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# An adaptive content based H.264/AVC rate control in low bit rate video

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ABSTRACT

In this paper, we analyze a rate control formula, which is Laplacian based model, then propose a content based equation for an enhanced JVT-G012 algorithm. Based on the simple and fast characteristics of the JVT-G012 algorithm, which is very suitable for real time embedded systems, we integrate the equation into the JVT-G012 algorithm to create an efficient quantizer. However, active local motion will produce error distortion and influence the determination of the quantization parameter. To solve this problem, a modified histogram based detector is proposed. Combining this detector with the equation refines the predicted quantization parameter more precisely. It is shown both theoretically and experimentally that a well-designed quantizer not only improves video quality, but also maintains the designed bit rate budget. In addition, our algorithm can achieve superior results to existing algorithms-up to 0.72 dB without large computation loading.



## 1. Introduction

Rate control plays an important role in the H.264/AVC video encoder, which is the newest standard from the ITU-T Video Coding Experts Group and the ISO/IEC Moving Pictures Experts Group such as MPEG-2 Visual [1], H.263 [2], MPEG-4 Visual [3], and H.264/AVC [4]. Several coding parameters must be determined, such as the macro block (MB) type, quantization parameter (QP), and multiple reference frames. As a result, it is able to achieve much higher rate control efficiency than conventional video coding methods. For real time video applications, such as video surveillance and video conferencing, bandwidth is an important consideration. Usually, rate control regulates the coded bit stream by modifying the QP. Because the bandwidth is small and expensive, a low bit rate environment requires more accurate bit allocation and sufficient image quality. Without rate control, underflow or overflow will occur between the encode bit rate and available channel bandwidth. In other words, an encoder without rate control would be difficult to use. It is worthwhile to point out that the rate control algorithm has been developed in two parts. The Lagrange method is used to construct a new R-D model in [5,6], which propose an R-D optimized rate control algorithm with an adaptive initial QP determination scheme that differs from the JVT-G012 algorithm quadratic form [7]. Although these models can possible obtain the optimum QP, the correlation between two frames is calculated to modify the initial QP and the computational complexity is enormous. In addition, a near optimization searching method is proposed in [8] that is also based on the Lagrange method to pick up a suitable QP for achieving a more accurate bit rate budget. However, the complexity of the encoder increases proportionally with the number of iterations, and it depends on the initial QP and relative parameters, such as the Lagrange multiplier, block mode, and reference frames. Because the Lagrange method has a complex computation and cannot suit real time applications, the histogram of difference (HOD) is used to detect which frames are skipped to save encoding time; moreover, the HOD value is taken to modify the bit allocation and update the Lagrange multiplier in [9,10]. Secondly, the quadratic form, which is assumed as statistical distribution, is used as the main skeleton for more accurately modifying the mean absolute difference (MAD) prediction in [11,12] and to find a suitable QP. Both [11] and [13] propose an adaptive MAD prediction method. The frame complexity is the main consideration, and using the empirical MAD ratio to change the QP is their main contribution. Experiments confirm that the estimation error of the quadratic model can be significantly reduced to perform a simplified and efficient form in [12]. The second order term is dropped in the original quadratic model without sacrificing much performance, and the first order term is modified by a model parameter to approximate the original quadratic model and the order of the power can be changed in different frame types, such as I-, P-, and B-frame.

Here, methods with large computational complexity are not used because real time embedded systems have limited resources. Fortunately, there is a simple and fast quadratic form that is an efficient closed form, which was recommended and implemented in the H.264/AVC reference software JM 15.0 [14]. Although the QP

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determination technique used in the JVT-G012 algorithm is state of the art, it is not sufficiently accurate for low bit rate video coding, and does not address the problem of local motion. Even if the JVT-G102 algorithm is selected as the main QP prediction method, the input frame must be assumed to have a specified statistical distribution. Determining this distribution function becomes an important issue because the frame content varies. To use the simple and fast model, we propose an equation constructed based on an analytic rate distortion function and fed into the JVT-G102 algorithm to refine the initial QP as a middle result. To avoid high computational complexity, the middle QP will be refined again as a final QP by a modified HOD.

The rest of this paper is organized as follows. In Section 2, we briefly review the original quadratic rate control model for QP computation. An enhanced equation will be analyzed and verified with the original quadratic model, and a modified HOD is added to solve the problem of local motion in Section 3. We then evaluate the proposed algorithm and exhibit the simulation results in Section 4. Finally, Section 5 gives the conclusions.

## 2. Overview of the statistically based rate distortion model

In [15], a mathematical rate distortion was derived and proved in detail. To fit this theorem, however, the selection of a suitable distribution model is important. In previous approaches, the Laplacian model was derived as the rate distortion equation – this has also been used in recent research [7,11,12], thus, this model is worth consideration. From [15,16], the relation between rate and distortion can be formulated as

$$R = \ln \frac{1}{1\sigma \times D} \tag{1}$$

where $R$, $\sigma$ and $D$ represents the bit rate budget, variance and distortion respectively. Eq. (1) can be expanded by a Taylor series to build the new model. It is modified by substituting QP and MAD for $D$ and $\sigma$, respectively. The new model, following [17], is formulated as

$$R = X_1 \times \frac{\text{MAD}}{\text{QP}} + X_2 \times \frac{\text{MAD}}{\text{QP}^2} \tag{2}$$

Thus, the QP can be obtained when the coefficients and target bit rate are given; this formula is adopted by the JVT-G102 algorithm. Because it is simple and fast, it is suitable for real time implementation. However, past approaches, such as [9,10,18], show that JVT-G102 cannot provide a suitable solution to accurately estimate the QP of a P-frame at a low bit rate. Even if these approaches solve this problem and provide acceptable results, the computation loading is too large.

## 3. Proposed adaptive content based algorithm

### 3.1. Analyze and verify a Laplacian based model on the JVT-G012 algorithm

Although the JVT-G102 algorithm cannot accurately obtain a QP in low bit rate video immediately, the result is quite close to the real requirements. Even if a two pass algorithm in [12] is proposed to enhance the JVT-G102 algorithm, the computation is still large. Consequently, we propose an efficient equation for the JVT-G102 algorithm that will improve performance and provide a low computational burden. Eq. (1) shows that the relation between rate and distortion can be demonstrated, and the relation between rate and QP is formulated in (2). We can modify (1) to create a new equation as

$$D = \frac{1}{\sigma \times e^R} \tag{3}$$

**Table 1**
Performance of two methods in term of average PSNR, and bit rate.

| Methods | JVT-G012 | JVT-G012+(3) | Gain |
|---|---|---|---|
| Test video sequence: Mother and Daughter (24 kbps) | | | |
| Average PSNR (dB) | 35.33 | 35.28 | −0.05 |
| Bit rate (kbps) | 24.54 | 24.60 | – |
| Test video sequence: Hall (32 kbps) | | | |
| Average PSNR (dB) | 35.99 | 36.13 | +0.14 |
| Bit rate (kbps) | 32.18 | 32.14 | – |
| Test video sequence: Highway (48 kbps) | | | |
| Average PSNR (dB) | 37.08 | 36.93 | −0.15 |
| Bit rate (kbps) | 48.70 | 49.17 | – |

In (3), we assume that the distortion $D$ is variable when bit rate $R$ and variance $\sigma$ are given by current MB, the initial distortion $D$ is predicted by the JVT-G102 algorithm. Note that $D$ can be replaced by the mean square error or mean absolute difference for a fast and simple implementation. A well defined relation [19] is constructed as follows:

$$D \propto \text{QP} \tag{4}$$

Thus, we can adjust QP under the predicted term of the target budget to satisfy the equation. But, multiple iterations are not acceptable for real time application in resource limited systems. Nevertheless, the first result in (3) can be used as guidance to refine the initial $\text{QP}_{\text{initial}}$; then we can combine (3) with the JVT-G102 algorithm to create a more efficient rate control algorithm. The JVT-G102 algorithm calculation produces the $\text{QP}_{\text{initial}}$, (3) converts it to an inequality to increase or decrease the $\text{QP}_{\text{initial}}$. In general, if $D > 1/(\sigma \times e^R)$ then $\text{QP} = \text{QP}_{\text{initial}} - 1$; otherwise $\text{QP} = \text{QP}_{\text{initial}} + 1$. The $\text{QP}_{\text{initial}}$ determination for an I-frame is not considered; this only focuses on the P-frame level.

The beginning experimental results, including the average peak signal to noise ratio (PSNR) and bit rates, are given in Table 1. The simulated conditions are described in Section 4. It focuses on three parts: the bit rates, the PSNR, and enhanced PSNR. Although this method can improve image quality, only partial test video sequences are efficient.

Fig. 1 shows a frame by frame PSNR comparison; in addition, we analyze the drop of PSNR in the visual domain. From the 80th frame to the 99th in Fig. 1(c), the PSNR is influenced by the add adjustment equation, (3). In the original video sequence, the object in the frame has active local motion from back to front (Fig. 1(c)). For this reason, a noticeable result that can be addressed is the local motion problem and (3), which can provide smooth frames but does not apply to active local motion. Unfortunately, (3) refines the $\text{QP}_{\text{initial}}$ from the JVT-G012 algorithm in the wrong direction.

### 3.2. Proposed rate control algorithm

Even if multiple iterations are avoided, a single QP determination may be not accurate enough to compare with the real QP and active local motion can reduce the PSNR when (3) is applied. The QP must be decreased to improve the PSNR due to active local motion; the QP should be also increased to improve the bit rate budget when the local image is inactive and motionless. An efficient and fast detection method becomes important. The histogram based methods are considered first, as they are useful and directly detect image content variation [20]. To maintain low complexity computation and local motion, block level processing and HOD which is defined at frame level operation are considered. A detailed description of HOD is given in [20]. The modified calculation equation, HODB, is given as

$$\text{HODB}(b_n, b_{n-1}) = \sum_{i > |\text{TH}|} \text{hod\_block}(i) \tag{5}$$

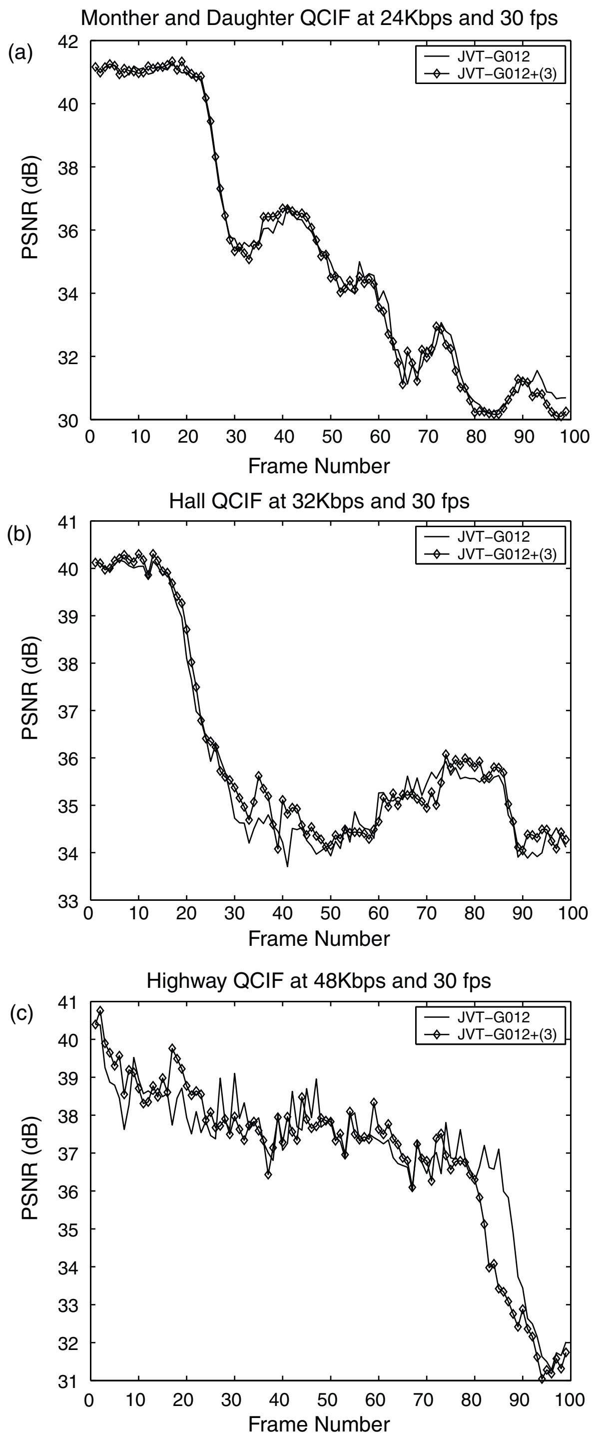


**Fig. 1.** PSNR comparison between JVT-G012, and JVT-G012 with Eq. (3) for three standard test sequences: (a) "Mother and Daughter", (b)"Hall", and (c) "Highway".

where $i$ is the index of the histogram bin, the histogram of difference block is from hod_block($i$), $N_{\text{pixel}}$ is the number of pixels and TH is a threshold for determining the proximity of the position to zero. $b_n$ and $b_{n-1}$ indicate the current block and previous block, respectively. Some excellent results are demonstrated and proven in [18]. From a physical viewpoint, the HODB value is generally increasing monotonically. Generally speaking, the block contains more information if the HODB is nonzero. Although the descriptive algorithm in section A decreases the PSNR during active local motion, it can enhance the PSNR in smooth areas. Thus, we try to keep the property and use the HDOB to avoid the influence of active local motion.

In JVT-G012, the bit allocation only focuses on predefined target bits and buffer status to compensate for bit cost. To meet the real time embedded system, two concepts of data-reuse and lower computation should be considered for bit allocation. Thus, we propose a modified equation in (6) that uses the HODB value for target bit adjustment without large computation. The target bit prediction, $T_{\text{all}}$, is defined in [4,14].

$$R = (0.9 + \text{HODB} \times \varphi) \times T_{\text{all}} \tag{6}$$

The parameter $\varphi$, obtained from experiments, is set to be

$$\varphi = \begin{cases} 5, & 0.9 < \text{HODB} \leq 1 \\ 0.9, & \text{HODB} \leq 0.9 \end{cases} \tag{7}$$

After, Laplacian based model and reused HODB information to provide efficient modification to improve the $\text{QP}_{\text{initial}}$ from JVT-G012. The full algorithm can be described as follows.

Step 1: Let $R$ be the target bit budget for current frame, $R_i$ for $i$th MB and $i = 1$. N is the total number of MBs in the frame after assigning the Laplacian model.
Step 2: Obtain the HODB value according to the previous reconstructed and current frame in the co-located MB. Adjust the $R_i$ adaptively by (6).
Step 3: With the JVT-G102 algorithm, use $R_i$ and the predicted MAD to get the initial QP, $\text{QP}_{\text{initial}}$, by (2).
Step 4: Select (3) as an adjustment equation and transfer to an inequality. Calculating variances $\sigma$. If $D > 1/(\sigma \times e^{R_i})$ then $\text{QP}_{\text{tmp}} = \text{QP}_{\text{initial}} - 1$; otherwise $\text{QP}_{\text{tmp}} = \text{QP}_{\text{initial}} + 1$.
Step 5: Select (5) as an adjustment equation. Calculate the histogram hod_block($i$) and set TH to 32. If HODB > 0 then $\text{QP}_{\text{final}} = \text{QP}_{\text{tmp}} - 3$; otherwise $\text{QP}_{\text{final}} = \text{QP}_{\text{tmp}} + 3$.
Step 6: Use $\text{QP}_{\text{final}}$ to encode the current MB $i$ and set $i = i + 1$. If $i \leq N$, go to step 2 to encode next MB. Otherwise stop the encoding procedure.

Overall, an efficient formula can be summarized as in (8). From the viewpoint of a real time embedded system, (8) can be implemented in parallel because the input data is independent and has a low computational complexity.

$$\text{QP}_{\text{final}} = \begin{cases} \text{QP}_{\text{initial}} + 4, D < \dfrac{1}{\sigma \times e^R} \bigcap \text{HODB} \leq 0 \\ \text{QP}_{\text{initial}} + 2, D > \dfrac{1}{\sigma \times e^R} \bigcap \text{HODB} \leq 0 \\ \text{QP}_{\text{initial}} - 2, D < \dfrac{1}{\sigma \times e^R} \bigcap \text{HODB} > 0 \\ \text{QP}_{\text{initial}} - 4, D > \dfrac{1}{\sigma \times e^R} \bigcap \text{HODB} > 0 \end{cases} \tag{8}$$

For a clearer description, Fig. 2 depicts integrating our algorithm into the JVT-G012 block diagram. In addition to the shadow blocks in rate control in the proposed functions, all other functions are built in the original H.264/AVC encoder system. The main goal of rate control is to provide a more accurate QP for quantization. The computation complexity of QP selection should be limited to meet real time applications. The implementation also considers the memory requirement in the embedded system due to limited hardware resource. Fig. 2 shows directly calculating the HODB without extra buffer allocation and sending the HODB value to the bit allocation adjustment and QP adjustment, after deciding the final target bit rate and final QP. Thus, the proposed algorithm is very suitable to integrate on the current H.264 encoder embedded system.

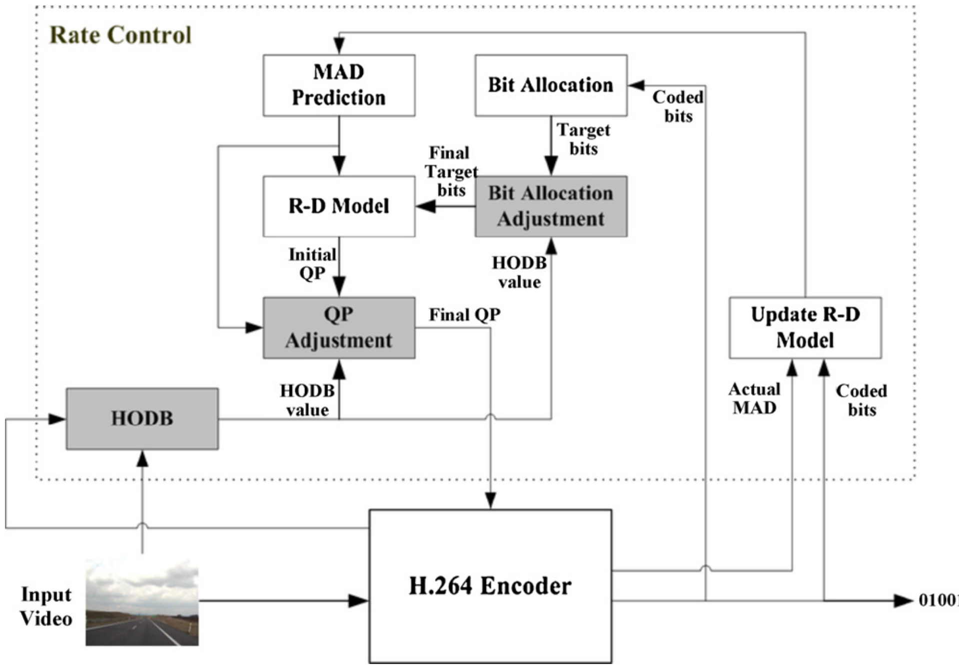


**Fig. 2.** Integration of JVT-G012 and our proposed algorithm block diagram in H.264/AVC.

## 4. Experimental results

The adaptive context based rate control algorithm with a Laplacian based model and a HOD method was incorporated into the JM H.264/AVC reference software [14]. The evaluation was conducted with the first 100 frames of six QCIF test sequences. For the low bit requirement, 24, 32, and 48 kbps were selected. The test target bit rate is 24 kbps for "Grandmother", "Mother and Daughter", and "Miss-America", 32 kbps for "Akiyo", "Bridge-far", and "Hall", and 48 kbps for "Carphone", and "Highway". Each sequence is coded at 30 fps with an IPPP structure, which indicates only one I-frame in first frame and P-frame in residual frames, thus the influence of I-frames can be reduced and ignored. There are five reference frames and the search window is set to 15. Context adaptive variable length coding, rate distortion optimization, and rate control are enabled. The residual parameters are fixed equally. As a reference, the performance of the JVT-G102 algorithm and [13] were compared with our proposed algorithm. Although three layer rate control algorithm is presented in [13], only using the block complexity ratio to modify the Lagrange multiplier layer provides the best mode decision and QP selection. Our algorithm also uses block complexity to select a suitable QP, thus, [13] becomes a fair comparison.

Fig. 3(a)–(c) shows a frame by frame comparison in PSNR terms for three standard test sequences: "Mother and Daughter", "Hall", and "Highway". The effectiveness of our algorithm is further indicated by the fact that our algorithm improved the video quality more than JVT-G102 algorithm and [13]. Indeed, our algorithm enhanced the PSNR to a greater degree than the two algorithms overall. Comparing Figs. 1(c) and 3(c) from the 80th to the 99th frame shows that the degree of PSNR enhancement improved significantly and avoids the local motion problem. Moreover, comparing Figs. 1(c) and 3(c) from the 15th to the 25th frame shows that the enhanced PSNR is maintained, even when the HOD method is applied. The PSNR is close to the two algorithms under smooth conditions and superior when active local motion is produced. Detailed results are given in Table 2. Our algorithm is close to the required bit rate budget, which means that the algorithm can achieve the PSNR enhancement and still match the required bit rate. To evaluate the bit rate mismatch quantification further, a useful formula

**Table 2**
Performance of three algorithms in term of average PSNR, PSNR Std. deviation, bit rate and $\Delta R$.

| Methods | Average PSNR (dB) | PSNR std. deviation | Bit rates (kbps) | $\Delta R$ |
|---|---|---|---|---|
| Test video sequence: Grandma (24 kbps) | | | | |
| JVT-G012 | 36.17 | 2.91 | 24.21 | 0.88 |
| Wang [13] | 35.83 | 2.87 | 24.21 | 0.88 |
| Our | 36.55 | 2.26 | 24.19 | 0.79 |
| Gain | +0.38/+0.72 | – | – | – |
| Test video sequence: Mother and Daughter (24 kbps) | | | | |
| JVT-G012 | 35.33 | 3.83 | 24.54 | 2.25 |
| Wang [13] | 35.01 | 3.94 | 25.60 | 6.67 |
| Our | 35.48 | 3.61 | 24.54 | 2.25 |
| Gain | +0.15/+0.47 | – | – | – |
| Test video sequence: Miss-America (24 kbps) | | | | |
| JVT-G012 | 39.39 | 2.31 | 24.44 | 1.83 |
| Wang [13] | 38.94 | 2.69 | 25.25 | 5.21 |
| Our | 39.53 | 1.30 | 24.28 | 1.17 |
| Gain | +0.14/+0.59 | – | – | – |
| Test video sequence: Akiyo (32 kbps) | | | | |
| JVT-G012 | 39.70 | 1.35 | 32.12 | 0.38 |
| Wang [13] | 39.25 | 1.54 | 32.28 | 0.88 |
| Our | 39.77 | 1.16 | 32.19 | 0.59 |
| Gain | +0.07/+0.52 | – | – | – |
| Test video sequence: Bridge-far (32 kbps) | | | | |
| JVT-G012 | 39.52 | 0.08 | 32.10 | 0.31 |
| Wang [13] | 39.67 | 0.10 | 32.22 | 0.69 |
| Our | 39.96 | 0.46 | 32.35 | 1.09 |
| Gain | +0.44/+0.29 | – | – | – |
| Test video sequence: Hall (32 kbps) | | | | |
| JVT-G012 | 35.99 | 2.09 | 32.18 | 0.56 |
| Wang [13] | 35.82 | 2.16 | 32.20 | 0.63 |
| Our | 36.16 | 1.93 | 32.17 | 0.53 |
| Gain | +0.17/+0.34 | – | – | – |
| Test video sequence: Carphone (48 kbps) | | | | |
| JVT-G012 | 34.18 | 1.52 | 48.45 | 0.94 |
| Wang [13] | 33.80 | 2.11 | 49.89 | 3.94 |
| Our | 34.21 | 1.26 | 48.25 | 0.52 |
| Gain | +0.03/+0.41 | – | – | – |
| Test video sequence: Highway (48 kbps) | | | | |
| JVT-G012 | 37.08 | 1.95 | 48.70 | 1.46 |
| Wang [13] | 36.84 | 1.55 | 49.10 | 2.29 |
| Our | 37.41 | 1.07 | 48.94 | 1.96 |
| Gain | +0.33/+0.57 | – | – | – |

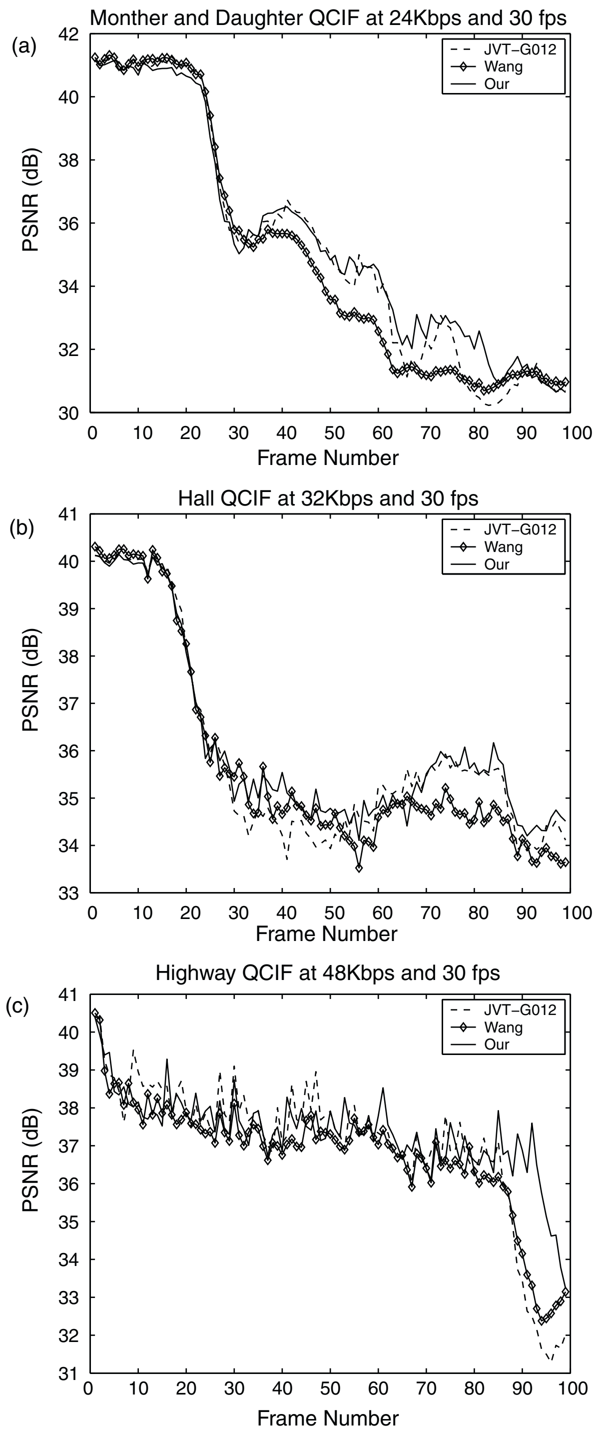


**Fig. 3.** PSNR comparison among JVT-G012, Wang [13], and our proposed algorithm for two standard test sequences: (a) "Mother and Daughter", (b) "Hall", and (c) "Highway".

[6] is used in the paper.

$$\Delta R = \frac{R_{\text{test}} - R_{\text{budget}}}{R_{\text{budget}}} \times 100\% \tag{9}$$

where $R_{\text{test}}$ is the bit rate of the test algorithm and $R_{\text{budget}}$ is the target bit rate. A small $\Delta R$ means that test algorithm can achieve the required bit rate. The gain in Table 2 denotes the comparison of our algorithm to the JVT-G102 algorithm and [13]. In our algorithm, the performance with respect to video quality was enhanced by an average of 0.49 dB and a maximum of 0.72 dB compared to [13] and by an average of 0.21 dB and a maximum of 0.44 dB compared to the JVT-G012 algorithm. Not only did the average PSNR improve dramatically but the standard deviation is lower than that of the existing algorithms. Finally, all PSNR standard deviations are shown and our proposed algorithm maintains a lower deviation than the other two algorithms for test video sequences. Comparing Tables 1 and 2 shows more excellent results. Although (3) can improve the QP prediction, active local motion will lead to inaccurate QP, which decrease the PSNR and waste the bit rate budget. To correct the QP prediction, the HODB method is applied to modify QP quickly and accurately.

**Table 3**
Comparisons of main computation amounts in two different algorithms per MB.

| | Wang [13] | Our |
|---|---|---|
| # of addition | 256 | 256 |
| # of subtraction | 256 | 256 |
| # of multiplication | 1 | 0 |
| # of division | 3 | 1 |
| # of square root | 1 | 0 |

The comparison of calculation units presents the low computation property of the proposed algorithm. Both [13] and our proposed algorithms are built on the JVT-G012, which is compared in terms of addition, subtraction, multiplication, division and

**Fig. 4.** Visual comparison of the original (top), JVT-G102 (middle), Wang [13] (third), and the proposed algorithm (bottom). These frames are the 81th and 33th in the test video sequences "Mother and Daughter" and "Hall", respectively.

**Fig. 5.** Visual comparison of the original (top), JVT-G102 (middle), Wang [13] (third), and the proposed algorithm (bottom). These frames are the 95th and 78th in the test video sequences "Highway" and "Grandma", respectively.

square root operations. Thus, the MB level describes and analyzes extra computation in [13] and in our proposed algorithm. In [13], the adaptive Lagrangian multiplier in the *i*th MB is the main contribution and computation. The formula is expressed as follows.

$$\lambda_i = \lambda_i \times \left(\frac{\mathrm{MAD_{frame}}}{\mathrm{MAD_{MB}}}\right)^{\frac{1}{4}} \quad (10)$$

where $\mathrm{MAD_{frame}}$ and $\mathrm{MAD_{MB}}$ are the actual MAD in the previous frame and co-located MB respectively. In (10), the numbers of multiplication and square root operations are equal to 1. The addition and subtraction operation for actual MAD calculation are equal to 256 respectively, because the linear regression prediction does not obtain MAD, moreover, the division, operation is 3. The HODB computation is also the main contribution and computation in the proposed algorithm without square root operation. The number of subtraction operations is 256 for two MB operations and the number of addition operations is 256 for histogram accumulation. Table 3 presents the comparison of five mathematical operations with two different algorithms.

The division and square root operation has large computation loading, thus avoiding or reducing the operation requires implementing in hardware or in the firmware level [21]. Table 3 clearly shows that the proposed algorithm is less than [13] in division and square root. Since the digital signal processor (DSP) based system produces multiple multiply-accumulates per cycle, implementing our algorithm in the DSP-based embedded system reduces the addition and multiplication operations. The histogram function has also been recently built into the DSP core, such as TI TMS320DM6437 [22], due to this very popular function for image and video processing. Thus, HODB computation is not necessary.

Figs. 4 and 5 shows actual video sequences to demonstrate that our algorithm suits real applications. The three algorithms (JVT-G102, [13], and our proposed algorithm) are demonstrated simultaneously when the test video sequences "Mother and Daughter", "Hall", "Highway", and "Grandma" are selected. From visual comparison, our proposed algorithm can select a more precise QP to provide an acceptable visual image quality. It is clear that our proposed algorithm can achieve a higher PSNR than the existing algorithms and reduces the bit rate mismatch ratio.

## 5. Conclusion

This paper has presented an efficient rate control algorithm for a H.264/AVC video encoder. Through rate control model analysis, an adjustment equation is constructed, based on a statistical model. However, during active local motion the QP will be refined in an incorrect direction. Considering frame complexity and then adaptively enhancing the QP prediction accuracy of the JVT-G102 algorithm, using the HOD method, not only produces a superior result during smooth frames but also generates outstanding results during active local motion. Experimental results show that our algorithm requires no pre-encoding processing and can achieve effective improvements in PSNR-it provided more enhancement than either [13] or the JVT-G102 algorithm. In addition, all algorithms also can be kept on a limited bit rate budget. Thus, our algorithm is suitable for H.264/AVC video rate control even if ported into a real time embedded system.

## Acknowledgement

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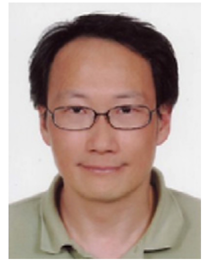

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