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Bit Allocation Algorithm based on SSIM for 3D Video Coding

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Abstract

The 3D video system has broad application prospects and has become a new research hotspot at home and abroad in the video field. However, there are still many problems in multi-view video coding rate control in a three-dimensional video system. Therefore, this paper proposes a rate allocation algorithm based on structural similarity index measurement (SSIM) for 3D video coding. In this paper, we first analyze the correspondence between the weights of inter-view rate and the correlation between viewpoints, and then we establish the multi-view video main view and non-main view bit allocation calculation model. Finally, the view layer, frame layer, and macro block layer respectively perform bit allocation and rate control. The experimental results show that the proposed method can effectively control the bit rate of multi-view video coding while maintaining the multi-view video coding quality under limited bandwidth compared with the existing view layer fixed ratio allocation rate.

Keywords: 3D video coding; structural similarity index measurement; rate control; bit allocation

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1. Introduction

Currently, common videos are two-dimensional or unrealistic three-dimensional scenes. Multiview video is a new type of video with real three-dimensional stereoscopic and viewpoint interaction functions. Users can select and examine 360-degree 3D scenes from multiple angles with naked eyes. It has become a new hotspot for scholars at home and abroad [1-3].

The premise of rate control is to ensure that the constant output bit rate is buffered at a constant speed after the buffer is used. This problem is actually translated into ensuring that the buffer cannot overflow or underflow. Therefore, many rate control strategies both focus on the buffer filling control. Some of these methods use a large number of statistics to find the connection between the buffer filling degree and the quantization level; some adjust the quantization level directly according to the buffer level; some find a function that reflects the subjective quality and is then optimized according to the constraints of the buffer to find the corresponding relationship between the buffer filling degree and the quantization level. However, the effective rate allocation of multi-view video coding (MVC) is not only reasonable allocation of code rates between different frames but must also be reasonably distributed between the various viewpoints [4]. It is well known that for the same video, the bit rate assigned to the I frame will be greater than that assigned to the B frame. Similarly, the bit rate of the base view allocation in the multi-view video is also greater than that of the non-base view point. It is more appropriate to allocate the bit rate to the specific base view and non-base view. Literature [5] uses Lagrangian. The multiplier method is used to optimize the rate distortion between viewpoints, so that the coding quality of each viewpoint tends to be consistent. However, the particularity of the base view in multi-view video is not considered. Chang et al. [6] used MPEG-2 and H.264/AVC based encoders to encode the left and right viewpoints of stereo video and established a gradient-based inter-view quantization distortion model to optimize the bit rate allocation scheme between viewpoints. However, it has a great influence on the accuracy of the rate control. In [7], by simplifying the base-point Cauchy distribution rate distortion model and analyzing the influence of base-view distortion on the quality of non-base viewpoints, a bit-distribution optimization model of base-view and non-base-view points is established. This method only considers two viewpoints. The existing MVC standard adopts a fixed ratio allocation scheme in the allocation of the view layer layer rate,

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and it is not optimized when the view layer layer rate is allocated.

There are many organizations in foreign countries engaged in research on multi-view video coding rate control, such as Germany HHI, the United States, South Korea, and Japan. In [8], a rate control based on the visual weight for multi-view video is proposed. This method allocates the number of bits according to the visual weight better, fully considers the special structure of multi-view video coding, and analyzes the QP and different levels of B-frame. In [9], a new rate control scheme is proposed for scalable video coding similar to multi-view video coding, and it achieves higher rate control accuracy. At the same time, literature [10] also targets energy scalable video coding. Based on the JND model, the macroblock layer energy control is reasonably allocated energy. In addition, some scholars have conducted research on the rate control of stereo video [11-12].

There are also many domestic and foreign scholars engaged in rate control research for multi-view video coding [13-15]. Xiao [14] proposed a scalable rate allocation algorithm for different bandwidths. Fang [15] proposed an analysis model for estimating virtual visual distortion in 3D video and used the combined frequency domain time domain analysis method to estimate the virtual visual distortion caused by the distortion of the depth image. The estimation model is accurate but complex.

The above multi-view video coding rate control algorithm does not take into account the combination of human visual characteristics for rate control. Research on human visual characteristics shows that people pay more attention to some areas with large information in the scene and are sensitive to the distortion of these areas [16-17]. Therefore, an effective subjective video quality evaluation based on the perceived characteristics of HVS is established. The method is also used to guide the specific coding process as an important research topic.

From the above analysis, it can be seen that in addition to achieving higher coding efficiency, multi-view video coding needs to meet the requirements of different channel bit rates. The MVC algorithm needs to support a flexible quality allocation strategy between different viewpoints and adopts a corresponding rate allocation strategy within the coding structure. However, the fluctuation of the video quality between the viewpoints must be limited to the range perceived by the user or required by the system to ensure video quality balance between viewpoints. To this end, multi-view video coding needs to further study low-complexity coding and reasonable code rate control to ensure video quality balance between views, and it is applied to the 3DTV/FTV system.

Different 3D videos have different video characteristics and scene parameters. Usually, different 3D videos require different bit allocations to obtain the best coding efficiency, which requires complex video pre-processing to calculate the appropriate code rate ratio. Therefore, this paper proposes an improved 3D video coding rate control algorithm after analyzing the characteristics of insufficient bit allocation between views and multi-view video coding in existing video rate control. The experimental results show that the proposed rate control algorithm based on structural similarity index measurement (SSIM) has a control accuracy of over 98%.

2. Rate Control Algorithm for MVC

The multi-view video sequence is obtained by continuously shooting the same scene by the camera array; therefore, there is a very high content correlation between the viewpoints. The strength of the correlation between viewpoints reflects how much redundancy exists between viewpoints. In this paper, the inter-viewpoint rate allocation of different multi-view video must take into account the difference in the correlation between the viewpoints.

In order to be compatible with the international coding standard H.264, the bit allocation and rate control proposed in this paper are based on the H.264 rate control algorithm, the most important of which is how to perform reasonable rate allocation between each viewpoint. The requirements of viewpoint video coding ensure the balance of video quality between viewpoints. Based on previous research, the algorithm is further improved. The key steps of the algorithm proposed in this paper are as follows.

2.1. View Level Rate Control

Before the encoding, the bits between the viewpoints are difficult to allocate. In this paper, the bits are allocated reasonably at different viewpoints according to the correlation between the viewpoints. In the architecture of multi-view video coding, the primary view is first encoded, and since the main view does not refer to other views, the generated code rate is independent. The non-primary view refers to the coded image frame of the same view and the image of the coded view to perform predictive coding, and the generated code rate has a large relationship with the reference view.

Before the 3D video coding rate control, the bits between the viewpoints are difficult to allocate, and it is impossible to accurately assign a reasonable bit to each viewpoint. We assign a weight to each viewpoint. w_k represents the weight of the K viewpoint. The total number of bits allocated to the K^{th} viewpoint GOP_K within each coded GGOP picture group is given by Equation (1).

$$T_{GOP}(n_{k,0}) = T_{GGOP}(sn_{i,0}) \cdot w_k \tag{1}$$

The weighting factor w_k of each viewpoint is obtained by Equations (2) and (3).

$$w_k = \frac{\zeta_k}{\sum_{m=0}^{N_{view}-1} \zeta_m} \tag{2}$$

$$\zeta_k = \gamma_k \times SSIM(S_k, S_o) \tag{3}$$

$SSIM(S_k, S_o)$ represents *SSIM* between S_k and S_o. *A* and *B* indicate that two different cameras acquire two images at the same time. *L*(*A*, *B*), *C*(*A*, *B*), and *S*(*A*, *B*) are the brightness comparison, contrast comparison, and structural information comparison of the two images respectively. Then, the *SSIM* between *A* and *B* can be achieved by Equation (4).

$$SSIM(A,B) = (L(A,B))^{\phi} \cdot (C(A,B))^{\varphi} \cdot (S(A,B))^{\gamma} \tag{4}$$

Among them, ϕ, φ, γ can adjust the proportion of brightness, contrast, and structural information, which is given by Equation (5).

$$L(A,B) = \frac{2E(a)E(b) + \lambda_1}{E(a)^2 \cdot E(b)^2 + \lambda_1},\ C(A,B) = \frac{2\sigma(a)\sigma(b) + C_2}{\sigma(a)^2 \cdot \sigma(b)^2 + C_2},\ S(A,B) = \frac{\sigma(ab) + C_3}{\sigma(a) \cdot \sigma(b) + C_3} \tag{5}$$

In the equation: *E*(*a*) and *E*(*b*) are the mean values of *A* and *B* respectively; $\sigma(a)^2$ and $\sigma(b)^2$ are the standard deviations of *A* and *B* respectively; $\sigma(ab)$ is the covariance of *A* and *B*; and λ_1, λ_2, and λ_3 are constants that are set to avoid instability when the denominator tends to zero.

2.2. Target Bit Rate for Frames

In order to improve coding efficiency, multi-view video coding uses a relatively complex hierarchical B-frame prediction structure, as shown in Figure 1. This predictive structure has many advantages not only to support time grading, but also to greatly improve coding efficiency. However, it brings considerable difficulties to MVC rate control. H.264 rate control only needs to control the rate of the I frame and P frame. In the hierarchical B frame prediction structure, B frames of different time layers are independent of each other. Therefore, it is necessary to solve the problem of B frame bit allocation and complexity of different frames in different time layers.

The MVC six different frame types are as follows: intraframe coding (I frame), only temporal direction unidirectional prediction, only time direction bidirectional prediction, only unidirectional prediction between viewpoints, only bidirectional prediction between viewpoints, and both time and inter-view prediction.

In the pre-allocated control strategy, the control variable is mainly the margin generated by the difference between the generated codeword and the pre-allocated codeword. The margin here can be divided into two categories: one is the margin of the previous frames. The accumulation is formed; the other is generated in this frame. The former is called inter-frame margin, while the latter is called intra-frame margin. The roles of the two are different, and the applicable control methods should be different. The inter-frame margin should be uniformly controlled throughout the entire frame, and the intra-frame margin should be controlled and adjusted within this frame.

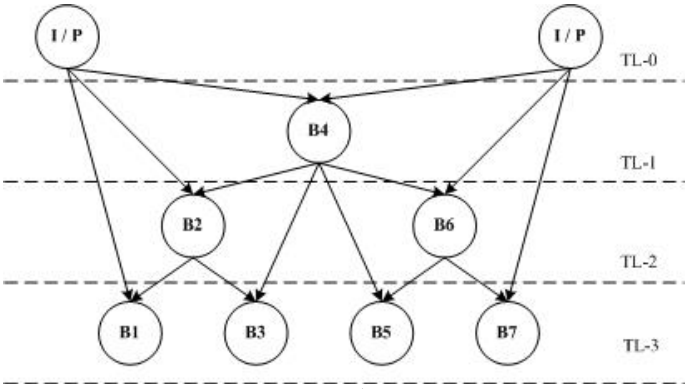

Figure 1. Hierarchical B-frame prediction structure

The number of allocated bits is allocated according to the structure and frame type of the GOP. Generally, the I frame is allocated the greatest number of bits, the P frame is allocated the next greatest number of bits, and the B frame is allocated a smaller number of bits. This is because the I frame may be used as the reference frame of the subsequent P frame and B frame, so the quality of the I frame directly affects the subsequent frame. The general B frame is not used as the reference frame of other frames, so the B frame does not affect other frames. The layer target bit number pre-allocation can be subdivided into a calculation target buffer level and an allocation target bit. The first step is to consider the cache capacity limit. The second step is to consider the network bandwidth, frame rate, and remaining bits that can be allocated in the GOP.

In the 3D video coding frame layer rate allocation, the bit allocation per frame is determined by the target buffer capacity, the frame rate, and the actual buffer size. The residual energy of the current coded frame is not taken into account, which may cause image quality degradation or frame skipping. In this paper, considering the above factors, the B-frame (or P-frame) target allocation bits $T(j)$ are calculated by Equation (6).

$$T(j)=\frac{\sum_{l=1}^{L}W(l)\cdot 2^{n}}{\sum_{l=1}^{L}\frac{SAD_{l}}{SAD_{a}}\cdot W(l)+\sum_{l=1}^{L}W_{B}(l)\cdot(2^{n}-1)}+\varphi(j) \tag{6}$$

$W(l)$ represents the weight of each frame complexity, and $W_B(l)$ represents the weight of B frame. SAD_a represents the average of the sum of absolute differences for all frames. $\varphi(j)$ is related to the current target buffer fullness.

2.3. Basic Unit Layer Rate Control

The basic unit generally refers to a frame or a macroblock. If the basic unit layer is a frame, the main task of the layer rate control is to adjust the quantization parameter of the frame according to the target number of bits of the current frame. If the basic unit layer is a macroblock, the main task of the layer rate control is to further adjust the quantization parameter of the macroblock according to the image complexity of each macroblock on the premise of determining the target number of bits of the frame. At the same time, in order to satisfy the smoothness of the visual, it is necessary to ensure that the difference between the quantization parameter of the basic unit layer and the quantization parameter of the previous basic unit layer is not too large, and the difference between the average quantization parameter values of all the basic unit layers of the previous frame is also not too large. The rate control algorithm flow of the basic unit layer is similar to the previous research results in reference [18]. The detailed block diagram is shown in Figure 2.

According to the early H.264 basic unit layer rate control algorithm, the basic unit layer bit allocation evenly distributes the allocated bits of each frame to each basic unit layer of the frame. Thus, all macroblocks in the same basic unit layer are encoded with the same quantization parameters. However, in reality, different macroblocks in the same basic unit layer have great differences, and even macroblocks in the same basic unit have great differences in image content, texture, active time domain, and other complexities. Therefore, in order to control the 3D video coding rate more accurately, this paper uses different quantized values according to the active time domain and complexity of its macroblock, and it is calculated by Equation (7).

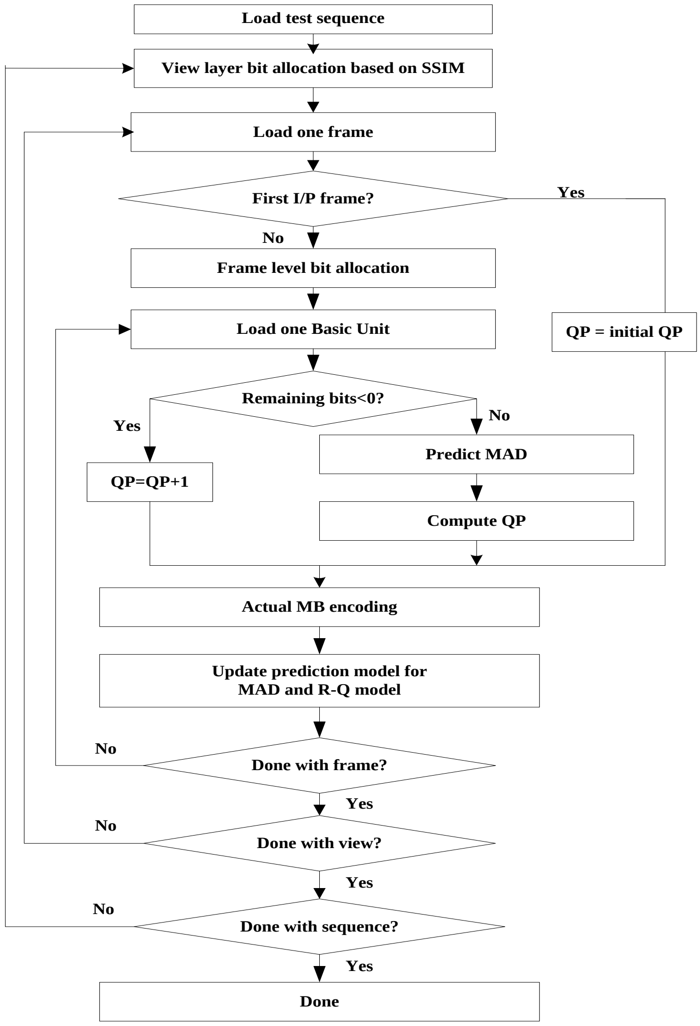

Figure 2. Rate control algorithm based on SSIM for MVC

$$T_U = \frac{fd_{mbi}}{fd_{unit}} \cdot \frac{f_r(n_{i,j})}{N_{ub}} + \gamma_u \tag{7}$$

In the above formula, $f_{rb}(n_{i,j})$ and N_{ub} represent the remainder bits of current frame and the number of remainder units, respectively. fd_{mbi} and fd_{unit} respectively represent the activity of the i^{th} macroblock in the current basic unit layer. As the predicted value of the domain and the predicted value of the active time domain of the current base unit, γ_u is related to the current target buffer fullness.

3. Experimental Results

In order to verify the rate control algorithm proposed in this paper, four standard 3D test sequence tests such as Exit, Ballroom, Vassar, and Flamenco2 are used in this paper. In this paper, the rate control algorithm is compared with reference [15] and the multi-view rate control algorithm with fixed bit allocation.

The PSNR fluctuation diagram is given from Figure 3. Compared with reference [15], the rate control algorithm proposed in this paper has relatively small PSNR fluctuations, and the frame quality changes before and after are relatively stable and have better visual effects. It can be seen from the above results that the PSNR variation of the model rate control algorithm is small, which ensures a smooth transition of image quality and does not appear visually obvious. Image quality changes; the image quality using the fixed rate control algorithm is low and has large fluctuations. Due to the limited space, this paper only gives a histogram representation of the rate control structure of two test sequences from Figures 4 and 5.

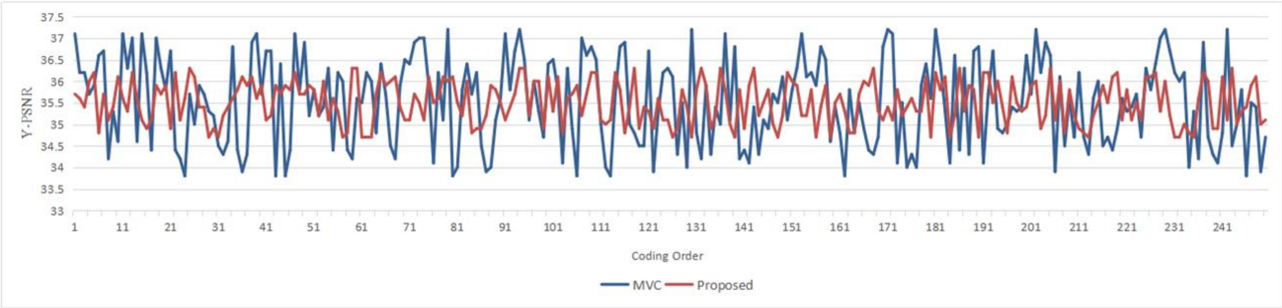

Figure 3. Objective quality fluctuations

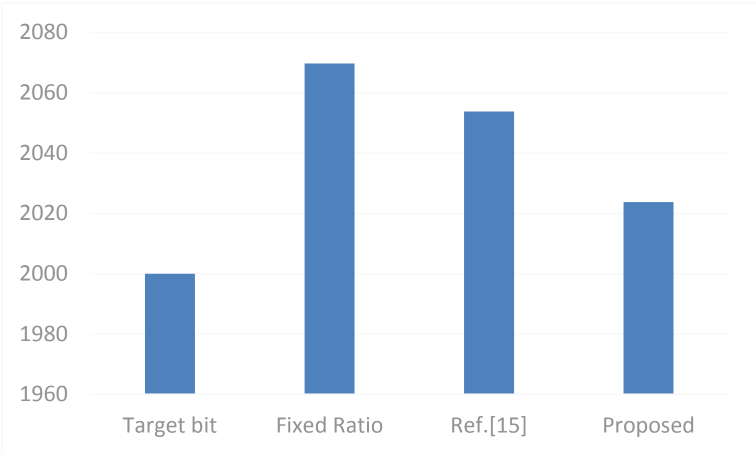

Figure 4. Ballroom sequence experiment result with histogram

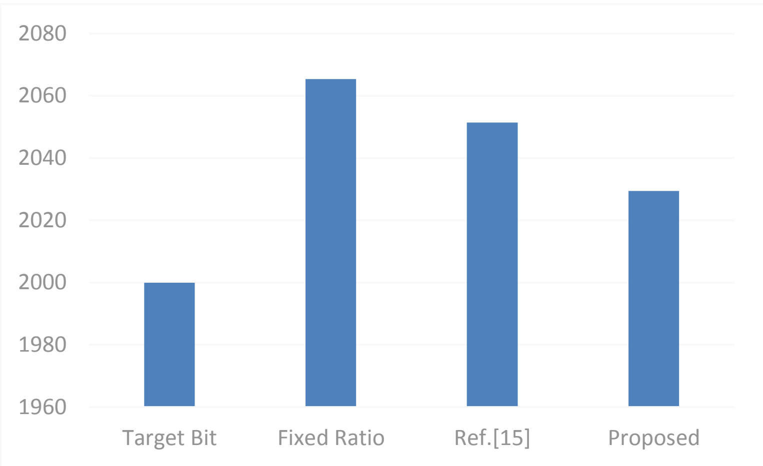

Figure 5. Vassar sequence experiment result with histogram

Table 1 shows the simulation results of multi-view video coding rate control. The target bits of Exit, Ballroom, Vassar, and Flamenco2 are 500, 1000, 1500, and 2000kbps, respectively. The code rate control errors of the three algorithms calculated from Table 1 are 3.21%, 2.18%, and 1.38%, respectively. Compared with reference [15], the rate control algorithm proposed in this paper has a more accurate code rate and a smaller code rate deviation.

In summary, the inter-viewpoint bit allocation algorithm proposed in this paper can not only effectively control the bit rate of multi-view video coding, but also has small PSNR fluctuations and improve visual effects. The main reason is that the proposed algorithm fully exploits the correlation between viewpoints, which results in not only reasonable bit allocation and rate control among views, but also the frame layer and the basic unit layer rate control.

Table 1. Simulation results

Sequences	Target Bit rate (kbps)	Fixed Ratio		Ref. [15]		Proposed	
		Actual generated bits (kbps)	Rate control error (%)	Actual generated bits (kbps)	Rate control error (%)	Actual generated bits (kbps)	Rate control error (%)
Exit	500	515.8	3.2	512.3	2.5	507.3	1.5
	1000	1026.6	2.7	1016.6	1.7	1002.6	0.3
	1500	1555.1	3.7	1546.1	3.1	1528.1	1.9
	2000	2059.4	3.0	2045.4	2.3	2017.4	0.9
Ballroom	500	518.8	3.8	514.8	3.0	509.8	2.0
	1000	1038.1	3.8	1031.1	3.1	1016.1	1.6
	1500	1537.4	2.5	1525.4	1.7	1511.9	0.8
	2000	2069.8	3.5	2053.8	2.7	2023.8	1.2
Vassar	500	513.0	2.6	508.0	1.6	501.0	0.2
	1000	1025.9	2.6	1019.9	2.0	1008.9	0.9
	1500	1540.2	2.7	1528.2	1.9	1510.2	0.7
	2000	2065.4	3.3	2051.4	2.6	2029.4	1.5
Flamenco2	500	516.7	3.3	511.7	2.3	504.2	0.8
	1000	1031.0	3.1	1025.0	2.5	1015.0	1.5
	1500	1549.1	3.3	1534.1	2.3	1513.1	0.9
	2000	2073.0	3.7	2051.0	2.6	2031.0	1.6
Average			3.1		2.3		1.1

4. Conclusions

In the research of 3D video coding algorithms, rate control has always been one of the most concerned aspects of scholars at home and abroad. For 3D video coding rate control, current research has not been carried out in depth. After analyzing the characteristics of the existing video rate control and multi-view video coding, this paper proposes a rate control algorithm based on SSIM for MVC. The algorithm basically involves the entire rate control process, from bit-to-view bit allocation to bit allocation and rate control for each macroblock, thus ensuring the accuracy of the 3D video coding rate control algorithm. In the future, we will further study the correlation between viewpoints to improve the rate control algorithm more effectively. Exploring the perceptual characteristics of the human eye to different viewpoints and the hidden features of the human eye to the auxiliary viewpoints, different coding methods and corresponding code rate allocation strategies can be adopted for different viewpoints within the coding structure to improve coding efficiency and maintain the inter-viewpoints. The fluctuation of video quality is limited to the scope of user perception or system requirements, that is, to ensure video quality balance between viewpoints, to study the visual field and time complexity of multiview video and human visual perception of different views, and to explore a target bit allocation scheme that is reasonable in different viewpoints and time domains.

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