# New Rate Control Optimization Algorithm for HEVC Aiming at Discontinuous Scene

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*Abstract:* To combat with lagging rate control (RC) parameter setting in encoding video sequences with discontinuous scenes, a novel RC algorithm at group of picture (GOP) level is proposed for high efficiency video coding (HEVC) in this paper. Firstly, the variation of GOP is analyzed and used to detect the discontinuous scene. Then, a new bit allocation algorithm is presented by constructing the correlation between bit allocation for every GOP and the intensity of scene change. Finally, the impact of RC parameter updating at the frame level is investigated to obtain high accuracy of bit allocation for discontinuous scenes. Experimental results show that compared with the current RC algorithm for HEVC, the proposed algorithm can obtain better performances on purpose of reducing the fluctuation of peak-signal-to-noise-ratio and rate-distortion optimization with almost the same encoding complexity for HEVC.

*Key-words:* High efficiency video coding, rate control, discontinuous scene, video quality fluctuation

## 1 Introduction

Rate control (RC) can be used to provide considerable guidance to practical video coding including the color video coding, depth video coding and multi-view video coding [1-2] by adaptively adjusting the amount of bit rates in order to avoid insufficient or excessive buffers when video bit streams are transmitted over networks with finite bandwidth [3]. By adopting efficient RC algorithms in practical video coding systems, a lot of performance benchmarks may be improved, such as less packet loss, higher bandwidth utilization and better perceptual visual quality [4]. As a powerful tool for optimizing video coding systems, RC has been widely researched. In H.264/AVC [5], G012 RC algorithm [6] was adopted based on fluid flow traffic model. A rate distortion (RD) correlation model [7] was proposed in high efficiency video coding (HEVC) standard whose coding efficiency was much higher than H.264/AVC. In this RD correlation model, the traditional rate-quantization (R-Q) model [8] was replaced with Lagrange multiplier $\lambda$ domain-based rate-lambda (R-$\lambda$) model [7]. The so-called $\lambda$ domain-based R-$\lambda$ model involves not only complex quadtree partition of coding units (CU) [9], but also more inter and intra prediction modes, which consequently caused extreme difficulties for precise R-Q model calculation before the prediction modes are selected. Meanwhile, previous studies have demonstrated that Lagrange multiplied $\lambda$ plays a more determinant role than quantization parameter (QP) in controlling bit rates for HEVC.

The current RC optimization algorithms for HEVC mainly aimed at enhancing rate estimation accuracy, stabilizing peak signal to noise ratio (PSNR) and improving overall RD performance. Li et al. [7] proposed $\lambda$-domain RC which has been integrated into the HEVC reference software for a more accurate rate estimation. But discontinuous scenes weren’t taken into consideration by this scheme. In [10], a more accurate linear RC model in $\rho$-domain based on quantization parameter is proposed, which has been proved very effective but was more complex. Wang et al. [11] established a hierarchical RC structure at group of picture (GOP) level by optimizing both GOP level bit allocation and global RD performance. But the bit allocation in the GOP is fixed and not suitable for the dramatic changing frames. Si et al. [12] modified R-Q and distortion-quantization (D-Q) models by analyzing Laplacian distribution of residuals in HEVC and gained less fluctuation of PSNR. In addition, Seo et al. [13] adjusted QP of coding tree units (CTU) according to Laplacian distribution of residuals and achieved more accurate for rate estimation. But the residuals are not stable for all kinds of sequence and unavailable before encoding. Lee et al. [14] changed the frame-level RC scheme based on texture and nontexture rate models, which is difficult to adaptively adjust RC model parameters before encoding. In summary, the current RC algorithm for HEVC generates bit rates which are closed to target bit rates, but it is only efficient to encode smooth video sequences, namely the video sequences with less abrupt scene changes which are defined as the discontinuous scene. When the aforementioned methods are applied to the video sequences with discontinuous scenes, they may fail allocating bits appropriately or updating parameters in real-time, which leads to huge difference between actual bits and target bits. What's more, the perceptual characteristic of human vision, such as the salient region or motion region, can be used to guide RC [15-17]. Overall, the discontinuous scenes increase the demand of new adaptive RC models for HEVC.

For the above problem, this paper proposes a new GOP level bit allocation algorithm and RC parameter updating for frame level based on the variation of GOP. The main technical contributions of this paper are as follows, (1) lower PSNR fluctuations of the decoded video, (2) better rate-distortion performance. The remaining of this paper is organized as follows: In section II, we describe the proposed RC algorithm in detail. Experimental results are shown and analyzed in section III. Finally, the conclusions of this work are drawn in section IV.

## 2 Proposed RC Algorithm for Discontinuous Scene

Fig. 1 shows the framework of the proposed RC algorithm for discontinuous scenes. Firstly, we analyze the variation of GOP for discontinuous scene changes and research the bit allocation without RC operation. Then, we optimize RC algorithm through the next two points. A new bit allocation algorithm is established according to the above researches by constructing the correlation between bit allocation for every GOP and the intensity of scene changing, include reducing bits for slowly changing frames and adjusting smooth window intensely changing frames. The RC parameter λ is updated according to intensity of scene change to obtain high accuracy of bit allocation for discontinuous scenes.

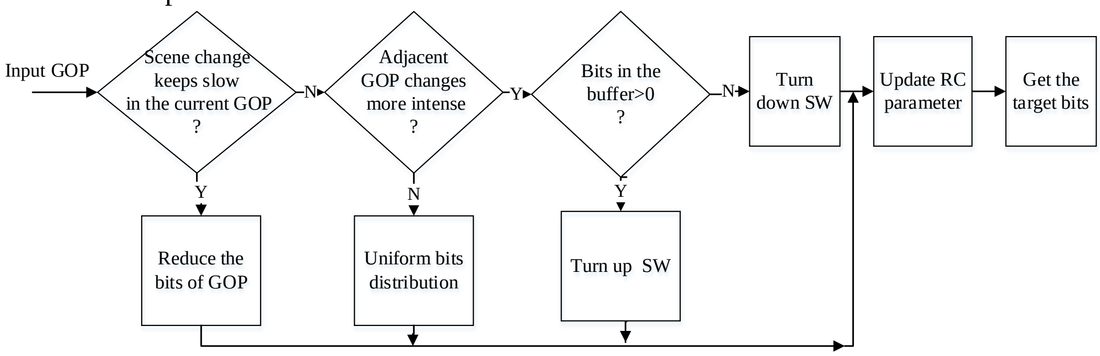



Fig. 1 Framework of the proposed RC algorithm

### 2.1 Scene Variation Factor for describing variation of GOP

In general, sum absolute difference (SAD) of the co-located pixels between two frames can not distinguish continuous scene, but be used to detect the discontinuous scene. Therefore, we use the difference of the first and last frames within the GOP to reflect the variation of discontinuous scene changes. Let $D_{Bpp}^{M}$ denote the SAD value between the first and last frames within the *M*-th GOP, which can be expressed by

$$D_{Bpp}^{M} = \frac{1}{R \times C} \sum_{i=1}^{L} \sum_{j=1}^{H} \left| G_1^M(i, j) - G_N^M(i, j) \right| \quad (1)$$

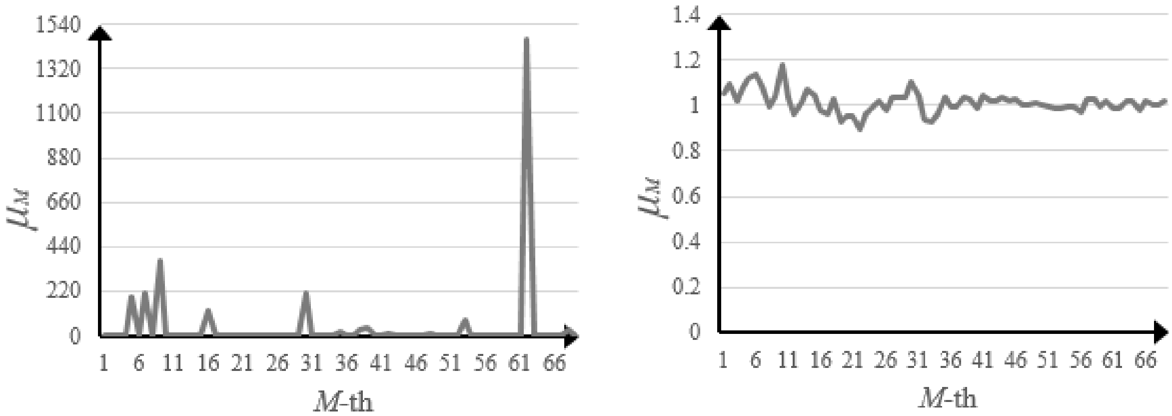
where *L* and *H* are numbers of the row and column of a frame, respectively, $G_1^M(i, j)$ is the pixel at $(i, j)$ of the first frame within the *M*-th GOP, and *N* is number of frames in a GOP.

In order to describe the discontinuous scene changes of adjacent GOPs in video, a scene variation factor (SVF), $\mu_M$, is defined with adjacent $D_{Bpp}^{M}$ as follows

$$\mu_M = \frac{D_{Bpp}^{M}}{D_{Bpp}^{M-1}} \tag{2}$$

where $D_{Bpp}^{M}$ denotes the SAD value in the current GOP, and $D_{Bpp}^{M-1}$ denotes the SAD value in the previous GOP. When $\mu_M$ maintains around 1, it indicates that adjacent GOPs have the similar variation. When $\mu_M$ is much less than 1, it indicates that the previous GOP varies more dramatically, otherwise, it indicates that the current GOP varies more dramatically. Therefore, the violent-changing frame which belongs to part of the discontinuous scene is defined, when $\mu_M$ is not equal to 1.

Here, we analyze many representative test sequences that their GOP's size is 4 and 8, respectively. Fig. 2 shows the variation of adjacent GOPs in different sequences, in which the horizontal axis is the $M$-th GOP in a sequence and the vertical axis is SVF. Fig. 2(a) represents the discontinuous scene, while Fig. 2(b) represents the continuous scene. Experimental results show that $\mu_M$ keep around 1 in the sequences of continuous scene, such as Fig. 2(b) BQMall sequence. From Fig. 2(a), it is clear that $\mu_M$ in video sequences with discontinuous scenes is unstable, which implies that $\mu_M$ can be used to reflect the variation of a video and detect the discontinuous scene in the video. The different sequences which GOP's size is 8 have the similar phenomenon shown in Fig. 2.




(a) SlideEditing sequence (b) BQMall sequence

Fig. 2 SVF in the different sequences which GOP's size is 4

## 2.2 Analysis for the Current RC Algorithm in HEVC

The current HEVC's RC algorithm [7] adopts Eq. (3) to allocate bits for GOP level. From Eq. (3), the buffer size does not be considered in this RC algorithm, which evenly allocates bits for each GOP, then taking the difference of the actual coding bits and the target bits as the buffer status. This bit allocation algorithm for GOP level has no problem in the sequences of the continuous scene which is shown in Fig. 2(b).

$$T_{AvgPic} = R_{PicAvg} + \frac{R_{PicAvg} \times N_{coded} - R_{coded}}{SW} \tag{3}$$

where $R_{PicAvg}$ is the average target bits per picture, $N_{coded}$ is the number of coded pictures, $R_{coded}$ is the bit cost on coded pictures, $SW$ is the size of a smooth window, and $T_{AvgPic}$ denotes the final average target bits per picture.

However, uniform bits distribution is not suitable for the video with discontinuous scenes, which not only causes frame-level RC inaccurate, but also makes error parameter updating. Hence, this paper studies the bit allocation of all frames without RC operation that means the smallest PSNR fluctuations. The actual coded bits, denoted as $b$, are expressed in terms of bit-per-pixel (bpp), and changes in the GOP are expressed in terms of $D_{Bpp}$. They are calculated by Eqs. (4) and (1).

$$b = \frac{R}{f \cdot L \cdot H} \tag{4}$$

where $f$ is the frame rate, and $R$ denotes the actual coded bits. The slow-varying frame which also belongs to part of the discontinuous scene is defined, when $b$ is less than 0.14 based on statistics of a large number of video sequences.

The relationship between $D_{Bpp}$ and $b$ is shown in Fig. 3, where the horizontal axis is $D_{Bpp}$ with the GOP size of 4, and the vertical axis is bpp for the slow-varying frame. The threshold $T$ which is shown in Fig. 3 is defined to distinguish whether the vast majority CUs adopt skip mode [9] in the slow-varying frames, and set to 0.04 in the experiments.

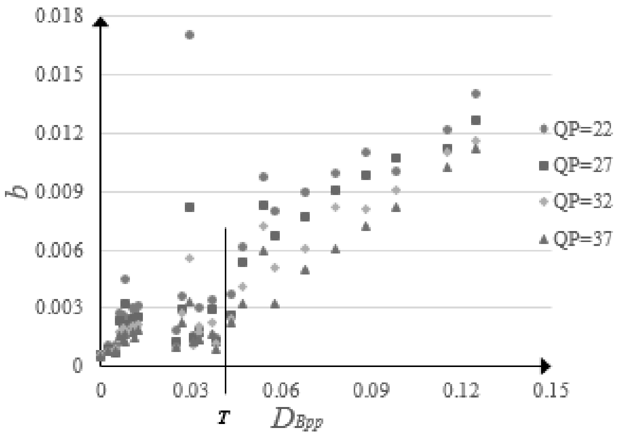



Fig. 3 Scatter plot of $D_{Bpp}$ and bpp in the slow-varying frames

### 2.3 Proposed RC Optimization Algorithm

We optimize RC Algorithm in two steps based on the proposals of HEVC standard, such as K0103 [18] which is consistent with the λ-domain RC, M0036 [19] and M0257 [20]. Firstly, a new bit allocation algorithm is established for GOP level based on the intensity of scene change. The adjustment for bit allocation algorithm is two-fold. In one respect, we use the relationship shown in Fig. 3 to reduce bits of the slow-varying frames, so that the number of target bits is closer to that of the actual coded bits. On the other hand, the buffer restrictions are reduced according to SVF for violent-changing frames. Meanwhile, the upper limit of the target bits is taken into account. Secondly, we take SVF to adjust the updating range of the frame-level's RC parameters.

From Fig. 3, it is found that bpp is only related to QP or target bits when $D_{Bpp}$ is smaller than the threshold $T$, because the actual encoder adopts skip mode and has nothing to do with the actual image content when the adjacent frames keep still or change slowly. In contrast, bpp is linear with $D_{Bpp}$ when $D_{Bpp}$ is larger than the threshold $T$ and the scene change keeps slow, as the actual bit is related with image content when the residual information need to be encoded.

Thus, a new bit allocation algorithm for slow-varying frames is proposed to meet the above conclusions by Eq. (5), where $R_{PicAvg}$, the first term of Eq. (3), is modified to $R^{M}_{PicAvg}$. However, the $R_{PicAvg}$, the second term of Eq. (3) keeps still to measure the buffer status, because the encoder takes the constants bit rate (CBR) mode. Finally, Eq. (3) is revised into Eq. (6).

$$R^{M}_{PicAvg} = \begin{cases} \alpha \times R_{PicAvg} & 0 < D_{Bpp} \le T \\ D_{Bpp} \times R_{PicAvg} & T < D_{Bpp} < \delta \\ R_{PicAvg} & others \end{cases} \quad (5)$$

$$T_{AvgPic} = R^{M}_{PicAvg} + \frac{R_{PicAvg} \times N_{coded} - R_{coded}}{SW} \quad (6)$$

where $R^{M}_{PicAvg}$ is the average target bits per picture after modulation in Eq. (5). $\alpha$ is the factor to allocate bits for skip mode, and set to 0.01 to estimate bits of all headers for CUs and frames in the experiments. $\delta$ is defined to decide whether the current RC Algorithm adopts the aforementioned modulation for the slow-varying frames, and set to 0.14.

The current HEVC's RC algorithm reduces the objective quality of frame due to the effect of buffer for violent-changing frames. Therefore, a new bit allocation algorithm for violent-changing frames is proposed to improve the quality of video by Eq. (7), slightly reducing the buffer restraints. The modulation factor $\eta$ is defined according to SVF to allocate more bits for violent-changing frames in Eq. (7), where we can find that the bit allocation algorithm keeps still for the sequences which has the continuous scene, as $\eta$ is equal to 1 when SVF is around 1, while we allocate additional bits for violent-changing frames. Meanwhile, we limit the bits of GOP in an interval to prevent buffer overflow. The $R_{PicAvg}$ value do not be modified to improve allocation bits directly, because the experiment found that RD performance can be greatly improved with the direct change of $R_{picAvg}$ in the coding results, but the bit buffer and fluctuation of PSNR is seriously influenced. Therefore, we adjust $SW$ according to the buffer status in Eq. (8). Experimental results show that changing $SW$ can be the best method to adjust the buffer restraints.

$$\eta = \begin{cases} 1 & \mu_M \le 1 \\ 1 + \dfrac{(\mu_M - 1)}{10} & 1 < \mu_M \le 2 \\ 1 + \dfrac{(\mu_M - 1)^{0.5}}{10} & 2 < \mu_M \le 26 \\ 1.5 & \mu_M > 26 \end{cases} \quad (7)$$

$$SW = \begin{cases} SW / \eta & R_{PicAvg} \times N_{coded} - R_{coded} > 0 \\ SW \times \eta & R_{PicAvg} \times N_{coded} - R_{coded} < 0 \end{cases} \quad (8)$$

To reduce the fluctuation of quality for the discontinuous scene, the current HEVC's RC algorithm does smoothing process between the encoder parameter for the previous frame and the current frame. For example, the current HEVC's RC adopts the Eq. (9) to smooth the range of $\lambda$ for the frame-level. But it is not appropriate for discontinuous scenes because of the wide adjustable range of the frame level $\lambda$ in the [0.1, 10000]. If we directly use Eq. (9) to smooth $\lambda$ for violent-changing frames, the RD performance will be the local optimum. Therefore we take the modulation factor $\eta$ to expand the smooth range for λ according to experiences using Eq. (10) which makes the RD performance likely closer to the optimal value.

$$\lambda_{lastPic} 2^{\frac{-10.0}{3.0}} \leqslant \lambda_{currPic} \leqslant \lambda_{lastPic} 2^{\frac{10.0}{3.0}} \quad (9)$$

$$\lambda_{lastPic} 2^{\frac{-10.0}{3.0}} / \eta \leqslant \lambda_{currPic} \leqslant \lambda_{lastPic} 2^{\frac{10.0}{3.0}} \times \eta \quad (10)$$

where $\lambda_{currPic}$ represents Lagrange multiplier of the current frame level, and $\lambda_{lastPic}$ representing Lagrange multiplier of the previous frame level.

## 3 Experimental Results

To test the effectiveness of the proposed algorithm, optimizing bit allocation in the discontinuous sequences, HEVC reference software HM12.0, is selected as the test platform. Class F sequences [21] are tested with HEVC Main Profile random access (RA) and low delay (LD). Target bits are obtained without RC by encoding four QP points, {22, 27, 32, 37}. In addition, Class A-E sequences [21] are also tested in order to verify that the proposed algorithm has no influence on other sequences of discontinuous scenes. The current HEVC's RC algorithm in HM12.0 is selected as the anchor algorithm. Contrast results among the proposed algorithm and anchor algorithm are shown in Table 1 and Table 2. Experimental results are presented in the form of BD-PSNR (Bjøntegaard delta peak signal-to-noise rate) and BD-RATE (Bjøntegaard delta bit rate) [22], which represents the R-D performances. Besides, RC accuracy [13], standard deviation of PSNR($\sigma_{PSNR}$) [12][23] and $\Delta T$ [11] represent rate estimation accuracy, volatility of performance about the decoded video and computational complexity of the encoder, respectively. As shown in Table 1, the proposed algorithm is tested under the structure of RA and LD configuration [24], respectively. By employing the results of λ-domain RC which has been integrated into HEVC as the anchor, the luminance (Y) coding performance gain of the proposed RC scheme for the discontinuous scene is up to 0.3% and 1.5% on average for RA and LD configuration, respectively. As we can see, the proposed has a little effect on the RA configuration and the performance of color components (UV) is unstable. Because the LD configuration only exists forward references, while the RA configuration exists the forward and backward references, where the moving target or new scene can be searched. Therefore, the proposed algorithm obtains better results on the LD configuration. From Table 1, the proposed has little effect on the sequences, BasketballDrillText and ChinaSpeed, which have the dramatically changing but continuously changing. So it is acceptable to allocate bits uniformly for continuously changing in each GOP, which implies that the proposed has little impact on the Class A – E. Also，the proposed algorithm are tested on the Class A – E in the experiment, which shows the little effect.

Table 1 Overall Performance for LD and RA mode

| | BD-RATE | | | | | |
|---|---|---|---|---|---|---|
| | **Random Access** | | | **Low Delay** | | |
| | Y | U | V | Y | U | V |
| BasketballDrillText | -0.1% | -2.0% | -1.2% | 0.3% | 0.7% | 0.1% |
| ChinaSpeed | 1.0% | -6.4% | -4.7% | -0.9% | -3.1% | -3.3% |
| SlideEditing | -0.1% | 2.3% | 3.2% | -2.2% | -0.6% | 0.0% |
| SlideShow | -1.9% | -10.2% | 7.5% | -3.1% | 0.8% | 0.9% |
| **Average** | **-0.3%** | **-4.1%** | **1.2%** | **-1.5%** | **-0.6%** | **-0.6%** |

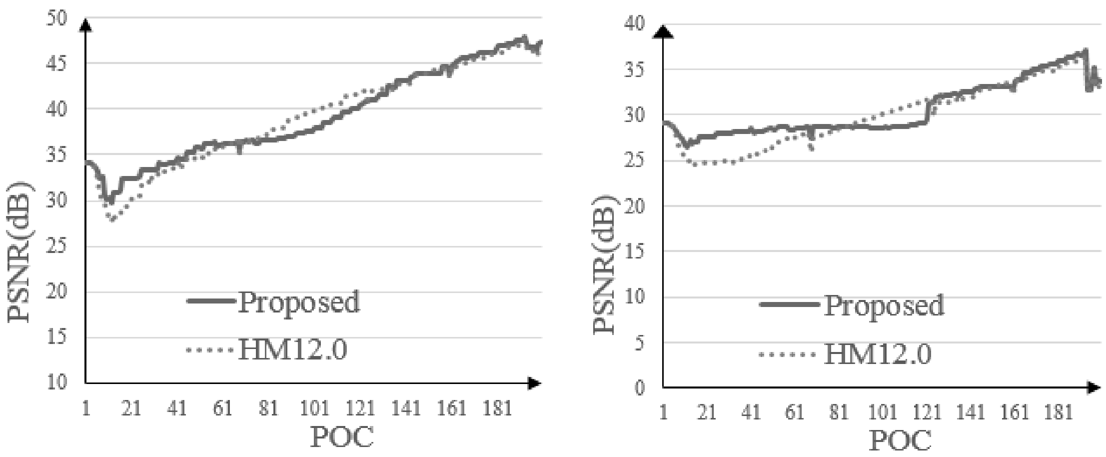
Table 2 RC accuracy, $\sigma_{PSNR}$, BD-PSNR and ΔT (%) for LD

| QP | RC accuracy (%) | | Y $\sigma_{\mathrm{PSNR}}$ | | Y BD-PSNR (dB) | $\Delta T$ (%) |
|---|---|---|---|---|---|---|
| | Original | Proposed | Original | Proposed | | |

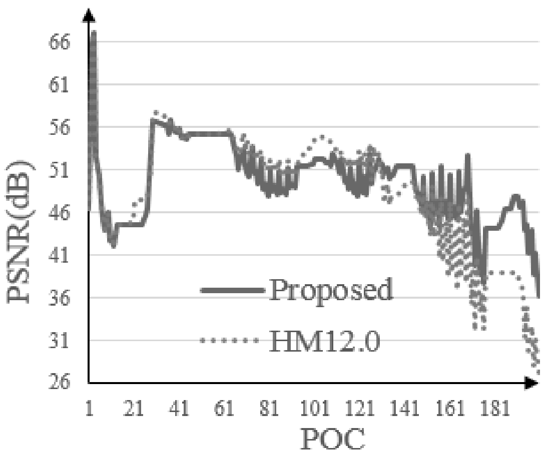
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Basketball DrillText | 22 | 0.01 | 0.01 | 0.729 | 0.723 | -0.013 | -1.47 |
| | 27 | 0.01 | 0.01 | 0.923 | 0.922 | | -1.48 |
| | 32 | 0.00 | 0.01 | 1.070 | 1.071 | | -2.23 |
| | 37 | -0.03 | 0.00 | 1.051 | 1.061 | | -0.64 |
| ChinaSpeed | 22 | 0.00 | 0.00 | 1.260 | 1.255 | 0.049 | -3.87 |
| | 27 | 0.00 | 0.01 | 1.384 | 1.378 | | -3.18 |
| | 32 | 0.00 | 0.01 | 1.531 | 1.531 | | -1.13 |
| | 37 | -0.01 | -0.01 | 1.529 | 1.528 | | -0.56 |
| SlideEditing | 22 | -1.09 | -0.17 | 5.367 | 4.980 | 0.252 | -1.06 |
| | 27 | 3.48 | 2.15 | 5.119 | 4.552 | | -1.64 |
| | 32 | 5.94 | 5.42 | 4.450 | 3.957 | | 0.03 |
| | 37 | 8.29 | 9.15 | 3.433 | 2.939 | | -1.25 |
| SlideShow | 22 | 7.55 | 2.95 | 7.120 | 4.897 | 0.293 | -3.09 |
| | 27 | 1.27 | 1.04 | 7.439 | 6.412 | | -4.09 |
| | 32 | 7.60 | 7.61 | 5.417 | 5.011 | | -1.74 |
| | 37 | 3.18 | 4.66 | 5.454 | 5.312 | | -1.00 |

From the parameter details of LD mode in Table 2, it is clear that the proposed algorithm has a little effect on the RC accuracy, and even becomes worse. Because this study does not adjust CU-level RC, but the bit allocation of GOP-level and updating parameter of frame-level. $\sigma_{PSNR}$ of the luminance component has an obvious reduction, which means the decoded video has less smaller fluctuations for discontinuous scenes sequence. Figs. 4(a) - 4(d) show the PSNR fluctuation followed by POC in details, which also confirms the reduction of PSNR fluctuations on the whole. SlideEditing-S and SlideShow-S shown in Table 3 obtained by skipping the original sequence SlideShow and SlideEditing, have the better R-D performances and smoother video quality than the anchor algorithm. From Table 3, it further verified the reliability of the proposed algorithm. Moreover, we also observe the coding time consuming and the objective quality of the proposed algorithm. Experimental results show that the proposed method has a slight impact on the encoding complexity from the parameter $\Delta T$ in the Table 2 and Table 3. As can be seen from the R-D curve in Fig. 5(a) - 5(d), the decoded videos have the better R-D performances and objective quality with the same bits.

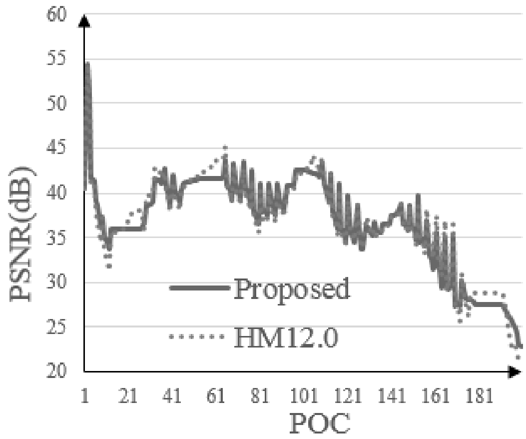
In summary, we can see that the proposed algorithm makes PSNR fluctuation reduce effectively in most cases for discontinuous scenes. It is shown that the proposed algorithm has improved the overall RD performances from BD-RATE and BD-PSNR. Meanwhile, it has no effect on the complexity of the encoder. However, the proposed algorithm could has much room for improvement in RC accuracy.




(a) SlideEditing QP=22 (b) SlideEditing QP=37




(c) SlideShow QP=22

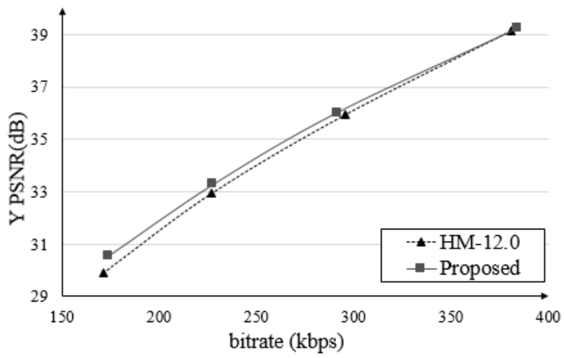



(d) SlideShow QP=37

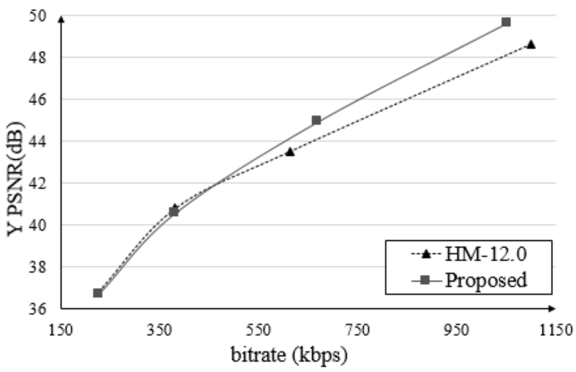
Fig. 4 PSNR fluctuation comparison for the proposed algorithm with HM12.0 anchor

Table 3 RC accuracy, $\sigma_{PSNR}$, BD-PSNR and ΔT (%) for adjustment Class F sequence

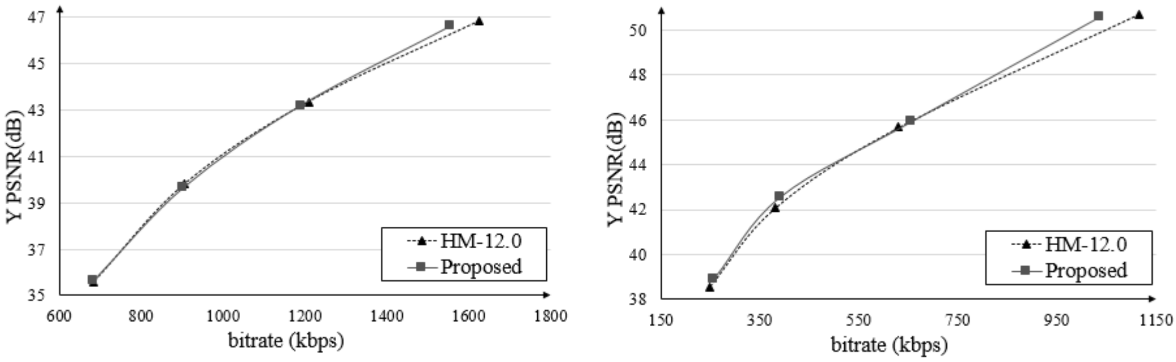
| | QP | Y $\sigma_{PSNR}$ | | BD-RATE (%) | | | Y BD-PSNR (dB) | $\Delta T$ (%) |
|---|---|---|---|---|---|---|---|---|
| | | Original | Proposed | Y | U | V | | |
| SlideEditing-S | 22 | 4.042 | 3.729 | -9.6 | -7.7 | -7.5 | 1.308 | -0.88 |
| | 27 | 4.039 | 3.346 | | | | | -0.24 |
| | 32 | 3.801 | 2.891 | | | | | -0.84 |
| | 37 | 3.012 | 1.775 | | | | | -0.54 |
| SlideShow-S | 22 | 4.101 | 3.548 | -1.8 | -0.4 | -1.9 | 0.170 | -2.11 |
| | 27 | 4.327 | 3.757 | | | | | -2.33 |
| | 32 | 3.686 | 3.688 | | | | | -1.01 |
| | 37 | 3.801 | 3.811 | | | | | 0.26 |




(a) LD SlideEditing




(b) LD SlideShow




(c) RA SlideEditing (d) RA SlideShow

Fig. 5 RD curves of the performance comparison for the proposed algorithm with HM12.0 anchor

# 4 Conclusion

To satisfy the quality for coded video with discontinuous scenes, this paper proposes a new rate control (RC) algorithm based on variation of GOP for high efficiency video coding (HEVC). The novelty of the proposed RC algorithm lies in that the scene variation factor is defined to adjust bit allocation algorithm and the updating range of λ value. It's verified that the proposed GOP level RC algorithm can achieve smaller fluctuations of the objective quality and better performance than the current HEVC's RC algorithm for sequences of the discontinuous scene.

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