HEVC-BASED DEBLOCKING FILTER WITH RAMP PRESERVATION PROPERTIES

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ABSTRACT

The paper presents an HEVC-based deblocking filter that improves perceptual quality of reconstructed video on the content that exhibits a lot of chaotic motion, such as water, fire or smoke while providing similar quality on "normal" video content, such as the content with linear motion. The filter is also capable of efficiently suppressing block artifacts in smooth areas with slowly changing samples intensity. The objective performance of the proposed deblocking filter is on average similar to the HEVC deblocking.

***Index Terms*—**Deblocking, HEVC, subjective quality, block-based coding, video compression

1. INTRODUCTION

The HEVC video coding standard was finalized in January 2013 [1], [2]. It substantially improves compression of video, especially on the high resolution content compared to the previous standards, such as H.264/AVC. To provide efficient compression of both smooth and highly detailed areas of high-resolution sequences, the size of the inter-predicted blocks in HEVC can vary from 4 × 8 and 8 × 4 luma samples to 64 × 64, while the sizes of transforms and intra-prediction partitions vary from 4 × 4 to 32 × 32 samples. HEVC uses two in-loop filters: a deblocking filter and a sample adaptive offset (SAO) filter, applied to the output of the deblocking filter.

HEVC deblocking filter attenuates artifacts that are created by relatively independent encoding of blocks in a picture and improves the subjective and objective quality of the reconstructed video, especially at lower bitrates. However, at a later phase of HEVC standardization some remaining block artifacts were reported for the sequences with high level of chaotic motion [4], such as sequences showing fire, moving water, smoke etc. Encoder-side approaches attenuating these remaining block artifacts by using deblocking control parameters were proposed in [8], [7], [9]. Another group of approaches addressed this problem by relaxing the deblocking decisions thresholds and clipping parameters used in HEVC deblocking, which results in stronger filtering is certain areas of the reconstructed picture, where the artifacts were more likely to appear [4], [5], [6]. The approaches modifying the HEVC deblocking filter were not adopted (for certain reasons including the codec specification stability at the end of the standard development). Therefore, the encoder-side approaches should be used to attenuate artefacts in the difficult video content. This paper argues that the block artifacts in difficult content can be better handled by changing the so-called strong deblocking filter in HEVC and the strong filtering decisions. The original idea of this paper was presented in HEVC standardization in [11], with some additional results and development reported in [12], [13].

The paper is organized as follows. First, a short description of the HEVC deblocking filter is given in Section 2. Section 3 explains how the remaining block artifacts appear and how they can be attenuated by an encoder approach. Section 4 presents the proposed deblocking filter. Finally, the subjective and objective performance is reported in Section 5, and Section 6 concludes the paper.

2. HEVC DEBLOCKING FILTER DESCRIPTION

In HEVC deblocking, only the block boundaries aligned with the 8 × 8 pixel grid are processed to decrease the worst case complexity [3]. The deblocking is applied to the CU, PU or TU boundaries if at least one of the following conditions is fulfilled: at least one of the adjacent blocks is intra-predicted or has non-zero transform coefficients, the difference between the motion vectors of the adjacent blocks is at least one integer sample or motion vectors point to different reference frames. Then, for a luma block boundary that satisfies these conditions, further deblocking decisions are made based on the values of samples adjacent to the block boundary [3].

The following expression evaluates whether the deblocking is applied to a four-sample segment of a vertical block boundary:

$$|p_{2,0} - 2p_{1,0} + p_{0,0}| + |p_{2,3} - 2p_{1,3} + p_{0,3}| + |q_{2,0} - 2q_{1,0} + q_{0,0}| + |q_{2,3} - 2q_{1,3} + q_{0,3}| < \beta, \quad (1)$$

where threshold β depends on the average of quantization parameters QP of the adjacent blocks, $p_{i,j}$ is the sample value on row j and i samples away from the block boundary on the left side of the boundary and $q_{i,j}$ is the corresponding sample on the right from the boundary (as shown in Fig. 1).

$p3_0$	$p2_0$	$p1_0$	$p0_0$	$q0_0$	$q1_0$	$q2_0$	$q3_0$
$p3_1$	$p2_1$	$p1_1$	$p0_1$	$q0_1$	$q1_1$	$q2_1$	$q3_1$
$p3_2$	$p2_2$	$p1_2$	$p0_2$	$q0_2$	$q1_2$	$q2_2$	$q3_2$
$p3_3$	$p2_3$	$p1_3$	$p0_3$	$q0_3$	$q1_3$	$q2_3$	$q3_3$
Block P				Block Q			

Fig. 1. Four-sample segment of vertical block boundary with adjacent blocks.

HEVC deblocking uses two filters: a "normal" deblocking filter and a "strong" deblocking filter. The strong filter is applied to the block boundary if all of the following expressions are true for lines $j = 0$ and $j = 3$, otherwise the normal filter is used:

$$|p_{2,j} - 2p_{1,j} + p_{0,j}| + |q_{2,j} - 2q_{1,j} + q_{0,j}| < \beta/8, \quad (2)$$

$$|p_{3,j} - p_{0,j}| + |q_{0,j} - q_{3,j}| < \beta/8, \quad (3)$$

$$|p_{0,j} - q_{0,j}| < 2.5\, t_C. \quad (4)$$

Variable t_C is obtained from a table as t_C (QP), when both adjacent blocks are inter-predicted and t_C(QP+2) when at least one of adjacent blocks is intra-predicted [2], [3]. In the following, the row index is omitted for brevity if not needed.

Then the sample values are modified as

$$p_i' = p_i + \Delta_i, \quad (5)$$

where p_i and p_i' are the values of the sample before and after modification respectively, and the value of Δ_i is obtained as

$$\Delta_i = \mathrm{Clip3}(-c, c, \delta_i), \quad (6)$$

where c is a clipping parameter dependent on the QP, Clip3(a,b, x) function clips the variable x to the range (a, b):

$$\mathrm{Clip3}(a,b, x) = \mathrm{Max}(\, a, \mathrm{Min}(b, x)\,), \quad (7)$$

and δ_i is the modification value obtained as the result of the filtering operation.

While the normal filter modifies from zero to two samples on each side of the block boundary, the strong filter modifies three samples on each side of the boundary. The strong filtering is applied to pixels p_0, p_1, and p_2 as in (5), after clipping of the following δ_0, δ_1, and δ_2 values:

$$\delta_0 = (\, p_2 + 2p_1 - 6p_0 + 2q_0 + q_1 + 4\,) >> 3, \quad (8)$$

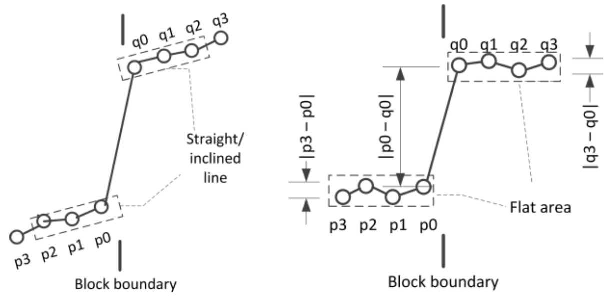
$$\delta_1 = (\, p_2 - 3p_1 + p_0 + q_0 + 2\,) >> 2, \quad (9)$$

$$\delta_2 = (\, 2p_3 - 5p_2 + p_1 + p_0 + q_0 + 4\,) >> 3 \quad (10)$$

where ">>" denotes a bit-wise shift to the right. The filtering operations for samples in block Q can be obtained by inverting symbols p and q in the formulas.

The clipping operation in HEVC deblocking is used to limit the degree of filtering to avoid excessive smoothing. In the case of strong filtering, the value of c in (6) is set equal to $2t_C$ for all modified samples.

It follows from equations (1)–(4) that the strong filter is typically applied when the signal is flat on both sides of the block boundary and the difference between the values of samples p_0 and q_0 is small (as in Fig. 2 (b)). The normal filter is applied when the signal at the side of the block boundary has a form of an inclined line (ramp) or the distance between the values of p_0 and q_0 is greater than $2.5\, t_C$ (see Fig. 2 (a)).



(a) (b)

Fig. 2. Signal (in one dimension) on the sides of block boundary resulting in positive deblocking filtering decisions for: (a) HEVC normal filter, (b) HEVC strong filter

The HEVC deblocking filter can be adjusted on a slice or picture level by sending parameters beta_offset_div2 and tc_offset_div2 in the slice header or picture parameters set (PPS) to control the amount of filtering. The parameters specify the offsets (divided by two) that are added to QP before determining the β and t_C, respectively.

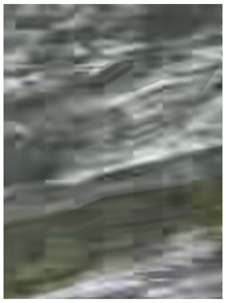
3. BLOCK ARTIFACT ANALYSIS AND ENCODER APPROACH

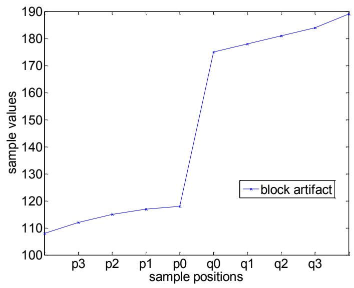
In a hierarchical coding structure, used in many video coding applications, the encoder often uses QP cascading in order to improve compression efficiency [18]. The improvement in compression efficiency is achieved by coding with better quality pictures at lower hierarchy levels, which are used for prediction of pictures at higher hierarchy levels.

However, in video sequences with chaotic motion, e.g. showing water, smoke, or fire, the QP cascading may cause block artifacts in pictures at higher hierarchy levels [7]. An example of these artifacts is shown in Fig. 3. Fig. 3(a) shows an example of block artifacts in a *Riverbed* sequence at base QP = 37 at the boundaries of 32 × 32 blocks. A block artifact in one dimension from the same picture is shown in Fig. 3(b).

The subjective quality in a hierarchical coding structure can be improved by modifying the deblocking filter strength on a picture level. When an encoder uses hierarchical coding structure and QP cascading, the deblocking parameter tc_offset_div2 (and to certain extent beta_offset_div2) can be used to increase the deblocking strength for pictures at higher hierarchy levels, which improves the subjective quality on sequences with chaotic motion [9], [7]. The suggested deblocking parameters are shown in Table 1.

The parameters shown in Table 1 enable stronger modification of sample values by the deblocking for pictures at higher hierarchy levels. However, one can see that the shape of a typical block artifact, to which the HEVC strong filter is applied (Fig. 2(b)), is different from a block artifact in Fig. 3(b), where the signal on the sides of the block boundary has a shape of an inclined line (ramp). This means





(a) (b)

Fig. 3 Sequence *Riverbed*, base QP 37: (a) part of a picture at hierarchy level 3, (b) block artifact in one dimension, luma.

Table 1. Proposed values of tc_offset_div2 for hierarchy levels in Random-Access GOP8 and Low-Delay GOP4 structures

Hierarchy level	**tc_offset_div2**	
	RA (GOP8)	**LD(GOP 4)**
Intra	0	0
Hierarchy level 0	1	1
Hierarchy level 1	3	3
Hierarchy level 2	4	5
Hierarchy level 3	6	

that although the signal is quite smooth, the strong deblocking will not be applied. Instead, a normal deblocking filter will be used, which modifies at most two samples from the boundary. Obviously, modifying two boundary samples on each side might not be enough to attenuate a block artifact between two 32 × 32 or 16 × 16 blocks. In order to enable strong filtering for such block artifacts, threshold $\beta/8$ in (3) can be relaxed by signaling beta_offset_div2. However, this would result in significant increase of threshold β in (1) and effectively turn the deblocking on for most of block boundaries in the picture. Moreover, applying the strong deblocking filter to a signal that has a form of a inclined line (ramp) may result in artifacts described later in Section 4.2 and shown in Fig. 4(a).

4. PROPOSED FILTER

4.1. Deblocking filter decisions

In the proposed deblocking filter, the deblocking decisions for applying the strong filtering are modified by replacing equation (3) for lines $j = 0$ and $j = 3$ by the following condition:

$$| p_{3,j} - 2p_{2,j} + p_{1,j} | + | q_{3,j} - 2q_{2,j} + q_{1,j} | < \beta/8 \quad (11)$$

The proposed condition turns on the strong filter when four samples on each side of the block boundary approximate a straight or inclined line. Therefore the strong filter will also be applied to such signal as in Fig. 3(b) if the threshold in equation (4) is relaxed, for example by using the tc_offsets_div2 values from Table 1. Since threshold t_C in (4) is also a clipping parameter, signaling tc_offsets_div2 will also allow greater modification of sample values.

4.2. Deblocking filter operations

The deblocking filtering operations need to be jointly designed with the deblocking filtering decisions. The proposed strong filter decisions: (2), (11), and (4) enable application of the strong filter to the signal that has a form of an inclined line (ramp) crossing the block boundary even when there is no block artifact. The HEVC strong filter was designed to work on the signal that is flat on both sides of the block boundary. When applied to a ramp, it distorts the signal as shown in Fig. 4(a), which may result in subjective and objective quality degradation. Therefore, changing the deblocking decisions also requires changing the filtering operations.

The following filter is proposed for the strong filtering mode, which requires replacing (8), (9) and (10) by the following equations:

$$\delta_0 = (p_2 + 2p_1 - 6p_0 + 2q_0 + q_1 + 4) >> 3 \quad (12)$$

$$\delta_1 = (p3 + 2p_2 - 6p_1 + p_0 + 2q_0 + 4) >> 3 \quad (13)$$

$$\delta_2 = (3p_3 - 5p_2 + p_1 + q_0 + 4) >> 3 \quad (14)$$

The result of applying the proposed filter to a signal that has a form of a ramp crossing the block boundary is shown in Fig 4(b). One can see that distortion of the signal is significantly smaller compared to the HEVC strong deblocking filter.

Clipping thresholds have also been adjusted. Samples closer to the block boundary can be modified stronger than the samples further away from the boundary, as follows

$$t_{C1} = (3t_C + 1) >> 2, \quad (15)$$

$$t_{C0} = (3t_{C1} + 1) >> 1, \quad (16)$$

$$t_{C2} = (t_{C1} + 1) >> 1, \quad (17)$$

where t_{C0}, t_{C1}, and t_{C2} are the clipping thresholds used for samples p_0, p_1, and p_2 respectively.

The proposed deblocking enables strong filtering operations on smooth signal that has a shape of a ramp and is able to efficiently attenuate block artifacts on the content such as water or fire. To efficiently attenuate strong block artifacts at higher hierarchy levels, as the one shown in Fig. 3(b), the proposed deblocking is best combined with adaptation of parameter tc_offset_div2 as in Table 1.

5. RESULTS

This section contains the subjective performance comparison of the proposed approach on difficult sequences containing chaotic motion and the objective performance comparison on "normal" test sequences used in HEVC *common test conditions* (CTC) [17]. The results are provided for *All Intra* (AI), *Random Access* (RA), *Low-Delay* (LDB), and *Low-Delay without B* frames (LDP) coding conditions [17]. The following six "difficult" sequences have been used in the subjective test: *Riverbed* (QP32, RA), *Riverbed* (QP37, RA), *WestWindEasy* (QP37, LDB), *DucksTakeOff* (QP37, LDB), *ChinaSpeed* (QP37, LDB), *RedKayak* (QP37, RA, first 10 seconds).

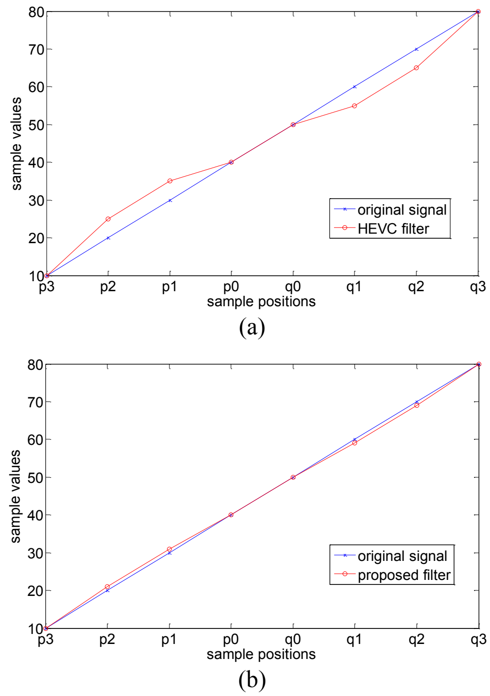


Fig. 4. Modification of ramp signal by HEVC strong filter and proposed filter. Blue-original signal, red–filtered signal. HEVC filter (a) distorts the ramp stronger than the proposed filter (b).

The first compared approach is the proposed deblocking filter implemented on the HEVC reference software HM9.1 [16] and with tc_offset_div2 parameter set as in Table 1. Another tested configuration is HM9.1 with tc_offset_div2 parameter as in Table 1. The reference is HM9.0 in common test conditions (equivalent to HM9.1 under CTC [17]).

The subjective performance results were obtained at an informal subjective viewing test with expert subjects held at the JCT-VC meeting [14]. The test procedure was similar to the stimulus comparison method [20]. The tested sequence and the reference are shown one after another twice in the ABAB order. The order of the tested approach and the reference was randomized for every test and sequence and identities of the tested approaches and the reference were hidden (the test subjects were shown labels A or B instead). Test subjects were asked to rate B compared to A on the discrete scale from –2 to 2. The average scores and 95-percent confidence intervals were calculated for every tested approach and test sequence. Dell 3008WFPt display with 30" diagonal was used in the test. The proposals in each test session were evaluated by a group of three or two experts. In total, 20 subjects participated in the test.

The test results are shown in Fig. 5. One can see that HM9.1 with tc_offsets_div2 shows statistically significant difference (non-overlapping confidence interval) with the HM9.0 reference only on one of six test sequences. The proposed filter with tc_offsets_div2 adjustment is better than the reference on five of six test sequences.

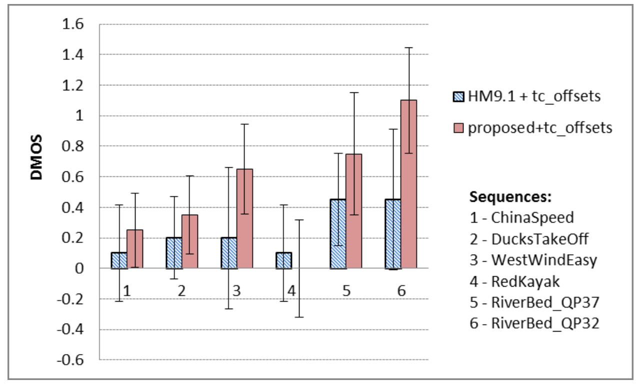


Fig. 5. DMOS scores of the proposed filter with tc_offset_div2 and HEVC deblocking filter with tc_offset_div2.

Comparison of the proposed deblocking filter to HM9.1 on “normal” test sequences can be found in [15] (publicly available online) and does not show statistically significant difference between the HEVC and the proposed deblocking.

The objective performance has been evaluated by calculating the Bjøntegaard-delta rate (BD-rate) [19], i.e. the average bitrate change at the same quality, between the HEVC deblocking filter (HM9.0 in CTC) and the proposed deblocking on CTC sequences [17]. The results show that the proposed deblocking without tc_offset_div2 adjustment results in average BD-rate = 0.1% (i.e. 0.1% bitrate increase) on LDB configuration and in BD-rate = 0.0 on three other configurations (AI, RA and LD-P). The proposed deblocking with tc_offset_div2 results in BD-rate equal to 0.0%, 0.0%, 0.2%, and -0.1% compared to HM9.0 in CTC in AI, RA, LDB and LDP configurations respectively.

The results indicate that the proposed deblocking combined with tc_offset_div2 adjustment improves the subjective quality compared to the reference in more test sequences than the encoder-only approach of tc_offset_div2 adjustment, while showing similar performance to HEVC deblocking on common video sequences.

6. CONCLUSIONS

The proposed strong deblocking filter is based on HEVC deblocking and enables strong deblocking filtering of a signal that has the shape of a ramp. The proposed deblocking together with the encoder adjustments improve the subjective quality of the reconstructed video on difficult sequences containing chaotic motion such as the sequences containing water, fire, and smoke, while showing similar performance to HEVC deblocking on “normal” content.

7. ACKNOWLEDGEMENTS

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