Image Characteristic Based Rate Control Algorithm for HEVC

Mayan Fei, Zongju Peng*, Weiguo Chen, Fen Chen
Faculty of Information Science and Engineering, Ningbo University, Ningbo 315211 China
*pengzongju@126.com; fmy175@163.com

Abstract: - Rate control plays an important role in high quality video coding. In this paper, a rate control algorithm based on video characteristics is proposed. Firstly, we put forward a novel bit allocation algorithm for intra frame by analyzing the relationship among the image characteristic, bit per pixel and quantization step. The image gradient is used as image characteristic. In frame layer, different bit allocation model are applied according to frame type and assign the rational bit to frame according the complexity of video content. In largest coding unit (LCU) layer, it also chooses different strategies of bit allocation according to the type of LCU. To be more specific, the bit of a LCU without previously coded collocated LCU is assigned on the basis of its image complexity. Otherwise, the bit of a LCU is assigned by using the gradient of residual belonging to collocated LCU. Experimental results show that the proposed algorithm is better than the state-of-the-art rate control algorithm in terms of the accuracy of rate control and the coding quality, the average of PSNR has been improved by 0.15dB. Maximal PSNR gaining can reach 0.67dB.

Key-Words: - high efficiency video coding, rate control, image characteristic, largest coding unit

1 Introduction

With the continuous development of video compression and broadband network, high-definition video related applications are becoming particularly popular. However, the information in high definition video is huge, only by compressing original signal using video coding can them be effectively stored and transferred. To satisfy the increasing demands of storing and transmitting high definition video contents over the Internet, high efficiency video coding (HEVC) standard is proposed in early 2013 by the Joint Collaborative Team on Video Coding (JCT-VC) [1]. It only require a half of the bit-rate in H.264/AVC encoder to achieve the same subjective visual quality [2]. The improvement of compression ratio is largely due to the fact that HEVC adopted some new techniques such as the expanded prediction and transform block sizes with a flexible coding structure. Those new techniques pose new challenges in developing an efficient rate control for HEVC.

In video communication applications, video data is transmitted over a limited network bandwidth. To make the most effective use of the limited network bandwidth while maintaining optimized visual quality of reconstruction video, rate control play a crucial role for video compression and communication applications [3]. Superabundant or over-reduced bits stream will be produced in video encoder without an effective rate control. Accordingly, There are many rate control have been proposed for various video coding standards in past few years. For example, the test model near-term (TMN) for H.263, the joint model (JM) for H.264, etc. However, research on HEVC rate control is still left dormant. A few scholars have tried to extend some rate controls in previous video coding standards to the early version of the HEVC reference software [4]-[5]. The authors in [4] introduced the quadratic method of H.264 into the HEVC reference software. The authors in [5] studied the ρ-domain method in HEVC. Nevertheless, due to the different coding structure of HEVC from the previous video coding standards, the rate control used in previous video coding standards are not suitable for HEVC. Thus, it is urgent need to make a specific rate control on HEVC.

Recently, some research of rate control on HEVC had been done [6]-[10]. Li et al. [6][7] proposed the R-λ algorithm. It has better rate control performance, but it also has some drawbacks. i.e., for intra frames, the process of frame layer bit allocation is without considering the characteristics of video content and largest coding unit (LCU) layer bit allocation is based on the idea of average allocation, not considering characteristics of frames. For B/P frames, the weights of frames in a group of picture (GOP) are predefined and not so adaptive. Wang et al. [8] proposed a rate-GOP based frame level rate control scheme for HEVC. Though this scheme acquired a better R-D performance, it neglected the characteristic of image. Meddeb et al. [9] proposed a region-of-interest (ROI) based rate control scheme for video conference application. More bits are allocated to ROIs which are obtained by a face detection algorithm. Wang et al. [10] modified the R-λ model by using the image gradient to represent the image complexity, and adjusted the bit of LCU according to the complexity of LCU. But it is only applicable to the structure of all intra frame case.

With respect to the above shortcomings, we propose a rate control algorithm which is based on image characteristics. In frame layer, we present a bit allocation strategy for I-frame according to its image complexity, a proper number of bits are allocated to an I-frame, and a Rate-Complexity-QP (R-C-Q) model which is used to calculate the quantization step based on both its image complexity and pre-assigned bits for I-frame. In addition, we also develop a bit allocation strategy for P/B frame in accordance with its image complexity. In LCU layer, we modify the strategy of bit allocation according to different types of LCU. Experimental results demonstrate that the proposed rate control algorithm can achieve better coding quality than that of the state-of-the-art rate control strategy with less bit rate mismatching and deviation of PSNR.

The rest of the paper is organized as follows. In Section 2, we briefly describe the image complexity measurement. In Sections 3 and 4, we describe the rate control strategies for intra and inter frames, respectively. The experiment results are analyzed in Section 5. The conclusion is given in Section 6.

2 Image Complexity Measurement

In general, the encoding bits of each frame are mainly from quantized residual information and entropy coding. In [11], it has been demonstrated that there is a very strong linear relationship between the encoding bit rate and the percentage of zeros among the quantized transform coefficients. That is, the relationship can be characterized as

$$\begin{aligned} R &= \theta \times (1-\rho) \\ &= \theta \times (1-\frac{N_{zero}}{N}) \\ &= \alpha \times N_{non\_zero} \end{aligned} \tag{1}$$

where R is the encoding bits of a frame, ρ is the percentage of zeros among the quantized transform coefficients. The larger value of ρ, the less the residual information. θ and a are two model parameters. N, N_{zero} and N_{non_zero} are the total number of pixels in a frame, the numbers of zeros and the numbers of non-zeros among the quantized transform coefficients of one frame, respectively.

Since HEVC utilizes the spatial correlation of the coding unit in the process of intra prediction [12], it resulted that the number of residual signal directly related to image complexity [13]. In addition, non-zeros coefficients are from the quantized transform of residual information. We can assume that relationship between the video texture complexity and N_{non_zero} can be defined as:

$$C = k \times N_{non\_zero} \tag{2}$$

where K is model parameter. Combining (1) and (2) gives:

$$R = \beta_f \times C \tag{3}$$

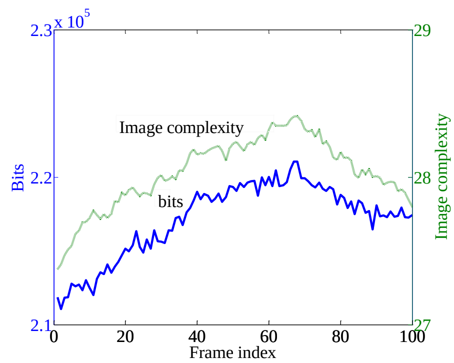
where β_f is model parameter, R and C are coding bits and the complexity of image, respectively.

At present, there are a variety of image complexity measurement methods [4][10]. For example, absolute error and gradient of image are often used to describe the image complexity. We adopt image gradient to measure the complexity of image [10]. Gradient is calculated as:

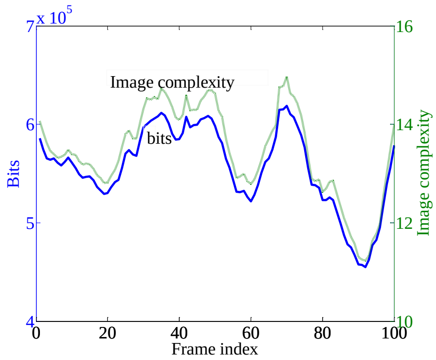
$$C = \frac{1}{H \times W} \sum_{i=0}^{H-1} \sum_{j=0}^{W-1} (\left|I_{i,j} - I_{i+1,j}\right| + \left|I_{i,j} - I_{i,j+1}\right|) \tag{4}$$

where $I_{i,j}$ is the (i, j)th luminance value in image. H and W are the height and width of image, respectively.

To verify the relationship between R and C in the formula (3), we conducted a series of experiments. Fig.1 shows the relationship between complexity of image and coded bits with sequences *BQSquare* and *RaceHorseC* when quantization parameter is 22. From the Fig.1, obvious linear relationship between R and C has been presented. The coded bits of frames are changing simultaneously with the complexity of image.



(a)



(b)

Fig. 1 The relationship between image complexity and bits. (a) *BQSquare*, (b) *RaceHorseC*.

3 Rate Control Strategy for Intra Frame

The rate control algorithm in HEVC can be roughly divided into two processes: bit allocation and quantization parameter calculation. The process of bit allocation is based on some strategy to assign the target bits which is set by users to group of picture (GOP) layer, frame layer and largest coding unit layer. The process of quantization parameter calculation is also divided into two steps: the first step is to calculate the corresponding Lagrange multiplier according to the pre-assigned bits. Another step is to calculate the quantization parameter by using the Lagrange multiplier from the first step. The purpose is making the output rate to get close the target rate.

3.1 Frame Layer Bit Allocation for Intra Frame

In the encoding process, intra frame is critical, the coding quality of which directly affects subsequent coding frames. However, with the diversification of video content, various types of movement, ranging from a single small target movement to more than one big moving targets, even to camera movement, might occur. In a relatively short period of time, intra frame may be used as reference for subsequent coding frame. But with drastic movement of objects in sequence or the camera shift, an intra-frame might be no longer used as a reference frame for subsequent coding. If the bits allocated to intra frames are not enough, the quality of subsequent coding frames will deteriorate. If the bits for intra frame are excessive, the quality of intra frame has improved. However, if intra frame are not referenced as a long term for subsequent frame, the kind of allocation strategy will cause the waste of bits, if the wasted bits of intra frame are assigned to subsequent coding frame, it is will relieve shortage of bits for follow-up frame. Based on the above analysis, we can see the bit allocation of intra frame is very essential.

To tackle the above mentioned problems, we introduce image characteristics into the intra frame bit allocation process. The allocation strategy is as follows:

$$IntraBits = \alpha_f \times \left(\frac{C_i}{bpp}\right)^{\beta_f} \times Bit_{avg} \tag{5}$$

$$bpp = \frac{Bit_{avg}}{W \times H} \tag{6}$$

$$Bit_{avg} = \frac{R_{tar}}{f} \tag{7}$$

where *IntraBits* is the pre-assigned bits of intra frame, α_f and β_f are model parameters. C_i is the image complexity of *i*-th frame, Bit_{avg} is the average bit, R_{tar} is target bit rate, f is frame rate, bpp is bit per pixel, W and H are width and height of image, respectively.

In order to verify the proposed bit allocation strategy for intra frame which incorporates image complexity, we have done some experiments. Firstly, we encoded the first 300 frames of four standard WVGA (832×480) test sequences and four standard WQVGA (416×240) test sequences using intra-pattern with different quantization (22, 27, 32, 37). Secondly, the bit rate of encoded is used as the target bit rate of the rate control, experimental conditions keep the same except the rate control is enable. After coding, we fitted the data which contain image complexity and coded bit, and found that the result is very close to the strategy which is proposed by us, the correlation coefficient is up to 0.9948.

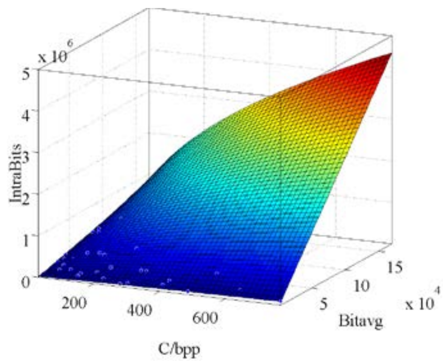


Fig.2 Intra Bit Allocation Model

3.2 LCU Layer Bit Allocation for Intra Frame

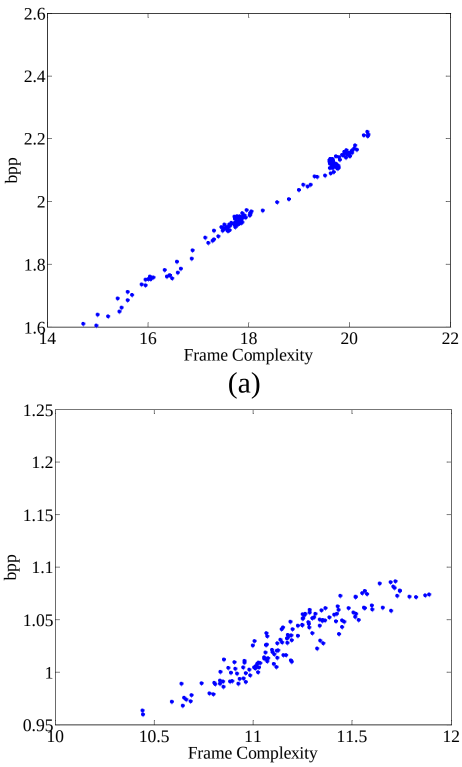
When the frame level *IntraBits* is allocated, the proposed LCU level bit allocation strategy is based on the image complexity of each LCU in the current frame.

$$T_{LCU} = \frac{IntraBits - Bit_H - Coded_{Silce}}{\sum_{i \in NotCodedLCUs} C_{LCU}} \times C_{LCUCur} \quad (8)$$

where Bit_H is the estimated header bits, which is obtained by averaging the header bits of the previous picture belonging to the same picture level. $Coded_{Slice}$ is the number of bits coded in current frame. C_{LCU} is the image complexity of LCU.

3.3 Intra Frame R-C-Q Control Model

In order to determine the relationship among bit rate of I frame, image complexity measured by gradient and quantization parameter (QP), we conducted a two-step exploration. In the first step, a series of sequences are encoded with fixed quantization parameter and the distribution of generated bits and image complexity on the frame level for different sequences are illustrated in Fig.3. From Fig.3, a strong linear relationship has been presented between image complexity and coded bits.



(b)

Fig.3 The relationship between frame complexity and bit rate at fixed QP=22. (a) *BlowingBubbles*, (b) *BasketballDrill*.

In addition, for various QPs, similar linear relationship exists as well. Therefore, it is safe that we express *R*, *C* and *QP* relationship in the following manner:

$$R(C_i, QP) = \alpha_f \times C_i \times f(QP) \quad (9)$$

where $R(C_i, QP)$ is I frame bit rate, a_f is model parameter, C_i is the image complexity of *i*-th frame calculated by (4).

In the second step, we try to find out what the function of QP should be. It is well known that QP and Q_{step} have the following relationship:

$$Q_{step} = 2^{(QP-4)/6} \quad (10)$$

where *QP* is the quantization parameter, Q_{step} is the quantization step.

According to (9) and (10), it can be derived that

$$\frac{R(C_i, Q_{step})}{C_i} = \alpha_f \times f(Q_{step}) \quad (11)$$

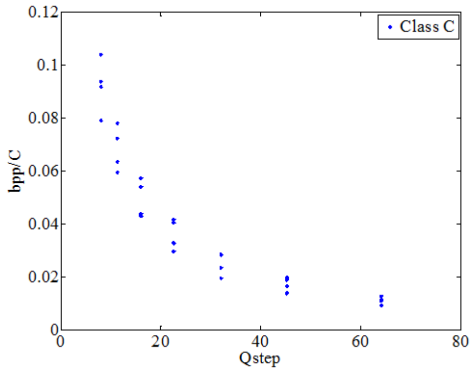
For a particular frame in the video sequence, the complexity of image is fixed. In order to determine the relation model between I frame bit rate and quantization step at a fixed image complexity, we choose the first 300 frames of four standard WVGA (832×480) test sequences and four standard WQVGA (416×240) test sequences whose video features such as texture complexity and movement degree vary and encode them as I frame. Each sequence is encoded using QP ranging from 22 to 48 at an interval of 4, and the statistic data of the 10th frame of each sequence are collected to find out the rate-complexity-quantization (R-C-Q) relationship. Fig.4 shows the distribution of bit rate and QP of the 10th frame in some sequence at different QPs. Q_{step} and *bpp/c* in the Fig.4 are quantization step, the result of *bpp* divided image complexity measured by gradient, respectively. From Fig.4, we can observe that I frame bit rate fits power function with Q_{step} very well at all quantization levels, which is expressed as follows:

$$\frac{bpp}{C_i} = \alpha \times (Q_{step})^{\beta} \quad (12)$$

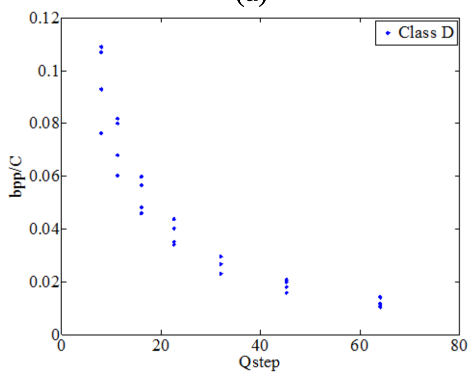
where Q_{step} is quantization step, α and β are model parameters. Based on our experiments, we have found that typical values of β are in the range of -1.037 to -0.8402, and α in the range of 0.4968 to 0.8161. For simplicity, the moderate parameters are initialized as α = 0.6564, β = -0.9385. During our parameter updating procedure, the value of β is fixed and the parameter α is updated by using:

$$\alpha_{i+1} = \varepsilon\alpha_i + (1-\varepsilon)\frac{bpp}{C_i \times Q_{step}^{\beta}} \tag{13}$$

where ε is a forgetting factor with typical value of ε = 0.5, C_i is the image complexity of i-th frame calculated by (4).



(a)



(b)

Fig.4 the relationship between Q_{step} and bpp/C at different Q_{step}. (a) Class C, (b) Class D.

4 Rate Control Strategy for P/B Frame

4.1 Frame Layer Bit Allocation Strategy

In K0103, hierarchical bit allocation algorithm is used for rate control. We use simple low delay coding structure to illustrate the rationale, which is shown in Fig.5. $f4n$+1, $f4n$+3 and $f4n$+5 belong to the first level; $f4n$+2 and $f4n$+6 belong to the middle level; $f4n$+4 and $f4n$+8 belong to the last level. The frame level target bit is assigned according to the weight of each frame, without considering the complexity of the image characteristic between frames. This might lead to the side effect of allocation too many bits to smooth areas while complex areas lack in bits. In order to overcome this shortcoming, we use the formula (4) to calculate the complexity of the current frame, and the bit allocation strategy for P/B frame is defined as:

$$T_{Slice} = \frac{T_{GOP} - Coded_{GOP}}{\sum_{i \in NotCodedSlice} \omega_i} \times \omega_{SliceCur} \times \frac{N_{Slice} \times C_{Slice}}{\sum_{i \in N_{Slice}} C_i} \tag{14}$$

where T_{GOP} is target bits of a GOP, N_{Slice} is the GOP size, C_{Slice} is the complexity of image, $Coded_{GOP}$ is the number of bits in the current GOP, $\omega_{SliceCur}$ is the weight of picture level bit allocation for current picture.

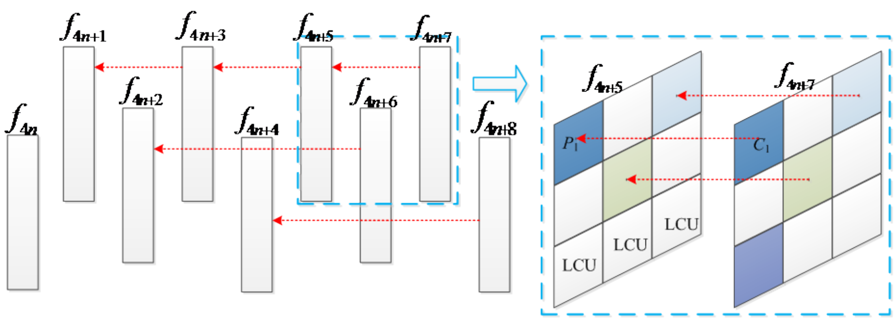


Fig.5 Pictures level under low delay coding structure

4.2 LCU Layer Bit Allocation Strategy

In K0103, LCU layer bit rate allocation is calculated according to the prediction error (in form of mean absolute difference (MAD)) of collocated LCU in the previous coded frame belonging to the same level, as Fig.5 shows. For example, if the current coding LCU is C_1which belongs to $f4n$+7, the MAD of the P_1 in $f4n$+5 is used as the reference of C_1. In addition, MAD is calculated by:

$$MAD_{LCU} = \frac{1}{N_{pixels}} \sum_{\{AllPixelsInLCU\}} \left| P_{org} - P_{pred} \right| \tag{15}$$

where N_{pixels} is the number of pixels in the current LCU, P_{org} and P_{pred} are the pixel value of the original signal and the pixel value of the predicted signal, respectively.

However, the prediction signal is inaccurate. On the one hand, the error prone P_{pred} is optimal in the LCU sense rather than globally optimal. To be more specific, the predicted LCU is obtained by traversing only available modes at depth zero and selecting the one leading to minimal rate distortion (RD) cost, rather than by the normal LCU recursive coding strategy. However, the normal LCU recursive coding strategy checks the available modes at all depths and finds the optimal predicted LCU. On the another hand, We can't find an accurate prediction block with a once motion estimation for LCU due to the fact that the size of LCU is 64×64, and video content exist diverse motion object. Furthermore, in the process of inter frame coding, since HEVC has introduced a new coding technique which names merge mode on the basis of SKIP mode in H.264. SKIP or MERGE mode is used in the most of region within a frame, and this area is just not produce residual. Those areas only need a small amount of bits to transmit the index of encoding mode.

Through the above analysis, we use the gradient of residual which is acquired after accurately motion estimation of LCU to substitute MAD. Let $res_{i,j}$ be the pixel value of (i, j) position in residual frame, and define ε_i as the gradient of residual LCU. The formula is as follows:

$$\varepsilon_i = \frac{1}{H \times W}\sum_{i=0}^{H-1}\sum_{j=0}^{W-1}\left(\left|res_{i,j} - res_{i+1,j}\right| + \left|res_{i,j} - res_{i,j+1}\right|\right) \tag{16}$$

where W is width of LCU, H is height of LCU.

Thus, the bit allocation strategy on the LCU layer is modified to:

$$T_{LCU} = \frac{T_{Slice} - Bit_H - Coded_{Silce}}{\sum_{i \in NotCodedLCUs} \varepsilon_i} \times \varepsilon_{LCUCur} \tag{17}$$

5 Experimental Results

In order to verify the proposed rate control algorithm, we conducted extensive experiments on HEVC reference software HM11.0. The experiments were conducted to the first 300 frames of sixteen standard test sequences except the sequence of Kimono and ParkScene were coded 240 frames. The GOP size is set to 4. The motion search range is 64. The RDO and rate control are enabled. We use the test bit rates adopted by JCTVC-A204 [14] as the target bit rate and the rest of configurations are detailed in [15].

In order to evaluate the accuracy of the proposed rate control algorithm, the bitrate mismatch is defined as follows

$$RCM = R_{actual} - R_{target} \tag{18}$$

where R_{actual} and R_{target} denote the actual coding bit rate and target bit rate, respectively. The rate control accuracy grows with the decreasing of the absolute value of *RCM*. We also used the standard deviation of the PSNR to measure the fluctuation of the quality. $PSNR_{std\_deviation}$ is defined as:

$$PSNR_{std\_deviation} = \sqrt{\frac{\sum_{i=1}^{N}(PSNR_i - \overline{PSNR})^2}{N-1}} \tag{19}$$

where $\overline{PSNR}$ is the average of PSNR, $PSNR_i$ is the PSNR of the i-th frame, N is the number of frames to be encoded. A smaller value of $PSNR_{std\_deviation}$, indicates the scheme with a smaller of fluctuation of the quality.

Tables 1 and 2 show the results of the experiment. From the table 1, we can observe that our proposed method is better than reference [7]. The maximal and minimal values of *RCM* are 8.49kbits and 0.00kbits with our proposed method, respectively. While [7] brought about the maximal and minimal values of *RCM* are 52.04kbits and 0.01kbits, respectively. This means that image complexity is preferable to optimize the frame level bit allocation in the frame layer. The bit rate mismatch of *Traffic* has increased slightly, the reason is that the sequence of *Traffic* is taken by a fixed camera on the highway and the image characteristic is very similar in a GOP, leading to improved ineffective. Compared with [7], the bit rate mismatch of *Kimono* is smaller duo to our proposed algorithm considered the image complexity in the process of bit allocation. In addition, the content of *Kimono* is that a lady walk on the road and the background is pretty complexity. Our proposed method will rational adjust the bit rate according to the different parts of the image complexity.

Table 1 The results of bit rate mismatch

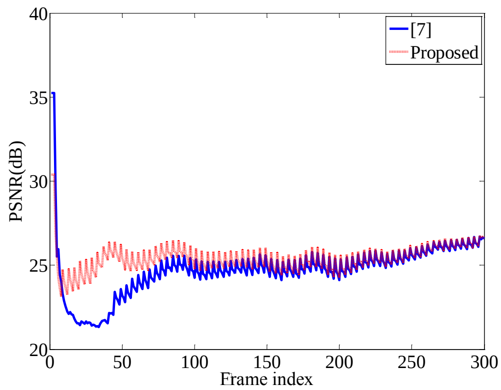
Sequence type	Sequence	Target bit rate(kb/s)	Actual bit rate(kb/s)		*RCM*(kb/s)	
			[7]	Proposed	[7]	Proposed
class A	Traffic	2500	2499.46	2491.51	-0.54	-8.49
	PeopleOnStreet	2500	2500.59	2500.55	0.59	0.55
class B	Cactus	2000	2000.22	2000.12	0.22	0.12
	BasketballDrive	2000	2000.64	2000.98	0.64	0.98
	Kimono	1000	947.96	1000.32	-52.04	0.32
	ParkScene	1000	1003.12	999.65	3.12	-0.35
class C	BasketballDrill	384	384.07	384.05	0.07	0.05
	BQMall	384	384.10	383.96	0.10	-0.04
	PartyScene	384	384.32	384.22	0.32	0.22
	RaceHorsesC	384	383.73	383.92	-0.27	-0.08
class D	BasketballPass	256	256.08	256.00	0.08	0.00
	BlowingBubbles	256	256.08	256.04	0.08	0.04
	BQSquare	256	256.03	256.06	0.03	0.06
	RaceHorses	256	256.01	256.03	0.01	0.03
class E	FourPeople	256	256.01	255.99	0.01	-0.01
	Johnny	256	255.95	256.07	-0.05	0.07

From the table 2, we can observe that the PSNR of our proposed method achieves a gain of up to 0.67dB, and average PSNR gain is 0.15dB compared with [7]. Although the PSNR of some sequence has decreased compared with the reference method, but the deviation of the PSNR is small, and therefore the visual quality is not affected greatly. The reason why PSNR of *PartyScene* has increased by 0.67dB is that its complexity texture, the reference method doesn't consider the image characteristic in the process of bit allocation, causing the poor coding quality. However, our proposed method gives full consideration to the characteristics of the image in the intra frame bit allocation, and assign the redundant code bit to the subsequent coding frame while guarantee the quality of the intra frame. This strategy make the follow-up coding frames have enough bit to code. In the coding process of P/B frame, the bit allocation for LCU has referred to the gradient of residual belonging to collocated LCU. It will make more rational bit allocation and improve the quality of the encoding. The deviation of PSNR in [7] is averagely 1.52, but our proposed method is averagely 1.40. Fig.6 shows the fluctuation of PSNR belonging to two sequences. From the Fig.6, we can observe that the deviation of PSNR has made an improvement, this is because the proposed algorithm can better allocate reasonable bit rate to frames according to the complexity of each frame.

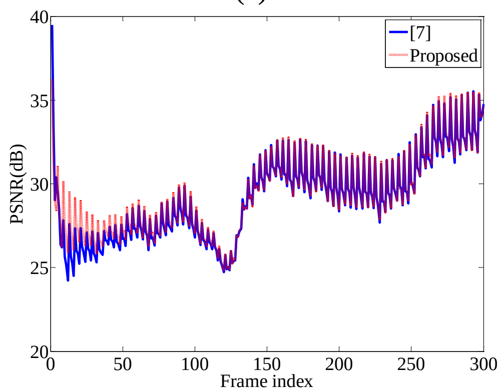
Table 2 The results of PSNR and the deviation PSNR

Sequence type	Sequence	Target bit rate(kb/s)	PSNR(dB)		Delta PSNR(dB)	The deviation of PSNR	
			[7]	Proposed		[7]	Proposed
class A	Traffic	2500	36.49	36.47	-0.02	0.73	0.79
	PeopleOnStreet	2500	27.20	27.27	0.07	2.24	2.22
class B	Cactus	2000	33.99	33.95	-0.04	0.79	0.78
	BasketballDrive	2000	34.02	34.11	0.08	1.33	1.37
	Kimono	1000	36.19	36.31	0.12	1.55	1.71
	ParkScene	1000	33.16	33.21	0.04	0.72	0.68
class C	BasketballDrill	384	31.80	31.75	-0.05	1.08	1.06
	BQMall	384	30.14	30.31	0.16	2.39	2.27
	PartyScene	384	24.75	25.42	0.67	1.69	0.84
	RaceHorsesC	384	29.20	29.40	0.20	2.61	2.41
class D	BasketballPass	256	31.97	32.03	0.06	2.55	2.50
	BlowingBubbles	256	29.67	29.92	0.25	1.45	1.28
	BQSquare	256	29.46	29.66	0.20	1.00	0.63

	RaceHorses	256	31.28	31.42	0.14	1.95	1.81
class E	FourPeople	256	34.33	34.81	0.48	0.60	0.76
	Johnny	256	38.57	38.61	0.04	1.61	1.21
Average	-----	-----	-----	-----	0.15	1.52	1.40



(a)

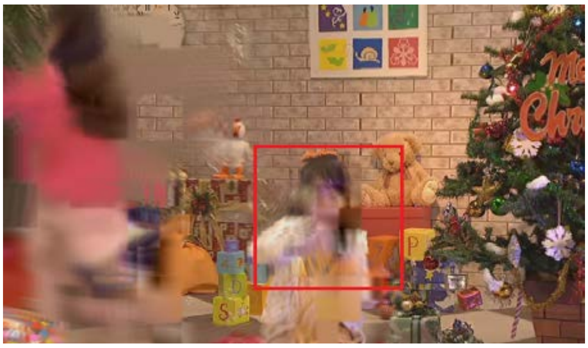


(b)

Fig.6 The deviation of PSNR. (a) *PartyScene*, (b) *RaceHorsesC*.

Fig.7 shows the quality of *PartyScene* at different rate control algorithm. 7(a) and 7(b) are the result of our proposed method and reference method, respectively. From the figure 7(c) and 7(d), we can obviously observe that our method has obtained a favorable visual quality. The obvious reason is that our proposed algorithm has considered image complexity in the process of bit allocation, i.e., the area which has fully image complexity will be assigned more bits than the flat region.

(a)



(b)

(c) (d)

Fig.7 The quality of 39th frame in *PartyScene* under different rate control. (a) Reference [7], (b) Proposed method, (c) The enlarged image of reference [7], (d) The enlarged image of proposed method

6 Conclusion

Rate control plays a key role in video coding and communication systems. In this paper, we presented a novel bit allocation strategy on fame layer and LCU layer based on image complexity. In the frame layer, we established the bit allocation model for intra frame, and assigned a rational bit according the image complexity of ones in each GOP. In the LCU layer, we established quantization calculation model for LCU which is belong to intra frame, and assigned bit for LCU in P/B frame with a new strategy. Experimental results show that our proposed method has good performance in the PSNR, the deviation of PSNR and the quality of coding.

Acknowledgment: This work was supported by the national natural science foundation of China under Grant 61171163, Grant 61271270, and Grant U1301257, National Key Technology Research and

Development Program of the Ministry of Science and Technology of China Grant 2012BAH67F01.

References

[1] Sullivan, G. J., Ohm, J. R., Han, W. J., and Wiegand, T. Overview of the high efficiency video coding (HEVC) standard. *Circuits and Systems for Video Technology, 22*(12), 1649-1668, 2012.

[2] Ohm, J. R., Sullivan, G. J., Schwarz, H., Tan, T. K., and Wiegand, T. Comparison of the coding efficiency of video coding standards—including high efficiency video coding (HEVC). *Circuits and Systems for Video Technology, 22*(12), 1669-1684, 2012.

[3] Chen, Z., and Ngan, K. N. Recent advances in rate control for video coding. *Signal Processing: Image Communication, 22*(1), 19-38, 2007.

[4] Choi, H., Yoo, J., Nam, J., Sim, D., and Bajic, I. V. Pixel-wise unified rate-quantization model for multi-level rate control. *IEEE Journal of Selected Topics in Signal Processing, 7*(6), 1112-1123, 2013.

[5] Liang, X., Wang, Q., Zhou, Y., Luo, B., and Men, A. A novel rq model based rate control scheme in HEVC. In *Visual Communications and Image Processing (VCIP)* (pp. 1-6), 2013.

[6] Li, B., Li, H., Li, L., and Zhang, J. (2012). Rate control by R-lambda model for HEVC. *Jt. Collab. Team Video Coding (JCT-VC) of ITU-T SG*, *16*, 1-11.

[7] Li, B., Li, H., Li, L., and Zhang, J. λ Domain Rate Control Algorithm for High Efficiency Video Coding. *IEEE transactions on image processing: a publication of the IEEE Signal Processing Society*, *23*(9), 3841-3854, 2014.

[8] Wang, S., Ma, S., Wang, S., Zhao, D., and Gao, W. Rate-GOP based rate control for high efficiency video coding. *IEEE Journal of Selected Topics in Signal Processing, 7*(6), 1101-1111, 2013.

[9] Meddeb, M., Cagnazzo, M., and Pesquet-Popescu, B. Region-of-interest-based rate control scheme for high-efficiency video coding. *APSIPA Transactions on Signal and Information Processing, 3,* e16, 2014.

[10] Wang, M., Ngan, K. N., and Li, H. An Efficient Frame-Content Based Intra Frame Rate Control for High Efficiency Video Coding. *Signal Processing Letters, 22*(7), 896-900, 2015.

[11] He, Z., and Mitra, S. K. Optimum bit allocation and accurate rate control for video coding via ρ-domain source modeling. *Circuits and Systems for Video Technology, 12*(10), 840-849, 2002.

[12] Lainema, J., Bossen, F., Han, W. J., Min, J., and Ugur, K. Intra coding of the HEVC standard. *Circuits and Systems for Video Technology, 22*(12), 1792-1801, 2012.

[13] BenHajyoussef, A., and Ezzedine, T. Analysis of Residual data for High Efficiency Video Coding (HEVC). *IJCSNS International Journal of Computer Science and Network Security*, *12*(8), 90-93, 2012.

[14] Baroncini, V., Ohm, J. R., and Sullivan, G. (2010). Report of subjective test results of responses to the joint call for proposals (cfp) on video coding technology for high efficiency video coding (HEVC). *ISO/IEC JTC1/SC29/WG11 MPEG2010 N*, *11275*.

[15] Bossen, F. (2013). Common test conditions and software reference configurations. Doc. JCTVC-K1100. In *11th Meeting: Joint Collaborative Team on Video Coding (JCT-VC) of ITU-T SG* (Vol. 16).