Bit Allocation for Variable Bitrate Video

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***Abstract*— In this paper we propose a special bit allocation method which can be used in most rate control algorithms in variable rate video applications. In real-time video communication applications, we need a constant short-term average bitrate, while in variable bitrate applications such as streaming and local recording applications, a constant long-term average bitrate is sufficient and more short-term variation in bitrate is acceptable. In comparison with constant bitrate video, a variable bitrate video can provide better visual quality and coding efficiency for compressed video sequences. Furthermore, while more variation in bitrate is possible we have additional degrees of freedom to control the encoding parameters. We propose a special bit allocation algorithm to take advantage of this freedom in variable bitrate video. We introduce a new type of frame namely SPP frame (SPecial P frame) that can be used in combination with I, P, B and other types of frames in different encoders including H.263, MPEG-4 and H.264/AVC encoders. We propose a simple method to implement the SPP frames independently of the rate control algorithm. The experimental results show that the SPP frames can considerably increase the total average quality of variable rate encoded video.**

Keywords*— *Bit Allocation, Control, Rate, Video.

Topic area—Multimedia Processing.

I. INTRODUCTION

Digital video applications are increasing and different applications have their own 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 acceptable. In comparison with constant bitrate video, a variable bitrate video can provide better visual quality and coding efficiency for video sequences. A video rate control algorithm can work in different regions in the rate-distortion space from constant rate region to constant quality region. While variation in bitrate is acceptable, 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. Proposed methods in [1], [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. The described algorithm in [4] provides a variable bitrate video by controlling the quantization scale (QS) on a per picture basis. The QS is calculated based on two other QSs, which correspond to constant rate and constant quality rate controls.

In this paper we propose new bit allocation method for rate control which can be used independently as complementary part in most variable rate control algorithms. Although each variable rate control algorithm has its own constraints and strategy for bit allocation, it can utilize the new proposed method, as a complementary part, in combination with its own strategy. We propose a simple method for implementation of the new bit allocation method independent of the rate control algorithm using a control block placed between the rate controller and the encoder. This paper is organized as follow: Section 2 presents an overview of the proposed bit allocation method. Section 3 presents details of the proposed method. Simulation results are provided in Section 4. The paper is concluded in Section 5.

II. ALGORITHM OVERVIEW

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. We introduce a new type of frame, namely SPP (Special P) frame to take advantage of variable rate video. A SPP frame is a P-frame with a special location and bit budget. The proposed SPP frame can be used as an independent complementary tool for most variable rate control algorithms designed for different compression standards such as H.263, MPEG-4 and

H.264/AVC to provide a variable bit rate with a high visual quality and compression performance. Although the proposed SPP frames can be used in combination with other types of frames, here we consider just I-frame and P-frame.

We assume that the control is done at frame and higher levels. While control at Macroblock level in constant rate applications provides more precise bitrate control, in variable bitrate video it is not recommended for two reasons. First, control in Macroblock level needs to calculate quantization scale for each Macroblock and this increase the complexity of the controller and the header bits. Second, different quantization scales for different macroblocks provide different visual quality for macroblocks in one frame. Since the goal of variable rate video is to provide more constant visual quality and compression performance, control in macroblock level is not recommended.

To perform an efficient control at the frame and higher levels, the rate control algorithm allocates a suitable bit budget to each frame. Although a complete rate controller has several parts, here we focus on the bit allocation part for P-frames. To use the bit budget efficiently, we propose an I-frame followed by a large number of P-frames. Furthermore, an I-frame can be inserted in case of a scene-cut. The proposed bit allocation algorithm is applied to P-frames utilizing the SPP frames. We replace a P-frame with a SPP frame in special location between the P frames. 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. The amount of common details between an SPP frame and the following frames is becoming less and less related to motion activities in the video sequence. So the effect of the SPP frame will disappear after a number of subsequent frames. The amount of details which should be carried by an SPP frame and frequency of SPP frames are two important parameters that depend on the video content. We propose a simple method to determine these parameters.

An SPP-frame is a new concept in this paper that can be used as an independent complementary tool in variable rate control algorithms to improve the visual quality in compressed video. The idea of SPP frame is not suitable for constant rate applications in which we can not allocate very different bit budgets to one type of frames.

III. DETAILS OF THE ALGORITHM

In constant bitrate video, the quantization scale of I-frames is relatively higher than the quantization scale of neighboring P-frames to provide a constant bitrate. Therefore, the visual quality of I-frames is generally lower than P-frames'. On the other hand in variable bitrate video with relatively constant quantization scale, an I-frame can have a quality close to or even better than neighboring P-frames at the expense of a relative large bit budget. In this case, practical results show that an I-frame with high quality, as a reference frame, can improve the quality of subsequent P-frames. The improvement in quality of P-frames resulting from a high quality I-frame is limited to a small number of P-frames. We can not improve the quality of the whole P-frames by just increasing the number of high quality I-frames in short intervals because of large bit budget required for I-frames.

For efficient bit budget allocation, we use an I-frame followed by a large number of P-frames. Furthermore we introduce the SPP frame which simulates the effect of high quality I-frames at no cost. In this paper we introduce the SPP-frame as a new frame that can be used in combination with I-frames and P-frames in video encoding. In fact the SPP-frame is a P-frame whose location and bit budget are determined in special way.

Consider the simple block diagram for encoding P-frames shown in fig. 1. In this diagram P(n+1) denotes an uncompressed P-frame and P(n) denotes the uncompressed P-frame before P(n+1). P(n+1)+E(n+1) and P(n)+E(n) show the reconstructed version of the P(n+1) and P(n) frames. E(n+1) and E(n) are the quantization errors in these frames. C(n) denotes the motion compensated frame used for encoding P(n+1). If the quantization scale used for encoding R(n+1) is greater than the quantization scale of R(n), then in this case E(n+1)>E(n). The higher quantization scale distributes the quantization error over more frequency components. Therefore, the signal R(n)+E(n) has some high frequency information which is not available in the signal R(n+1)+E(n+1). This high frequency information will appear in C(n) and finally it will show in P(n+1)+E(n+1) which is the reconstructed version of P(n+1). While consequent frames have common information in all frequency components, it is expected that the quantization error of E(n+1) is decreased by

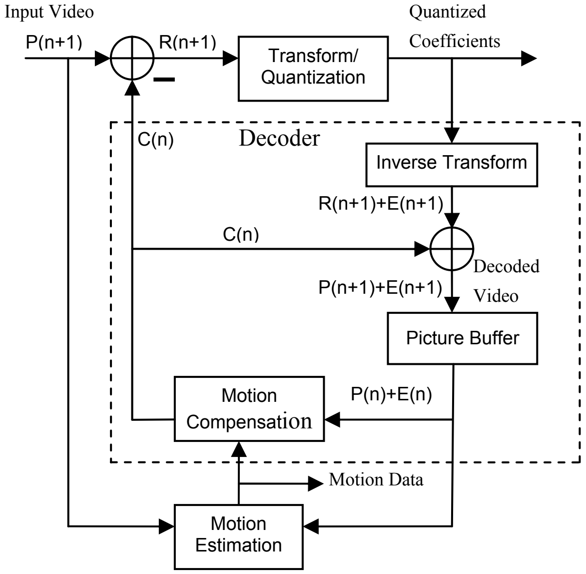

Figure 1: Simple diagram for encoding of P-frames

the injection of high frequency information available in the previous frame. This enhancement in quality will not occur if the quantization scale used for R(n+1) is smaller than that of R(n) or even if several consequent frames are encoded with equal quantization parameters. Furthermore, no enhancement occurs if the high frequency information is totally different between adjacent frames. In the worst case, as long as there is no enhancement, the quantization error is limited to E(n+1). The SPP frame makes use of this effect.

The SPP frame is a P-frame with a relatively small quantization parameter and high bit rate in special locations. It carries more details that increase the quality of subsequent frames while the total average rate is constant. When we send these details in a SPP-frame with relatively low quantization scale, the higher quantization scale in the following frames removes the details from prediction error while these details are available at the decoder. Therefore, the details are sent in one frame and used in several frames. This can increase the total average quality with the same total bitrate.

The quantization scale and the location of SPP frames are very important parameters which should be selected carefully. The aim is to take advantage of SPP frames without any cost in average rate and delay. If we allocate a large bit budget to a SPP frame, we should decrease the bit budget of subsequent frames to provide a long term constant rate. The quality of the subsequent frames may degrade as a result. The idea is to find an optimal way to relocate bit budget from subsequent frames to SPP frame. As for the quantization scale of SPP frame, it is calculated from the quantization parameter of the P-frame at the same location which is computed by the rate controller independent of SPP frames:

$$Q_{SPP} = Q_P \times (\Delta + \lambda \times Q_P^{LA} / Q_P^A) \qquad (1)$$

Where Q_P is value of the quantization parameter calculated by the rate control for the normal P-frame in location of SPP frame and independently of the SPP frame. Q_P^{LA} denotes the local average of quantization scales on a number of P-frames close to the SPP frame. Q_P^A denotes the average of quantization scale on all encoded P frames. Δ and λ are two constant coefficients smaller than one which are defined heuristically. In definition of function (1) we consider two assumptions. First, the allocated bit budget to SPP-frame is proportional to that of the replaced P-frame so the quantization scale of SPP-frame is proportional to quantization scale of the replaced P-frame. Second, when Q_P^{LA} has a large value relative to Q_P^A, it means there are high changes between adjacent frames. In this case, the effect of SPP-frame becomes limited to smaller number of subsequent frames and therefore, a relatively smaller bit budget is allocated to the SPP-frame. This is done by increasing the quantization scale of the SPP-frame according to the local average of quantization scales. The quantization scale of subsequent frames is not known and hence Q_P^{LA} is estimated from the previous frames as follows:

$$Q_{SPP} = Q_P \times (\Delta + \lambda \times Q_{SI}^A / Q_P^A)\,, \qquad (2)$$

where Q_{SI}^A denotes the average of quantization scales on all P-frames from last SPP or Intra frame to the current frame. SPP frames are implemented independently of the rate control and a simple control block for SPP frames is placed between the rate control and the encoder. The SPP control block takes the quantization scale of P-frames from the rate controller and if it decides to replace a P frame with a SPP frame then it computes the quantization scale of the SPP frame, otherwise it transfers the quantization scale without any changes. The constant coefficients used here depend on the encoder. For example, 0.56 and 0.08 values for Δ and λ, respectively, provide good results in H.263 and MPEG-4 encoders.

To increase the total average quality without any loss in other parameters such as total rate and delay, the location of SPP-frame should be selected carefully. SPP frames do not have constant frequency or intervals such as other frames in a GOP. SPP frames are inserted in a video stream according to certain conditions.

$$if\,(Conditions) \Rightarrow Insert \quad SPP \quad Frame\,. \qquad (3)$$

While related to the application and rate control algorithm more different conditions can be considered, we propose the following essential conditions:

1) SPP Interval: SPP interval defines the distance between two SPP frames or between one Intra frame and the next SPP frame. As a condition, we propose a minimum value for the SPP interval. In other words, a normal P frame can be replaced by a SPP frame if its distance from previous SPP frame or Intra frame is equal to or greater than a minimum value

$$N(\min) \le SPP \quad Interval\,. \qquad (4)$$

We define the minimum value of SPP interval as below:

$$N(\min) = \phi - \theta \times Q_{SI}^A / Q_P^A\,, \qquad (5)$$

where ϕ and θ are two constant coefficients. Good results were obtained with values of 31 and 9 for ϕ and θ, respectively, in MPEG-4 and H.263. In definition of the above condition we assume that while encoding frames before SPP-frame have larger quantization scales, it means there are high changes between adjacent frames. In this case, the effect of SPP-frame becomes limited to a smaller number of subsequent frames. Therefore, the SPP-frames should be closer together and at the same time according to formula (2) the bit budget of SPP frames will decrease in this case.

2) Buffer Fullness: This condition can be used in buffer constraint applications such as streaming. We propose two conditions related to receiver buffer fullness in streaming applications. A SPP frame can be inserted if:

$$B > (\ Min(B) + \alpha \times R_P\ ), \qquad (6)$$

$$B > B_S \times MFL\,, \qquad (7)$$

where B and B_S denote the receiver buffer fullness and buffer size respectively. R_P shows the allocated bits to normal P-frame in place of SPP-frame by the rate controller and independent of the SPP controller. α and MFL (Margin Factor for Low fullness) are two constant values. Typical values for α and MFL are 2 and 0.2 respectively. The condition defined in (6) prevents using SPP frame while the bitrate is increasing and at the same time the buffer has its minimum fullness during whole encoding process. This condition prevents increasing the streaming delay unnecessarily. The condition (7) prevents using SPP frame when the buffer is close to under flow. Similar conditions can be used according to the application.

To increase the total average quality without any increase in total rate from the first-order rate-distortion model it can be extracted

$$\frac{N+1}{Q_{P0}} = \frac{1}{Q_S} + \frac{N}{Q_P}, \qquad (8)$$

where the N is the number of P-frame that should compensate the extra bits allocated to the SPP frame. Q_{P0} denotes the average quantization scale of (N+1) P-frames in normal sequence without any SPP frames. Q_S and Q_P denote the quantization scale of the SPP frame and N P-frames after the SPP frame, respectively. To extract the equation (8) the total bit budget for (N+1) frames in two cases (with and without SPP frame) is equalized. Using (8) typical numerical results show that the changes of quantization scale on the P-frames followed by the SPP frame are negligible. Therefore the SPP control block just tunes the location and the quantization scale of SPP frame without any more interaction with the rate controller. After encoding a SPP frame, the quantization scales of subsequent frames can be tuned by the rate controller according to remained bit budget and its own bit allocation strategy. Hence the proposed SPP frame can be implemented independently of the rate control algorithm and this is one of the main advantages of the proposed method.

IV. SIMULATION RESULTS

To evaluate the new bit allocation technique we used our variable rate control proposed in [4] with H.263 and MPEG-4 encoders. We implemented the rate control algorithm with and without SPP frame. A number of 25 commonly used video sequences were used to evaluate the effect of SPP frames. The results show that the proposed SPP frames provide good enhancement (about 0.32 dB in PSNR in H.263 encoder and 0.24 dB in MPEG-4 encoder) in the average quality of encoded video. Table 1 shows a part of encoding results on the ten video sequences, with and without SPP-frame, in 64 kb/s by H.263 and MPEG-4 encoders. Two cases have been compared in terms of average PSNR. As it is shown in table 1, the quality improvement in video sequences with low motion such as Salesman is higher than in those with high motions such as Foreman. Furthermore, we have compared the results of encoding with and without SPP frames graphically. Fig. 2 shows the results for the Paris sequence in 64 kb/s. There is a considerable difference in overall YSNR (PSNR of luminance). The impulses in the PSNR curve related to SPP frames are not so noticeable visually while the overall improvement in the PSNR for all frames is perceptible visually.

TABLE I.: COMPARISON OF RESULTS OF ENCODING WITH AND WITHOUT SPP-FRAME IN A VARIABLE RATE VIDEO BY H.263 AND MPEG-4 ENCODERS. TWO CASES HAVE BEEN COMPARED BY AVERAGE OF PSNR IN 64 KB/S.

Video Sequence	**PSNR of Luminance (dB)**			
	H.263		**MPEG-4**	
	Without SPP	***With SPP***	***Without SPP***	***With SPP***
Mobile	23.46	23.57	23.59	23.69
Table Tennis	32.77	33.04	32.98	33.17
Foreman	31.56	31.56	31.74	31.77
News	36.79	37.29	37.4	37.35
Salesman	38.41	39.22	38.87	39.38
Hall	39.16	39.40	38.99	39.80
Paris	31.37	32.04	31.81	32.52
Container	37.74	37.90	37.67	37.83
Silent	36.81	37.42	36.93	37.57
Sailboat	39.05	39.53	39.29	39.51

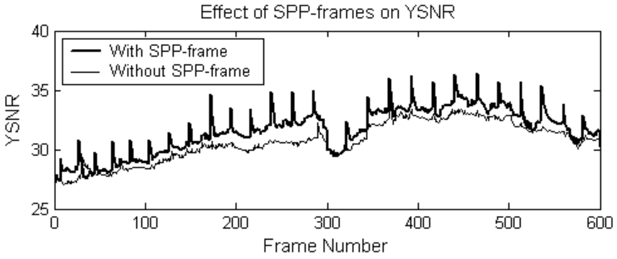

Figure 2: Results of using SPP-frames in video encoding.

V. CONCLUSIONS

In this paper we proposed a special bit allocation technique using SPP frames which can be used in most rate controllers in variable rate video applications where more short-term variation in bitrate is acceptable. We propose a method to implement the SPP frames independently of the rate controller. Simulation results show that it can efficiently increase the total average quality of encoded video.

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