DIRECT TRANSCODING OF AVC/H.264 BITSTREAMS FOR BITRATE REDUCTION WITH MINIMIZED VIDEO QUALITY LOSSES

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ABSTRACT

The paper deals with transcoding of AVC/H.264 bitstreams where some bitrate reduction is required. For single-layer bitstreams, often Cascaded Pixel Domain Transcoders (CPDT) are used unaware of the fact that such transcoders are complex and very inefficient when used for bitrate reduction not exceeding 30% of the primary bitrate. In order to avoid these disadvantages, the authors propose structured truncation of bitstreams. For bitrate reductions not exceeding 30%, for the transcoder proposed, the rate-distortion performance is very close to that of nonscalable AVC. For various bitstream structures, extensive experimental results are reported in the paper. Moreover, computational effort in the proposed transcoder much lower than that of CPDT.

Keywords: Transcoding, bitrate, fine grain scalability.

1. INTRODUCTION

The paper deals with two important issues that reflect the same technical problem in video coding:
- bitrate scalability,
- homogeneous transcoding, i.e. bitstream transcoding resulting in a bitstream being compliant with the same video coding standard as the input one.

In the paper, both issues are considered in the context of the state-of-the-art video codec MPEG-4 AVC/H.264 [1].

Bitrate scalability is an important issue [2] that was studied during many years, and quite recently, efficient Scalable Video Coding (SVC) extension to MPEG-4 AVC/H.264 has been established [1]. For scalable coding tools, the key issue is related to compression performance that should remain close to that defined by the "rate-distortion curve" of the respective nonscalable encoding. Fine Grain Scalability (FGS) is the tool allowing at least quasi-continuous bitrate reduction yielding graceful degradation of video quality [3]. This functionality is not supported by Scalable Video Coding (SVC) extension of MPEG-4 AVC/H.264 [1] because of poor compression performance of the proposed tools.

On the other hand, recently, transcoding of video bitstreams has gained lots of attention [4-6]. Among various transcoder architectures, Cascaded Pixel Domain Transcoder (CPDT) is mostly used as reference. It consists of a full decoder and full encoder (cf. Fig. 1). In the case of homogeneous transcoding, both decoder and the encoder are compliant with the same video compression standard, i.e. with MPEG-4 AVC/H.264 in our considerations. Here, we consider homogeneous transcoding for bitrate reduction.

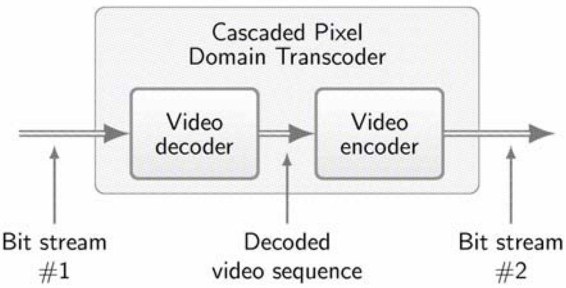

Figure 1 - Cascaded Pixel Domain Transcoder (CPDT).

Cascaded Pixel Domain Transcoder (CPDT) has very complex implementations. Therefore, very many papers are dealing with its complexity reduction [4-6]. Unfortunately, in references, attention has not been paid to inevitable losses of video quality during transcoding in a CPDT.

In this paper we will show that video quality loss due transcoding in CPDT is described by a an universal curve being a function of relative bitrate reduction. Moreover we are going to propose much simpler transcoding scheme that yields lower quality losses. The respective characteristics will be shown in comparison to those of CPDT.

2. CASCADED PIXEL DOMAIN TRANSCODER AND ITS COMPRESSION PERFORMANCE

The input Bitstream #1 is encoded with quantization parameter index QP_F. In the transcoder, a new Bitstream #2 is produced that is encoded with quantization parameter index QP_T. Transcoding is used for bitrate reduction, therefore we expect that $QP_T > QP_F$. For a transcoder, quality of video recovered from Bitstream #2 should be also measured with respect to the original video that was originally encoded into Bitstream #1 (Fig. 1). However, this original video is not available in a transcoder. In CPDT, encoding is optimized with respect to the decoded video that contains already coding artifacts from the first encoding. Therefore the second encoding is not optimal (cf. Fig. 2).

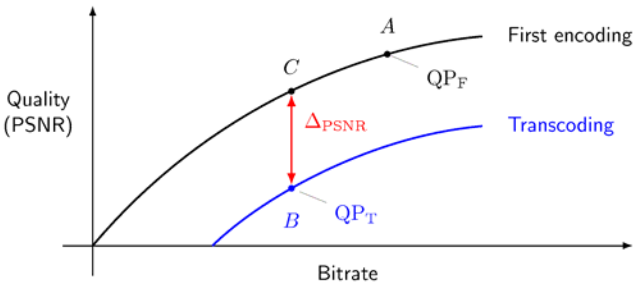

Figure 2 – Video quality loss due to transcoding.

For the original Bitstream #1, the respective video quality is denoted by point C while the quality of the output Bitstream #2 is denoted by the point B. Assume that video quality is measured by PSNR index, then the loss of video quality due to transcoding is Δ_{PSNR} (Fig. 2).

In order to measure systematically the quality loss due to transcoding in CPDT, experiments have been performed using various test sequences and AVC/H.264 reference software (JM ver. 13.2) [7]. The experiments yield the following conclusions. The maximum loss of quality is related to moderate reduction of bitrate of about 20-30%. For higher bitrate reductions exceeding 50%, the loss of quality due to CPDT is smaller and vanishes to almost zero as bitrate reduction exceeds 80%. Therefore CPDT is extremely inefficient for moderate bitrate reductions not exceeding 30%.

The conclusion is also that there exists an universal shape of the curve that represents video quality loss Δ_{PSNR} as a function of relative bitrate reduction (Fig. 3). The shape of this curve appears to be similar for various test sequences and various encoder configurations assuming that configuration of the original encoder producing Bitstream #1 is the same as that of the encoder within CPDT. The abovementioned curve is similar to that already found for MPEG-2 requantization [8,9].

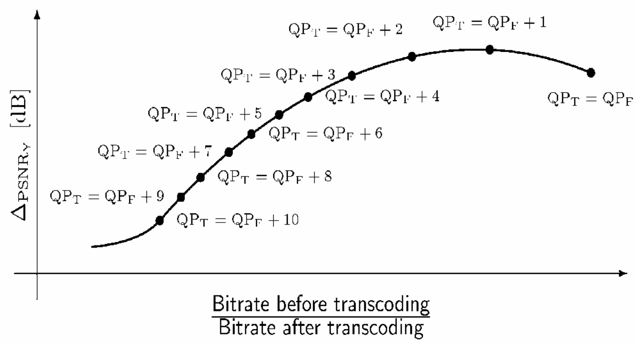

Figure 3 – Quality loss due to transcoding in CPDT. The universal curve based on experimental results.

In the paper, we prove the video quality loss may be substantially reduced by avoiding of decoding and encoding. Here, we propose an algorithm for structured truncation of AVC/H.264 bitstream that reduces numbers of bits allocated for transform coefficients. In that way also the transcoder complexity is substantially reduced as compared to CPDT.

3. REQUANTIZATION AND DRIFT

For interframe video coding, requantization or removal of transform coefficients inevitably yields drift. This phenomenon is related to systematic errors in reference frames that cannot be removed by decoding of differential images. Drift is present in P- and B- frames but it is accumulated in consecutive P- frames. Requantization of transform coefficients in B-frames affects only requantized frames.

Drift is accumulating until end of Group of Pictures (GOP) when an I-frame is encoded at the beginning of the consecutive GOP. In digital television and similar applications, GOPs are relatively short as their length should not exceed 0.5 second. It means that drift is being accumulated in few P-frames only.

The conclusion is that requantization of the last P-frames does cause less drift. We also show that fine requantization in all P-frames results in acceptable drift for GOP consisting of about 12 pictures.

4. REQUANTIZATION OF I-PICTURES

Requantization of I-frames also results in strong drift as these frames are used as reference for P- and B-frames.

In AVC/H.264 bitstreams, there exists a tool of intraframe prediction that is used in I-frames. Therefore usually change of a single transform coefficient results in changes of many samples in various blocks predicted from the current block containing the coefficient initially changed. All these changes will accumulate within the phenomenon of drift affecting all consecutive P- and B-frames in many blocks.

In order to deal with the problem, we have developed an original algorithm of selection of transform coefficients that may be modified at relatively lowest cost, i.e. causing smallest distortions in other blocks of the I-frame. The algorithm is applicable to all I-macroblocks in I-, P- and B-slices.For the sake of brevity, details of this algorithm have to be omitted here.

5. VIDEO TRANSCODING USING STRUCTURED TRUNCATION OF AVC/H.264 BITSTREAMS

We propose to use much simpler transcoder shown in Fig.4. It comprises only bitstream parsing, transform coefficient modifications, entropy encoder and bitstream formatter (Fig. 4). Complexity of this transcoder is only about 1% of the complexity of CPDT.

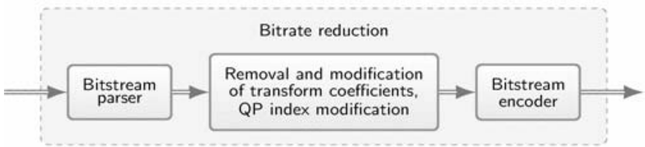

Figure 4 - Bitrate reduction via bitstream truncation.

Actual bitstream reduction is achieved by removal and modification of transform coefficients. Simultaneously a new value of QP is written into the bitstream. We have developed a systematic algorithm [10] that describes how to select the bits to be removed from the bitstream in order to maximally reduce the potential quality losses.

Bitstream truncation algorithm:

1. Eliminate coefficients with absolute value equal to 1 in B slices (for better subjective quality starting from macroblocks located more peripherally in pictures).
2. Divide all coefficients' values in B slices by 2 and put into bitstream QP index value increased by 6 for the respective macroblocks.
3. Repeat steps 1 and 2 for P slices, starting from the last P in GOP and continuing towards the beginning of GOP.
4. Eliminate half of coefficients with absolute value equal to 1 in B slices.
5. Eliminate half of coefficients with absolute value equal to 1 in P slices.
6. Eliminate rest of coefficients with absolute value equal to 1 in B slices.
7. Eliminate rest of coefficients with absolute value equal to 1 in P slices.

The algorithm stops when required bitrate reduction is achieved.

Note, that I-macroblocks remain unchanged by this basic algorithm.

In order to estimate compression performance of the transcoder proposed, extensive experiments have been performed for many 4CIF (704 × 576), 30Hz sequences. Two GOP structures have been considered of:

a) 3P3B (I-B-B-B-P-B-B-B-P-B-B-B-P-B-B-B) and

b) 4P2B (I-B- B-P-B-B -P-B- B-P-B- B-P-B-B GOP) .

The primary quantization parameter index QP_F was set the same for I and P images while B images had values of QP_F increased by 2. For binary encoding and decoding only CABAC encoder and decoder have been used.

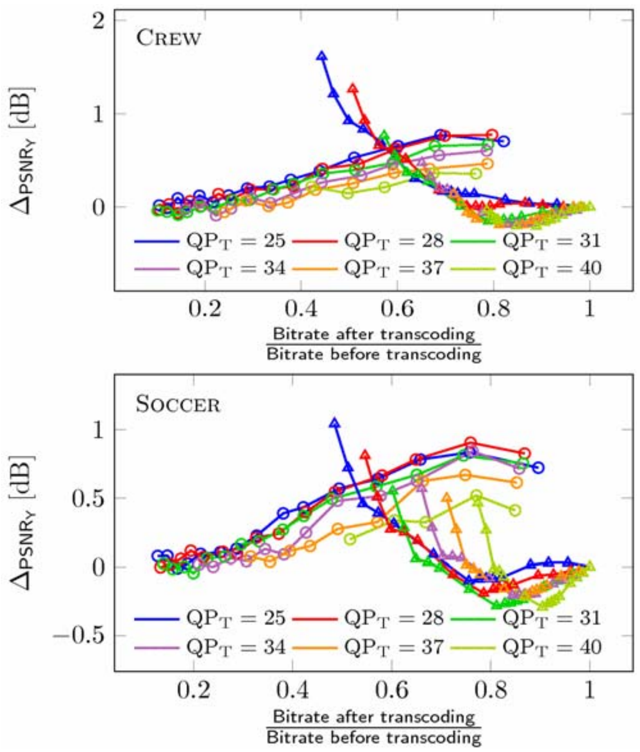

Figure 5 – Quality loss for cascaded transcoder (—o—) and proposed method (—▲—) (GOP: 3P3B, $QP^I=QP^P=QP^B$-2, loop filter ON, no Intra macroblocks in P and B images).

Here, we present only a portion of the experimental results obtained. In the experiments reported in this section, no operation on I-macroblocks has been done. Firstly, we have assumed that there is no I-macroblock in all P- and B-pictures. This assumption seems to be somewhat unrealistic. However experimental results prove that this assumption yields only small reduction of compression performance. On the other hand, it helps to obtain somewhat larger range of bitrate reduction (Figs. 5). For bitrate reduction of order 35% or less, compression performance of the structured truncation transcoder is superior to that of CPDT.

Similarly, modification of GOP structure does not affect significantly the compression characteristics (Fig. 6).

The useful range of bitrate reduction depends on initial bitrate. This range is larger for higher initial bitrates and decreases as the initial bitrate is decreasing. Such behavior is obvious; for higher bitrates there are more small coefficients that may be removed without severe impact on video quality.

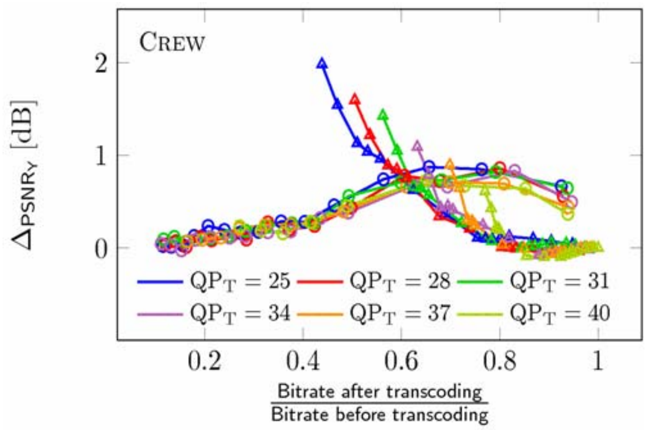

Figure 6 - Quality loss for cascaded transcoder (—o—) and proposed method (—▲—) (GOP: 4P2B, $QP^I=QP^P=QP^B$-2, loop filter OFF, no Intra macroblocks in P and B images).

6. I-FRAMES IN STRUCTURED TRUNCATION TRANSCODING

In the previous experiments, I-frame where not modified, and even there was no I-macroblock in other pictures. Such an assumption slightly reduces primary compression performance but increases the range of efficient bitrate reduction of the structured truncation transcoding.

If I-macroblocks are present in P- and B-pictures, and they are unmodified during transcoding, the bitrate reduction range is reduces that makes the approach less attractive (see Fig. 7).

Presence of many I-macroblocks in P- and B-pictures may decrease significantly the useful range of bitrate reduction. On the other hand, this decrease of the useful range of bitrate reduction may be also reduced by use of the algorithm for truncation of selected coefficients in I-frames.

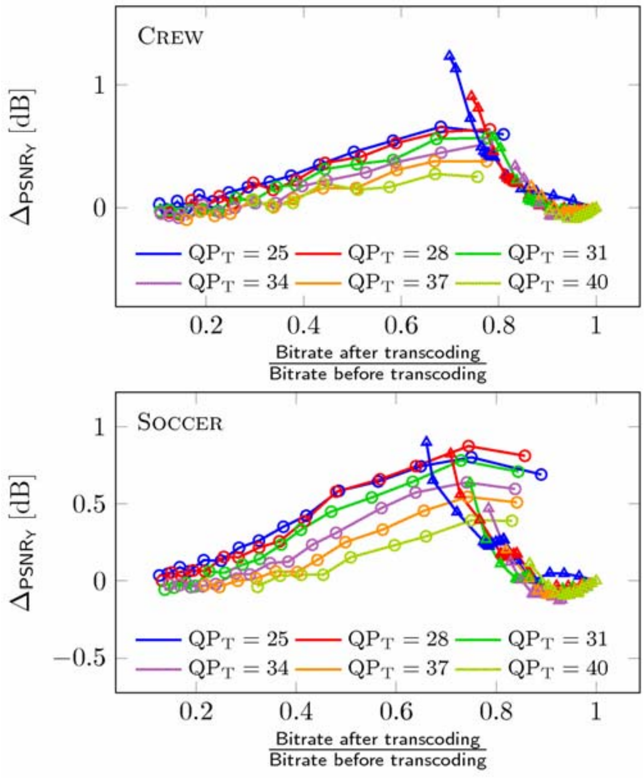

Figure 7 - Quality loss for cascaded transcoder (—o—) and proposed method (—▲—) (GOP: 3P3B, $QP^I=QP^P=QP^B$-2, loop filter ON, Intra macroblocks in P and B images allowed).

7. CONCLUSIONS

The paper presents the following original results;

a) Universal curve representing video quality loss due to cascaded pixel-domain transcoding;

b) Efficient transcoding algorithm allowing small or even negligible quality losses and very low complexity as compared to CPDT;

c) Experimental verification of the properties of the transcoder proposed;

d) Discussion on influence of I-macroblocks on the performance of the transcoder proposed.

Described are experimental results that show that the proposed transcoder provides bitrate reduction with very small or negligible loss of quality for bitrate reductions not exceeding about 30%, i.e. for the bitrate reduction range where CPDT is extremely inefficient.

The paper proves, that for typical bitstreams used in digital television as well as for digital media storage, drift may be accepted for moderate bitrate reductions.

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