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A NOVEL VARIANCE-BASED INTRA-FRAME RATE CONTROL ALGORITHM FOR H.264/AVC

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Abstract. To enhance image quality and retain a limited bit budget, intra-frame in the frame type selection plays a significant role in video coding systems because the frame is treated as a key frame for temporal domain reference. This paper presents an algorithm to predict accurate quantization parameters by developing variance-based distortion measurements. Firstly, the intra-frame rate control in JVT-G012 is analyzed before discussing possible drawbacks. Current algorithms includes JVT-G012 and Yan's algorithm based on mean square error metrics for intra-frame rate controls are compared to show that the proposed distortion metric is useful to estimate quantization parameters. Experimental results show that the proposed algorithm can significantly improve video quality up to 0.19 dB and 1.28 dB, compared with the algorithm JVT-G012, which is implemented in the H.264 reference software JM 15.0 and Yan's algorithm.

Keywords: intra-frame, JVT-G012, quantization parameter, rate control, JM15.0.

1. Introduction

Image quality is a significant issue in multimedia applications, such as video streaming and surveillance technologies. To achieve higher image quality in video encoding systems, the rate control method must first be implemented, and for an accurate fitting of the image quality, a large number of intra-frame must be inserted in each image grouping. The purpose of a rate control is to predict a suitable quantization parameter (QP) for intra-frame under the specified bits target. However, the work is difficult, one main reason being that the image content is time-varied, and the fixed QP cannot fit for all images. In the H.264/AVC video coding standard, the QP specifies the quantization step size, which subsequently influences image quality and bit budget. The QP also affects rate-distortion optimized mode-decision and motion-estimation process. The QP can be used to control the bit stream, thereby maximizing the coding efficiency without overflow or underflow channel rates. Li et al. [1] proposed an approximated quadric model in JVT-G012; a one-pass rate control method to predict a possible QP for H.264/AVC, and a linear model to predict distortion by utilizing the mean absolute difference (MAD) to solve the chicken-and-egg issue. In the quadric model, which was derived in Chiang and Zhang [2], because the QP is a typical closed-form, it can be acquired directly. Due to its efficiency, JVT-G012 has been adopted in H.264/AVC reference software. The MAD prediction must be precise to attain a quadratic form, rending the observations above particularly noteworthy. Encoding the current P-frame might cause a possible issue with JVT-G012 because the bit budget and buffer constraint are given. Therefore, providing an estimate of the QP is difficult because the quadratic model is inadequate when the MAD is not precise and the complexity of the current frame is not utilized. This issue highlights the necessity for designing a rate control algorithm that includes frame-complexity for H.264/AVC.

Overall, rate control strategy can be divided into two parts: intra-frame and inter-frame. However, the implementation of an efficient rate control algorithm should help achieve the balanced allocation between image quality and the assigned bits budget, due to the limited bandwidth in a wireless environment. Several rate control methods for H.264/AVC are either intra-frame or inter-frame, especially the inter-frame rate control methods [3]-[8] and the intra-frame rate control methods [5],[12]-[14]. The first method consists of the optimal rate control combining a rate model and a distortion model [3]-[5], and the other method consists of the real-time rate control [6]-[8].

The original quadratic model is based on statistic distribution, and the rate-distortion theory is applied to generate an R-Q(rate-quantization)/R-D(rate-distortion) model. The method of selecting the distribution model, rate model, and distortion model is becoming a significant topic. A new rate distortion model combining several logarithmic functions and adjusting the boundary of each function has been proposed in Wei et al. [3]. This algorithm is based on video sequence statistics during the encoding process.

The Lagrange method has also been used to construct a new R-D model in Liu et al. [4] and Wang and Kwong [5]. These studies propose an R-D optimized rate control algorithm with an adaptive initial QP determination scheme that is unlike the JVT-G012 quadratic form. Though these studies present new models, calculating the MAD requirement still requires looking to previous MAD values. Even if these models are excellent and robust enough to determine the QP shift, the deciding the final QP still involves predicting the MAD. Secondly, the models in [6]-[8] use a quadratic form as the main skeleton to more accurately modify MAD prediction. Studies in Jiang and Ling [6] and in Wang and Yan [7] propose adaptive MAD predictions. Frame complexity, which combines a buffer status operation, is the main consideration in this approach, and the MAD ratio and empiricism are used to change the QP. Experimental results in Kwon et al. [8] show that the estimation error of the quadratic model can be significantly reduced to perform a simplified and efficient form. The original quadratic model can drop second-order term without sacrificing any considerable performance, and a model parameter can modify the first-order term, much like original quadratic model. The order of power can also be changed to a different frame type. In the current video coding standard H.264/AVC, for inter-frame rate control, estimating the QP requires the quadratic equation when the assumed source is the Gaussian source distribution model expressed by the Taylor series. A more efficient scheme in video coding systems comprises the intra-frame encoding. Because the intra-frame is treated as a reference frame for post P-frame or B-frame encoding, the two processes of motion estimation and compensation according to reference frame will influence the results of bits consumption and PSNR degree. If the QP for an intra-frame is too small, a large number of bits are overspent to encode the intra-frame, and the subsequent inter-frame cannot allocate enough target bits. The intra-frame rate control algorithm has been embedded in the reference software JM 15.0 [9], which is based on bits per pixel (BPP), frame rate, and the bits budget to decide QP. Although the BPP can provide a reference QP value for intra-frame encoding, the image-complexity property and the wide range of QP are not utilized to enhance overall video quality. In Wang and Kwong [5] and in Wu and Kim [12], according to image and larger video training, obtaining an approximate equation is necessary to estimate the QP value. For actual application, the information of image density and gradients is used in Wang and Kwong [5], and an image distortion such as MAD is also employed in Wu and Kim [12] as the indicator, to calculate the final QP value. In Hsia and Wang [13], image edge characteristics and BPP are applied to construct an equation for QP estimation. The image edge characteristic applies a Laplacian matrix of Gaussian (LoG) operators. In Zhou et al. [14], according to extensive experimentation results, the combination of image gradients and histograms, both including luminance and chrominance coefficients, is extremely useful to represent QP estimation under the exponent-based equation.

To achieve correct QP estimation for intra-frame rate control, this study proposes an algorithm based on variance-based distortion measurements, integrated on the current video encoding system JM15.0. The proposed model uses variance between the current and previously reconstructed MB to acquire different distortion in off-line training with a specified QP range. After obtaining the model parameters, the study implements them for real video sequence in the intra-frame rate control.

The remainder of the paper is organized as follows: Section 2 reviews the intra-frame rate control in JVT-G012 for QP computation. Section 3 introduces the proposed intra-frame rate control algorithm with a variance-based distortion. Section 4 evaluates the proposed algorithm and presents simulation results. Finally, Section 5 offers conclusions.

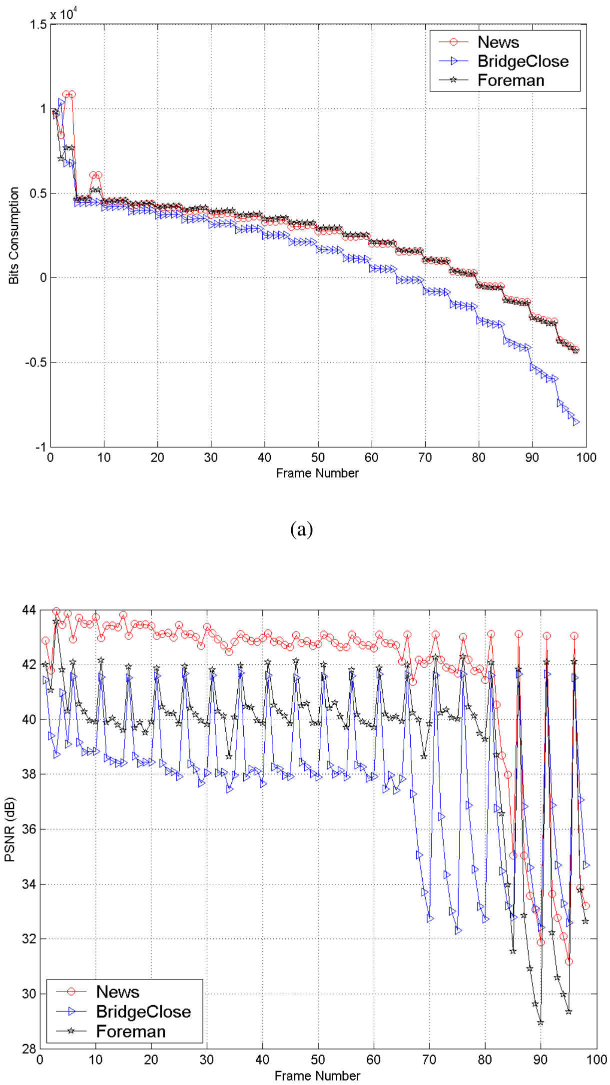
2. Intra-frame rate control analysis in JVT-G012

Each first frame in a picture group is a critical reference frame for post processing. In JVT-G012 [1], the algorithm of intra-frame QP selection is formulated as follows:

$$QP = \begin{cases} 35, BPP \leqslant L_1 \\ 25, L_1 < BPP \leqslant L_2 \\ 20, L_2 < BPP \leqslant L_3 \\ 10, BPP > L_3 \end{cases} \quad (1)$$

$$BPP = \frac{R}{F \times W \times H}\,, \quad (2)$$

where R is the assigned bit rate, F is the frame rate, and W and H connote image width and height, respectively. The set of three parameters $\{L_1, L_2, L_3\}$ are predefined as $\{0.1, 0.3, 0.6\}$ for QCIF video sequences and $\{0.2, 0.6, 1.2\}$ for CIF video sequences, respectively. However, unsuitable BPP leads to uncontrollable bits allocation and image quality because the image content is not considered. The large QP is selected in the formula (1) when a large budget R is applied in the formula (2). However, if the image content is complex the QP should be slightly reduced to maintain complete image quality.



(a)

(b)

Figure 1. Comparison of the bits consumption and corresponding PSNR are shown in "News", "Bridge-close" and "Foreman" video sequences

To prove the condition of unsuitable QP estimation in Li et al. [1], the "News", "Bridge-close" and "Foreman" video sequences in Figure 2 are selected for evaluation. For the main parameters comprising 300 Kbps for the target bit rate, 30 fps frame rate, the encoding structure is IPPPPIPPPP, and JVT-G012 decides the entire intra-frame QP is constant by Li et al. [1]. The presence of an unbalanced bit allocation is worth noting. Because several frames consume more bits in the front video sequence, the status of bits underflow occurs in the hind video sequence. Though the large number of bits is used to encode frames between the 1^{st} and 5^{th} frame when a small QP is applied, the increase in image quality is barely noticeable. During the interval between the 61^{st} and 99^{th} frame, the image quality is large reduced to balance the target bits budget, resulting in unsmooth visualization. In summation, the two drawbacks comprise the uncontrollable bits allocation and noticeable decay in image quality. Thus developing an efficient rate control algorithm for intra-frame is an essential strategy.

3. Proposed variance-based intra-frame rate control algorithm

This section comprises three parts: the mean square error (MSE)-based distortion measurement, the variance-based distortion measurement performed via theoretical deduction to analyze the distortion property, and the variance-based intra-frame rate control algorithm.

3.1. Analysis of MSE-based distortion measurement

Wang and Kwong [11] verified the relation between MSE and quantization step (Q_{step}). Obtaining Q_{step} requires estimating MSE from the previous frame. A real application equation is expressed as follows:

$$Q_{step} = \rho \times MSE, \tag{3}$$

where ρ is the variable for difference video sequences. To fit Q_{step} estimation more accurately, however, Yan and Wang [10] have proposed a gradient-based equation to modify the formula (3) as follows:

$$Q_{step} = \eta \times MSE^{prev} \times \left(\frac{Grad^{curr}}{MG} \times \frac{1}{1 - \frac{BF^{prev}}{Buffer_{Size}}} + \theta\right) + \varepsilon, \tag{4}$$

Where η, θ and ε are variables for difference video sequences. MSE^{prev} is the previous frame MSE and BF^{prev} is the previous buffer fullness after encoding the i^{th} group of picture (GOP). $Grad^{curr}$ is the gradient value of the current frame, and MG is the average gradient value of the previously encoded I-frame in this sequence. According to various encoding test sequences, the relationship between Q_{step} and the gradient value is quasi-linear. This study also considers the buffer fullness to further improve the

QP estimation and avoid the buffer overflow or underflow. The image complexity and bits buffer status are used to adaptively modify Q_{step} because the MSE cannot accurately reflect QP estimation.

According to the above analysis, the distortion will primarily influence Q_{step} the estimation; thus, attempting to discuss the relation between distortion and QP becomes an important topic. Distortion is performed via the quantization process in the video encoding system. According to the theoretical definition, the MSE can be expressed as follows:

$$\begin{aligned} MSE &= \frac{1}{N}\sum_{i=0}^{N}(x_i^{Curr} - x_i^{Quan})^2 \\ &= \frac{1}{N}\sum_{i=0}^{N}(x_i^{Curr} - \frac{x_i^{Curr}}{QP})^2 \\ &= \frac{1}{N}\sum_{i=0}^{N}(x_i^{Curr})^2(1 - QP^{-1})^2 \ , \end{aligned} \tag{5}$$

where N represents all the image pixels, x_i^{Curr} and x_i^{Quan} are the current image and the quantized image at the i^{th} pixel, respectively. In the formula (5), the MSE is influenced by image content and QP value. The increase in QP enlarges the MSE when the image content is constant, and vice versa.

3.2. Deduction and analysis of the variance-based distortion measurement

The theorem in [9] provides the original definition of the rate-distortion form used in this study. This section discusses several necessary aspects for enhanced modeling operation. The relation between rate (R) and distortion (D) can be formulated as follows:

$$R(D) = s \times D + \int_{-\infty}^{\infty} Q(u)\ln(\lambda(u))du \tag{6}$$

where $s \leqslant 0$, $d(u, v)$ is an error metric measurement, D and $\lambda(u)$ are defined as follows:

$$\begin{aligned} D &= \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \lambda(u)Q(u)P(v)e^{sd(u,v)}d(u,v)dudv \\ \lambda(u) &= [\int_{-\infty}^{\infty} P(v)e^{sd(u,v)}d(u,v)dv]^{-1} \end{aligned} \tag{7}$$

Consider a source, $Q(u)$, that outputs an independent Gaussian random variable. The original source can be treated as $P(v)$, which is also an independent Gaussian random variable, with the assumption that a squared-error distortion measure is $d(u, v) = (u - v)^2$. Suppose the terms σ and β represent the standard deviation of the output $Q(u)$ and input $P(v)$ source, respectively. Taking $Q(u)$ and substituting $P(v)$, into the formula (7) yields the following relation:

$$D = \frac{\alpha^2\beta^2}{\alpha^2 + \beta^2} + (\frac{\alpha^2}{\alpha^2 + \beta^2})^2\alpha^2 \, , \tag{8}$$

where $\alpha^2 = \frac{-1}{2S}$. Therefore, α^2 is directly related to the parameter S, whereas β^2 is unrestricted. Thus β^2 is chosen to satisfy $\alpha^2 + \beta^2 = \sigma^2$, producing the following relation on S:

$$D = \alpha^2 = \frac{-1}{2S} \ . \tag{9}$$

The expression for $R(D)$ then becomes

$$R(D) = \frac{1}{2}\ln(\frac{\sigma^2}{D}) \, . \tag{10}$$

The formula (10) is a well-known equation that can be expressed via the Taylor series to perform a close-form equation for QP estimation in the current H.264 rate control scheme.

According to the aforementioned observations in the formula (9), the distortion is evidently arbitrarily variable. The condition $\alpha^2 + \beta^2 = \sigma^2$ and the formula (9) lead to the following equation:

$$D = \sigma^2 - \beta^2 \, . \tag{11}$$

The analytic result (11) is an analytic and novel equation to estimate distortion. This equation is used to develop an efficient rate control algorithm. This study performs a new variance-based distortion measurement. The formula (12) shows a detailed deduction process for evaluating the distortion:

$$\begin{aligned} D &= \sigma^2 - \beta^2 \\ &= \frac{1}{N}\sum_{i=0}^{N}(x_i^{Curr} - M_\alpha)^2 - \frac{1}{N}\sum_{i=0}^{N}(x_i^{Quan} - M_\beta)^2 \\ &= \frac{1}{N}\sum_{i=0}^{N}(x_i^{Curr} - M_\alpha)^2 - \frac{1}{N}\sum_{i=0}^{N}(\frac{x_i^{Curr}}{QP} - \frac{M_\alpha}{QP})^2 \\ &= \frac{1}{N}\sum_{i=0}^{N}(x_i^{Curr} - M_\alpha)^2(1 - QP^{-2}) \, , \end{aligned} \tag{12}$$

where N comprises all the image pixels, x_i^{Curr} and x_i^{Quan} are the current image and the quantized image at the i^{th} pixel, respectively. The terms M_α and M_β are the mean value of the current image and quantized image. This distortion, D, comprises two items to compare with the formula (5): the first item is the consideration of the image mean, and the other is the new QP equation.

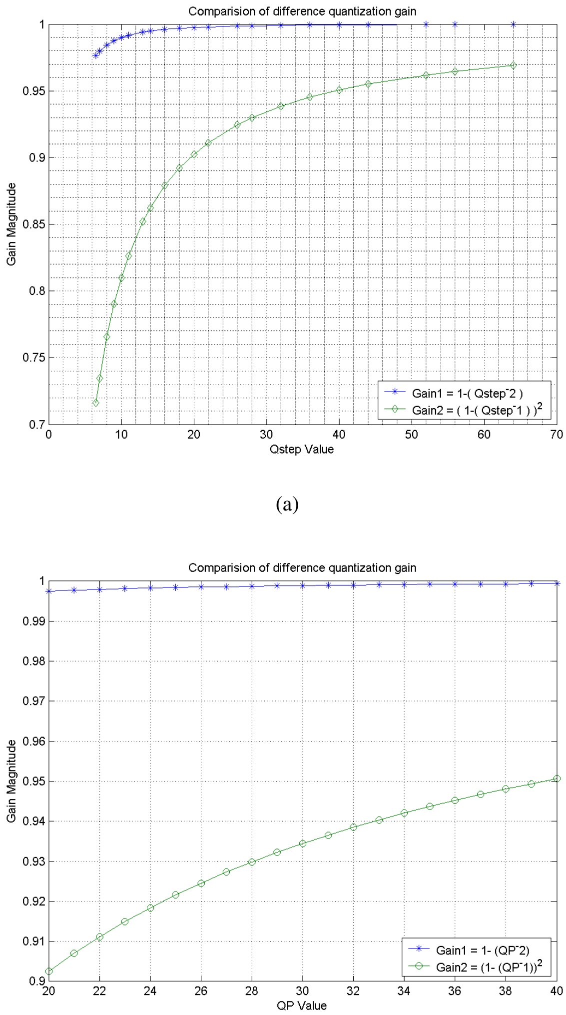
3.3. The study's proposed intra-frame rate control algorithm

In past approaches Wang and Kwong [11], the estimated QP could be obtained via distortion, and the relative parameters are obtained via pre-training, the main reason being that the QP estimation of the first frame in the video sequence is not referential to any frame. Although the MSE can reflect actual QP estimation, the precision is not accurate. Due to this reason, the image content is considered in Yan and Wang [10] for adaptive QP modification. The training procedure requires the linear relationship between QP and the distortion, but the intrinsic problem is not clearly identified. To compare the formulas (5) and (12), the main effect item is QP for distortion obtainment. Explaining the QP effect necessitates setting the bit rate to 400 kbps and the range of Q_{step} from 6.5 to 64 (QP is between 20 and 40) to plot the relationship. Figure 2 shows the selection of two different variables to present the gain magnitude. Results demonstrate that the linear mapping property in Gain1 is a better fit than Gain2, and the vibration is also small because this property can perform a more accurate QP estimation in the training procedure than the nonlinear mapping property [12]-[14]. Thus, selecting a variance-based distortion for QP estimation is more suitable than selecting an MSE-based distortion.

When the variance-based distortion utilizes either of the two parameters, the linear mapping property is also sustained. The QP parameter is more suitable than Q_{step} for constructing the quantization-distortion (Q-D) relation equation, as follows:

$$QP = \gamma \times D + \delta \ , \qquad (13)$$

Where γ and δ are variables for difference video sequences. The formula (13) also includes the image complexity through the variance information to more accurately reflect the QP estimate. To integrate the intra-frame QP estimation in JVT-G012, the description of the algorithm is represented as follows: if the input frame is first in the entire video sequence, QP value estimation can be achieved via the formula (1), restoring the reconstructed image variance. If the input frame is the first frame in the next GOP, the distortion could be calculated via current frame variance and the previous intra-frame variance. According to the distortion, the estimated QP value can be obtained by the formula (13). The QP estimation for the inter-frame is calculated by the JVT-G012 quadric close-form, which is also implemented in JM15.0. A whole view of the intra-frame rate control is depicted in Figure 3.



(a)

(b)

Figure 2. Comparison of the difference quantization gain is shown in two different equations: (a) using the Q_{step} variable, and (b) using the QP variable

4. Experimental results

This study used H.264/AVC reference software JM15.0 [9] to evaluate the proposed rate control algorithm. The conducted evaluation required using the first 100 frames of five QCIF test sequences. The test

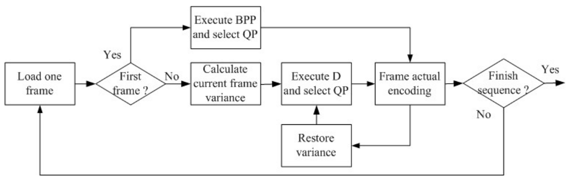


Figure 3. Integration of JVT-G012 and variance-based intra-frame rate control

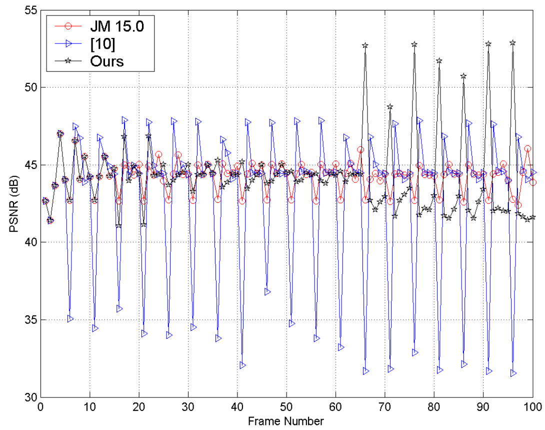


Figure 4. PSNR comparison of JVT-G012, Yan and Wang [10] and our proposed algorithm on "Highway" video sequence

target bit rate is 300 Kbps for " Foreman," and " News," and 400 Kbps for "Bridge-close," "Highway," and "Grandma." Each sequence was coded at 15 fps according to the IPPPPIPPPP structure. The reference frame was set to 5, and the search window was set to 15. CAVLC, RDO, and rate control were also enabled. The study equally selected other relative parameters for JM15.0 [1], Yan and Wang [10], and the proposed algorithm. To obtain the model parameters in the off-line operation, five QPs were attempted, including 20, 25, 30, 35, and 40 in the first frame of the video sequence, and their respective distortions D were recorded. Via linear regression and recorded distortions D, the good Q-D performance curve was constructed. Table 1 lists the model parameters of γ and δ on various test sequences.

Figure 4 shows the frame-by-frame PSNR comparison of three algorithms for the "Highway" video sequences. Since the JVT-G012 algorithm in the intra-frame QP estimation is not adaptive, all the intra-frames utilize the same QP. Yan and Wang [10] predicted that QP can sometimes be unsuitable; for example, a disadvantage is that the inter-frame only uses the large QP to preserve the target budget. Our proposed algorithm leads to image quality enhancement in the 65^{th} frame, 71^{st} frame, 75^{th} frame, 81^{st} frame, 85^{th} frame, 91^{st} frame and 96^{th} frame in Figure 4 especially. The proposed algorithm significantly enhances the PSNR in intra-frame and also holds suitable quality in inter-frame when compared to JVT-G012 and Yan and Wang [10].

Figure 5 displays the bits consumption for "Foreman" and "News" test video sequences. The figure demonstrates that the proposed algorithm can maintain smoother and more suitable bits operation than both JVT-G012 and Yan and Wang [10], because both use QP values which are too small for previous frames, consuming large numbers of bits. In our algorithm, bit allocation is smoother, not only for intra-frames, but also for inter-frames because the intra-frame receives suitable QP and saves bit count for post inter-frame encoding. Our result sustains smooth image quality and is highly suitable for limited bandwidth networks.

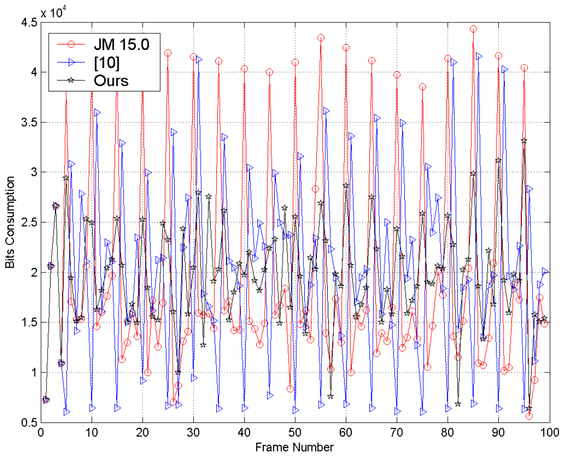
The proposed algorithm is more adaptive, producing smooth frame type changes, because it can adjust the QP by using complexity measurements. This study adopts a formula in Wang and Kwong [5] to further evaluate the bit rate mismatch quantification, as follows:

$$\triangle R = \frac{\mid R_t - R_b \mid}{R_b} \times 100\% \, , \qquad (14)$$

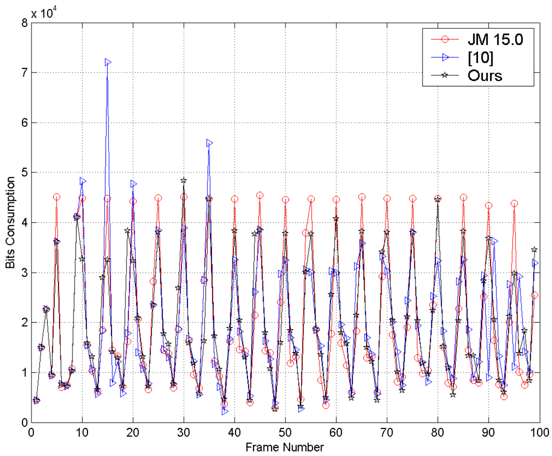
where R_t is the bit rate of the test algorithm and R_b is the target bit rate. $\triangle R$ represents the degree of mismatch in the produced bit rate, and the small $\triangle R$ indicates that the QP-produced bit rate is closer to the budget, and vice versa. Table 2 presents detailed numerical simulation results, showing that the proposed algorithm can provide excellent performance, up to 0.19 dB and 1.28 dB better PSNR than JVT-G012 and Yan and Wang [10], respectively, while the output bit rate is also close to the target budget. This table also displays two gains, Gain 1 and Gain 2, to depict the performance improvement over JVT-G012 and Yan and Wang [10], respectively. Compared with JVT-G012 and Yan and Wang [10], the proposed algorithm improves results in all test sequences. These results show that the proposed algorithm produces lower $\triangle R$ results than JVT-G012 for the News sequence. Table 2 also shows that the proposed algorithm is capable of controlling precision for the target bit rate. Moreover

Table 1. Model parameters of Q-D model with different video sequences

Video Sequences	γ	δ
Foreman	0.0465	-67.3608
News	0.5885	-40.2565
Bridge-close	0.4794	-77.6881
Highway	0.8383	-135.2993
Gradma	0.9146	-57.6692



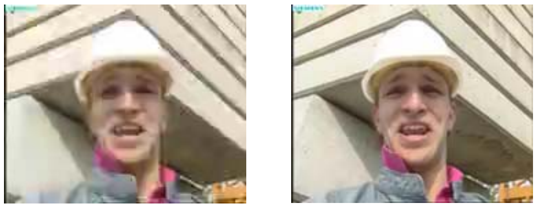
(a)



(b)

Figure 5. Bits consumption comparison of JVT-G012, Yan and Wang [10] and the proposed algorithm, on two different video sequences: (a)"Foreman" and (b)" News"

the proposed algorithm presents better image quality than both JVT-G012 and Yan and Wang [10]. Furthermore, the bit rate variation is near equal to JVT-G012 and Yan and Wang [10]. Thus, the proposed algorithm can be applied to real-time multimedia data streaming and can produce excellent image quality.



(a)

(b)

(c)

Figure 6. Visual comparison of Yan and Wang [10] (left) and the proposed algorithm (right) in three different video sequences: (a) "Foreman," (b) "News" and (c) "Highway." The frame is in the 56^{th}, 91^{st} and 96^{th} location, from the top

Worth noting is that since all the inter-frame QP estimates in Yan and Wang [10] are unsuitable, the inter-frame should increase QP to balance the overall bits target. To further improve fitting the algorithm to real visualization application, Figure 6 shows the results of decoding frames with the Yan and Wang [10] versus the proposed algorithm in three test video sequences, the 56^{th} frame in "Foreman", the 91^{st} frame in "News," and the 96^{th} frame in "Highway" respectively. The moving objects include the face in Figure 6(a), the dancer and reporter in Figure 6(b), and

Table 2. Performance of three algorithms in term of average PSNR, PSNR Std. deviation, bit rate and △ R

Video Sequences	Method	Average PSNR(dB)	PSNR Std. Deviation	Bit Rates (kbps)	△ R
Foreman	JVT-G012	43.25	17.18	298.63	0.46
(300 kbps)	[10]	42.87	18.17	298.97	0.34
	Ours	43.39	17.16	298.34	0.55
	Gain 1	+0.14	-	-	-
	Gain 2	+0.52	-	-	-
News	JVT-G012	47.26	19.09	299.50	0.17
(300 kbps)	[10]	47.25	19.34	299.67	0.11
	Ours	47.42	19.34	300.38	0.13
	Gain 1	+0.16	-	-	-
	Gain 2	+0.17	-	-	-
Bridge-close	JVT-G012	41.76	16.48	399.81	0.05
(400 kbps)	[10]	41.63	16.74	400.21	0.05
	Ours	41.95	16.21	399.60	0.10
	Gain 1	+0.19	-	-	-
	Gain 2	+0.32	-	-	-
Highway	JVT-G012	44.23	17.58	400.08	0.02
(400 kbps)	[10]	42.96	17.86	400.13	0.03
	Ours	44.24	17.25	400.76	0.19
	Gain 1	+0.01	-	-	-
	Gain 2	+1.28	-	-	-
Gradma	JVT-G012	47.93	19.45	400.69	0.17
(400 kbps)	[10]	47.86	19.44	398.49	0.38
	Ours	48.12	18.96	398.62	0.25
	Gain 1	+0.19	-	-	-
	Gain 2	+0.26	-	-	-

the road sign in Figure 6(c), though they are blurry, and the block effect is especially clear. The proposed algorithm can evidently improve the image quality compared to the currently used algorithm.

5. Conclusions

This paper presents a variance-based intra-frame rate control for H.264/AVC. The purpose of this paper is to make use of the advantage in the relationship between distortion and QP, in order to develop a more efficient method for intra-frame rate control. Experimental results show that the proposed algorithm can simultaneously improve both the PSNR and the bit rate. This algorithm is also constructed on a one-pass scheme. Numerous simulation results show that the proposed algorithm can also achieve a higher average PSNR and lower bit rate mismatch. The balanced bit allocation and control are suitable for strict network environment. Thus, this algorithm is better suited to H.264/AVC rate control than existing algorithms. In further work, we shall attempt to develop an adaptive method for model parameter switching and dynamic training.

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