UNIVERSAL MODELING OF MONOSCOPIC AND MULTIVIEW VIDEO CODECS WITH APPLICATIONS TO ENCODER CONTROL

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ABSTRACT

The paper deals with AVC, HEVC and VVC video encoder modeling using a universal formula for the output bitrate as a function of the quantization step. It is shown that this model is relatively accurate and may be used for bitrate control. Moreover, from the model for AVC, the models for HEVC and VVC can be quickly derived, thus reducing the processing time needed for VVC model parameters derivation. The model is applicable to multiview plus depth video coding, both using simulcast and MV-HEVC or 3-D HEVC. The applications to bitrate control for coding of multiview plus depth video are considered together with the relevant experimental data.

Index Terms— Video encoder model, multiview video, rate control.

1. INTRODUCTION

Efficient video encoder control is a research problem that has gained a lot of attention in the context of AVC [25], HEVC [1,2] and VVC [3,4] technologies. In this paper, we focus on the control of the bitrate produced by a video encoder. The basic parameter that is used in bitrate control (also called rate control) is the quantization parameter QP that defines the quantization step size Q for transform coefficients. In the constant bitrate (CBR) mode, the goal of adjusting the value of quantization step size Q is to match the available channel throughput.

In this paper, we deal mostly with stereoscopic video (two synchronous views) with two depth maps. So, the quantization parameters need to be estimated both for views (QP) and for depth maps (QD).

The straightforward approach is to select the basic value of Q or QP for a whole group of pictures, then for individual frames, and then possibly adjust the value of Q for individual coding units [8, 18, 28-32]. Depth quantization is mostly defined by certain relations between QP and QD.

For the abovementioned tasks, one of the useful approaches is to use encoder models. For the sake of conciseness, we need to skip a comprehensive review of the techniques for rate control but we focus on the approach based on using encoder models. An applicable model may be expressed as

$$B = f(Q, \Phi), \tag{1}$$

where B is the bitrate or number of bits per group of pictures or per frame, Φ is a vector of parameters that depend on video content. The model very often used for P-frames is the one from the reference software of AVC [19],

$$B(Q,a,b) = a \cdot \frac{MAD}{Q} + b \cdot \frac{MAD}{Q^2}, \tag{2}$$

where a and b are model parameters. The Maximum Absolute Difference (MAD) is the mean of all absolute values of luma prediction errors from the whole frame. Later, this model has also been adapted to HEVC (e.g., [5]). Various improvements of the above-mentioned model have been proposed for AVC and HEVC codecs (e.g., [6-10, 38]).

In [11-13] and other, newer papers, a rate-quantization (R-Q) model was proposed for applications in HEVC rate control. For other approaches to rate control, a rate model was proposed, linking ρ with the bitrate (ρ-R model) in [14, 15], where ρ is the percentage of zeroes among quantized transform coefficients. In [16, 17], an R-λ model was used, where λ denotes the slope of the R-D (rate-distortion) curve.

Unfortunately, much less work has been done for VVC so far. Also for encoder modeling and rate control in coding of multiview plus depth video, not enough research has been done yet. In this context, rate control has been studied for HEVC, e.g., in [33], but not with the use of modeling. For AVC, bit allocation between views and depth was studied, e.g., in [34, 35].

2. UNIVERSAL ENCODER MODEL

For AVC, as well as for HEVC and VVC, we consider the model that was previously successfully used for AVC encoders in [18], where its high accuracy was experimentally demonstrated in comparisons with other models

$$B(Q, \Phi) = \frac{a}{Q^b + c}, \tag{3}$$

where $\Phi = [a\ b\ c]$ is the vector of parameters that depend on sequence content, and Q is the quantization step. For a given encoder and given video content, the model parameters are estimated by minimizing the maximum

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relative approximation error over the respective interval of Q values (and corresponding interval of the values of quantization parameter QP)

$$\min_{\Phi} \max_{Q} \varepsilon(Q,\Phi), \tag{4}$$

$$\varepsilon(Q,\Phi) = \frac{|B_X(Q) - B(Q,\Phi)|}{B_X(Q)} \cdot 100\%, \tag{5}$$

where $B_X(Q)$ denotes the measured number of bits and $B(Q, \Phi)$ denotes the value calculated from the model. For the experiments, the quasi-Newtonian minimization was used, although other techniques may be also applicable.

3. MODEL ACCURACY

In this section, accuracy is estimated using the reference software for AVC [19], HM [20], and VVC [21]. Each encoder was configured according to the MPEG common test condition documents: [22] for AVC, [23] for HEVC, and [24] for VVC. A set of 14 standard MPEG/JVET test sequences (diverse resolutions and frame rates) was used: *PeopleOnStreet*, *Traffic, Kermit, Poznan_Block2, Poznan_Fencing, Butterfly, Flowers, Ballet, Breakdancers, Keiba, Racehorses, Basketball Drill, Basketball_Pass,* and *BQSquare*.

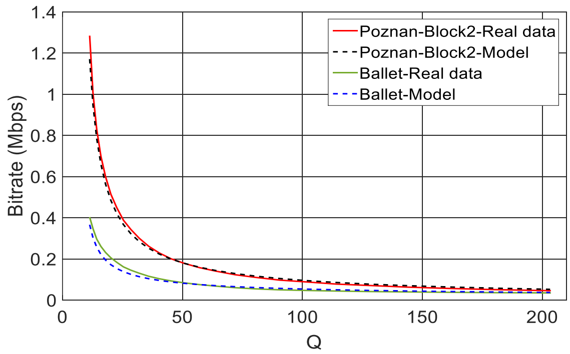

Fig. 1. The experimental and approximated bitrates for *Poznan_Block2* and *Ballet* sequences for the HEVC codec.

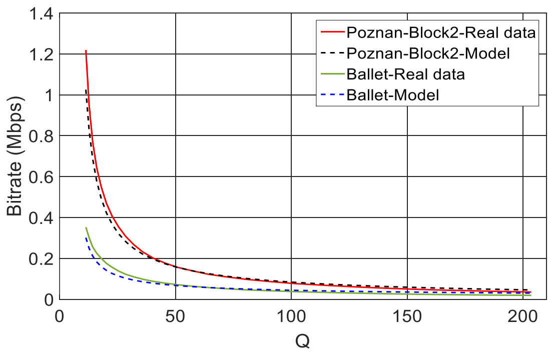

Fig. 2. The experimental and approximated bitrates for *Poznan_Block2* and *Ballet* sequences for the VVC codec.

The accuracy of bitrate estimation is quite satisfactory for a rough estimation of bitrate as a function of the quantization step (Table I, Figs. 1 and 2). The accuracy of the model is better for large frames (like I and P), whereas the relative errors are larger for the frames with smaller numbers of bits (like B-frames). The average error values from Table I are estimated for a wide range of QP. In practical applications, the range is mostly narrower, so the accuracy would be better. For the sake of brevity, the relevant experimental results must be omitted here.

TABLE I. RELATIVE APPROXIMATION ERRORS.

Frame type	Relative error [%] (Eq. 5) for $QP\in(25,50)$					
	AVC		HEVC		VVC	
	mean	*std. dev.*	*mean*	*std. dev.*	*mean*	*std. dev.*
I	3.47	2.55	1.96	1.54	2.36	1.97
P	4.58	3.46	3.35	2.39	4.11	3.42
B0	5.30	3.67	9.32	7.94	10.15	9.28
B1	6.28	3.92	8.49	5.97	10.70	8.62
B2	4.28	2.97	16.23	9.23	23.60	15.50
B3	3.61	2.54	17.97	10.61	27.66	17.62
GOP	3.99	3.13	12.44	6.95	19.40	13.91

4. DERIVATION OF THE MODEL PARAMETERS FOR HEVC AND VVC FROM AVC PARAMETERS

For a given video sequence, the functions $f(Q, \Phi)$ (cf. Eq. 3) are very similar for AVC, HEVC and VVC encoders (cf. Fig. 3).

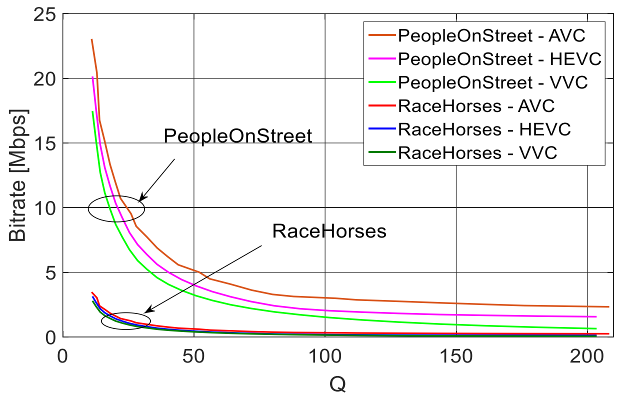

Fig. 3. Experimental curves for *PeopleOnStreet* and *RaceHorses* sequences for different codecs.

Therefore, we propose to estimate the model parameters (Eq. 3) for VVC and HEVC encoders from the AVC model parameters for the same video sequence or for the same frame. The VVC or HEVC model can be obtained in the following steps:

1. Estimate *a, b, c* parameters (cf. Eq. 3) for AVC;
2. Estimate parameter *a* of the VVC or HEVC model from the value of *a* for AVC

$$a\ (HEVC) = \alpha_{HEVC} \cdot a\ (AVC), \tag{6}$$

$$a\ (VVC) = \alpha_{VVC} \cdot a\ (AVC), \tag{7}$$

where α_{HEVC} and α_{VVC} are general constants derived using a large training set of video sequences;
3. For VVC or HEVC, use the parameters b and c as obtained for AVC.

Using the video sequences and codec configurations mentioned at the beginning of Section 3, the values of the constants α_{HEVC} and α_{VVC} (cf. Eq. 6 and 7) have been estimated for I-, P- and B-frames (Table II).

TABLE 2. PARAMETERS α_{HEVC} AND α_{VVC} FOR THE TRAINING SET OF VIDEO SEQUENCES (AS IN SEC. 3).

Frame	I	P	B0	B1	B2	B3	Average
α_{HEVC}	0.69	0.69	0.89	0.85	0.83	0.39	0.65
α_{VVC}	0.61	0.59	0.75	0.71	0.66	0.30	0.54

In order to demonstrate the usefulness of the proposed procedure for modeling the HEVC and VVC encoders, the results are provided for the following verification set of MPEG video clips: *Poznan_CarPark, FourPeople, ChinaSpeed, BQMall, Blowing bubbles* (cf. Table III).

TABLE III. MEAN RELATIVE APPROXIMATION ERROR FOR THE VERIFICATION SET.

Frame type	Relative error [%] (Eq. 5)			
	HEVC		VVC	
	mean	*std. dev.*	*mean*	*std. dev.*
I	6.37	1.96	6.86	2.39
P	11.83	4.37	11.88	4.26
B0	15.79	5.74	18.30	6.03
B1	20.67	4.68	22.89	5.47
B2	25.41	7.80	30.15	8.70
B3	28.70	8.63	30.35	10.89
GOP	14.77	6.61	18.96	9.36

Here, the idea is to reduce the effort of estimation of the model parameters for VVC and HEVC, thus maybe compromising the model accuracy. However, the above results demonstrate that the model from Eq. 3 can be efficiently used for highly complex HEVC and VVC encoders. The model needs three parameters (a, b and c) to be estimated. In principle, it needs 3 encodings with 3 different QP values, but the results of this section demonstrate that for HEVC and VVC, it is enough to make 3 encodings with much less complex AVC for the same context in order to obtain similar accuracy of the model. The universal constants α_{AVC} and α_{HEVC} are to be used according to Table II. In the proposed approach, VVC encodings are replaced by AVC encodings. This approach significantly reduces the estimation time, as each video encoding is 5-10 times faster for AVC than for VVC [26]. The respective reduction is smaller for HEVC, therefore, the approach is more interesting for VVC than for HEVC.

5. ENCODER MODELING FOR COMPRESSION OF MULTIVIEW PLUS DEPTH VIDEO

Here, we demonstrate that the model from Eq. 3 can be used for multiview plus depth (MVD) video for both simulcast coding (using HEVC and VVC) and for coding using specialized multiview and 3D codecs (MV-HEVC and 3D-HEVC). For simulcast coding and for MV-HEVC, the depth maps are encoded into bitstreams that are separate from those for the views. The experimental data are provided for the case of 2 views with 2 corresponding depth maps. Nevertheless, the further considerations remain valid also for higher numbers of views and depth maps, according to the authors' experience.

The first challenge is related to bit allocation between the views and depth maps [27]. The content of the neighboring views is nearly the same, and the quantization parameter QP may be the same for the all the neighboring views. Similarly, the quantization parameters QD for depth may be the same for all the corresponding depth maps. Experimental data analysis leads to a conclusion that some (QP, QD) pairs correspond to the curve of the maximum PSNR [36], e.g., as in Fig. 3.

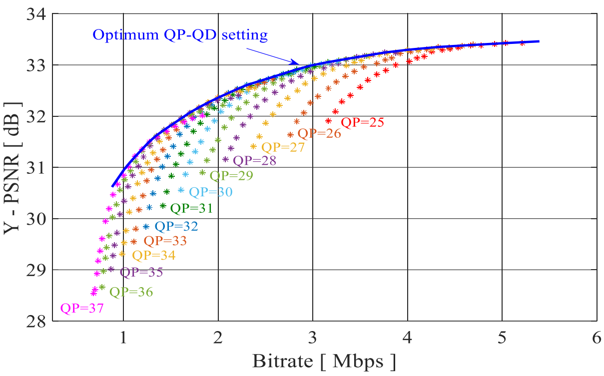

Fig. 3. The curve of the maximum PSNR (for luma). Each dot corresponds to a pair (QP,QD) for the *Flowers* test sequence.

Further studies [37] have implied that the value of QD (the quantization parameter for depth) can be chosen as a function of QP

$$QD = \kappa \cdot QP + \beta \quad , \tag{8}$$

where κ and β are the constants specific for the codec types (like AVC, HEVC, VVC). The analysis of experimental data for various MVD test sequences demonstrates that the values of κ and β are similar for different MVD content. Therefore, for codec modeling, we use the average values (Table IV).

TABLE IV. MODEL PARAMETERS DERIVED FOR VARIOUS TEST SEQUENCES AND VARIOUS CODECS.

Sequence	HEVC		VVC		MV-HEVC		3D-HEVC	
	κ	β	κ	β	κ	β	κ	β
Ballet	1.38	-18.48	1.15	-6.15	1.39	-15.28	1.13	-1.64
Breakdancers	1.27	-9.00	1.30	-10.65	1.26	-8.43	1.17	-4.19
Butterfly	1.17	-11.96	1.19	-12.86	1.10	-7.86	1.05	-3.84
Flowers	1.22	-12.28	1.18	-9.91	1.26	-11.97	1.06	-0.44
Poznan_ CarPark	1.44	-18.65	1.50	-21.27	1.41	-14.29	1.25	-7.55
Kermit	1.13	-11.44	1.22	-14.58	1.15	-11.21	1.20	-11.34
Average	1.20	-11.27	1.22	-11.25	1.20	-9.41	1.11	-3.40

The encoder-specific and content-independent constants κ and β (see the last row of Table IV) may be used to calculate QD for a given QP. As QP is directly related to the view quantization step Q, the model from Eq. 3 can be easily applied for MVD video (Table V and Fig. 4). The modeling accuracy is similar as for single-view video compression, both for bitrate modeling and for frame size modeling (Table VI).

TABLE V. BITRATE APPROXIMATION ERROR FOR THE MODEL FROM EQ. 3 FOR MVD SEQUENCES.

Sequence	Mean relative error [%] (Eq. 5)							
	HEVC		VVC		MV-HEVC		3D-HEVC	
	mean	*std. dev*	*mean*	*std. dev*	*mean*	*std. dev*	*mean*	*std. dev*
Ballet	6.11	5.11	3.34	3.02	3.73	2.77	3.03	3.19
Break_ dancers	10.94	7.03	2.88	2.19	2.44	1.89	3.18	2.99
Butterfly	8.49	5.40	4.70	3.57	2.55	2.31	1.29	1.32
Flowers	4.84	3.30	4.73	3.37	6.40	4.21	1.88	2.00
Kermit	2.81	2.01	1.69	1.67	1.92	2.29	4.87	2.83
Poznan_ CarPark	3.65	2.60	1.99	1.46	1.83	1.19	2.26	1.61
Poznan_ Block2	2.09	1.36	0.93	0.91	1.17	0.85	2.58	1.65
Poznan_ Fencing	8.13	5.11	4.57	4.17	5.87	3.58	2.63	1.41
Average	5.88	3.99	3.10	2.54	3.24	2.39	2.71	2.13

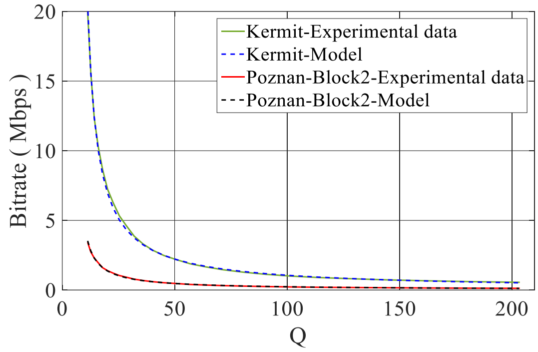

Fig. 4. The experimental and approximated values for bitrates for *Poznan_Block2* and *Kermit* MVD sequences (HEVC codec).

TABLE VI. APPROXIMATION ERRORS FOR FRAMES AND GOP SIZES FOR MVD SEQUENCES.

Frame type	Mean relative error [%] for sequences from Table V			
	HEVC		VVC	
	mean	*standard. deviation*	*mean*	*standard. deviation*
I	2.91	2.17	2.28	1.94
P	6.02	4.17	5.97	4.37
B0	7.03	5.94	5.82	5.18
B1	9.74	6.30	6.46	5.78
B2	11.18	6.82	7.51	7.28
B3	11.49	6.78	10.08	8.34
GOP	5.88	3.99	3.10	2.54

6. APPLICATIONS TO BITRATE CONTROL FOR MULTIVIEW PLUS DEPTH VIDEO

The prime application of encoder modeling is bitrate control. From Eq. 1 and a given target *B,* one can estimate *Q*, and then *QP* and *QD* (see also Eq. 8). The model (Eq. 3) has 3 content-dependent parameters. Their estimation calls for encoding a video clip (or a video frame like I-frame) with 3 different values of *QP*. Nevertheless, in practical applications, we start with an initial value of *QP* close to that unknown target value of *QP*. Therefore, the model (Eq. 3) may even be simplified to

$$R(Q,\Phi) = \frac{a}{Q^{1.11}-3.5} \,. \qquad (9)$$

This way, the number of content-dependent parameters is reduced to one, thus compromising the model accuracy. Now, there is only one content-dependent parameter *a*, whereas the two other parameters from Eq. 3 become constants with values obtained from experimental data. The loss of model accuracy has only limited influence on *QP* and *QD* choice, as the modeling is performed in a limited range of bitrates.

The model-based bitrate control is demonstrated for three different MVD test sequences. For randomly chosen target bitrates, the average control errors are estimated as presented in Table VII for HEVC and VVC encoders, both for frame-level and GOP-level control.

TABLE VII. BITRATE ERROR FOR MVD RATE CONTROL.

Model	HEVC		VVC	
	Frame level	GOP level	Frame level	GOP level
With one parameter	3.55 %	0.45 %	3.01 %	1.29 %
With 3 parameters	1.91 %	0.37 %	2.56 %	0.79 %

Obviously, the usage of a 3-parameter model exhibits smaller control errors, whereas the errors for a single-parameter model are still quite moderate. Please note that Eq. 9 corresponds to an extremely simplified case of a single-parameter model with the same constants for HEVC and VVC encoders. Adapting the model constants (Eq. 9) to the encoder type improves the bitrate control accuracy, i.e., the accuracy of the choice of *QP* and *QD*.

7. CONCLUSIONS

The paper implies the following conclusions:

- The model from Eq. 3 is universal in the sense that it is applicable to AVC, HEVC and VVC encoders.
- The model exhibits good accuracy of the estimated bitrate with average errors below 5% for AVC, and below 20% for HEVC and VVC.
- The average errors for the estimated numbers of bits in I- and P-frames are below 5%.
- For given content, the model parameters can be roughly estimated for VVC and HEVC from the parameters for AVC by scaling one of the model parameters by a content-independent constant.
- This way, the model for VVC may be obtained from the model for AVC in 5-10 times shorter processing times than by direct estimation for VVC.
- The model is applicable for multiview plus depth video coding with similar accuracy for both simulcast coding (using HEVC or VVC) and for MV-HEVC or 3D-HEVC encoders.
- The model-based bitrate control exhibits acceptable errors even for the simplified model version with only one content-dependent parameter.

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