

A Method of Bit-rate Control within Macro-blocks using Information of Coded Block Pattern in a Video Codec

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Abstract— In this paper, we propose a novel bit-rate control using information of coded block pattern (CBP) based on statistical moments with respect to the amount of the bits from each macro-block, in an encoding of general video codec such as H.264/AVC and HEVC. Since the proposed bit-rate control is based on the simple computation using the quantization rules in the video codec, it is not necessary for an additional computation, such as a DCT or quantization, to estimate bits for a control of bit-rate. Based on the rate control using the statistical moments, to obtain a more finest video quality, it is necessary to rate control within macro-blocks. For the purpose of a rate control without a discrete cosine transform and quantization, the proposed algorithm employs a mean and a variance of each 4x4 block in a macro-block that is evaluated with the information of motion estimation. Since bit-rates generated by encoding is proportional to a mean and variance, it is possible to raise up or fall down the quantization parameter for a macroblock with a unit value. In addition, since an optimal rate-control is conducted by the Hamiltonian, it is unnecessary to evaluate an accurate bit-rate per 4x4 blocks.

As a result, the proposed algorithm can be applied to a single pass encoding, and it can provide enough encoding speed with respect to various applications even requiring real-time without any serious degradation of video quality.

Keywords— Coded block pattern, Hamiltonian, Rate control, Video Codec

I. INTRODUCTION

In general, almost all video-compression standards including MPEG-4 Part 10 AVC/H.264 have been developed as a means of reducing the total amount of data required for transmitting video while maintaining as high a quality as possible despite compressing the video data during the encoding process [1]. While there are a lot of techniques used within video codes to improve the quality of low bit-rate video, service providers tend to desire even smaller bit-rates with better video quality. One of the easiest ways to achieve such requirements from service providers is rate-control, which is performed by controlling a quantization parameter in a video codec [2]-[4].

In practice, most video encoders have adopted a rate-control, which is performed after the video encoding for a

frame or group of pictures (GOP) [5]. This type of control is called two-pass or multi-pass rate-control. Although two-pass or multi-pass rate control has demonstrated good performance, since practical rate controls require a time delay, a real-time rate control that is performed during the video encoding process is needed. Moreover, for better video quality and rapid encoding speed, it is necessary to control the bit-rate with the unit of a macro-block. When rate-control for the unit of a macroblock is applied to video encoding, it is possible to assign more bits to represent each macro-block, including complex areas of a picture. On the other hand, it is also possible to assign fewer bits for a macroblock containing a simple or plain area.

In this paper, we propose a bit-rate control using information of CBP which is evaluated in the process of motion estimation (ME), to each macroblock. In the process of ME, since the ME process is based on the evaluation of difference of pixels in a block at a different time, we can obtain the information of an average difference and a variance, with respect to each 4x4 block. In a conventional rate control for a unit of macroblock, based on the first or multiple ordered Taylor series, a rate controller predicts the number of bits with respect to a target macroblock. After that, using the predicted number of bits, the controller changes the quantization parameter for the macroblock. While the conventional method is effective when the complexity of the target macroblock is similar to that of a previous macroblock, it is not effective when the complexity of the target macroblock is different from the previous one. Therefore, the controller should predict the number of bits generated in a current macroblock, independently on the number of bits generated by other macroblocks. Moreover, since the quantization process is conducted after the motion estimation process, the controller should change the quantization parameter without any information generated by the process of the discrete cosine transform (DCT). In other words, the controller should only use the information generated by the process of the motion estimation.

This paper is organized as follows: Section 2 discusses the basic theory of the paper; In section 3, we verify a proof of the proposed theorem; Finally, section 4 provides the conclusions.

II. FUNDAMENTAL THEORY

In this section, we introduce a fundamental analysis for the proposed rate control scheme based on the prediction of CBP. In H.264/AVC video codec, the CBP is defined through the following calculation. Let $X \in R^{4 \times 4}$ is the result of the DCT with respect to a 4x4 block in a macroblock. When the previous assumption is hold, the CBP is evaluated by the following quantization process:

$$X_Q(i, j) = \frac{X(i, j) \cdot Q[(QP+12)\%6, i, j] + 2f}{2^{16 + \frac{QP+12}{6}}} \quad (1)$$

where (i, j) is the index of the i -th row element and the j -th column element respectively, $X_Q(i, j) \in R$ is the i -th row and the j -th column element of the quantized $X \in R^{4 \times 4}$, $X(i, j) \in R$ is the i -th row and the j -th column element of $X \in R^{4 \times 4}$, QP is the quantization parameter of the H.264/AVC, is $Q[(QP+12)\%6, i, j]$ a quantization function, which is remainder of 6 with respect to $QP+12$ for the i -th and j -th element, and f is the level offset of the quantization.

When the result of (1) is 0 for all $i, j \in [0, 3]$, the CBP for the 4x4 block is 0. Instead of it, the CBP is 1.

The prediction to the occurrence of bit in a 4x4 block is that the result of DCT is considered as the result of the probability density function (PDF) that is defined with two statistical moments such as a Laplace or Gaussian distribution. Since we consider the model of the bit-occurrence in a 4x4 block as a probability density function, we should define the first ordered statistical moments, i.e. a mean, and the second ordered moments, i.e. a variance, as following equations.

$$\begin{aligned} m_{4 \times 4} &= \sum_{i=0}^3 \sum_{j=0}^3 (P(i, j, t-1) - \bar{P}(i, j, t)) \\ V_{4 \times 4} &= \frac{1}{16} \sum_{i=0}^3 \sum_{j=0}^3 (P(i, j, t-1) - m_{4 \times 4})^2 \end{aligned} \quad (2)$$

In the equation (2) and (3), $P(i, j, t-k)$ is the pixel with the i -th row and the j -th column component in a 4x4 block at time $t-k$, $\bar{P}(i, j, t)$ is the predicted pixel through the ME process in a video codec with the i -th row and the j -th column component in a 4x4 block.

For instance, the average of the input data for DCT is equal to the DC component of DCT. Moreover, for AC component of DCT, if the variance is beyond a threshold, the CBP will be 1, otherwise, it will be 0. Therefore, the prediction of the bit-occurrence in a 4x4 block is a combination with the direct calculation of DC component and the estimation of the AC component, as follows:

$$\begin{aligned} Eh(m_{4 \times 4}, V_{4 \times 4}, QP) &= \frac{m_{4 \times 4} \cdot Q[(QP+12)\%6, 0, 0] + 2f}{2^{16 + \frac{QP+12}{6}}} \\ &+ u(V_{4 \times 4} - (15 + \theta_t)) \end{aligned} \quad (4)$$

where $u(x)$ is a unit step function such that it is 1 when x is larger or equal to 0, otherwise, it is 0, and θ_t is threshold that

is evaluated as $2.5 \sim 3.5$ by a least mean square, for the estimation of the effect to the AC component of DCT.

For the prediction of the bit-occurrence in a P-frame of a video codec, we use the equation (4). In a B-frame, since the bit-occurrence is small in comparison to the case of a P-frame when the quantization is somewhat high, we use the following equation that is a brief equation of (4) when the quantization parameter is larger than 28.

$$Eh(m_{4 \times 4}, V_{4 \times 4}, QP) = \frac{m_{4 \times 4} \cdot Q[(QP+12)\%6, 0, 0] + 2f}{2^{16 + \frac{QP+12}{6}}} \quad (5)$$

While the equation (5) is sufficient to predict the bit-occurrence in a B-frame, it is also possible to use the equation (4) as a predictor for a B-frame.

III. A RATE CONTROL FOR A MACROBLOCK

In the previous section, we introduce the equation for the prediction of the bit-occurrence in a 4x4 block. Using the equation (4) and (5), it is possible to predict all CBPs in a macroblock, as a bit-occurrence in each 4x4 block of a macroblock. If the CBP of a macroblock is predicted, we can control the quantization parameter to each macroblock using the strength of the bit-occurrence with $m_{4 \times 4}$ and $V_{4 \times 4}$.

In viewpoint of video quality, the sharp changing of the quantization parameter is not recommended. Therefore, the rate control for a macroblock should be conducted with small changing of the quantization parameter, and it should be also conducted within a limited range. Furthermore, if the DC component of DCT exists, and the AC component does not exist, it is good for video quality not to change the quantization parameter. On the contrary, if the DC component of DCT does not exist and the AC component of DCT exists, since the variance of the AC component is small in this case, we do not set the strength of the bit-occurrence. Consequently, the strength of the bit-occurrence can be defined as follows:

$$W_{4 \times 4} = Eh(m_{4 \times 4}, V_{4 \times 4}, QP) \times V_{4 \times 4} \quad (6)$$

where, $W_{4 \times 4}$ is the strength of the bit-occurrence for a unit 4x4 block in a macroblock.

In general, even though the value of the DC component is large, if the variance in a 4x4 block is small, the amount of bits in a 4x4 block is smaller than 32bits. However, when the complexity of a macroblock is increased with the high value of the DC component and the high variance, the amount of bits are dramatically increased in proportion to the multiplication with $Eh(m_{4 \times 4}, V_{4 \times 4}, QP)$ and $V_{4 \times 4}$, as shown in (6). Since the strength $W_{4 \times 4}$ is a inverse proportional function of the quantization parameter QP , if QP is increased, the strength $W_{4 \times 4}$ is decreased, and if QP is decreased, the strength $W_{4 \times 4}$ is increased. Consequently, when we increase the quantization parameter, in proportion to the strength, the amount of bits in a 4x4 block is decreased. Furthermore, since we change the quantization parameter with a unit macroblock, we should define the strength of the bit-occurrence as follows.

$$W_m = \sum_{k=1}^{16} W_{4 \times 4}(k) \quad (7)$$

where k is the index of a 4×4 block in macroblock.

We can set a control rule for the quantization parameter using the strength of the bit-occurrence in macroblock, as follows:

$$QP_c = \begin{cases} 0 & W_m < \alpha \\ 1 & \alpha \leq W_m < \beta \\ 2 & \beta \leq W_m \end{cases} \quad (8)$$

where α and β are parameters which are evaluated by experiment. Typically, α is 32 or 64, and β is 128 or 160.

On the contrary, when the strength of a macroblock maintains 0 for several macroblocks, we should decrease the quantization parameter in order to keep video quality. Therefore, the inverse control rule for the quantization parameter to current macroblock $W_m(t)$ is as follows

$$QP_c = \begin{cases} 0 & \sum_{k=0}^l W_m(t-k) > \eta \\ -1 & \eta \geq \sum_{k=0}^l W_m(t-k) > \kappa \\ -2 & \sum_{k=0}^l W_m(t-k) \leq \kappa \end{cases} \quad (9)$$

where l is a limit index of the previous macroblock, which is defined by experiment, η and κ are parameters for the control rule, which are defined by experiment. Typically, l is 8, η is 4, κ is 1 or 0.

Consequently, the rate control for the current macroblock indexing with t can be defined as follows:

$$QP(t) = QP_F + QP_c(t) \quad (10)$$

where QP_F is the quantization parameter for the current frame.

In the equation (10), since the quantization parameter QP_F is fixed for all macroblocks in the current frame, the changing of the quantization parameter is limited by ± 2 . While the proposed rate control is sufficient to maintain video quality, if more changing of the quantization parameter is needed, it is possible to change the quantization parameter making an adaptation form for the current frame such that

$$QP(t) = QP(t-1) + QP_c(t) \quad \forall t \geq 0, m \leq QP(t) \leq M \quad (11)$$

where m is the minimum value of the quantization parameter for a macroblock, and M is the maximum value. In the H.264/AVC, if the value of the quantization parameter is decreased or increased with 6 to the current value of the quantization parameter, the amount of bits is increased or decreased 2 times respectively. Consequently, we recommend the limit value of the quantization parameter such that

$$m = QP_F - 6, \quad M = QP_F + 6 \quad (12)$$

Using the equation (12), it is possible to control the bit rate sufficiently with the 2 times of the margin in comparison to a regular bit-rate.

IV. EXPERIMENTAL RESULTS

To verify the effectiveness of the proposed algorithm, we measure the PSNR performance for certain types of commercial high-definition data. We use the H.264/AVC encoder based on JM reference 9.6, that are compiled using Microsoft's Visual C++ 9.0 and Intel C++ Compiler. To maintain consistency, we encoded a test sequence using the H.264/AVC encoder with the proposed algorithm and the JM 9.6 reference encoder. Next, using the JM 9.6 reference decoder, we measured the average PSNR of the H.264/AVC video sequence coded by the proposed H.264/AVC and JM 9.6 encoders.

We conducted our test on four high-definition video sequences provided by the Korean Broadcasting System (KBS). The resolution of the video sequences is 1920x1080 with a 4:2:0 color space. An image frame from each of the video streams is shown in Fig. 1. The title, "A field of rape blossoms" represents blossoms swaying in the wind. Since each blossom in the field independently requires its own encoded bits, the bit rate of the video will be extremely high no rate control for the unit block is used. For the video clip titled, "A rotational temple," the picture in the frame rotates counter clockwise. Thus, it also requires a high bit rate for encoding. In comparison to the previous 2 videos, the video clip titled, "A clip of a melodrama," requires a smaller amount of encoded bits. However, since the quantization parameters for each block are not changed dramatically, it is good for testing the stability of the control algorithm. For the "action-drama" video clip, the background of the video does not change frequently. However, objects in the frame, such as the action hero, do change quite a lot. Thus, this video is good for testing the performance of the control algorithm.

The server used in all experiments has two physical Intel X5570 CPUs with a total of sixteen logical cores using additional hyper-threading at 2.97GHz. The target rate for the tested HD videos with a 1920 x 1080 resolution is 4Mbps.

Fig 2 shows the average PSNR via bit-rate for each test video. In Fig 2, simulation results shows that the proposed control algorithm performs with the superiority about 0.86 dB as an average PSNR, in comparison to the conventional rate control in the reference encoder.

V. CONCLUSIONS

We propose a rate control for a macroblock based on statistical moments which are derived by the results of the motion estimation process. Using the statistical information derived by the motion estimation, it does not require any additional feedback information from the DCT or the quantization process. Consequently, the proposed algorithm is very easily applied to video codec such as the H.264/AVC, or other video standard. Moreover, the proposed algorithm shows a superior performance in comparison to a conventional H.264/AVC encoder under the target nit rate. The proposed rate control can be used in other video codecs as a rate controller, with appropriate modification.



Figure 1. Represented pictures of the video stream used in the experiment; (Upper Left) A field of rape blossoms, (Upper Right) A rotational temple, (Lower Left) A clip of a melodrama, (Lower Right) A clip of an action-drama

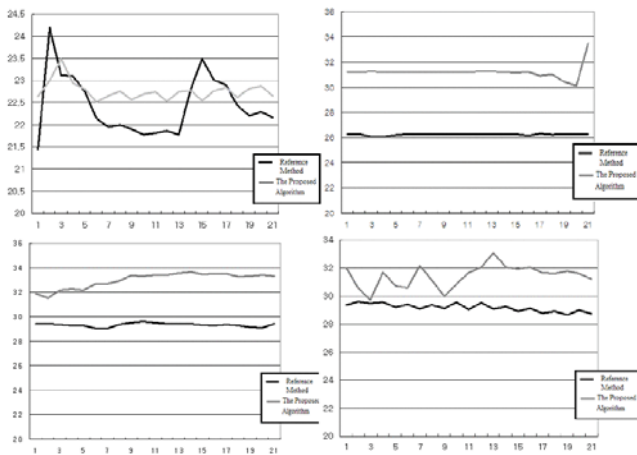


Figure 2. Comparison of an SNR performance. Each picture of result is correspondence with Figure 1. Thick Line : Reference encoder, Gray Line: The proposed algorithm

ACKNOWLEDGMENT

This work was supported by the IT R&D program of MCT/KOCCA[2-09-1205-001-10987-09-001 Development of DCI-compliant digital cinema distribution management and copyright protection technology].

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