Fuzzy Rate Controller for Variable Bitrate Video in Mobile Applications

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Abstract— **In this paper we propose a low-complexity fuzzy video rate controller designed for real-time variable bitrate applications with buffer constraints. The algorithm is optimized for streaming application in mobile devices. Furthermore, the proposed algorithm can be used for local recording application so as the recorded video may be streamed in future. Today, many mobile phones include a digital camera that can be used to capture and encode video in real-time. We assume that no memory for storage of uncompressed video is available in mobile phones. Therefore, look-ahead and multi-pass rate controls are not possible. Furthermore, considering the processing power and, more importantly, battery life constraints in mobile devices, the proposed algorithm needs to be as simple as possible.**

The described variable bitrate (VBR) bit rate control algorithm controls the quantization scale (QS) on picture basis. The QS is mainly controlled by a fuzzy controller such that it minimizes the variation of QS to provide encoded video with high visual quality so as to utilize the variable bitrate benefits as much as possible.

The proposed rate control algorithm (RCA) has been implemented in the MPEG-4, H.263 and H.264/AVC standard video codecs and the experimental results show that it provides high level average quality for encoded video while it strictly obeys buffering constraints.

Index Terms—**Control, Fuzzy, Mobile, Rate, Streaming, Variable, Video.**

I. INTRODUCTION

Mobile devices with a built-in digital video camera are becoming popular. In addition to conversational services, where low delay, constant bitrate rate control algorithms are required, streaming and local recording applications (with the mobile device acting as capture and encoder) are also of importance. Many mobile phones are equipped with a digital video camera, which can capture, encode and record the video in real-time. The modern networks such as 3G mobile phone networks, Bluetooth, or WLAN, allow for the real-time transmission of the encoded video file to a connected PC. Consequently, all forms of multimedia communication such as streaming, file sharing, progressive file download and others become possible.

The rate control constraints for local recording and streaming differ significantly from those for low delay video communication over bandwidth-limited links. In real-time video communication applications, a constant, short-term average bitrate is required to ensure low delay. In contrast, for streaming and local recording applications, a constant long-term average bitrate is sufficient and a significant short-term variation in bitrate is acceptable.

In comparison with constant bitrate (CBR) video, a VBR video rate control can provide better visual quality and coding efficiency for most video content. A video rate control algorithm can operate in different regions in the rate-distortion space between the constant rate region and the constant quality region. Normally, a VBR rate control algorithm operates closer to the constant quality optimum, which results in a better average quality [1]. Minimizing the overall distortion is, in many cases, roughly equivalent to minimizing the variation in quality [2]. While for VBR rate control a loose control on frame level is sufficient, CBR rate control algorithms usually operate in sub-frame control levels such as slice level and macroblock level to control the bitrate precisely. A CBR rate controller with control in macroblock level needs to calculate quantization scale for each macroblock and this increase the complexity of the controller and the header bits. Morover, 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.

Many real-time variable rate control algorithms have been proposed specific to local recording [1], [3], [4] and streaming [5], [6]. Furthermore, we proposed another variable rate controller for the both applications including streaming and local recording applications in our previous work [7]. The key concept in [1] is to suppress the fluctuation in quantization scale as much as possible. The buffer constraint, which is essential in streaming applications so as to allow for well-defined buffering requirements at the player, is not considered in this algorithm. The methods proposed in [3] and [4] attempt to satisfy a target bit-budget constraint. In other words, they utilize the total storage size as a constraint for encoding a number of frames. Due to the potentially open-ended recording session, in our application a target file size is unknown and the algorithm is hence not appropriate. The algorithm presented in [5] is a low complexity frame-layer bit rate control for streaming video applications. Although this algorithm utilizes a virtual buffer, two other parameters

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predominantly control its operation: a large time interval and a large bit budget. The virtual buffer, which is essential in streaming, does not play an active role in this algorithm. They assume in case of overflow, the decoder can notify the transmission protocol to stop sending bits. The SPEM (Smooth Pursuit Eye Movement) rate control scheme introduced in [6] is designed for real time encoding and streaming over a constant bit rate channel. This method works near the constant bit rate region, and cannot utilize the variable bit rate benefits. Our previous rate control algorithm presented in [7] is an advanced rate controller that can be tuned for a wide rage of applications from constant quality to constant rate applications. It provides a variable bitrate video using constant rate and constant quality control parameters. It performs very well and it is a low-complexity algorithm from the implementation points of view but it has many tuning parameters that should be adjusted for different applications.

There are more other rate control algorithms such as [8], [9] which may be tuned to provide a kind of variable bitrate video but they are not suitable for our application for two reasons. First, they are too complex from the implementation point of view. Second, they have been targeted for CBR applications and they do not utilize completely the VBR benefits.

In this paper we propose a VBR fuzzy rate control algorithm with buffer constraint, which operates near the constant quality region in the rate-distortion space. Studies on a large number of video rate control algorithms show that although they may be built based on the results of rate-distortion theorem, usually they utilize heuristics formulas and coefficients which are tuned experimentally. We proposed the fuzzy controller for video rate control because many theoretic and heuristic relationships can be included in the IF-THEN fuzzy rules and fuzzy membership functions (MSF) simply. Comparing with our previous algorithm in [7] the new proposed algorithm has lower complexity from processing and tuning power points of view. It can be tuned more easily and still it can provide encoding results very similar or even better than our previous algorithm. For more comparison, we believe that the complexity of the proposed algorithm is less than even TMN5 rate control algorithm.

This paper is organized as follow: Sections II and III present overview and detailed description, respectively, of the new fuzzy rate control algorithm. Simulation results are provided in Section IV. A short summary is presented in Section V.

II. ALGORITHM OVERVIEW

We propose a simple fuzzy video rate control algorithm optimized for real time mobile applications. The proposed rate control algorithm (RCA) provides a relatively constant visual quality with low buffering delay, buffer size, processing memory and processing power. The proposed RCA utilizes a virtual buffer (receiving model) and a simple fuzzy controller. The rate of encoded video is controlled just by the quantization scale (QS) on picture basis. We consider two types of frames: Intra frames and Inter frames. The QS for an Intra frame is calculated based on QS of previous encoded frames and QS of Inter frames are computed based on QS of previous frame and three other QSs which correspond to constant quality, constant rate and fuzzy control. From the system point of view the main part of computed QS is a delayed version of previous QS and the main part of control or variation in QS is provided by the fuzzy controller. Two other QSs provide application dependent fine tuning relative to the output of the fuzzy controller.

As can be seen in the block diagram shown in fig.1, the fuzzy controller uses two input signals: the fullness of the virtual buffer and resulting output video bitrate. The fuzzy controller provides a quantization scale (Q_{Fuz}) as output which is added to the previous QS ($Q_{\mathrm{Pr}e}$) to build the final QS for the current frame (Q_{Cur}). The main control is performed by Q_{Fuz} which outputs a positive or negative value. Furthermore, we use two other feedback loops, one related to quality regulation and another one related to bitrate regulation, to provide more control on the system for different applications. The quality controller compares the quality of the previous encoded frame with the average quality of all encoded frames and provides an output (Q_Q) which drives the quality of next frames towards the average. The average rate controller compares the total average bitrate with the target rate and controls the QS to obtain the target bitrate more closely. The final quantization scale for the current frame is sum of the previous QS and the outputs of three controllers:

$$Q_{Cur} = Q_{\mathrm{Pr}e} + Round(Q_{Fuz} + Q_Q + Q_R), \qquad (1)$$

where Q_R is the output of average rate controller. The outputs of three controllers are real numbers therefore we perform a round operation on the sum value.

The main control is performed by the fuzzy controller which obeys the buffer constraint and provides the visual quality with minimum variation on the QS. The operation of the fuzzy controller can be tuned just by changing the virtual buffer size. The quality controller and the average rate

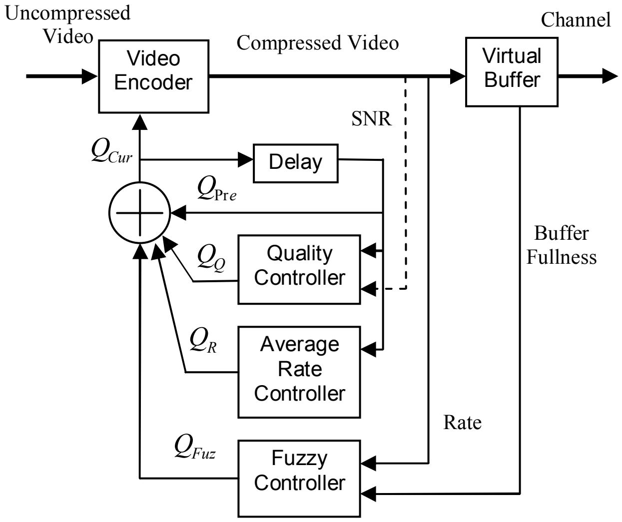

Figure 1. Block diagram of the fuzzy video rate controller.

controller are two auxiliary tools which can be tuned for different applications just by two tuning parameters. Therefore, the proposed RCA can be tuned for a wide range of applications just by tuning three parameters: Virtual buffer size, constant quality feedback gain and average rate feedback gain. The bigger quality gain provides more constant quality and the bigger average rate gain provides more constant rate. The typical value of virtual buffer size for variable bit rate application corresponds to 2 to 3 seconds of video with the target rate while for low delay communication the buffer size can be decreased.

III. DETAILS OF ALGORITHM

As can be seen in fig.1, the virtual buffer, fuzzy controller, quality controller and average rate controller are basic parts of the proposed video rate controller. The details of these parts are presented in this section.

A. Virtual Buffer

The virtual buffer used in this controller simulates the buffering process of the decoder in the receiving side of streaming. Although it utilizes a simple model, it nearly compromises with hypothetical reference decoder (HRD) models used in different standard video codecs. The occupancy of virtual buffer is updated after encoding each video frame as

$$BF(i+1) = BF(i) - FB(i) + \frac{TR}{FR}, \tag{2}$$

Where BF denotes the buffer fullness and FB shows the number of bits in the coded video frame. TR and FR denotes the target bitrate and frame rate respectively. The algorithm tries to derive the buffer fullness toward a reference value which is about the 60% of buffer size and the optimum value for initialization of buffer fullness is the reference value i.e.

$$BF(0) = 0.6 \times BS, \tag{3}$$

where BS denotes the buffer size.

B. Fuzzy Controller

The fuzzy controller is designed based on IF-THEN fuzzy rules which are designed based on our experience in design of our previous algorithm in [7]. The fuzzy controller has two input signal: The buffer fullness (*BF*) which is normalized by the buffer size (*BS*) and the current rate (*R*) normalized by the target bitrate (*TR*). For example, we can say: if the buffer fullness is close to the middle of buffer size and the current rate is close to the target rate, then do not change the quantization scale. Also we can say: if the buffer fullness is very low and current rate is much higher than the target rate, then increase the quantization scale with a large step. All the IF-THEN fuzzy rules are summarized in the table 1. The coordinates of the table are the input signals to the fuzzy controller and the contents of table are specifications for the output of the fuzzy controller. The normalized input signals are specified by their fuzzy membership functions (MSF). A number of seven MSFs for the rate and nine MSFs for the buffer fullness were selected during an optimization process. The content of table specifies the output of the controller. As an example from the table it can be expressed as:

TABLE I. SUMMARIZATION OF THE IF-THEN FUZZY RULES

R / TR	XL	VVL	VL	L	ML	M	MH	H	VH
VH	VXH	VXH	XH	VH	H	H	MH	M	M
H	VXH	XH	VVH	H	H	MH	MH	M	M
MH	XH	VVH	VH	H	MH	M	M	ML	ML
M	VVH	VH	H	MH	M	M	ML	ML	L
ML	VH	H	MH	MH	M	M	ML	L	L
L	H	MH	M	M	ML	ML	ML	L	VL
VL	MH	M	M	M	ML	L	L	VL	VL

BF / BS

if (*BF/BS* is VL and *R/TR* is MH) *Then* (Output is VH).

The letters H, L, M, V and X correspond to linguistic specifications of High, Low, Medium, Very and Extremely. The linguistic fuzzy rules and MSFs were designed based on our experiences in design of previous classic video rate controller [7]. Furthermore, an optimization process was performed for fine tuning of the fuzzy MSFs. For optimization, we defined two scaling factors for MSFs of each input which were scaling the MSFs in two sides of reference point during the process. The final distributions of MSFs are shown if fig. 2. The desired central values for the output of fuzzy system correspond to the table 1 are shown in the table 2. We used a well-known and simple fuzzy system with two inputs using “Product Inference Engine”, singleton fuzzifier, and centre average defuzzifier which is

$$f(x_1, x_2) = \frac{\sum_{i_1=1}^{N_1} \sum_{i_2=1}^{N_2} \bar{y}^{i_1 i_2} \mu_{A_1^{i1}}(x_1).\mu_{A_2^{i2}}(x_2)}{\sum_{i_1=1}^{N_1} \sum_{i_2=1}^{N_2} \mu_{A_1^{i1}}(x_1).\mu_{A_2^{i2}}(x_2)}, \tag{4}$$

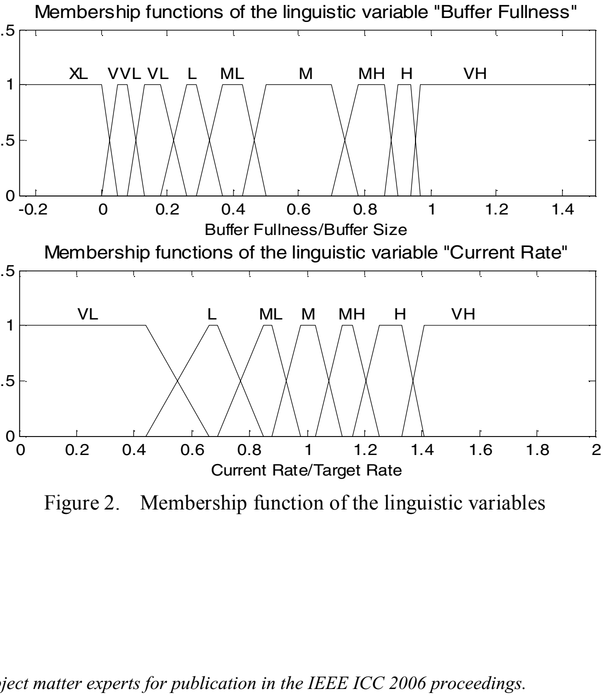

Figure 2. Membership function of the linguistic variables

TABLE II. DESIRED CENTRAL VALUES FOR THE OUTPUT OF FUZZY SYSTEM

R / TR	XL	VVL	VL	L	ML	M	MH	H	VH
VH	6	6	5	3	2	2	1	0	0
H	6	5	4	2	2	1	1	0	0
MH	5	4	3	2	1	0	0	-1	-1
M	4	3	2	1	0	0	-1	-1	-2
ML	3	2	1	1	0	0	-1	-2	-2
L	2	1	0	0	-1	-1	-1	-2	-3
VL	1	0	0	0	-1	-2	-2	-3	-3

BF / BS

where $f(x_1, x_2)$ denotes approximated output and $\{A_i^1, A_i^2, ..., A_i^{N_i}\}_{i=1,2}$ are fuzzy sets with $\{\mu_{A_1^{i_1}}(x_1)\}_{1\le i_1 \le N_1}$ and $\{\mu_{A_1^{i_2}}(x_2)\}_{1\le i_2 \le N_2}$ membership functions defined for inputs x_1 and x_2. The centre of output fuzzy set ($B^{i_1 i_2}$), denoted by $\bar{y}^{i_1 i_2}$, is chosen as output desired values. More information about the derivation steps of the above fuzzy system (4) are presented in [10]. The output of the fuzzy system can be expressed in a general form as

$$Q_{Fuz} = f(x_1, x_2) = f(BF/BS, R/TR) . \qquad (5)$$

C. Quality Controller

This block computes an additive term to the final QS based on the current quality and the average quality of the encoded video frames. The idea is while the fuzzy controller provides the buffer constraint, the quality controller provides less variation in quality by more usage of available buffer space. The quality QS or Q_Q is calculated by

$$Q_Q = \theta \times Q_{Avg}(PSNR - PSNR_{Avg}) \ , \qquad (6)$$

where Q_{Avg} is the average QS on all encoded frames and θ denotes the constant quality feedback gain. $PSNR$ and $PSNR_{Avg}$ are the PSNR of previous encode frame and the average PSNR on all encoded frames respectively. The PSNR values are computed based on the luminance component of video frames. The bigger constant quality gain provides more constant quality while it increases the fluctuations of buffer fullness. This means more usage from available space in the buffer and it means less variation in quality which is almost equal to maximization of total quality. The value of Q_Q is limited to the range of [-1, 1] to prevent unnecessary fluctuations in rate or distortion.

D. Average Rate Controller

This block computes another additive term to the final QS by comparing of the average bitrate with the target bitrate. In constant bitrate video the bitrate of encoded video is very close to the target bitrate. Furthermore in variable bitrate video after encoding a large number of video frames, the algorithm automatically produces an average bit rate which is very close to the target bit rate, but in short video sequences, it is possible to have a small difference between target bit rate and produced bit rate. In some applications it is desirable to have a bitrate close to target rate even for short video clips. The goal of the average rate controller is to provide a variable bitrate video with an average bit rate close to the target bit rate even in short video sequences. Furthermore, this block can be used to drive the operating points of the controller toward the constant rate applications. The output of the average rate controller is computed by

$$Q_R = \Phi \times Q_{Avg}\left(\frac{TotalEncodedBits \times FR}{TotalEncodedFrames \times TR} - 1\right), \qquad (7)$$

where Φ denotes the average rate feedback gain. FR and TR are the target frame rate and the target bitrate respectively. Like Q_Q, the value of Q_R is limited to the range of [-1, 1]. The feedback gain can be increased in short video sequence and also in constant rate applications. Furthermore it can be decreased in long video sequences and also in constant quality applications.

E. Quantization Scale of Intra Frames

The QS of Intra frame is calculated by a simple low pass filtering is performed on the previous local QS by:

$$Q_{Intra}(z) = H(z) \times Q_{\mathrm{Pr}e}(z), \qquad (8)$$

where Q_{Intra} results of filtering on previous QSs. $H(z)$ is an IIR filter with impulse response of

$$H(z) = \frac{m}{m + 1 - z^{-1}}, \qquad (9)$$

where m is a constant value smaller than one and good results are obtained with m=0.2.

IV. RESULTS

We implemented the proposed RCA on three standard video codecs including: MPEG-4, H.263 and H.264/AVC. It gave good results in all three codecs. In the table III the results of proposed RCA have been compared with the constant QS case as constant quality case in H.264 encoder. In the constant QS case, two consequent values of QS are used for encoding all video frames and the target bitrate is obtained by changing the number of frames encoded by each QS. The average results on a large number (20) of video sequences with QCIF format show that the proposed fuzzy RCA provides better PSNR and smaller buffer size for streaming in a lower bitrate than the constant QS case. The average PSNR provided by the proposed RCA is about 0.26 dB higher than constant QS case while the provided streams by the proposed RCA need a bit budget about 1.3% lower than those which provided by the constant quality case. Moreover the average required buffer size for streaming of encoded video streams by the proposed RCA corresponds to 0.8 second of video with the target rate which is less than 30% maximum HRD coded picture buffer size in H.264/AVC. On the other hand there is no limit on the required buffer size for streaming of encode video streams by the constant QS. Also we computed the variance of QS and SNR for the proposed algorithm. Small values for the variances of QS (4.6) and PSNR (2.4 dB) prove the constant visual quality. Furthermore we evaluated the proposed RCA in MPEG-4 and H.263 encoders. In these encoders we compared the proposed RCA with our previous RCA presented in [7]. The average results on a large number (28) of video sequences have been presented in the table IV. Two RCAs have been compared in terms of average bitrate, PSNR, streaming delay, streaming buffer size and quantization scale. The results show that the proposed fuzzy RCA performs as well as our previous RCA while our previous RCA gives very good results and also the new RCA is simpler from the implementation and tuning points of view. Moreover the strong similarity between the results of two RCAs shows that how well the fuzzy rules and MSFs have been defined according to previous experiences.

V. SUMMARY AND OUTLOOK

We proposed a real-time, simple video rate control algorithm which is optimized for streaming and local recording applications in mobile devices. We assume that no memory for storage of uncompressed video is available in mobile phones. Furthermore, the processing power and battery life are considered as constraints in mobile devices.

The described algorithm implements a variable bitrate (VBR) 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. This structure provides control over a wide range of applications from constant quality to constant rate. The algorithm utilizes the variable bitrate benefits as much as possible so as to minimize the variation of the QS scale, and to provide encoded video with high visual quality. Although all of the constraints including the streaming and the mobile constraints are obeyed in the algorithm, the experimental results show that it allows encoded video at a high level of average quality.

TABLE III. COMPARISON THE RESULTS OF PROPOSED FUZZY RATE CONTROLLER WITH THE CONSTANT QS CASE AS CONSTANT QUALITY CASE IN H.264/AVC ENCODER WITH TARGET RATE OF 64KB/S.

Video Sequence	Bitrate (kb/s)		PSNR (dB)		Buffer Size (Kbyte)	
	C.Q.	***Proposed***	***C.Q.***	***Proposed***	***C.Q.***	***Proposed***
Foreman	64.78	64.58	34.65	34.70	-	3.50
Carphone	64.90	64.21	35.08	35.42	-	3.16
News	65.03	64.24	39.84	40.17	-	5.97
Salesman	64.82	64.06	41.09	41.54	-	7.43
Container	64.82	63.96	40.04	40.15	-	3.58
Silent	64.89	63.87	38.08	38.91	-	6.24
Autumn	64.96	64.24	33.79	33.97	-	8.45
New York	64.96	64.33	35.66	36.03	-	3.27
Suzie	65.05	63.96	39.46	39.59	-	3.92
Glasgow	64.78	63.74	30.28	31.00	-	14.49
Table Tennis	64.70	63.67	34.66	34.89	-	8.53
Football	65.02	64.97	28.57	28.86	-	9.82

TABLE IV. COMPARISON THE RESULTS OF PROPOSED FUZZY RATE CONTROLLER WITH THE PRESENTED RCA IN [7] IN H.263 AND MPEG-4 ENCODER WITH TARGET RATE OF 64KB/S.

Average Values	H.263		MPEG-4	
	Reference	***Proposed***	***Reference***	***Proposed***
Bitrate (kb/s)	63.17	63.96	63.83	63.84
PSNR (dB)	32.02	32.26	32.29	32.40
Streaming Delay (s)	0.49	0.45	0.47	0.43
Streaming Buffer Size (kb)	8.0	5.3	6.3	5.1
Quantization Scale	12.08	12.14	11.86	12.00

The scalability and error resiliency and random access for streaming in mobile applications can be considered as additional constraints in design of rate controllers in future research works.

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