ANALYSIS OF RD MODELS FOR CODING EFFICIENCY IN H.264 STANDARD

Piotr Bobiński, Władysław Skarbek

Warsaw University of Technology, Institute of Radioelectronics, Nowowiejska 15/19, Warsaw, Poland

ABSTRACT

A novel analysis of rate-distortion relationship in video data is presented with application to H.264/ AVC codec. We develop the linear model for bitrate as a function of percentage of insignificant transform coefficients and show experimentally its feasibility for AVC video stream. Using of this model in the reference AVC codec leads to the increased coding efficiency and more stable bitrate control.

1. INTRODUCTION

The key issue in video compression is the optimal coder control, that is the selection of appropriate set of coding parameters, that will guarantee the demanded bitrate (calculated on the basis of actual transmission channel parameters) with minimal lost in fidelity of reconstructed video sequence [8]. In typical transform coding, both rate *R* and distortion *D* are controlled by the quantization parameter *q*. Usually they are characterized by the collection of functions in *q* domain: $R(q)$ and $D(q)$, called the *R-D* functions. The major issue becomes how to analyse, model and estimate the *R-D* functions for the specific video encoding scheme. In the paper we present the novel approach where the *R-D* functions are analysed and modelled in new domain of parameter ρ, which is the percentage of insignificant transform coefficients. Using this model, which has been previously proposed by Zhiai He and Sanjit K. Mitra for DCT-based video encoders [2], first we developed the bitrate control algorithm for the H.264/AVC video coding standard [3,4]. We achieved better results in comparison to algorithm from contribution JVT-G012 [6]: smaller deviation of generated bitrate (about 38%) and better coding efficiency (in RD sense) (about 1 dB).

2. SURVEY OF ALGORITHMIC FOUNDATIONS

2.1. R-D model in ρ domain.

It has been observed that zeros play a key role in transform coding, especially at low bit rates. All typical coding algorithms treat zeros in a special way and address most of the effort to efficient coding of them. Let's denote by ρ the percentage of the zeros among the quantized transform coefficients. It can be observed that ρ monotonically increases with the quantization parameter *q*, therefore there exist one-to-one mapping between ρ and *q* [2]. Hence *R* and *D* are also functions of ρ, denoted by $R(\rho)$ and $D(\rho)$ respectively. We show that the bitrate function in ρ domain: $R(\rho)$ is linear for the H.264/AVC video coder and is given by:

$$R(\rho) = \theta \cdot (1 - \rho) \qquad (1)$$

where θ is the parameter directly related to the frame content. Once θ is estimated, the rate curve in ρ domain can be constructed. For given ρ^* and related value of bitrate R^* the θ parameter can be calculated according to equation (1).

The one-to-one mapping between ρ and *q* can be directly computed from the distribution information of the transform coefficients. This is because in all typical transform coding systems each transform coefficient is quantized separately. In general [2]:

$$\rho(q) = \frac{1}{M} \sum_{|x| \le \Delta(q)} T(x) \qquad (2)$$

where *M* is the number of coefficients in the current video frame, Δ - quantization step (usually a function of quantization index *q*), and $T(x)$ – distribution of transform coefficients. Because the H.264 standard uses the integer transform [7], as a distribution of transform coefficients $T(x)$ we understand the histogram of coefficients values.

From the distribution of the transform coefficients, for any given quantization index *QP* we can compute with (2) the corresponding ρ. In software implementation we store the one-to-one mapping between ρ and *q* in a look-up table.

2.2. Bitrate control algorithm

The algorithm we developed exploits the concept of basic units [6] and can work on frame, slice or macroblock level. The basic unit is defined to be a group of contiguous macroblocks (in raster scan). The number of

macroblocks in the basic unit has to be the integer fraction of number of all macroblocks in a frame.
The steps in our scheme are given as follows:

1. Compute a target bit R_{fr} according to the predefined frame rate, the current buffer occupancy, the target buffer level and the available channel bandwidth.
2. Allocate the remaining bits to all non-coded basic units in the current frame equally.
3. Compute the corresponding ρ_{bu} parameter by using the linear R-D model (1) by:
$$\rho_{bu} = 1 - \frac{R_{bu}}{\theta} \tag{3}$$
and further the QP_{bu} from $\rho(QP)$ relationship (2) and linear interpolation,
4. Encode each MB in the current basic unit with the quantization index derived from step 3.
5. Update model parameters.

3. RESULTS ON R-D MODEL DESIGN FOR AVC TYPE CODECS

To show that linear, in ρ domain, bitrate model holds for H.264/AVC standard, we performed series of experiments, encoding the set of test sequences for all possible values of quantization index QP. For every frame we calculate value of ρ and the number of generated bits for luminance coefficients R_Y (excluding the motion vectors and the header information). In Fig. 1 we plot $R_Y(\rho)$ for several frames from the „Carphone" video sequence. The plots were generated for IPPP sequence structure with full range of QP values. It can be seen that $R_Y(\rho)$ is approximately a linear function. Further we study the correlation coefficient between R_Y and ρ, denoted by $C(R_Y,\rho)$. In Tab. 1 there are values of $C(R_Y,\rho)$ for several test video sequences and in Fig. 2 we plot the values of -$C(R_Y,\rho)$ for each frame in „Foreman" sequence.
It can be seen that the value of correlation coefficient is always larger than 0,9 and average value usually exceeds 0,98 which is close to 1. This implies that the linear relationship between ρ and R also holds for H.264/AVC codec.

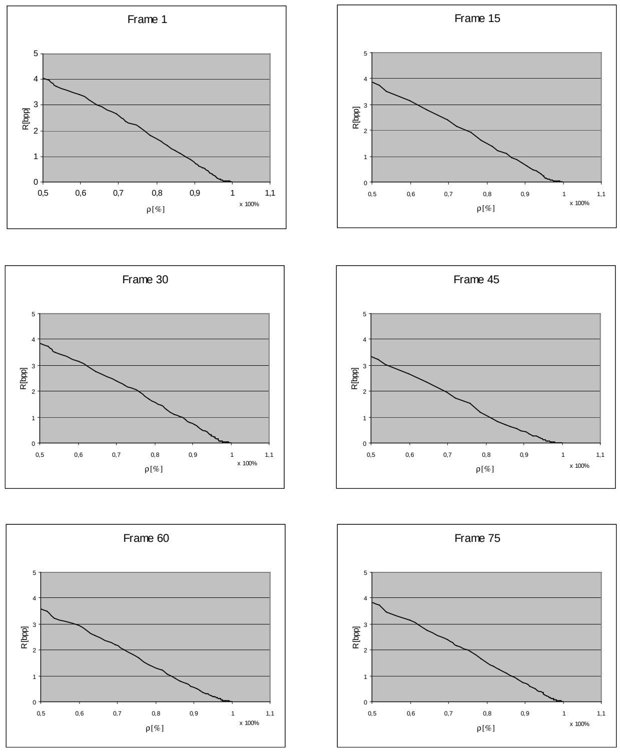


Figure 1. $R_Y(\rho)$ for several frames of „Carphone" sequence.

Table 1. The correlation coefficient between the coding rate R_Y and ρ in AVC video coding.

Sequence	$-C(\rho, R_Y)_{min}$	$-C(\rho, R_Y)_{max}$	$-C(\rho, R_Y)_{avg}$
carphone	0,984407	0,999338	0,998339
container	0,911208	0,984692	0,940773
deadline	0,921479	0,997625	0,967332
foreman	0,989972	0,999646	0,998364
mad	0,964488	0,993427	0,984186
news	0,849064	0,988506	0,951189
paris	0,969618	0,990884	0,981171

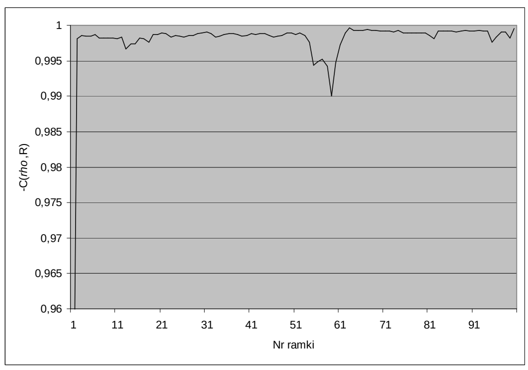


Figure 2. The correlation coefficient (inverse) between the coding rate R_Y and ρ in each frame of „Foreman".

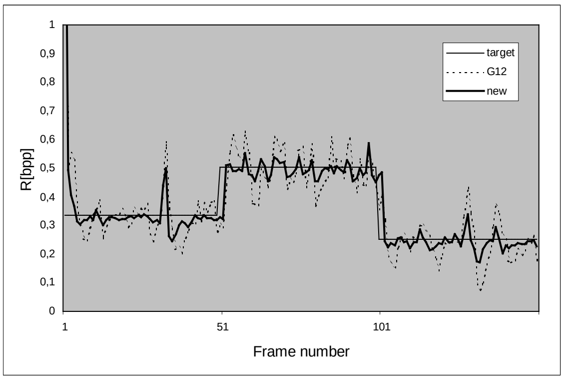
4. RESULTS ON BIT RATE CONTROL FOR AVC TYPE

To verify our scheme, we test our scheme in both the VBR case and CBR case in comparison with the G12 algorithm [6] which uses quadratic rate-distortion model similar to those proposed in [1][5].

The results for VBR case are plotted in Fig. 3 and gathered in Tab. 2 for different number of basic - N_{unit}. The bit rate curve for the VBR case is a predefined curve. The value δ in Tab. 2 is the standard deviation of generated bitrate and the R_t is the target bitrate.

It is shown that the number of actual generated bits is kept close to the bit rate curve (the deviation is smaller of 38% for our algorithm).

For the CBR case the target bit rate was first generated by coding a test sequence with a fixed quantization index *QP*. The computed rate was the input parameter for encoders using our and G-12 rate control scheme. The results are plotted in Fig. 4. For our algorithm the coding efficiency is improved in average by 1dB.



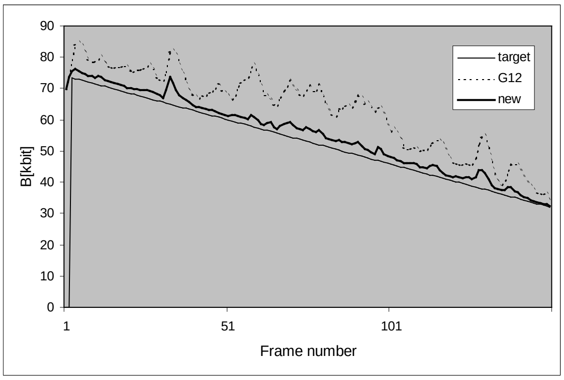


Figure 3. Bitrate (top) and buffer occupancy (bottom) for „Foreman” QCIF, R=128 kbps, 15 fps, N_{unit}=99.

Table 2. Results of bitrate deviation for several sequences.

Sequence	N_{unit}	G12 δ/R_t	new δ/R_t	improvement δ/R_t [%]
Container	1	0,565	0,551	2,56
	3	0,187	0,178	4,59
	9	0,159	0,115	27,75
	11	0,109	0,088	18,82
	33	0,087	0,060	31,07
	99	0,084	0,061	27,54
Foreman	1	0,488	0,304	37,60
	3	0,249	0,169	32,14
	9	0,208	0,118	43,29
	11	0,214	0,120	44,02
	33	0,204	0,108	47,02
	99	0,198	0,096	51,63
Mobile (CIF)	1	1,711	0,610	64,34
	3	0,557	0,244	56,26
	9	0,413	0,180	56,31
	11	0,432	0,180	58,34
	33	0,346	0,176	49,20
	99	0,316	0,168	46,78
			max	64,34
			min	2,56
			avg	38,85

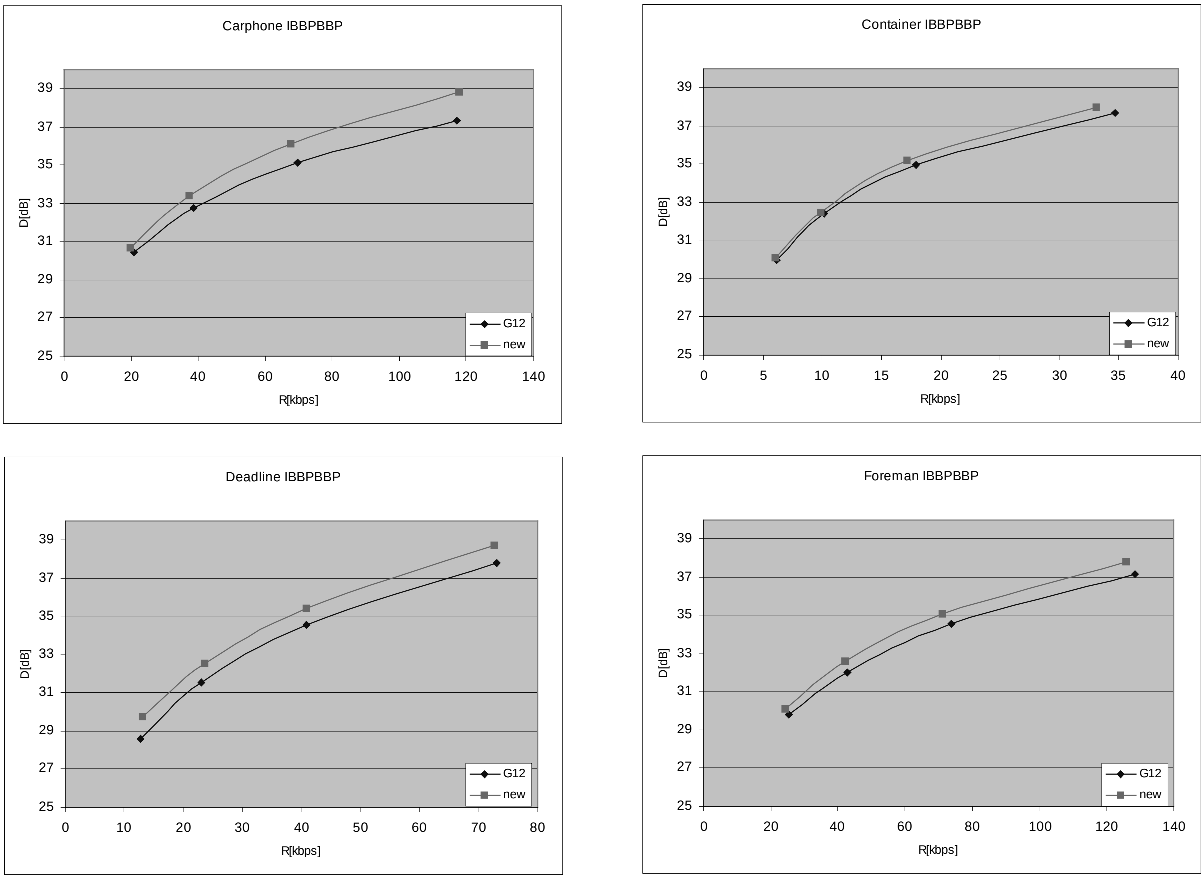


Figure 4. Results for several QCIF sequences, IBBPBBP structure.

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6. REFERENCES

[1] T. Chiang, Y. Q. Zhang: A new rate control scheme using quadratic rate distortion model, IEEE Transactions on Circuits and Systems for Video Technology, vol. 7,pp. 246--250, February 1997.

[2] Z. He, S. K. Mitra: A linear source model and a unified rate control algorithm for DCT video coding, IEEE Transactions on Circuits and Systems for Video Technology., vol. 12, pp. 970–982, November 2002

[3] ISO/IEC, Generic Coding of Audiovisual Objects – Part 10: Advanced Video Coding (MPEG-4 AVC), ISO/IEC 14496-10, October 2003.

[4] ITU-T Recommendation H.264, Advanced video coding for generic audiovisual services, May 2003.

[5] H.J.Lee, T.H.Chiang, Y.Q.Zhang: Scalable Rate Control for MPEG-4 Video, IEEE Transactions on Circuits and Systems for Video Technology, 10: 878-894, 2000.

[6] Z. G. Li, F. Pan, K. P. Lim, G. N. Feng, X. Lin, S. Rahardaj, Adaptive basic unit layer rate control for JVT, JVT-G012, 7th meeting, Pattaya II, Thailand, 7-14, March, 2003.

[7] H. Malvar, A. Hallapuro, M. Karczewicz, L. Kerofsky: Low-Complexity Transform and Quantization in H.264/AVC, IEEE Transactions on Circuits and Systems for Video Technology, July 2003.

[8] G. J. Sullivan, T. Wiegand: Rate-Distortion Optimization for Video Compression, IEEE Signal Proc. Magazine, vol. 15, no. 6, pp. 74-90, Nov. 1998.