Adaptive Macroblock Layer Rate Control for H.264/AVC Via Histogram-based R-D Estimation

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Abstract: In this paper, we propose a bit-rate control algorithm for H.264/AVC using the rate and distortion model estimated by the histogram of DCT coefficients. Since the proposed algorithm induces the rate and distortion model from the current macroblock instead of the previous coded frame or macroblock, it can effectively prevent the fluctuation of the output bits especially when scene change occurs, while keeping the quality in same level.

Key-Words: - rate control, H.264, RDO, histogram-based R-D estimation, chicken-egg problem

1 Introduction
The video compression standards like H.26x or MPEG-4 basically use DCT(Discrete Cosine Transform), quantization for DCT coefficients and VLC(Variable Length Coding). Since the quantization parameter determines the rate and distortion, the bit rate control scheme identifies the quantization parameter which has a minimum distortion within the target rate. For a CBR(Constant Bit Rate) condition, the bit-rate control must reduce the fluctuation of bits generated from a frame by frame. Because H.264/AVC[1] employs the RDO in motion estimation and mode decision[2][3], the rate control for H.264/AVC selects the quantization parameter for a given macroblock before estimating motion vector and deciding mode. H.264/AVC coder cannot know the information about the current block before selecting the quantization parameter to be used in motion estimation and mode decision. For this reason, the rate control algorithm presented in JVT-H014[4] guesses the information from the previous coded frame. The rate control algorithm employs the quadratic rate-quantization model to select quantization parameter for a given block. It solves the “chicken and egg” dilemma by means of the quadratic function using the estimated MAD and the estimated target bits. However it suffers from the fluctuation of the output bits when scene is changed or high motion appears. The proposed algorithm can solve this fluctuation of bits by allocating the rate on each frame equally. It uses the rate and distortion model estimated by the histogram of DCT coefficients. The proposed algorithm induces the rate and distortion model from the current macroblock instead of the previous coded frame or macroblock. As a result, it can reduce the bit fluctuation while keeping the quality of the encoded video in same level or a slight high level. In section 2, the problems of previous works are explained. In section 3, the proposed schemes are described. And, in section 4, the experimental results that compare our algorithm with [4] are presented.

2 Problems of Rate Control in H.264
Since H.264/AVC uses the quantization parameter in the RDO for motion estimation and mode decision, it needs the quantization parameter to encode a given macroblock, before motion estimation and mode decision. This fact let the rate control in H.264/AVC be more difficult than that in previous coding standards. The rate control uses the rate and distortion model of a given macroblock or frame to find the quantization parameter. Generally, the rate control in MPEG estimates the rate and distortion model from the header information and residual information of a given macroblock. However, H.264/AVC cannot get any information of a given macroblock before identifying the quantization parameter for the RDO. Most previous works have concentrated on estimating the information of a given macroblock before encoding. Because the information about the current macroblock cannot be obtained, the previous algorithms estimates the information about the current macroblock or frame from the previous coded macroblocks or frames. In [4], the rate control algorithm estimates the MAD of the current macroblock from the MAD of the same macroblock located in the previous frame. It also set the target rate for the current macroblock by the MAD ratio, which is...
the MAD of the same macroblock located in the previous frame divided by the sum of MAD of the remaining macroblock in the previous frame. The estimated value is reasonable if the characteristics between frames are not changed abruptly. However, there are statistical changes between frames in the natural scene. The rate control algorithm suffers from the fluctuation of bits between frames because its rate and distortion model cannot be matched to the characteristics of the current frame.

Since the rate and distortion values are estimated from the previous frame, the rate control algorithm which fully depends on the previous frame cannot choose the quantization parameter for the first P-slice. This fact means that the rate control algorithm cannot control the rate on the first P-slice. Thus, it chooses the same quantization parameter as the quantization parameter of the first I-slice for the first P-slice. In this approach, the generated actual rate can not be matched to the target rate. Its value may be very lower or very higher than the target bits in some cases. It affects on the rest of frames and the rate control in the rest of frames is getting more difficult.

3 The Proposed Rate Control Scheme
The proposed algorithm uses the rate and distortion model based on the histogram of the transform coefficients[5]. The rate and distortion model is estimated by using the information of the current macroblock instead of the same macroblock located in the previous frame. The rate and distortion model are generated by the number of non-zero transform coefficients after quantized by a selected quantization parameter.

3.1 Frame-Layer Rate Control
The proposed algorithm can control the rate for the first P-slice, whereas the rate control scheme in [4] encodes the first P-slice by the quantization parameter used in I-slice. Because the proposed algorithm can control the buffer after encoding the first I-slice, it has lower fluctuation of generated rate than [4]. Specially, it prevents the high fluctuation of bits in the earlier parts of sequence. The proposed algorithm calculates the target bits for the first P-slice by using followed equations and the target bits for the rest of P-slices by using the same manner as [4]. The proposed algorithm calculates the target bits for the current macroblock by using the MAD ratio in the previous frame.

![Fig.1 RDO diagram for the candidates quantization parameter](image)

\[
f(n_i) = \beta \times \bar{f}(n_i) + (1 - \beta) \times \hat{f}(n_i)
\]

\[
\bar{f}(n_i) = \frac{u(n_i)}{F_r} - \gamma \times \frac{Tbl(I)}{N_p}
\]

\[
\hat{f}(n_i) = \frac{T_r(n_i)}{N_p}
\]

where \(T_r\) is the remaining bits for the current GOP, \(u(n_i)\) is the channel rate at \(i\)-th frame, \(F_r\) is frames per second, \(N_p\) is the number of the remaining frames in the current GOP, \(f(n_i)\) is the bits to be allocated on the \(i\)-th frame, \(B_c\) is the buffer occupancy.

The proposed algorithm selects the same quantization parameter in [4] for the first I-slice. It estimates the target bits by the above method in the first P-slice and the target bits by using the same method in [4].

3.2 Macroblock-Layer Rate Control
After the frame level bit allocation, target bits for each macroblock are calculated by [4]. The proposed algorithm is concentrated on the better bit achievement than previous one. Therefore we use RDO scheme to achieve the bit allocation well.

The proposed algorithm sets the initial quantization parameter as that of the previous coded macroblock. It is used in motion estimation. Then, the proposed algorithm sets the candidate quantization parameters for the current macroblock as \(j+2, j+1, j, j-1, j-2\) if the initial quantization parameter is selected as \(j\) \((\in \{0,1,\ldots,51\})\). We restrict the range of candidate quantization parameters to prevent quality fluctuation and increasing complexity. The rate \((R(CQ_i, M_j))\) and distortion \((D(CQ_i, M_j))\) are calculated by histogram-based method in terms of the candidate quantization parameters and all possible coding modes as in Fig. 1. The RDO is performed on each candidate...
Fig. 2 Comparing generated bits between the proposed algorithm and JM9.3, and best mode is selected by (5). The proposed algorithm identifies the best quantization parameter as the candidate which has the minimum distance between the estimated bits and the target bits for a given macroblock as (6)

\[ M'_i(CQ_i) = \arg \min_{M_j} (D(CQ_i, M_j) + \lambda_{CQ_i} \cdot R(CQ_i, M_j)) \]  

(5)

\[ CQ'_i = \arg \min_{CQ_i} \left| R(CQ_i, M'_i) - R_T \right| \]  

(6)

where \( CQ_i \) is one of the candidate quantization parameters, \( M_j \) is one of the coding modes, and \( \lambda_{CQ_i} \) is a Lagrange multiplier used in the RDO for mode decision.

Finally, the rate control algorithm encodes a given macroblock by the identified quantization parameter, \( CQ'_i \) through these equations. While having the same merit of jointly optimizing coding mode decision and rate control, the proposed algorithm that solves coding mode selection and rate control in macroblock level can further improve the coding efficiency. Also, it improves the performance of rate control by using the histogram-based R-D estimation which is calculated by the information of the current macroblock.

Fig. 2 shows the bits generated from each rate control algorithms. The proposed algorithm alleviates the variation of bits which seriously occurred in [4]. Because the first P-frame was encoded at very high quantization parameter, [4] generates very low bits at

4 Simulation Results
Simulation used H.264/AVC JM9.3 reference software codecs[6] with the baseline profile and tested the two rate control schemes: the proposed algorithm, and the rate control algorithm[4] in JM9.3. In all cases, we encoded test sequences under the experimental conditions that the target frame rate was 10 and Intra update did not exist for various bit rates. Simulation used “Foreman”, “Susie” and “Tabletennis” sequence of QCIF format. The proposed algorithm sets the same quantization parameter as in [4] for the first I-slice.

In our algorithm, the quantization parameter is selected by (5) and (6) based on the estimated rate and distortion model. The proposed algorithm uses the real rate and distortion in this procedure. The real rate and distortion is calculated by the RDO process for all candidate quantization parameters and all coding modes. Simulations used the rate and distortion model estimated by the histogram of the transform coefficients.

Fig. 3 shows the generated bits when the scene change occurred. (Tabletennis, 100 kbps)
the first P-frame. This effects on the buffer control and the target bits. As a result, [4] suffers from high fluctuation of the output bits. Although the proposed algorithm is degraded a little in PSNR, there is almost no difference on the reconstructed frame at subjective viewing.

Fig.3 shows the generated output bits when the scene change occurs in 83-th frame. Although it is reasonable to allocate more bits in view of rate-distortion, it can not match the channel bandwidth. If video encoder can not match the channel bandwidth, the packet loss may be occurred. Although video encoder prevents the packet loss, it allocates the lower bits on the next frames. As a result, the performance of the rate control is degraded.

5 Conclusion

This paper proposes a bit-rate control algorithm for H.264/AVC using DCT coefficient histogram based rate and distortion estimation. The proposed rate control algorithm selects the quantization parameter matched target bits among candidate quantization parameters. And it uses the model induced form the information of current macroblock without any MAD prediction. Thus it can achieve the improvement of the rate control. Finally, it effectively prevents the fluctuation of the output bits in each frame while keeping the quality in same level.

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