic video. In the proposed SBRC method, left and right views carry out rate controlling in their respective given target bandwidth with their personal buffer. In the proposed UBRC and I-UBRC methods, the RC algorithm is divided into SGOP level, SFrame level and the Frame level. Two independent GOPs of left and right views are defined as a stereoscopic GOP (SGOP), a pair of the left and right frame is defined as a stereoscopic frame (SFrame).

A. Separate Buffer Rate Control (SBRC)

In SBRC method, left and right views respectively implement the rate controlling, and they are of the same allocation strategy. The block diagram of this method is shown in Fig.2. Firstly, in each view, target bits and initial QP are computed according to the available bandwidth. Then, target bits are allocated for GOP. Finally, QPs are computed for frames based on the corresponding R-Q model in frame level RC stage.

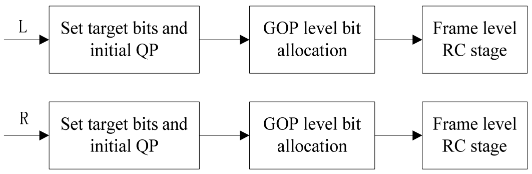


Figure 2. Block diagram of the proposed SBRC method

GOP level bit allocation: The total number of target bits for current GOP is updated frame by frame as

$$T_{GOP}(i,j) = T_{GOP}(i,j-1) - A(i,j-1) \quad (2)$$

where $T_{GOP}(i, j)$ denotes the target bits for the j-th frame in the i-th GOP, and $A(i, j)$ denotes the number of bits generated by the j-th frame in the i-th GOP.

Frame level rate control: By considering the remained bits, the first candidate target bits for the j-th frame in the i-th GOP are calculated as

$$\hat{T}(i,j) = \frac{T_{GOP}(i,j)}{N_{p,r}} \quad (3)$$

where $N_{p,r}$ is the number of the remaining P frames in the i-th GOP.

Meanwhile, considering the buffer constraints, the second candidate target bits for the j-th frame in the i-th GOP are calculated by

$$\widetilde{T}(i,j) = \frac{B}{F_r} + \gamma * (TB(i,j) - CB(i,j)) \quad (4)$$

where $CB(i, j)$ denotes the current buffer fullness, $TB(i, j)$ denotes the target buffer level, F_r is the frame rate, B is the available bandwidth, and γ is a constant and its value is 0.75.

The target bits is a weighted combination of $\hat{T}(i,j)$ and $\widetilde{T}(i,j)$

$$T(i,j) = \beta * \hat{T}(i,j) + (1-\beta) * \widetilde{T}(i,j) \quad (5)$$

where β is a constant and its value is 0.5.

Finally, the quantization step-size Q_{step} (i, j) can be computed by the quadratic R-Q model

$$T(i,j) = a_1 \times \frac{MAD(i,j)}{Q_{step}(i,j)} + a_2 \times \frac{MAD(i,j)}{Q_{step}^2(i,j)} + H(i,j) \quad (6)$$

where a_1 and a_2 are the model parameters, $H(i, j)$ is the sum of header bits and motion bits, $MAD(i, j)$ is the mean absolute difference between the original frame data and its prediction data.

B. United Buffer Rate Control (UBRC)

The SBRC method does not fully consider the correlation of the two views and network bandwidth requirements. In order to more fully utilize stereoscopic video features and better meet the bandwidth requirements, left and right views controlled with a united buffer. The UBRC method considers the different complexity between left and right views, and allocates bits according to the frame MAD in the frame level.

The block diagram of the proposed UBRC method is shown in Fig.3. It consists of three stages: 1) SGOP level bit allocation stage; 2) SFrame level bit allocation stage; 3) frame level RC stage. In the proposed UBRC method, total target bits and initial QPs are firstly set. Then target bits for SGOP and SFrame are allocated. Finally, in frame level RC stage, target bits are allocated and the quadratic R-Q model is used to compute QP for left and right frames.

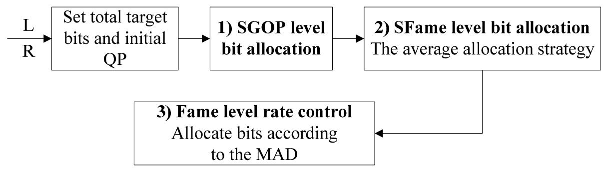


Figure 3. Block diagram of the proposed UBRC method

SGOP level bit allocation: In stereoscopic video, left-right image pairs are represented and encoded in a joint mode, the total number of target bits for current SGOP is updated as

$$T_{SGOP}(i,j) = T_{SGOP}(i,j-1) - A_L(i,j-1) - A_R(i,j-1) \quad (7)$$

where $T_{SGOP}(i,j)$ denotes the target bits for the j-th SFrame in the i-th SGOP, and $A_L(i,j)$ and $A_R(i,j)$ denote the number of bits generated by left and right frames of the j-th SFrame in the i-th SGOP, respectively.

SFrame level bit allocation: The task in this stage is to establish the target bits allocated to a SFrame. The target bits of a SFrame are determined based on its buffer level and remained bits in the SGOP.

By considering the remained bits, the first candidate target bits for the j-th SFrame in the i-th SGOP are calculated by

$$\hat{T}_{LR}(i,j) = \frac{T_{SGOP}(i,j)}{N_{p,r}} \quad (8)$$

where $N_{p,r}$ is the number of the remaining SFrames in the i-th SGOP.

Meanwhile, the second candidate target bits for the j-th SFrame in the i-th SGOP are calculated by considering the buffer constraints. $TB_{LR}(i,2)$ is the actual buffer occupancy after coding the first SFrame in the i-th GOP, the target buffer level for the subsequent SFrames is determined by

$$TB_{LR}(i,j) = TB_{LR}(i,j-1) - \frac{TB_{LR}(i,2)}{N_{p,r} - 1} \quad (9)$$

$$\widetilde{T}_{LR}(i,j) = \frac{B}{F_r} + \gamma * (TB_{LR}(i,j) - CB_{LR}(i,j)) \quad (10)$$

where CB_{LR} (i, j) denotes the current buffer fullness, TB_{LR} (i, j) denotes the target buffer level. The target bits for a SFrame are finally expressed as a weighted combination of $\hat{T}_{LR}(i,j)$ and $\widetilde{T}_{LR}(i,j)$

$$T_{LR}(i,j) = \beta * \hat{T}_{LR}(i,j) + (1-\beta) * \widetilde{T}_{LR}(i,j) \quad (11)$$

Frame level rate control: In the frame level, the MAD as the frame complexity is used to reasonably allocate the target bits for left and right frames

$$ratio = \frac{MAD_L(i,j)}{MAD_L(i,j) + MAD_R(i,j)} \quad (12)$$

where $MAD_L(i,j)$ and $MAD_R(i,j)$ are the MAD of left and right frames, respectively. The *ratio* is the MAD ratio between left and left-right frames. Then, $T_L(i,j)$ and $T_R(i,j)$ are computed as

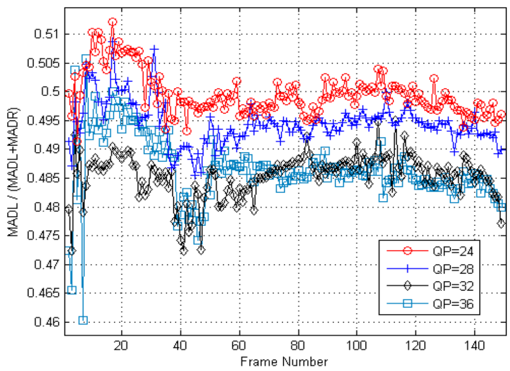
$$T_L(i,j) = T_{LR}(i,j) * ratio * \alpha \tag{13}$$

$$T_R(i,j) = T_{LR}(i,j) - T_L(i,j) \tag{14}$$

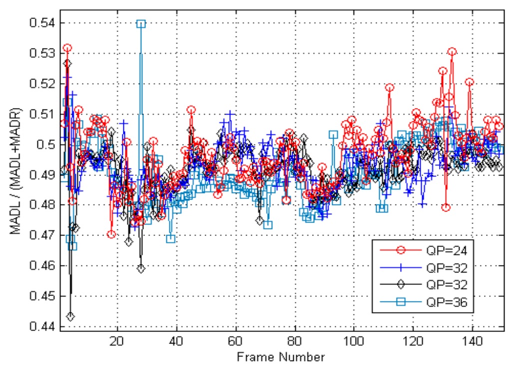
From the reference relationship of the coding structure, the left view is the main view which places a greater impact on video quality, so it is given a right weight α to adjust the rate allocation value closing to 0.6, the specific values of α identified from the following experiment.

Finally, left and right frames compute QP based on the quadratic R-Q model according to the corresponding target bits, respectively.

***α* value determination:** From the reference relationship of the coding structure, we can draw that the left view is important than the right view. α is used to quantify the importance of the left view and the bandwidth rational allocation. Through SBRC method experiments we can find that the optimal proportion of the view bit rate allocation is roughly 0.6:0.4. Therefore, UBRC method not only considers image coding complexity, but also let the target bits proportion of left view is 0.6. Experiments were firstly conducted over stereo video sequences of Aquarium and Crowd (320x240) to analyze the *ratio* of the left view to determine the optimum α value. Each sequence is 150 frames and the fixed QP coding is set to 24,28,32,36, respectively. The experimental results are shown in Fig.4.



a. *ratio* of Aquarium



b. *ratio* of Crowd

Figure 4. ratio of left view

As can be seen from Fig. 4, the ratio is not only relevant to sequence but also associated with bandwidth, but on the whole, the values of ratio generally are fluctuate around 0.5. Therefore, if the proportion of left-view bitrate is 0.6, α is set to 1.2.

C. Improved-United Buffer Rate Control (I-UBRC)

SFrame level bit allocation in the UBRC method does not consider the image self-characteristics with only using the average allocation strategy, and the frame level bit allocation barely considers the complexity of current frame relative to the whole video. In order to facilitate the RC for stereoscopic video, the I-UBRC method not only reasonably allocate the bitrates for each SFrame based on MAD in the SFrame level, but also the MAD of the coded frames is used for bit allocation in the frame level. The block diagram of the proposed I-UBRC method is shown in Figure 5.

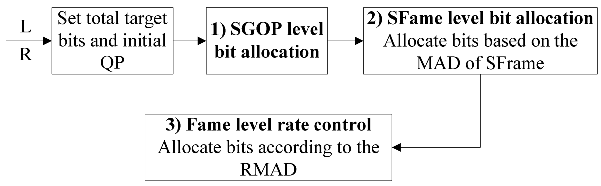


Figure 5. Block diagram of the proposed UBRC method

SGOP level bit allocation: It is the same to the SGOP level bit allocation in the UBRC method.

SFrame level bit allocation: The average allocation strategy in the SFrame level of the UBRC method is not very reasonable. $RMAD_{LR}$ is the ratio between current SFrame and the encoded SFrames, it is a simple and effective way to measure the relative complexity of SFrame. $RMAD_{LR}$ is calculated by

$$MAD_{LR}(i,j) = MAD_L(i,j) + MAD_R(i,j) \tag{15a}$$

$$AMAD_{LR}(i,j) = \frac{1}{j-1}\sum_{k=1}^{j-1} MAD_{LR}(i,k) \tag{15b}$$

$$RMAD_{LR}(i,j) = \frac{MAD_{LR}(i,j)}{AMAD_{LR}(i,j)} \tag{15c}$$

where $MAD_{LR}(i,j)$ is the MAD of current SFrame and $AMAD_{LR}(i,j)$ is the average MAD of encoded SFrames.

In order to be reasonably used for bit allocation, the RMADLR is nonlinear quantified by

$$C(i,j) = \begin{cases} 0.5 & RMAD_{LR} \le 0.8 \\ 0.6RMAD_{LR} & 0.8 < RMAD_{LR} \le 1.0 \\ 0.7RMAD_{LR} & 1.0 < RMAD_{LR} \le 1.8 \\ 1.8 & RMAD_{LR} > 1.8 \end{cases} \tag{16}$$

In addition, analysis shows that the position of the P frame also affects video quality, such as the previous P frame is more important than that behind, so we can cite parameter to quantify the P frame importance. Considering these two factors, allocation factor is calculated by

$$CI_{LR}(i,j) = C(i,j) + \zeta * \frac{N_{p,r}}{N_{SGOP}} \tag{17}$$

where ζ is a constant and its value is 1/6, N_{SGOP} is the number of the sFrames in a SGOP. Then, allocation factor is applied to the bit allocation in SFrame level. Equation (8) and equation (9) can be further adjusted as

$$\hat{T}_{LR}(i,j) = \frac{T_{SGOP}(i,j)}{N_{p,r}} * CI_{LR}(i,j) \tag{18}$$

$$TB_{LR}(i,j) = TB_{LR}(i,j-1) - \frac{TB_{LR}(i,2)}{N_{p,r}-1} * \frac{\sigma}{CI_{LR}(i,j)} \quad (19)$$

where σ is a constant and its value is 0.55.

Frame level rate control: The rate allocation is determined by MAD in the frame level of the UBRC method, but the MAD only reflects a frame coding information, we should have the information to measure the complexity of the whole video, so the *RMAD* is used in the frame level.

$$RMAD_L(i,j) = \frac{MAD_L(i,j)}{AMAD_L} \quad (20a)$$

$$RMAD_R(i,j) = \frac{MAD_R(i,j)}{AMAD_R} \quad (20b)$$

where $AMAD_L(i,j)$ and $AMAD_R(i,j)$ denote the average MAD of the encoded left and right frames, respectively. Equation (12) can be further modified as

$$ratio = \frac{RMAD_L(i,j)}{RMAD_L(i,j) + RMAD_R(i,j)} \quad (21)$$

Finally, $T_L(i,j)$ and $T_R(i,j)$ are recalculated using *ratio*. Left and right frames compute QP based on the quadratic R-Q model according to the corresponding target bits, respectively.

IV. Experimental Results and Analyses

To evaluate the performance of the proposed three RC method, six representative stereoscopic video sequences with different spatial resolutions, i.e., 'Aquarium' and 'Crowd' with the size of 320×240, 'Akko' and 'Rena' with size of 640×480, 'Soccer' and 'Puppy' with size of 720×480, were used in the experiments. The six test sequences are shown in APPENDIXE. In the experiments, IPPP coding structure was used to encode these sequences, and the SGOP size was set to 15. The total number of encoded frames in each view was 150. The target bitrates are generated by coding the test sequences with fixed QPs, and the fixed QP is set to 22, 27, 32 and 37.

A. Stereoscopic Video Rate Control Accuracy

Tab.1 summarizes average PSNR and the matching accuracy between the actually bitrate and the target bitrate. It can be seen from the Table 1 that the absolute inaccuracies of the proposed three rate control methods is within 0.62%, 0.38% and 1.91%, respectively. The SBRC method can achieve good control accuracy because the left and right views execute rate controlling independently. The I-UBRC method allocates bitrates based on the relative complexity of each SFrame in SFame level, the bits allocation fluctuation is large and controlling is poor. Hence, the rate control accuracy of the I-UBRC method is slightly lower than that of the SBRC and UBRC methods. To conclude, the proposed three methods can provide certain degree of rate control accuracy, Tab.1 has illustrated it.

TABLE 1.

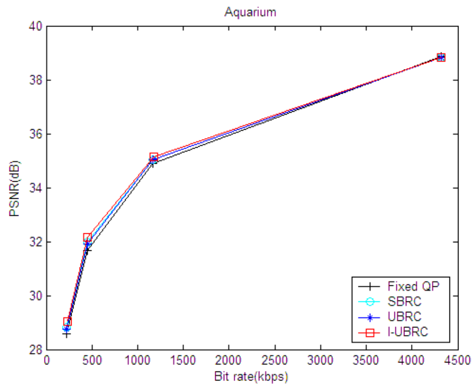
ACCURACY OF THE THREE RATE CONTROL METHODS

Sequence	Target (Kbps)	Bitrate (Kbps)			Average PSNR (dB)				Inaccuracy (%)		
	Fix QP	SBRC	UBRC	I-UBRC	Fix QP	SBRC	UBRC	I-UBRC	SBRC	UBRC	I-UBRC
Crowd	2710.75	2710.77	2710.73	2710.59	35.36	35.48	35.41	35.44	0.00%	0.00%	0.01%
	1399.04	1399.74	1399.93	1401.94	31.29	31.48	31.43	31.52	0.05%	0.06%	0.21%
Aquarium	1169.01	1166.58	1168.09	1171.75	34.90	35.05	35.02	35.15	0.21%	0.08%	0.23%
	450.99	451.88	451.11	453.64	31.66	31.97	31.92	32.17	0.20%	0.03%	0.59%
Akko	1565.61	1567.07	1568.51	1580.86	40.40	40.54	40.58	40.72	0.09%	0.19%	0.97%
	826.94	831.02	828.32	836.75	37.23	37.51	37.60	37.76	0.49%	0.17%	1.19%
Rena	1457.52	1458.53	1459.85	1462.39	42.66	42.71	42.77	42.85	0.07%	0.16%	0.33%
	718.52	721.64	719.02	722.25	39.55	39.68	39.73	39.80	0.43%	0.07%	0.52%
Soccer	2902.55	2903.41	2905.01	2906.79	38.44	38.49	38.57	38.60	0.03%	0.08%	0.15%
	1334.73	1335.67	1334.46	1340.51	35.69	35.76	35.84	35.92	0.07%	0.02%	0.43%
Puppy	862.94	866.59	866.12	875.31	38.20	38.29	38.24	38.47	0.42%	0.37%	1.43%
	446.41	449.17	448.11	455.06	35.48	35.35	35.40	35.66	0.62%	0.38%	1.94%

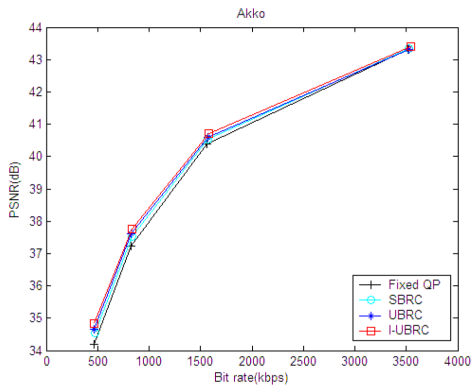
B. Stereoscopic Video Quality Comparison

The rate-distortion (RD) performance comparison results between the three methods and fixed QP coding are shown in Fig. 6. Compared with the fixed QP method, the proposed three RC methods can achieve almost the comparable RD performance under the same target bit. In addition, coding efficiency of I-UBRC method is the highest, followed is UBRC method, then is the SBRC method, finally is fixed QP coding.

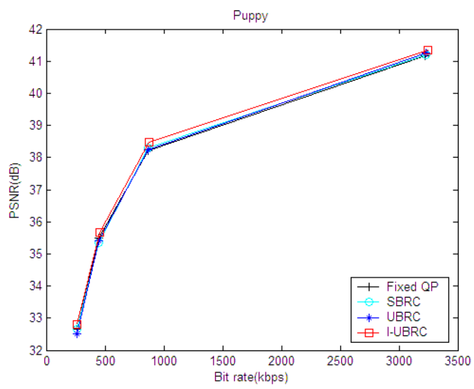
The PSNR differences of consecutive frames under target bits obtained fixed QP=27 with three methods is shown in Fig.7. It can be seen that the PSNR curve of the I-UBRC fluctuates slightly higher than that of the SBRC and UBRC, but the PSNR of all frames with the I-UBRC method is higher than other methods. In other words, the whole PSNR of the I-UBRC moves up.



(a) Aquarium

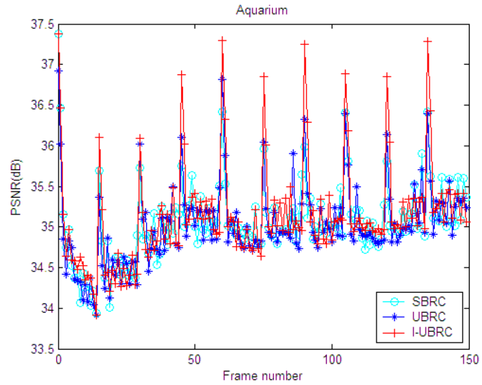


(b) Akko

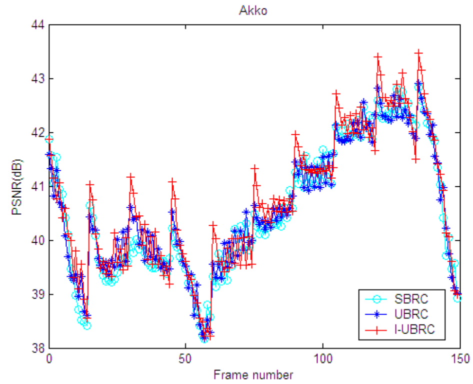


(c) Puppy

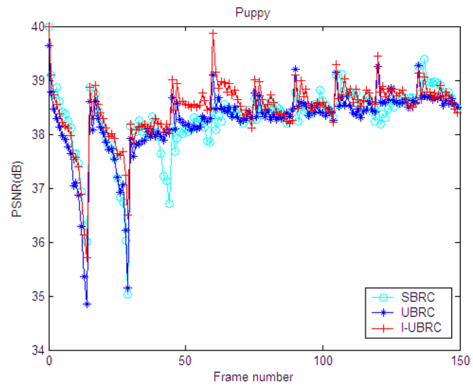
Figure 6. The RD performance comparisons between the three methods and Fixed QP coding



(a) Aquarium



(b) Akko



(c) Puppy

Figure 7. The PSNR fluctuation comparisons between the three methods

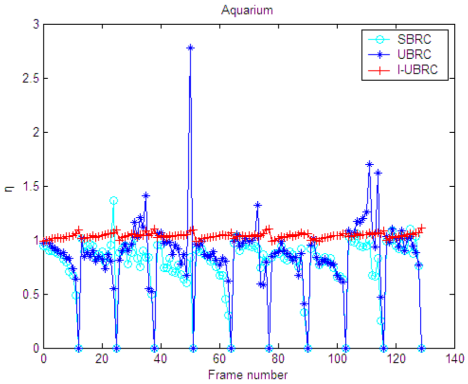
C. Stereoscopic Video Buffer Control

The buffer control accuracy is computed by

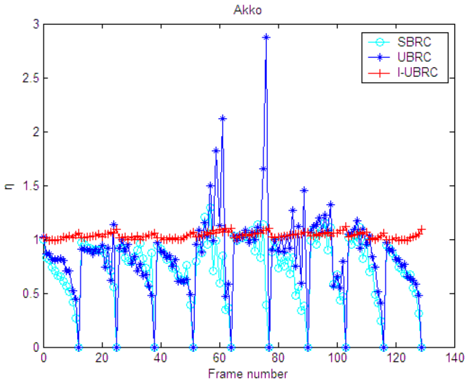
$$\eta = \frac{TB(i, j)}{CB(i, j)} \tag{22}$$

When the value of η is closer to 1, it indicates that the current buffer fullness is closer to the target buffer level and the buffer controlling is accurate.

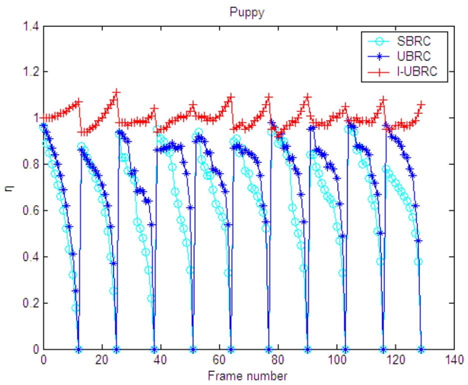
Fig. 8 shows the value of η fluctuation comparisons between the three methods under target bits obtained fixed QP=27. The I Frame and the first P Frame of the SGOP are removed because they are coded without buffer control. For the proposed I-UBRC method, the value of η is around 1, the fluctuation tends to be more stable. In other words, the proposed I-UBRC method can maintain suitable buffer control accuracy to prevent buffer from overflow and underflow compared with the buffer control of the proposed SBRC and UBRC methods.



(a) Aquarium



(b) Akko



(c) Puppy

Figure 8. The value of η fluctuation comparisons between the three methods

V. Conclusions

In this paper, three rate control methods are proposed for mobile stereoscopic video. In the SBRC method, left and right views carry out rate controlling in their respective given target bandwidth with their personal buffer. In the case of the given total bandwidth and a united buffer, the UBRC method reasonably allocate bitrates based on the MAD of left and right images in the frame level and the I-UBRC method maintains the constant quality by allocate bitrates among left and right views rationally according to the MAD ratio in the SGOP level. Experimental results show that the proposed three methods orient bit allocation and can accurately control the bit-rate as well as the high video quality.

Appendix

(a) Aquarium

(b) Crowd

(c) Akko

(d) Rena

(e) Soccer

(f) Puppy

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