A Simple One-pass Variable Rate Control Method for Fixed-Size Storage Systems

Kyungheon Noh[1], Seh-Woong Jeong[1], Jeahong Park[1] and Byeungwoo Jeon[2]
[1]Semiconductor SOC R&D Center, Samsung Electronics Co.,
26th Fl., IT R&D Center, Maetan-3Dong, Paldal-Gu, Suwon-City, Korea
Tel. +82-31-279-7539, Fax: +82-31-279-5522
[2]School of ECE, Sungkyunkwan University,
300 Chunchun-dong, Jangan-gu, Suwon, Korea
e-mail: [1] lololove@samsung.co.kr, [2] bjeon@yurim.skku.ac.kr

Abstract: This paper provides a frame-layer method for controlling bit rate of compresssed video data in real time. Our approach is easy to operate and can store encoded video data in real time without deteriorating the quality of an image. To provide ameliorated and consistent visual quality, a new concept named SOP (Set Of Pictures) and a new quantization parameter variation control algorithm based on a second-order rate-distortion model [2] are introduced. The total bit-budget is allocated efficiently to cope with unpredictable recording time by using the proposed algorithm and it is distributed to each frame. In the end, we show improved and consistent video quality with experimental results obtained from C-model of a MPEG-4 (simple-profile) encoder.

1. Introduction

In this paper, we propose a one-pass variable bit rate (VBR) control algorithm targeted for a low-complexity frame-layer bit-rate coding implemented for a fixed-size storage system. This rate control scheme is based on an accurate second-order rate-distortion model [2]. The data points for updating the model are selected in the same set of pictures (SOP) and pictures of a SOP are selected dynamically according to the picture characteristics estimated by the determined quantization parameter. The total available bit budget is allocated in real-time according to recording time increase. The variation of the quantization parameter (Qp) is restrained for consistent visual quality. By introducing the target rate adjustment, this procedure prevents the decoder buffer not only from underflow, but also from overflow.

In Section 2, we introduce the basic concept of rate control and its characteristics. In Section 3, we present the proposed one-pass VBR encoding algorithm, consisting of target bit rate allocation, quantization parameter (Qp) selection, alternative distortion measure, and scene change detection. In Section 4, we describe experimental results obtained with MPEG-4 video encoder on real video sequences to show that the proposed VBR encoding can provide more consistent and improved visual quality than the conventional rate control algorithms especially when the sequence has high activity. Finally, we conclude this paper in Section 5 with a summary of the proposed algorithm.

2. Rate Control and Its Characteristics

A digital video compression scheme such as MPEG-4 [1] and H.263 can generate an output bit stream with a constant bit rate (CBR) or a variable bit rate (VBR) according to its purpose. The CBR encoding has been widely accepted in practice because its implementation is easy and many digital video applications are indeed constrained by constant channel bandwidth. However, the characteristics of real video sequences undoubtlessly vary from frame to frame, therefore, the CBR coding suffers from inconsistent visual quality and low coding efficiency [4]. On the other side, the VBR encoding can usually provide consistent visual quality, and higher coding efficiency for many video sequences [5]. Digital video applications constrained by fixed-size stroage such as digital versatile disk (DVD), digital camcorder, and digital camera require the overall average bit rate be constant (long-term CBR coding), and a well-designed VBR algorithm can serve their purpose [4]. Psychological research suggests that the human visual system prefers a video sequence having consistent visual quality [6]. Since quantization determines the distortion, the small variation of a quantization parameter used in VBR usually results in similar distortion. Therefore, a VBR-encoded video sequence can be considered to have a consistent visual quality [7]. However, in realization, the VBR encoding also encounters difficulties such as coding delay and high complexity.

3. Proposed VBR Algorithm

Our paper proposes a new simple VBR encoding algorithm with a low coding delay that can be ignored in real time systems. We focus on applications that record video sequences in real time such as digital cameras, with emphasis on simplicity in implementation. Figure 1 shows the block diagram of the proposed VBR control method.

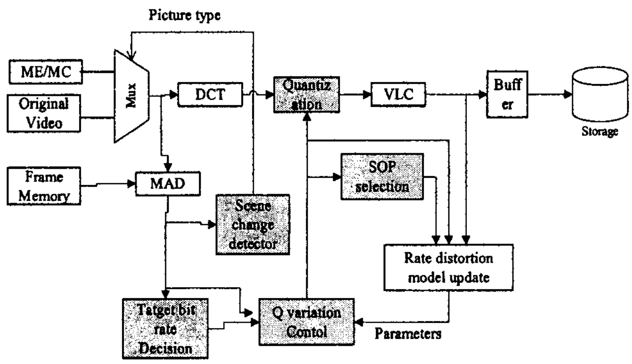

Figure 1. Proposed Block Diagram

The gray-colored blocks (target bit rate decision, quantization parameter variation control, set of pictures (SOP)) in Figure 1 are the ones designed in this paper and described in detail in following sub-sections. The available bit budget is allocated sufficiently according to recording time increase and the target number of bits to each video frame is assigned efficiently. Figure 2 explains proposed control flow of the encoder.

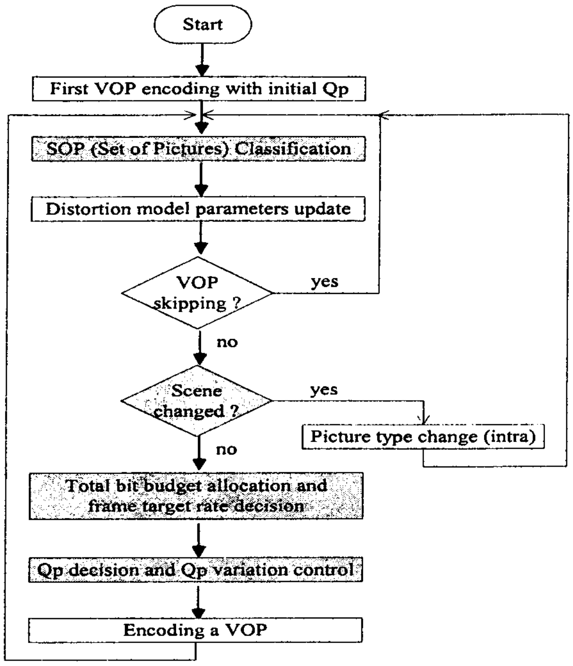

Figure 2. Control Flow

3.1 Target Bit Rate Decision

In the system of compressing digital video data and storing them in real time, the first problem we face is that total recording time is unpredictable. The simplest method in this situation is to allocate predetermined quantity of the bit estimate for n seconds at every n seconds. At this time the allocated total bit estimate is n × Rs where Rs denotes bit amount per second. The number of bit to be allocated per frame, R is calculated by following:

$R = Rr / Nr$

Rr: total available bit amount

Nr: the number of frames to be encoded

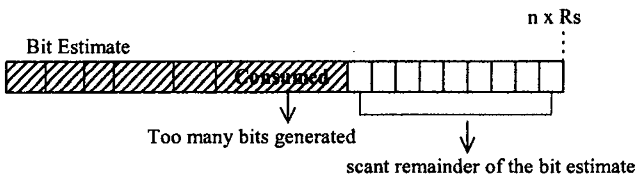

Figure 3. Bit Budget Problem (allocation per n seconds)

However, as shown in Figure 3, if some frame consumes too much of the bit budgets, following frames must suffer because remaining insufficient amount of bit budget is equally divided and allocated to the frames. This brings deterioration of video quality. To solve this problem, this paper proposes the quantity of bit estimate to be sufficiently allocated using VBR characteristics. Thus, even if a bit rate increases more than initially anticipated in a previous frame, the remaining frames can still spend sufficient quantity of the bit estimate, thereby preventing the deterioration of a video quality. Figure 4 shows the proposed method of bit estimate allocation.

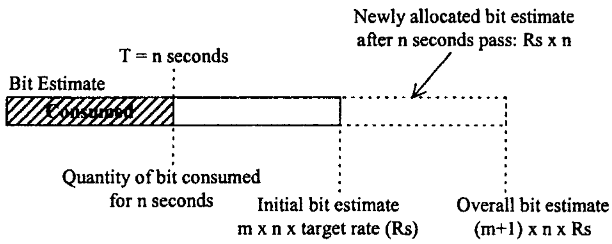

Figure 4. Proposed Bit Budget Allocation

The bit estimate required for m × n seconds is allocated as an initial bit estimate, and a bit estimate required for n seconds is added whenever n seconds passes during the encoding of video data. Proposed method results in a reduction in a quantization parameter rate by 5% on average, and a variation in the quantization parameter rate decreases by about 10%.

3.2 Practical Use of Motion Vector (MV)

The proposed method uses the rate-distortion function [2]:

$T = X1 \times MAD \times Qp{**}(-1) + X2 \times MAD \times Qp(-2)$

T: target bit rate per frame, X1, X2: modeling parameters

Qp: quantization parameter

MAD(mean absolute difference): encoding complexity

MAD represents an average absolute pixel differences between the present and the previous reconstructed frames. To reduce calculation load of MAD that is computed in pixel units, a slightly modified encoding algorithm with motion vector (MV) information is also proposed. The idea is that the bit amount to be generated can be anticipated by using the information of an average absolute MV values and the average MV differences between macroblocks (MB). We anticipate larger absolute MV values in case of faster movement and the higher activity of video data. In case of lager MV differences, we anticipate increased amount of bit generation. Additionally, since MV information is obtained before quantization, it is a good source representing encoding complexity of a current frame.

3.3 Quantization Parameter Variation Control

Smooth variation of quantization parameter (Qp) and efficient bit budget allocation over the whole recording time is important to gurantee consistent visual quality. Therefore, we develop a control algorithm ensuring smooth variation of Qp's, which is implementable with ignorable computational complexity. After calculation of a Qp value by using the rate-distortion function, Qp is readjusted by setting the maximum variation between frames in a limited range by the following equation and also setting the maximum and minimum values defined in the standard video compression:

$Qp(t) = \min ((1+K) \times Qp(t-1), Qp'(t), 31)$

$Qp(t) = max\ ((1\text{-}K) \times Qp(t\text{-}1),\ Qp'(t),\ Qpmin)$
Where, *Qp(t):* Qp to be used in the present frame
Qp'(t): Qp calculated by the rate-distortion function
Qp(t-1): Qp used in the previous frame
K: a coefficient of a Qp variation

The minimum Qp (Qpmin) is defined as 6, which is based on the facts that the quality of an image does not change much if Qpmin falls within a range from 1 to 6. A variation in Qp is finally controlled by adjusting the value K by the following equation and Figure 5.

$Qp(t) = (1 \pm K) \times Qp(t\text{-}1),\ K = L \times D$
L: limitation parameter used to determine maximum K
D: deviation parameter representing deviation degree of r
where $D = r / (1+L)$, if $1 <= r < 1+L$; $D = (1-L) / r$, if $1-L < r < 1$; and $D = 1$, otherwise.

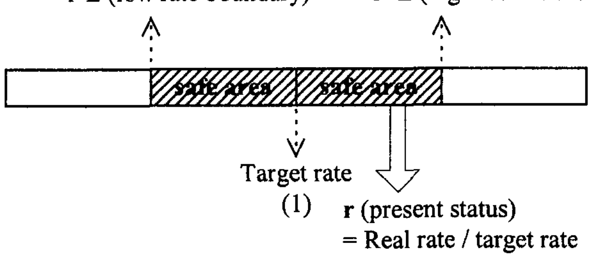

Figure 5. Bit Rate Status

Safe area denoting the range of the rate allowed by the VBR encoder is first set with respect to a bit rate. A present status r, which represents a degree how the generated rate of the present bit deviates from a target bit rate, is used to determine a parameter D together with a parameter L that is predetermined value (0.3) and determines an allowable range of a variable Qp as well as the range of safe area. The deviation parameter D indicates the degree that the present bit rate deviates from a target bit rate. K is adjusted according to the deviation degree. This adjustment reduces variation in the quantization factor, thereby maintaining the video quality as shown in Figure 6.

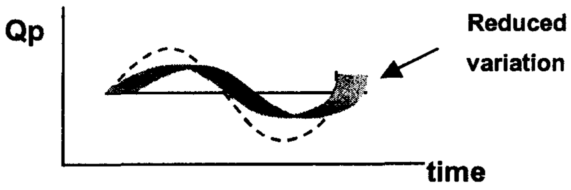

Figure 6. Qp Variation Control

Additionally, the level of a buffer must be checked against accidental overflow or underflow in the buffer. For instance, if the buffer fullness reaches above a predetermined level, overflow may occur in the buffer. In this case, the variation of the present Qp is adjusted to a range of the maximum variation to prevent overflow.

3.4 Set of Pictures (SOP)

After encoding with selected Qp, parameters X1 and X2 of the rate distortion function [2] are updated with the quantity of bit and Qp of the previous frames just before encoding of the next frame. The two values of bit and Qp are called "data points" and the selection of appropriate data points is equivalent to obtaining an exact Qp. To select appropriate data points, so called "set of pictures (SOP)", in which frames having similar complexity are grouped, is used in this paper. Since frames having the similar complexity are grouped into a SOP, data points in the same SOP group are selected and used. As a result, more appropriate data points can be selected through this procedure preventing selection of data points from frames having different characteristics. The number of frames in SOP is variable and the maximum and minimum numbers of frames in a SOP are predetermined. In this paper, the number of frames for each SOP is set in a range from 3 to 100 through experiments.

3.5 Scene Change Detection

If MAD is used as a distortion measure, scene change detection is simply realized by a following condition:
Current MAD > n × MAD average (or previous MAD), n=8

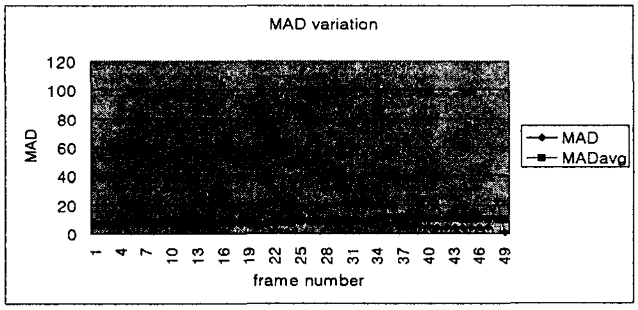

Figure 7. The variation of MAD

Figure 7 shows MAD variation in "table tennis" sequence having a scene change and there is a marked variation in a portion in which a scene change occurs. Scene change can be detected also by using MV information or by checking MB coding type instead of MAD use.

4. Experimental Results

The proposed algorithm is implemented in the encoding simulator of a c-model in accordance with the international standard MPEG-4, simple profile. A comparison and analysis with the rate control algorithm in MPEG-4 VM (verification model) 5 [1] is made with test sequences similar to real application of digital camera. The results in Table 1 and 2 show that the proposed VBR approach is able to achieve more consistent visual quality than the algorithm in VM5.

Table 1. Comparison of Bit Allocation Performance

	Allocation per 5 seconds				Proposed allocation			
	$\overline{Qp}$	σ_{Qp}	|Qp(t)-Qp(t-1)|	Avg Rate	$\overline{Qp}$	σ_{Qp}	|Qp(t)-Qp(t-1)|	Avg Rate
Stefan (cif, 1Mbps)	11.96	5.11	1.36	969,523	11.86	4.63	1.22	974,396
Coastguard (cif,512kbps)	9.37	1.41	0.36	490,918	9.10	1.29	0.30	499,733

Table 2. Comparison of Quality Performance

	VM5 algorithm				Proposed Algorithm			
	$\overline{Qp}$	σ_{Qp}	σ_{PSNR}	Avg Rate	$\overline{Qp}$	σ_{Qp}	σ_{PSNR}	Avg Rate
Stefan (cif, 1Mbps)	11.96	5.11	2.95	988,332	11.80	4.32	2.66	984,396
Coastguard (cif,512kbps)	9.37	1.41	1.00	505,460	9.01	1.20	0.90	510,733
Tennis (sif,300kbps)	12.09	3.60	2.21	290,802	11.62	3.52	2.09	295,866

$\overline{QP}$: total average of Qp

σ_{QP} : The standard deviation of Qp

σ_{PSNR} : standard deviation of luminance PSNR

| *Qp(t) – Qp(t-1)* |: The average of temporal Qp variation
Avg Rate: The average rate of the sequence

Table 1 shows the bit allocation result by the proposed algorithm compared to the conventional simple bit budget allocation method of allocating bits per every 5 seconds. The comparison shows that the proposed method has smaller standard deviation of Qp than the conventional method. The variation of Qp according to the proposed method is much less than that in the conventional method, which reduces deterioration of the visual quality.

Table 2 shows comparison result of quality. The quality is compared in two ways: standard deviation of Qp and PSNR. The proposed algorithm has standard deviation smaller for both Qp and PSNR by more than 15% compared with the algorithm in VM5. The average Qp is also improved noticeably [1].

Table 3. Performance Comparison (MAD vs MV)

	Using MAD		Using MV	
	$\overline{QP}$	σ_{QP}	$\overline{QP}$	σ_{QP}
Stefan (CIF@1Mbps)	11.96	25.46	11.99	24.52
Coastguard (CIF@512kbps)	9.37	1.76	9.45	2.11

Table 3 describes performance results in case of using MV information instead of MAD as a distortion measure. Needless to say, the performance using MAD is better than that using MV, however, the amount of calculation when using MAD is more than when using MV. The performance of the highly active video sequence "stefan" does not considerably change whether a variable bit rate is controlled using MAD or MV. A bit rate variation is not different much either (see Figure 8). Therefore, MV information can substitute the MAD as a distortion measure in a given system requiring reducing amount of calculation without sacrificing performance too much.

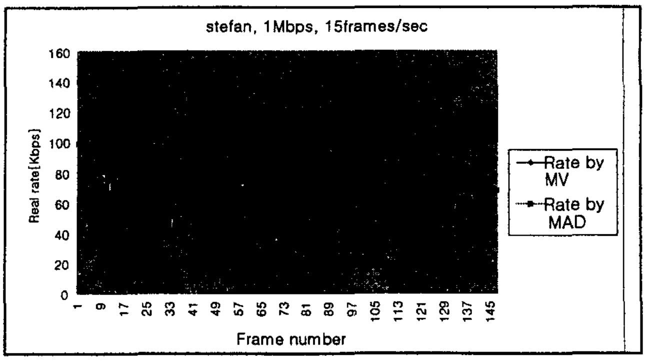

Figure 8. Variation of Bit Rate

5. Conclusion

In this paper, we propose a new bit-budget allocation method, quantization factor variation control, classification of pictures according to activity, and a new measure of encoding complexity by analyzing motion vector information. Each constituent method can be applied individually according to the type of application, one of them may be a storage system. The proposed one-pass VBR algorithm will be applicable to a real-time system and will provide outstanding video quality by quantization factor variation control plus the proposed new bit-budget allocation.

References

[1] "Coding of Moving Pictures and Audio," MPEG-4 Video Verification Model version 18.0, ISO/IEC JTC1/SC29/WG11, N3908, Jan. 2001.

[2] Hung-Ju Lee, Tihao Chiang, and Ya-Qin Zhang, "Scalable Rate Control for MPEG-4 Video," *IEEE Trans. Circuits Syst. Video Technol.*, Vol. 10, pp. 878-984, Sept. 2000.

[3] Jordi Ribas-Corbera, and Shawmin Lei, "Rate Control in DCT Video Coding for Low-Delay Communications," *IEEE Trans. Circuits Syst. Video Technol.*, Vol. 9, pp. 172-185, Feb. 1999.

[4] Yiliang Wang and Chang Wen Chen, "A Novel Two-Pass VBR Coding Algorithm for Fixed-Size Storage Application," *IEEE Trans. Circuits Syst. Video Technol.*, Vol. 11, pp. 345-356, March 2000.

[5] T. V.Lakshman, Antonio Ortega, and Amy R. Reibman, "VBR Video: Tradeoffs and Potentials," *in Proc. IEEE,* Vol. 86, pp. 952-972, May 1998.

[6] Mark R. Pickering and John F. Arnold, "A Perceptually Efficient VBR Rate Control Algorithm," *IEEE Trans. Image Processing,* Vol. 3, pp. 527-532, Sept. 1994.

[7] M. Hamdi, J. W. Roberts, and P. Rolin, "Rate control for VBR video coder in broad-band networks," *IEEE J. Select. Area Commun.*, Vol. 15, pp. 1040-1051, Aug. 1997.

[8] J. J. Chen and D. W. Lin, "Optimal bit allocation for coding of video signals over ATM networks," *IEEE J Select. Area Commun.*, Vol 15, pp. 1002-1015, Aug. 1997.