Rate Control Algorithm for H.264/AVC Video Coding Standard Based on Rate-Quantization Model

Seonki Kim and Yo-Sung Ho

Kwangju Institute of Science and Technology (K-JIST)
1 Oryong-dong Buk-gu, Kwangju, 500-712, Korea

E-mail: {*sunkee, hoyo*}*@kjist.ac.kr*

Abstract

The rate control is the essential part in video coding algorithms to maintain uniform picture quality for the given coding constraints. In this paper, we propose a new rate control algorithm for the H.264 video coding standard. We derive a rate-quantization model from the rate-distortion function based on the distribution of source data to be quantized. We also classify macroblocks in each frame into three groups according to their characteristics, and decide the quantization parameter for each macroblock. Experimental results show that the proposed scheme generates coding bits very close to target bits and provides improved coding efficiency at low bit rates.

1. Introduction

Although the rate control is not the normative part of the video coding standard, most video encoders employ appropriate rate control schemes to handle variable bit rate characteristics of the coded bitstream and produce good picture quality at given target bit rates. Therefore, conventional video coding standards include rate control schemes in their test models, such as MPEG-2 TM5 [1], MPEG-4 Q2 [2], and H.263 TMN8 [3].

Recently, the H.264 video coding standard has been developed jointly by ISO/IEC and ITU-T to achieve higher coding efficiency than existing video coding standards. The rate control part of H.264 has also been actively investigated [4]. Current studies for the rate control can be classified into two different categories: one is based on the buffer status to decide the quantization parameters, as in the MPEG-2 TM5 model, and the other is a model-based approach focused on the relationship between rate and distortion in order to select quantization parameters, as in the MPEG-4 Q2 model.

In this paper, we propose a rate control algorithm using a rate-quantization model, which is designed from the rate-distortion function of Laplacian distribution. In order to control fluctuation of picture quality within each image frame, we classify macroblocks into three different groups according to their characteristics. The quantization parameter for each macroblock is adjusted by the type of the previous macroblock. By computer simulations, we show that the proposed rate control scheme generates coding bits very close to target bits and provides higher coding efficiency.

2. Proposed Algorithm

2.1. Rate-Quantization Model

When we design a rate-quantization model, we should take account of two points: relationship between rate and distortion, and statistical characteristics of the source data. In general, the source data to be quantized has the Laplacian distribution

$$f_X(x) = \frac{\lambda}{2} e^{-\lambda|x|} \tag{1}$$

where λ denotes a distribution parameter. We define a distortion measure as the absolute difference of each sample. The rate-distortion function for the Laplacian distribution is

$$R(D) = \log_2\left(\frac{1}{\lambda D}\right) = \log_2\left(\frac{\sigma}{\sqrt{2}D}\right) \tag{2}$$

where $D = |x-y|$, x is the original data, and y is a reconstructed data. In Eq. (2), the rate is expressed by a logarithm function of the distortion. The distortion is changed by the quantization parameter value, which is determined during the encoding process. Therefore, we should check the actual variation of the bit rate as a change of the quantization parameter to justify the use of the rate-distortion function in Eq. (2).

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Fig. 1 displays the bit rate curve as a function of the quantization parameter in the H.264 coding algorithm, where σ is the standard deviation of source data and Q is the quantization parameter. As shown in Fig. 1, the bit rate curve can be modeled by the logarithm form.

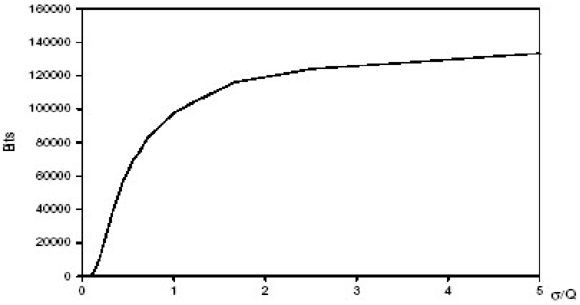

Figure 1. Rate curve for σ/Q.

At high bit rates, the distortion induced by the quantization is approximately uniformly distributed and the power of the quantization noise P is $Q^2/12$. However, the distortion of the quantization noise at low bit rates is not uniform. We define a distortion D for the quantization parameter Q by

$$D = \rho \times Q \tag{3}$$

where ρ denotes a distortion parameter. After encoding each macroblock, the distortion parameter is updated and classified according to the macroblock type. The proposed rate-quantization model can be expressed by

$$R(D) = \log_2\left(\frac{\sigma}{\rho \times D}\right). \tag{4}$$

2.2. Pattern Classification

In video coding algorithms, the prediction operation plays an important role for improving coding efficiency. The amount of residual data of complex macroblocks is larger than that of simple macroblocks. If we use the same quantization parameter to encode macroblocks of different types, quality degradation of the complex macroblock is much more distinguishable than others. In order to solve this problem, we classify macroblocks into three different groups: uniform macroblocks (Type 1), single-edge macroblocks (Type 2), and complex macroblocks (Type 3).

In order to measure the complexity of each macroblock, we employ the Sobel mask. After the masking operation, we compute the mean of the masked output values. If a pixel value is larger than the mean value, the pixel is regarded as an edge point. If the number of edge points in each macroblock is less than 16, the current macroblock is classified as Type 1. If the number of edge points exceeds 50, the current macroblock is classified as Type 3. Otherwise, the macroblock is classified as Type 2.

2.3. Rate Control Strategy

2.3.1. Frame-level rate control

In order to determine the quantization parameter, we should allocate target bits for the current image frame. In this paper, we employ a bit allocation algorithm similar to the method in the MPEG-2 TM5 model [1].

$$\begin{aligned} T_I &= \max\left\{\frac{R}{1+N_P X_P / K_P X_i}, \frac{BR}{8\times FR}\right\} \\ T_P &= \max\left\{\frac{R}{N_P}, \frac{BR}{8\times FR}\right\} \end{aligned} \tag{5}$$

where T_I and T_P denote the number of bits allocated to I and P frames, respectively. N_P is the number of frames to be coded in one GOP, and K_P is a constant. X_P is a complexity parameter, which is calculated from coding bits and the average value of quantization parameters used for the previous frame. R is the remaining bits in the GOP and is updated after encoding each frame by

$$R = R_{prev} - B_{used} \tag{6}$$

where R_{prev} is the remaining bits before encoding the current frame, and B_{used} is the coding bits for the current image frame.

2.3.2. Macroblock-level rate control

In order to decide the quantization parameter for the current macroblock, we use the rate-quantization model that is described in Section 2.1. We need some information to calculate the quantization parameter from the proposed rate-quantization model.

Statistical characteristics of the source data for the current macroblock should be known to calculate the quantization parameter. However, since H.264 encodes each macroblock at the block level, we should estimate the standard deviation of the current macroblock from those of adjacent macroblocks by

$$\sigma = \frac{\sigma_L + \sigma_T}{2} \tag{6}$$

where σ_L and σ_T represent standard deviations of the left macroblock and the top macroblock of the current macroblock, respectively.

In order to determine the quantization parameter, we also need the distortion parameter, which can in turn be obtained from the quantization parameter. Therefore, to avoid this chicken-and-egg problem, we simply predict the distortion parameter by

$$\rho = \frac{\rho_L + \rho_T}{2} \tag{7}$$

where ρ_L and ρ_T are distortion parameters of the left and the top macroblocks of the current macroblock, respectively.

The target bit used to encode the current macroblock is calculated by

$$B_P = \frac{1}{256} \times \frac{R_{FRM}}{N_{MB} - N_C} \tag{8}$$

where B_P denotes the target bits per pixel and R_{FRM} is the number of remaining bits after coding the previous macroblock. N_{MB} is the total number of macroblocks in the current frame, and N_C is the number of coded macroblocks in the current frame.

From the estimated standard deviation, distortion parameter, and target bits per pixel, we calculate the quantization parameter for the current macroblock by

$$Q = \frac{\sigma \cdot 2^{-B_P}}{\rho}. \tag{9}$$

2.3.3. Adjustment of quantization parameter

The quantization parameter is adjusted by the following rules according to the type of the current macroblock and the difference between the previous quantization and the current quantization parameters.

$$Q_F = \begin{cases} Q-1, \; if \; Q - Q_{prev} \le -2 \\ Q+1, \; if \; Q - Q_{prev} \ge 2 \end{cases} \tag{10}$$

$$Q_F = \begin{cases} Q-2, \; if \; Q - Q_{prev} \le -3 \\ Q+2, \; if \; Q - Q_{prev} \ge 3 \end{cases} \tag{11}$$

where Q_F denotes the final quantization parameter used for encoding. In order to minimize fluctuation of picture quality and blocking artifacts, we apply different adjustment methods. When the previous and the current macroblocks are of the same type, Eq. (10) is employed. Eq. (11) is adopted for different types of macroblocks.

2.3.4. Update parameters

After encoding the current macroblock, we update coding information, such as the standard deviation of the source data, the distortion parameter, and remaining bits. Statistical characteristics of the source data and the distortion parameter are used as coding information for the prediction operation of succeeding macroblocks. The distortion parameter is calculated by $\rho = D/Q$.

After encoding each macroblock, we update the number of remaining bits in the current frame by

$$R_{FRM} = R_{FRM} - B_{MB} \tag{12}$$

where R_{FRM} represents the number of bits that can be used to encode the remaining macroblocks in the current frame, and B_{MB} denotes the coding bits that are generated by encoding the current macroblock.

3. Experimental Results

In order to evaluate the performance of the proposed rate control algorithm, we use the JM6.1 reference software of the H.264 video coding standard. Table 1 shows simulation conditions for our experiment.

Table 1. Simulation conditions

Symbol Mode	CAVLC
RD Optimization	On
GOP Structure	IPPP
Reference Frame	1
MV Search Range	32
MV Resolution	1/4 pixel
Restriction Search Range	2

We have used only two types of pictures, I frame and P frame, since B frame is not included in the baseline profile of the H.264/AVC video coding standard. For simulations, we have tested several sequences, such as “Container,” “Foreman,” “Silent,” “News,” and “Mother and Daughter,” whose resolution is 176x144, at various target bit rates and picture frame rates. For performance evaluation, we compared our simulation results with those of the Siwei’s algorithm [4].

Table 2 shows coding bits per second generated by our proposed rate control algorithm. The difference between target bits and coding bits is less than 1 kbps.

Table 2. Target bits vs. coding bits for “Foreman”, “News”, and “Silent” sequences (kbps)

Test Sequences	Target Bits	Coding Bits
Foreman	48	48.08
	64	63.97
News	24	23.94
	33.6	33.63
Silent	33.6	33.66
	48	48.25

Fig. 2 and Fig. 3 display PSNR values for “Container” and “Mother and Daughter” sequences, where the solid line shows the result by the proposed scheme and the dashed line is obtained by the Siwei’s scheme [4]. As shown in Fig. 2 and Fig. 3, the proposed algorithm provides improved coding efficiency by 0.2 ~ 0.4 dB on the average. Fig. 4 and Fig. 5 demonstrate bit fluctuations in the encoding process for “Container” and “Mother and Daughter” sequences. The proposed algorithm encodes video sequences without large bit fluctuations over image frames except I frames.

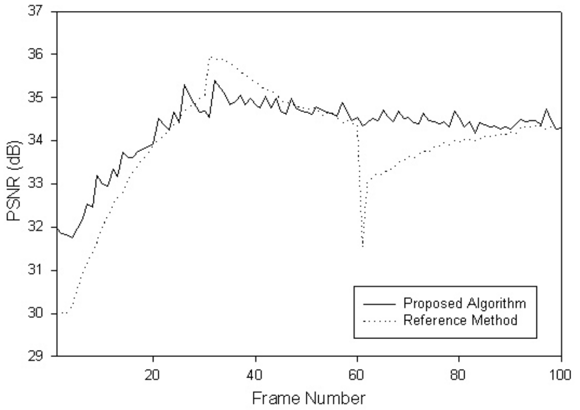

Figure 2. PSNR for "Container" (frame rate = 30fps, target bit rate=48kbps)

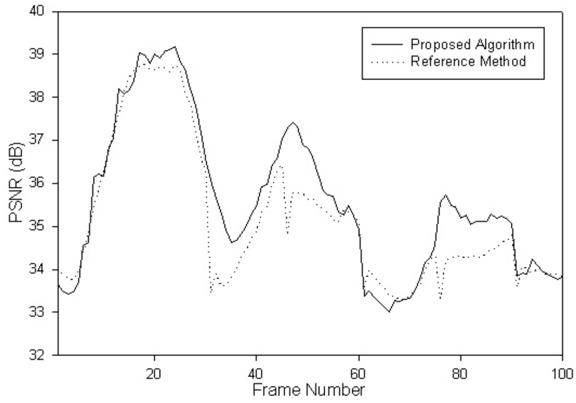

Figure 3. PSNR for "Mother and Daughter" (frame rate = 15fps, target bit rate=64kbps)

4. Conclusions

In this paper, we have described a new rate control algorithm for the H.264 video coding standard. We design the rate-quantization model based on the rate-distortion function of the Laplacian distribution. We also show that the bit rate curve can be modeled by the logarithm function. Through the pattern analysis for macroblocks, we obtain characteristics of macroblocks and adjust the quantization parameter calculated by the proposed rate-quantization model. Simulation results show that the proposed rate control scheme generates coding bits very close to target bits and provides improved coding efficiency at low bit rates.

5. Acknowledgement

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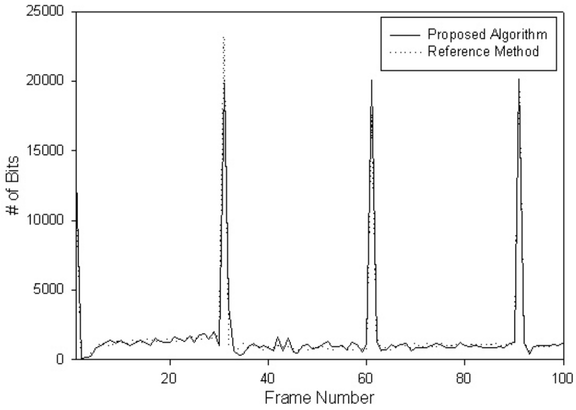

Figure 4. Bit fluctuation for "Container" (frame rate=30fps, target bit rate=48kbps)

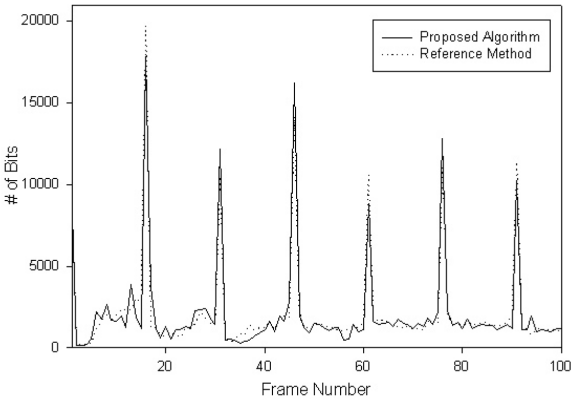

Figure 5. Bit fluctuation for "Mother and Daughter" (frame rate=15fps, target bit rate=64kbps)

6. References

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