Multi-Generation Encoding Using HEVC All Intra Versus JPEG 2000

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Abstract— **For the new HEVC compression technology, the analysis of accumulation of quality losses in multi-generation coding is still an open problem. In this paper, we describe the results of extensive experiments that demonstrate quality loss accumulation in 300 encoding-decoding cycles using the HEVC codec in the All Intra mode. For consecutive encoding cycles with constant encoder configuration, the coding quality loss decrease much slower than for JPEG 2000. However, for SD resolution, the HEVC intra-only encoder provides lower bitrates than JPEG 2000 with the same video quality. Therefore, even after 300 cycles, the HEVC All Intra usually provides lower bitrates than JPEG 2000 with the same decoded-video quality.**

Keywords— ***HEVC, JPEG 2000, multi-generation coding, multiple encoding-decoding cycles, bitrate***

I. Introduction

Some applications require random access to individual frames from encoded video bitstreams or very low encoding/decoding delay. For such applications, intraframe coding is used for video compression. The respective standards include DV/DVPRO, VC-2, VC-3, M-JPEG, M-JPEG XR, and M-JPEG 2000. The latter three correspond to still image compression standards, JPEG, JPEG XR and JPEG 2000 [1], [2], respectively. Many works (e.g. [3]) have demonstrated that among these three, JPEG 2000 provides the most efficient lossy compression. Therefore, JPEG 2000 is often used in commercial applications, and will be used as the reference in this paper.

The All Intra modes of video compression technologies constitute an attractive alternative to JPEG 2000. The advantage is that video coding technologies provide unified standards for both intraframe and interframe coding. Here, we mention the AVC (MPEG-4 Part 10, H.264) [4] and the recent HEVC (MPEG-H Part 2 and H.265) [5], [6], that provides significantly improved lossy coding performance over AVC, both in the intraframe and the interframe modes [3], [6], [7]. The HEVC intra-only codec was also compared to JPEG 2000 [3], [8]. In [3], the average bitrate gains of about 20% have been reported for HEVC used to compress test still images. In the work [8], the comparison was done for test video sequences, and for some cases, lower bitrates were demonstrated for JPEG 2000, and for HEVC All Intra – for the other cases. Definitely, for the new HEVC technology, such comparisons need further works.

In the course of such processing like nonlinear edition, video may be decoded and encoded again in several cycles. It is likely that the same encoder configuration is used in all cycles of such multi-generation coding. With this assumption for the intraframe video and image coding, the quality loss accumulation has been studied in some works [10]-[12]. The studies included the effects of multiple cycles of color transformations RGB $\leftrightarrow$ YC_BC_R, for which the error accumulation vanishes after about 3 cycles [9], [10]. For JPEG, there may occur something like very small quality oscillations after few cycles [10], [11]. The paper [12] reports much faster quality degradation for multiple encoding-decoding cycles of the interframe AVC coding (IBBP GOP) than for JPEG 2000. Also the multi-generation interframe HEVC coding was studied [13]. However, the results for HEVC All Intra are not available yet, according to the best knowledge of the authors.

II. Goal of the Work

The main goal of the paper is the analysis of the quality loss accumulation in the multi-generation HEVC All Intra lossy coding of SD video with moderate bitrates. Moreover, the multi-generation lossy coding using HEVC All Intra will be compared to lossy JPEG 2000. The experimental analysis will be made for the constant encoder configurations, i.e. using the same quantization steps in the consecutive encoding generations. As a measure of compression performance differences, we will use average bitrate differences for constant video quality defined by a respective PSNR value. The PSNR values reflect quite well small video quality variations for a single codec, while the comparisons between HEVC and JPEG 2000 are probably less precise but still used in the references [3], [8]. However, general conclusions may be drawn from experiments with many test video sequences for at least some quality levels. It yields quality assessments for at least many hundreds of video clips generated in consecutive cycles. For such extensive experiments, subjective quality assessments would be difficult. On the other hand, fast PSNR-based quality assessments allow us to analyze very high numbers of coding cycles, and to observe asymptotic codec behavior.

III. Methodology of Experiments

In the experiments, 12 SD TV (704x576, 4:2:0, 8-bit, 25/30 Hz) test video sequences (recommended by MPEG) have been used. These sequences: *Bluesky*, *City*, *Crew*, *Harbour*, *Ice*, *Pedestrian*, *Riverbed*, *Rushhour*, *Soccer*, *Station2*, *Sunflower* and *Tractor* cover wide range of content types.

The HEVC reference software version 10 [14] was used in All Intra mode with 4 quantization parameter index settings *QP* = 32, 37, 42, 47. Those *QP* values reflect broadcast video quality.

For JPEG 2000, the OpenJPEG [15] implementation was used with 4 different reduction values *r* = 24, 34, 53, 85 that correspond to a similar quality range as the *QP* values chosen for HEVC.

In a single experiment, the *QP* and *r* values remain unchanged in consecutive cycles. For the sake of brevity, we report the PSNR values for luma only. The reported bitrates are estimated for the whole bitstream including luma and chroma. For general compression efficiency comparisons, we use Bjøntegaard metric [16] that represents average shift of the rate-distortion curve along the bitrate axis.

IV. CHARACTERISTICS OF MULTI-GENERATION CODING USING HEVC ALL INTRA AND JPEG 2000

Our comparison results from an extensive experiment done for 12 test video sequences. Each sequence was encoded and decoded in 300 cycles using both HEVC All Intra and JPEG 2000 with four *QP* and *r* values respectively. For the sake of brevity, only the results for *Bluesky* sequence are reported in the plots (Figs. 1-4). For the other video sequences, the multi-generation behavior is qualitatively very similar. Therefore, the average values over all 12 sequences are shown in Fig. 5.

For HEVC All Intra (Figs. 1, 3, 5 top, Table 1), the quality loss is monotonically decreasing in consecutive cycles. Usually, after 30 cycles, the quality loss in a cycle is negligible (mostly below 0.001 dB per cycle). The quality loss after the second cycle is between 0.12 and 0.92 dB, while the total quality loss in 30 cycles is usually between 0.17 and 2.15 dB, depending on video content and the quantization used. All the next 270 cycles usually result in the total additional loss below 0.005 dB. The quality loss is partially compensated by the monotonic bitrate decrease observed after consecutive cycles with a fixed *QP* value. The relative bitrate reduction is larger for lower bitrates, i.e. higher *QP*. After 30 cycles, the total relative bitrate reduction varies between 1% and 19%, depending on video content (see Table 1). Nevertheless, after an arbitrary number of cycles, a rate-distortion curve is always shifted towards lower compression efficiency, as compared to the rate-distortion curve for the first cycle (see Fig. 6).

For JPEG 2000 (Figs. 2, 4 and 5 bottom), the quality loss is mostly below 0.2 dB even for a very high number of cycles. After just 3÷5 cycles, the per-cycle quality loss is negligible (often about 0.0001 dB). For encoding with constant reduction value r, the quality loss is accompanied with a very small bitrate increase that is mostly below 0.5%, after any number of cycles. After about 5 cycles, the very small bitrate increases start to fluctuate according to complicated patterns.

TABLE I
HEVC ALL INTRA MULTI-GENERATION CHARACTERISTICS (NEGATIVE NUMBERS CORRESPOND TO DECREASES OF BITRATE OR QUALITY).

	Parameter	Min.	Max.	Average
		over all video sequences		
After the 2nd cycle, *QP* = 32	Quality loss [dB]	-0.12	-0.76	-0.53
	Bitrate reduction [%]	-0.86	-6.42	-3.43
After the 2nd cycle, *QP* = 47	Quality loss [dB]	-0.18	-0.92	-0.46
	Bitrate reduction [%]	-2.41	-11.19	-6.44
After the 2nd cycle, average over 4 *QP* values	Quality loss [dB]	-0.12	-0.92	-0.52
	Bitrate reduction [%]	-0.84	-11.19	-5.01
After 10 cycles, average over 4 *QP* values	Quality loss [dB]	-0.17	-2.09	-1.11
	Bitrate reduction [%]	-1.16	-18.83	-9.00
After 30 cycles, average over 4 *QP* values	Quality loss [dB]	-0.17	-2.15	-1.15
	Bitrate reduction [%]	-1.16	-18.98	-9.13
After 300 cycles, average over 4 *QP* values	Quality loss [dB]	-0.17	-2.15	-1.15
	Bitrate reduction [%]	-1.16	-18.99	-9.14

V. MULTI-GENERATION CODING EFFICIENCY FOR HEVC ALL INTRA AND JPEG 2000

For the first encoding cycle, our experiment indicates that the HEVC All Intra codec provides bitrates lower by 20% ÷ 60% than JPEG 2000, by the same video quality (Fig. 6 and Table 2). Nevertheless, this bitrate reduction heavily depends on video content. This observation explains the result differences with respect to those from [3], [8].

The abovementioned gap between the first-cycle rate-distortion curves for HEVC All Intra and JPEG 2000 is so large, that after any number of cycles, HEVC All Intra is still clearly more efficient than JPEG 2000, at least for a wide range of SD content (Table 2).

TABLE II
THE AVERAGE BITRATE CHANGE (BJØNTEGAARD METRIC) RESULTED FROM SUBSTITUTION OF JPEG 2000 BY HEVC ALL INTRA. NEGATIVE NUMBERS CORRESPOND TO BITRATE DECREASES.

Test video sequence	HEVC first encoding vs. JPEG 2000 first encoding	HEVC after 300 cycles vs. JPEG 2000 after 300 cycles	HEVC after 300 cycles vs. JPEG 2000 first encoding
Bluesky	-28.46%	-14.79%	-12.52%
City	-43.63%	-30.00%	-27.88%
Crew	-40.07%	-25.53%	-21.15%
Harbour	-41.79%	-33.57%	-32.11%
Ice	-58.38%	-53.93%	-50.09%
Pedestrian Area	-45.72%	-34.53%	-32.21%
Riverbed	-30.50%	-30.73%	-28.32%
Rushhour	-40.96%	-31.05%	-28.13%
Soccer	-40.96%	-34.16%	-32.15%
Station2	-48.76%	-31.39%	-29.18%
Sunflower	-22.51%	-16.72%	-12.66%
Tractor	-32.89%	-24.02%	-22.12%
Average	**-39.55%**	**-30.04%**	**-27.38%**

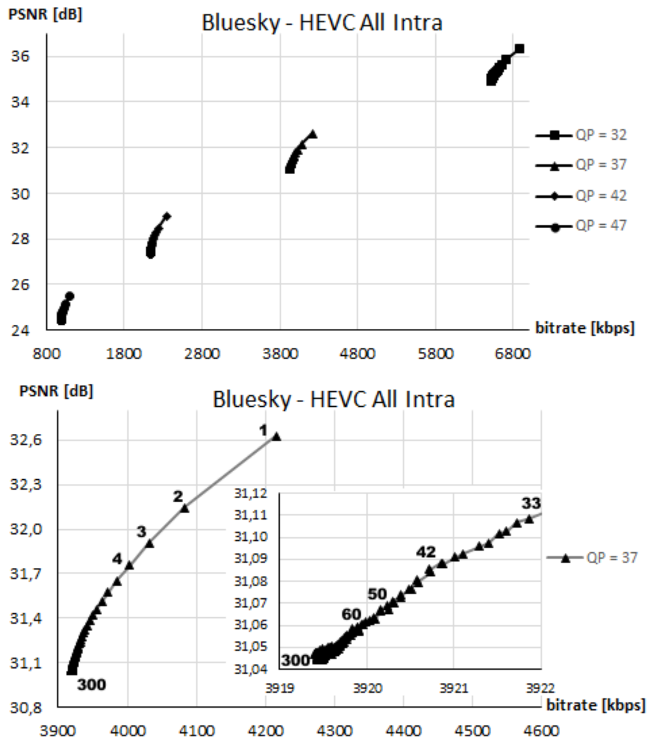

Figure 1. The rate-distortion pairs after each of the 300 cycles (Bluesky sequence and HEVC All Intra): for 4 different *QP* values (top) and the detailed view for *QP*=37 (bottom).

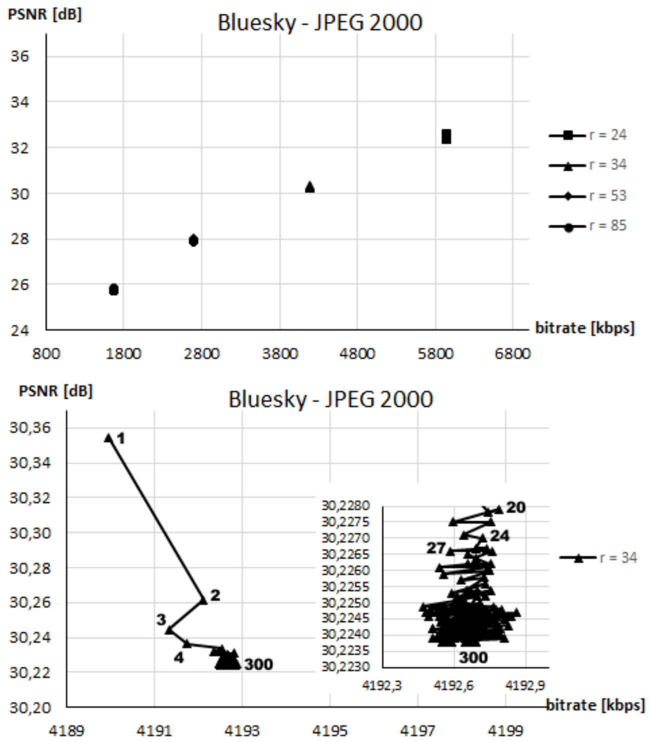

Figure 2. The rate-distortion pairs after each of the 300 cycles (Bluesky sequence and JPEG 2000): for 4 different reduction values r (top), and the detailed view for r = 34 (bottom).

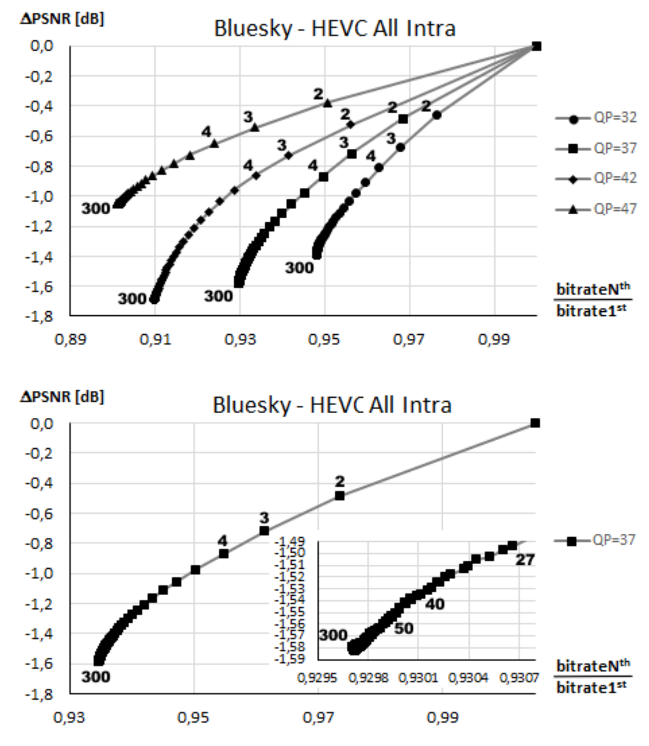

Figure 3. HEVC All Intra, Bluesky sequence: The quality loss and the bitrate reduction after consecutive cycles – relative values with respect to the first cycle obtained for various *QP* values (top), and the detailed view for QP = 37 (bottom).

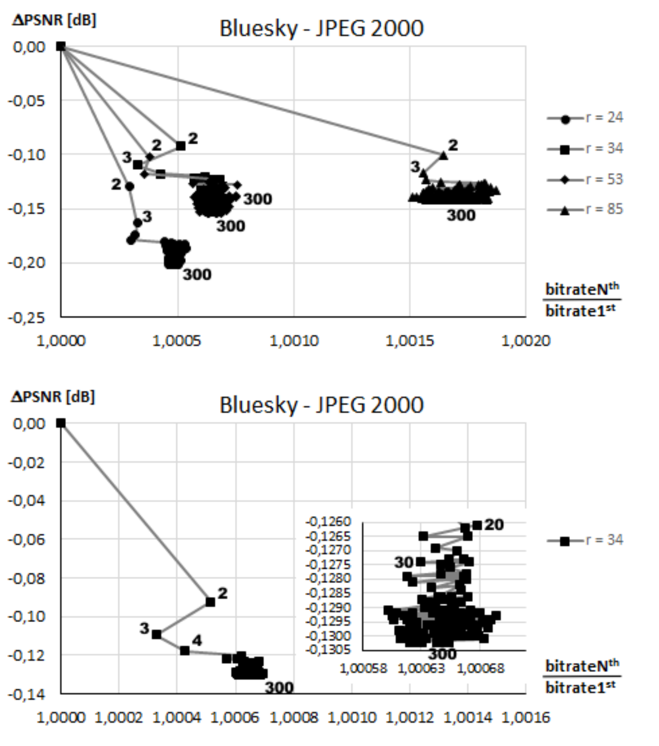

Figure 4. JPEG 2000, Bluesky sequence: The quality loss and the bitrate increase after consecutive cycles – relative values with respect to the first cycle obtained for various reduction values r (top), and the detailed view for r = 34 (bottom).

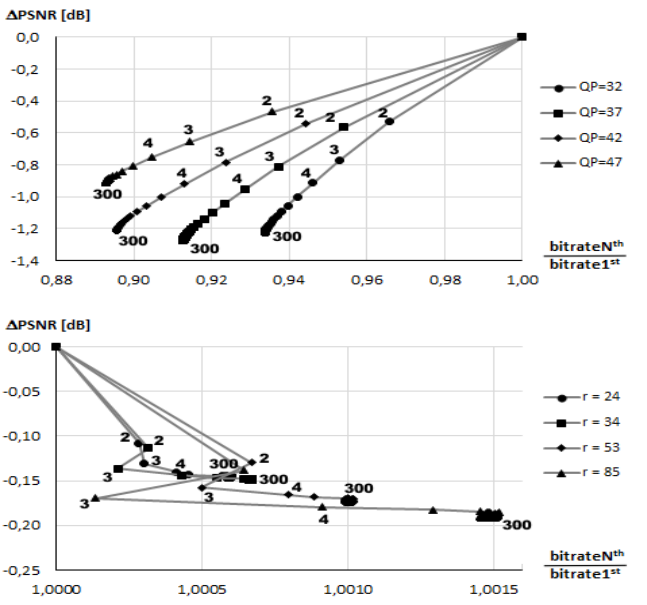

Figure 5. The quality loss and the bitrate change after each consecutive cycle, relative to the first cycle. The values are averaged over all 12 video sequences. Top: HEVC All Intra. Bottom: JPEG 2000.

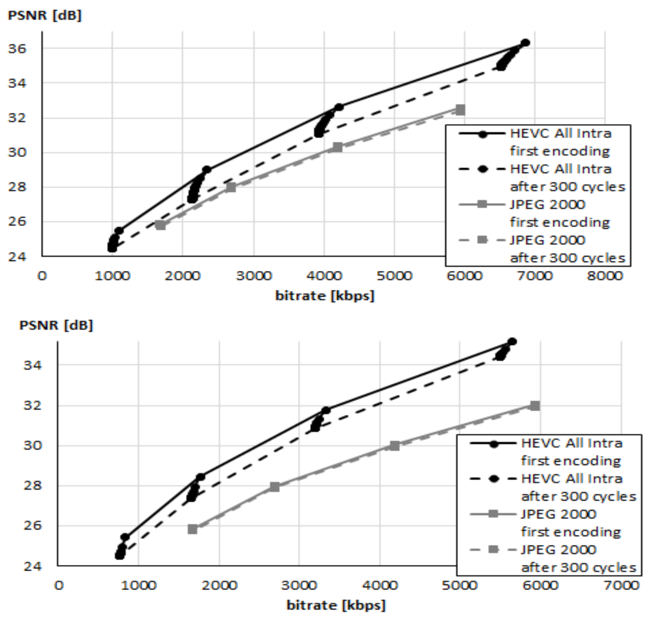

Figure 6. The rate-distortion curves after the first and the 300th cycle for Bluesky (top) and Harbour (bottom) sequences – for HEVC All Intra and JPEG 2000.

VI. Conclusions

For HEVC All Intra, the experimental results demonstrate monotonic decrease of quality and small monotonic decrease of bitrate after all consecutive cycles. The per-cycle quality losses also monotonically decrease to negligible values after a number of cycles. This multi-generation behavior of HEVC All Intra is qualitatively similar to the multi-generation behavior of HEVC with interframe coding [13]. For HEVC All Intra the accumulated quality loss may exceed 2 dB, while for JPEG 2000 it is mostly below 0.2 dB. Moreover, the per-cycle quality losses decrease much faster for JPEG 2000 than for HEVC All Intra. For JPEG 2000, after about 5 cycles, the per-cycle quality losses are already negligible and accompanied by negligible bitrate fluctuations. This multi-generation behavior of JPEG 2000 is qualitatively similar to that observed for JPEG [10], [11].

Moreover, for all SD sequences used and all moderate bitrates tested, HEVC All Intra exhibits better compression performance than JPEG 2000, even after high number of cycles.

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