

Region Based Minimization of Quantization Error Propagation in Variable Bitrate Video

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Abstract. A bit allocation method is proposed to minimize the propagation of quantization error and thereafter to increase the average quality of encoded video in variable bitrate video applications. In comparison with constant bitrate video, a variable bitrate video can provide better visual quality and coding efficiency for compressed video. Furthermore, while more variation in bitrate is possible we have additional degrees of freedom to control the encoding parameters. The proposed bit allocation algorithm takes advantage of this freedom in variable bitrate video to minimize the propagation of quantization error.

The proposed method is implemented by special inter/P macroblocks namely SPPMB (Special P Macroblock) independently of rate control algorithm. The SPPMB is an inter MB (Macroblock) with a high relative bit budget and with special spatial and temporal location. A normal inter MB is replaced with a SPPMB if some conditions are met. The SPPMB can be used in different encoding standards including H.263, MPEG-4 and H.264/AVC standards. The experimental results show that the proposed bit allocation method can considerably increase the total average quality of variable bit rate encoded video.

Index Terms—Bit allocation, rate control, variable bitrate, video coding

1. INTRODUCTION

Digital video applications are increasing and different applications have various constraints and benefits. While low delay video communication applications are constrained to constant bitrate, in digital video recording and streaming applications a variable bitrate with constant long-term average is preferred. In comparison with constant bitrate video, a variable bitrate video can provide better visual quality and coding efficiency for compressed video. Quality and bitrate of compressed video is controlled by a video rate controller. A video rate control algorithm can operate in different regions in the rate-distortion space from constant rate region to constant quality region. Regarding to the rate-distortion curve high variations in quality are made by small variations in bitrate in an operating point close to

constant rate and also high variations in bitrate are made by small variations in quality in an operating point close to constant quality region. In constant bitrate video applications a large variation in quality is accepted to provide a constant bitrate. On the other hand in variable bitrate applications, variation in bitrate is acceptable and we have additional degrees of freedom to control the encoding parameters.

Several real-time variable rate control algorithms have been proposed for local recording and streaming applications separately in [1]-[4]. Different types of constraints have been assumed for two applications. The described algorithm in [1] provides a variable bitrate video with buffer constraint by controlling the quantization parameter on a per picture basis. The quantization parameter is calculated based on two other quantization parameters, which correspond to constant rate and constant quality rate controls. Proposed methods in [2] try to satisfy a target bit-budget constraint. In other words, they use the total storage size as a constraint for encoding a number of frames. The algorithm in [3] is a low complexity frame-layer bit rate control for streaming video applications. In this algorithm the rate control is achieved by jointly adapting the frame rate and quantization scale.

In this paper we propose a new bit allocation method for rate control which increases the average quality of compressed video by minimization of propagation of quantization error. The proposed bit allocation method can be used independently as complementary part in most variable bitrate rate control algorithms. Although each variable rate control algorithm has its own constraints and strategy for bit allocation, it can utilize the proposed method, as a complementary part, in combination with its own strategy. We propose a simple mechanism for implementation of the new bit allocation method independent of the rate controller.

This paper is organized as follow: Section 2 provides background information for the propagation error. Section 3 presents an overview of the proposed bit allocation method. Section 4 presents details of the proposed method. Simulation results are provided in Section 5. The paper is concluded in Section 6.

2. Error Propagation

Several video compression standards have been specified for encoding video contents. Each compression standard supports certain types of frames such as I, P, B, IDR, SI, and SP frames. For different applications different combinations of frames can be used. A rate control algorithm allocates different bit budget to different types of frames according to the application at hand and practical constraints. In low delay video communication, the bit allocation is done mainly according to constant rate constraint. In this case, the rate controller tries to allocate the available bit budget equally between video units (macroblock, frame, GOP). On the other hand, in variable rate applications such as streaming and digital recording, more variations in bitrate are acceptable.

The proposed bit allocation method in this paper tries to increase the average quality of compressed video by minimization of propagation of quantization error in variable bitrate video. Mainly the allocated bit budget to an inter MB is consumed in two parts including motion information and transform coefficient information as:

$$B_i = M_i + T_i, \quad (1)$$

where B_i denotes the allocated bit budget to an inter MB in i th frame, M_i and T_i indicate the motion and transform coefficient information respectively. We divide conceptually the transform coefficient information in two parts. The first part includes information related to motion prediction error (P_i) and the second part is enhancement information (E_i) for the previous sent information or

$$T_i = P_i + E_i, \quad (2)$$

As examples, in perfect motion prediction conditions $P_i = 0$ and where quantization parameter for i th frame is larger than quantization parameter for $(i-1)$ th frame then $E_i = 0$. While motion activities are increasing in a video sequence the video rate control algorithm increase the quantization parameter and in this case $E_i = 0$ and while motion activities are decreasing the rate control algorithm decrease the quantization parameter to use the whole allocated bit budget and in this case $E_i > 0$.

In constant bitrate video the bit allocation is controlled in short-term based on MB or frame but in variable bitrate video it is possible to control the bit allocation in long-term based on a number of frames. As a special case consider a MB has a near perfect motion prediction during a time period. In these conditions, we assume the main part of bit budget is consumed by the

enhancement information. In usual bit allocation algorithms the information of consequent frames are sent from encoder to decoder during the time period as:

$$P_0 + E_0, P_1 + E_1, \dots, P_n + E_n$$

The available information for reconstruction of video frames during the time period in decoder side is:

$$P_0 + E_0, P_0 + E_0 + P_1 + E_1, \dots, P_0 + E_0 + P_1 + E_1 + \dots + P_n + E_n$$

If we could send the information in another order as

$$P_0 + E_0 + E_1 + \dots + E_n, P_1, \dots, P_n$$

then the available information for reconstruction of video frames during the time period is:

$$P_0 + E_0 + E_1 + \dots + E_n, P_0 + P_1 + E_0 + E_1 + \dots + E_n, \dots \\ \dots, P_0 + P_1 + \dots + P_n + E_0 + E_1 + \dots + E_n$$

The whole bit budgets used for transform coefficient information in two cases are equal to:

$$TotalBitBudget = P_0 + P_1 + \dots + P_n + E_0 + E_1 + \dots + E_n.$$

The total bit budget consumed in two cases are similar during the time period but in the second case, the frames are reconstructed with higher quality because they use the whole enhancement information while in the first case, only the last frame can use the whole enhancement information and the previous frames just use a part of enhancement information. In the second case, the average quality is increase with the same bit budget at the expense of variation in bit rate.

In our previous paper [4] we presented a special bit allocation algorithm for variable bitrate video. We introduced a new type of frame namely SPP frame (SPecial P frame) to take advantage of variable bitrate video. The SPP-frame is a P-frame which has special bit budget and location in a video sequence. A larger bit budget is allocated to the SPP frames compared to normal P frames. The SPP frame with larger bit budget carries more details to the decoder side. While adjacent frames have common details, the carried details can increase the quality of the following frames which are encoded with lower bit budget. In fact the SPP frames increase the total video quality by decreasing propagation of quantization error in the consequent frames. A special amount of details is carried once by a SPP frame which is appeared in several consequent frames. Utilizing SPP frame can increase the average quality of coded video.

Provided average quality in the studied case above depends on the motion prediction error. Moreover from the previous work we learned that the performance of SPP frames depends on amount of motion and motion properties in video content because the amount of common details between an SPP frame and the following frames become less in higher motion conditions.

In this paper the idea of SPP frame is extended to macroblock level to minimize the propagation of quantization error based on motion properties in different regions of video frames. We divide the video frames in to different regions based on motion properties in each region. Depending on the motion prediction process, the propagation of quantization error is different in each region. In static regions or in regions with relative simple motions, the quantization error may propagate just temporarily while in regions with complex motions, the quantization error is propagated temporarily and spatially too. The content of error also depends on the motion properties. The quantization error in a static region or in a region with simple motions in which perfect motion prediction is possible, can propagate to next frames without any change while in a region with complex motions the error may change between frames because of defective motion prediction and integration to new errors.

3. Algorithm Overview

We introduce the SPPMB to cope with different types of quantization error. An SPPMB is an intra/P macroblock with special temporal and spatial location and relative large bit budget which minimizes the propagation of quantization error to following frames. Where a near perfect motion prediction is possible, the SPPMBs carry high frequency information to the decoder side which increase the quality of several following frames with no any cost in bit budget. Temporal and spatial locations of SPPMBs and their bit budget are very important parameters which should be determined carefully to increase the average quality of variable bit rate video without any extra cost in average bit rate and delay.

Although the bit budget and location of SPPMB should be controlled by the video rate controller, we propose a simple method for implementation of SPPMB independent of the rate control algorithm using a control block placed between the rate controller and the encoder. Figure 1 shows a simple block diagram for implementation of SPPMB. The rate controller works at frame (or region in ROI video coding) level. It allocates a suitable bit budget to each frame and computes a QP (quantization parameter) for each frame. The SPPMB control block uses the QP computed by the rate controller as input and it determines the QP and locations of SPPMB in the frame. Any variable bitrate video rate controller with control on frame level such as our presented controller in [1] can be used in this structure. The SPPMB control block also uses a region map which defines the different regions in the video frames. The region map defines two or more types of regions

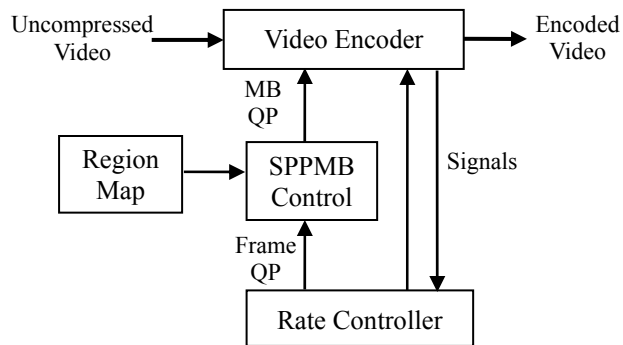


Figure 2. Diagram for implementation of SPPMB

according to motion properties in the frame. We define the region as a group of connected neighboring macroblocks which have similar motion properties in a number of consequent frames. As an example it can be said a number of connected macroblocks in a region have similar motion properties if following conditions are met:

$$T_1 < \text{Variance}(V_x) < T_2 \quad , \quad (3)$$

$$T_3 < \text{Variance}(V_y) < T_4 \quad , \quad (4)$$

where V_x and V_y denote the components of motion vector related to all MBs in the region. T_1 to T_4 are four thresholds. A region may include static background macroblocks with no motion, it may include background macroblocks with a simple motion such as panning or it can be related to an object in foreground with complex motions. Related to the application and video content, the region map can be fixed for a long time period or it can be modified during encoding. Extraction of region map can be automatic or it can be supervised by user. In this paper extraction of region map is not discussed and we show that the proposed bit allocation algorithm performs well even with a simple region map with two regions.

4. Implementation Details

The SPPMB is an inter MB with a relatively small quantization parameter and high bit budget in special locations. The quantization parameter and the location of SPPMB are very important parameters which should be computed carefully. The aim is to take advantage of SPPMB without any cost in average rate and delay. If we allocate a large bit budget to a group of SPPMBs in a frame, we should decrease the bit budget of the same group of MBs in subsequent frames to provide a long term constant bit rate in each region and consequently in whole sequence. The quality of the subsequent frames may degrade as a result. The idea is to find an optimal

way to relocate bit budget from corresponding MBs in subsequent frames to SPPMBs. As for the quantization scale of SPPMB, it is calculated from the quantization parameter of the whole frame which is computed by the rate controller independent of SPPMB:

$$Q_S = Q_P \times (\Delta + \lambda \times Q_{SI}^A / Q_P^A), \quad Q_S \leq Q_P, \quad (5)$$

where Q_S denotes the QP of SPPMB and Q_P is value of the QP calculated by the rate control for the P-frame independently of the SPPMBs. Q_{SI}^A (Average QP on a SPPMB Interval) denotes the average of QP on all corresponding P MBs from last SPPMB or Intra MB in the previous frames to the current MB. Q_P^A denotes the average of QP on all encoded corresponding P MBs. Δ and λ are two constant coefficients which are selected according to region map from a set of experimentally optimized parameters. In definition of function (5) we consider two assumptions. First, the allocated bit budget to SPPMB is proportional to that of the replaced normal inter MB so the QP of SPPMB is proportional to QP of the normal P MB at the same location. Second, when Q_P^{LA} has a large value relative to Q_P^A , it means there is larger prediction error in the current frames relative to average on all encoded frames. In this case, the effect of SPPMB becomes limited to smaller number of subsequent frames and therefore, a relatively smaller bit budget is allocated to the SPPMB. This is implemented by increasing QP of SPPMB according to ratio of the local average of QP to global average of QP. The constant coefficients used here depend on the encoder and the region map. Typical values of Δ and λ for a region map with only two types of regions in H.264 encoder are as below:

$$(\Delta, \lambda) = \begin{cases} (1,0) & \text{Complex_Motion} \\ (0.7,0.1) & \text{Simple_Motion} \end{cases}.$$

To increase the total average quality without any loss in total rate and delay, the location of SPPMB should be selected carefully. SPPMBs do not have constant temporal frequency or intervals. An inter MB is replaced with a SPPMB in an inter frame according to certain conditions. As an essential condition, SPPMB interval i.e. temporal distance between two corresponding SPPMB or one Intra MB and following SPPMB in consequent frames should be larger than a minimum value or:

$$D(\min) \leq \text{SPPMB Interval} \quad (6)$$

The minimum value of SPPMB interval is computed as:

$$D(\min) = \phi - \theta \times Q_{SI}^A / Q_P^A, \quad (Q_{SI}^A / Q_P^A) < \psi, \quad (7)$$

where ϕ, θ and ψ are constant coefficients which are

selected according to region map from a set of experimentally optimized parameters. In definition of the condition above we assume that while encoding corresponding MBs before SPPMB have larger quantization scales, it means there is higher prediction error relative to average. In this case, the effect of SPPMB becomes limited to a smaller number of subsequent frames. Therefore, the SPPMB should be closer together and at the same time according to formula (5) the bit budget of SPPMB will decrease in this case. Typical values of ϕ, θ and ψ for a region map with two types of regions in H.264 are as below:

$$(\phi, \theta, \psi) = \begin{cases} (\infty, 0, 0) & \text{Complex_Motion} \\ (30, 10, 2) & \text{Simple_Motion} \end{cases}.$$

As another condition the total number of SPPMB in one frame may be limited to a threshold to distribute the extra bit budget of SPPMBs between several frames and to prevent P frames with a large bit budget. This condition can be expressed as:

$$\text{Total Number of SPPMB} < \text{Threshold} \quad (8)$$

To increase the total average quality without any increase in total rate using the first-order rate-distortion model and numerical results in [4] we show that the required changes of quantization scale on the P frames followed by a SPP are negligible. The same results are applicable for the SPPMB. On the other hand the results of studied case in the section 2 indicate that sometime the extra bit budget can be close to zero. Therefore the SPPMB control block just tunes the location and the quantization scale of SPPMB frame without any more interaction with the rate controller. After encoding a P frame with a number of SPPMBs, the quantization scales of subsequent frames can be tuned by the rate controller according to its own bit allocation strategy. Hence the proposed SPPMBs can be implemented independently of the rate control algorithm and this is one of the main advantages of the proposed method.

The proposed bit allocation method can be used in ROI (Region Of Interest) video coding where the region map may be independent of ROI or even there may be some correlations between the region map and the ROI.

5. Results

To evaluate the proposed bit allocation technique we used our variable rate control algorithm presented in [1] with H.264/AVC encoder in a structure such as figure 1. A simple fixed region map with maximum two types region was used. As an example figure 2 depicts a region map

Table 1. Results of encoding with and without SPPMB using H.264/AVC in 64 kb/s

Video Sequence	PSNR of Luminance (dB)		
	Without SPPMB	With SPPMB	Improvement
News	40.37	40.79	0.42
Salesman	41.39	42.46	1.07
Hall	41.05	41.48	0.43
Paris	34.95	36.42	1.47
Container	40.25	40.72	0.47
Silent	38.91	39.59	0.68
Akiyo	45.95	46.47	0.52
Sailboat	40.80	41.88	1.08
Trevor	36.97	37.25	0.28
Table Tennis	35.09	35.71	0.62
Average	39.57	40.28	0.71

for the News video sequences with two regions. The regions marked with 0 and 1 correspond to region with complex and simple motion activities respectively. A number of commonly used video sequences were used to evaluate the effect of SPPMB. We implemented the rate control algorithm with and without SPPMB control block. The results show that the proposed bit allocation method provides a good enhancement about 0.71 dB in PSNR in the average quality of encoded video. Table 1 shows the results of encoding, in 64 kb/s encoded by H.264/AVC codec. Two cases have been compared in terms of average PSNR on luminance component.

To compare the proposed method to our previous method presented in [4], we encoded the video sequences by a region map with one and two types of regions. Although the overall average PSNR in two cases for corresponding regions are similar, more investigation results show that the average quantization scale decrease about 1.8 in the regions with complex motion activities. With similar PSNR, this considerable decrease in average quantization scale means higher visual quality in regions with complex motion in comparison with our previous method. Also we compared the results of this case with results of SPP frames provided by the H.263 and MPEG-4 codecs in [4]. Related to advanced motion estimation features in H.264/AVC the effect of SPPMB is much higher in H.264 than previous codecs.

More experiments on the region map resolution show that a simple binary region map with only two values almost enough for many cases. The binary map can be easily extracted by a simple thresholding process on different motion complexity criteria such as criterion presented by formula (3), (4).

1	1	1	1	1	1	1	1	1	1	1
1	1	1	0	0	0	0	0	1	1	1
1	1	1	0	0	0	0	0	1	1	1
1	1	1	0	0	0	0	0	1	1	1
1	1	0	0	0	0	0	0	0	1	1
1	1	0	0	1	1	1	0	0	1	1
1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1

Figure 2. A simple region map for the News video sequence

6. Conclusions

In this paper we proposed a special bit allocation technique using SPPMB which can be used in most rate controllers in variable bitrate video applications where short-term variation in bitrate is acceptable. SPPMB utilizes the advantage of variable bitrate video to minimize the propagation of quantization error and thereafter to increase the total average quality of compressed video. We propose a method to implement the SPPMB independently of the rate controller. Simulation results show that it can efficiently increase the total average quality of encoded video. Although the proposed method is a region based method, it can be implemented independent or even in combination with different region of interest (ROI) video coding methods.

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