Performance Analysis of HEVC In-Loop Filter

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Abstract: The need of high definition video (HDV) is growing day by day. Keeping in need of HDV, the Joint Collaborative Team on Video Coding (JCTVC) developed a new video coding project known as High Efficiency Video Coding (HEVC). The upcoming HEVC is designed to serve wide range of applications. However, it suffers from visually disturbing discontinuities known as blocking artifacts to achieve high compression ratio. HEVC employs in-loop filter to suppress these blocking artifacts. This paper describes the performance analysis of HEVC in-loop filter which comprises of deblocking and sample adaptive offset (SAO) filter. Various high definition video sequences of 1080p, 720p and 480p are used for evaluation. Simulation results show that in-loop filter can suppress blocking artifacts effectively without losing objective and subjective quality of video.
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1. Introduction

Block based transform coding schemes are used by most video coding standards like H.263, MPEG-4, H.264 and HEVC to exploit spatial redundancy (Gulistan, 2011). In these schemes, each picture is divided into blocks and each block is transformed using discrete cosine transform; quantized and entropy coded to generate compress bit stream. The quantization step divides the transformed coefficients by quantization table and are rounded to integer. In order to achieve higher compression ratio; the high-order transform coefficients are coarsely quantized (usually to zero). This results in loss of correlation between adjacent blocks which produces visually disturbing continuities known as blocking artifacts. Moreover, motion compensation process in video coding is another source of blocking artifacts. The interpolated pixels data from various reference frames is used for motion compensated blocks. The discontinuities on block edges of copied data may occur as there is never a perfect fit for this data.

Deblocking filters are employed to suppress blocking artifacts that are produced during video coding. Two main approaches are used for this purpose: post filter and in-loop filter. In post filter method, the filter is applied after the decoder and makes use of decoded parameters. The post filter operates on display buffer outside the coding loop and its use is optional as it is not a normative part of standards. The in-loop filter is employed within coding loop and applied to reconstructed frame in encoder and decoder. Table 1 elaborates deblocking filters used in different video coding standards (Ian, 2003; Gulistan, 2004).

Table 1: Deblocking filters for various standards

Standard	***Deblocking Filter***
H.261	Optional in-loop filter
MPEG-1	No filter
MPEG-2	No filter, post filtering often used
H.263	No filter
MPEG-4	Optional in-loop filter, post-filter processing suggested
H.264	In-loop filter, post-filter processing may also be used
HEVC	In-loop deblocking filter and sample adaptive offset filter

The upcoming High Efficiency Video Coding (HEVC) standard is the joint effort of ISO/IEC MPEG and ITU-T VCEG in a partnership known as Joint Collaborative Team on Video Coding (JCTVC). Performance analysis of HEVC shows its superiority by achieving around 50% bit rate improvement for high definition video in comparison with its predecessor H. 264/AVC standard [Gary et al, 2012; Gulistan et al, 2013). HEVC employs in-loop filter comprising of deblocking and sample adaptive offset (SAO) filter for suppression of blocking artifacts. This paper describes the performance analysis of HEVC in-loop filter for various high definition video sequences.

2. Overview of HEVC In-Loop Filter

HEVC has introduced two filters in the block of in-loop filtering named as De-blocking Filter (DBF) and Sample Adaptive Offset Filter (SAO) to reduce or suppress the blocking artifacts (Norkin et al, 2012). DBF takes input from the Inverse Scaling and

Inverse transform block and output of DBF is input of SAO as shown in Figure 1.

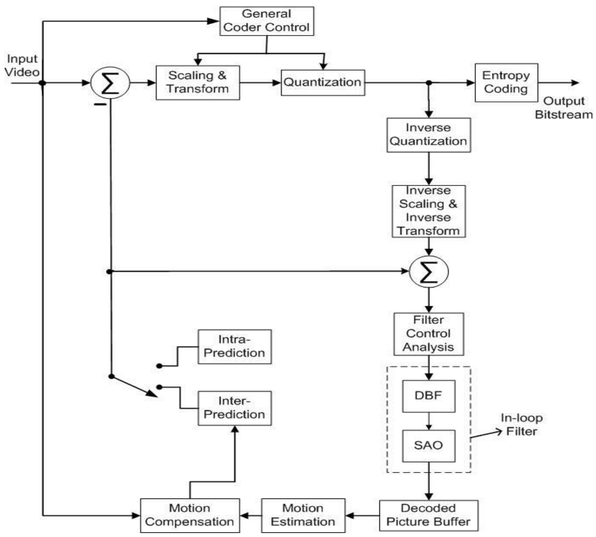

Figure 1. Position of in-loop filter in HEVC

Output of these two in-loop filters are used for prediction and motion compensation for incoming frames. The explanation of two filters is as follows:

De-Blocking Filter (DBF):

DBF in HEVC is more efficient than the previous standards due to its suitability of parallel processing. It provides good subjective quality and it is less complex than the previous ones. The blocking artifacts mainly appear due to misalignment of samples across block boundary. This is shown in Figure 2 in which p0-p3 and q0-q3 are samples in P and Q block respectively.

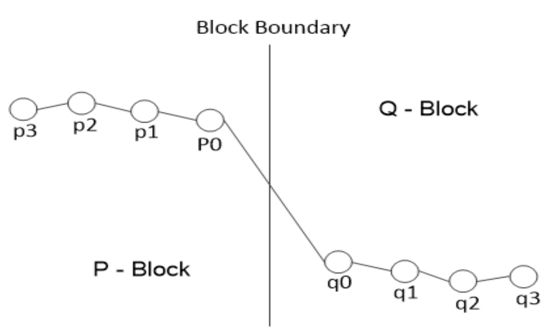

Figure 2. Misalignment of samples across block boundary

In HEVC the frame is divided into 64 x 64 pixels coding tree units with further division of 64 x 64, 32 x 32 , 16 x 16 and 4 x 4 blocks. In H.264 the block size used for filtering was 4 x 4 for but in HEVC DBF is applied on 8 X 8 sample grid's horizontal and vertical edges at transform unit (TU) or prediction unit (PU) block boundaries only. The boundary strength (bS) parameter is used to determine the type of filter to be applied. There are three possible values for bS: 0, 1 and 2 (Norkin et al, 2012). The flow chart for assigning bS values is shown in Figure 3.

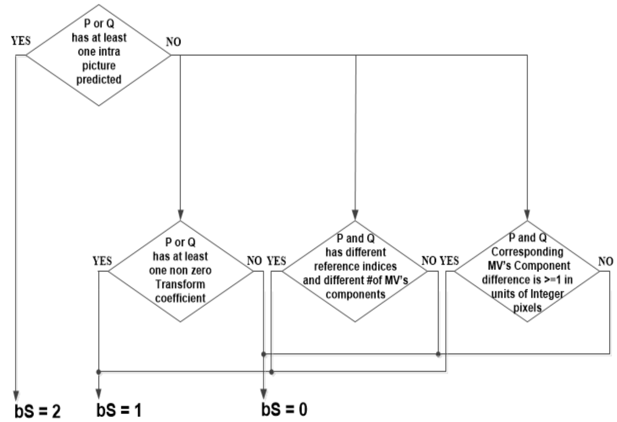

Figure 3. Boundary strength (bS) computation

The filter is applied on the samples only if they meet both conditions given in Eq. (1) and Eq. (2) (Auwera et al, 2011; Bross et al, 2013).

$$bS > 0 \quad (1)$$

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

where p and q are samples from first and last row of four-sample length filter across 8 X 8 sample grid boundary as shown in Figure 4. The parameter β depends on quantization parameter (Auwera et al, 2011).

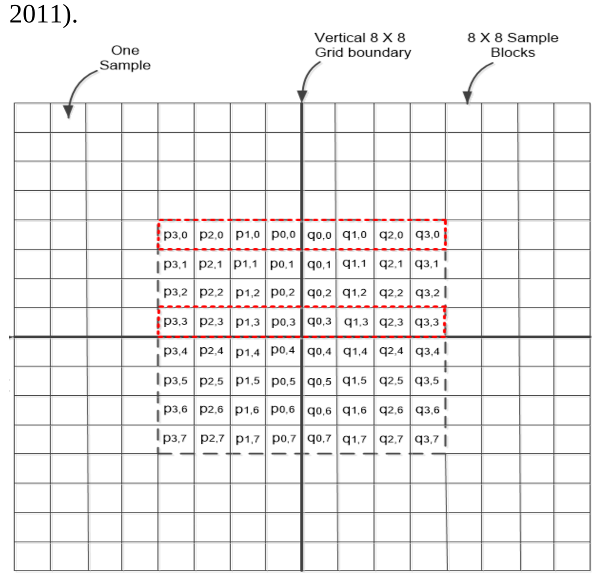

Figure 4. Four sample length filtering across 8 X 8 sample grid

The horizontal samples shown in Figure 4 are filtered for vertical boundary whereas for horizontal boundary, the vertical samples can be filtered by rotating Figure 4 to 90^0 clock wise. Once filter decision is made, then next step is to apply strong or normal filter according to following pseudo code (Bross et al, 2013).

If $(|p_{2,i}-2*p_{1,i}+p_{0,i}|+|q_{2,i}-2*q_{1,i}+q_{0,i}| > \beta/8$ **&&** $|p_{3,i}-p_{0,i}|+|q_{3,i}-2*q_{1,i}+q_{0,i}| > \beta/8$ **&&** $|p_{3,i}-p_{0,i}| > 2.5t_c)$

Strong Filtering;

else

Normal Filtering;

where β and t_c are the parameters of quantization parameter (QP) and their values changes according to QP values as given in the standard (Auwera et al, 2011). Luma filtering is applied on the samples when bS is 1 or 2 and chroma filtering is applied only when the bS is 2. In case of luma strong filtering three samples on either side of boundary are modified and for luma normal filtering two samples on both sides of boundary are modified .Chroma filtering modifies only one sample on each side of boundary as shown in Figure 5.

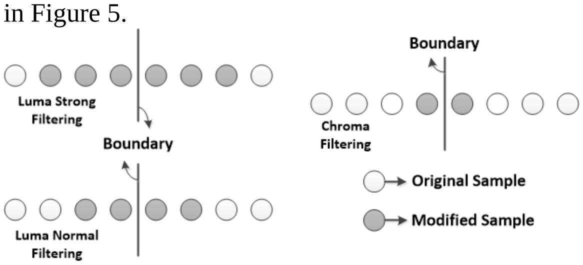

Figure 5. Luma and Chroma Filtering

Sample Adaptive Offset (SAO) filter:

Sample Adaptive Offset (SAO) is a new coding tool introduced in HEVC standard. SAO takes input from DBF and distributes samples into different categories by assigning them particular value or offset. The categorization is done on the basis of edges or intensities of the reconstructed samples and corresponding offset is assigned. There are two types of offset named as: Band Offset (BO) and Edge Offset (EO) (Chih-Ming et al, 2012). BO categorizes the whole range of samples intensities into 32 equal bands, which is further divided into two groups (Group 1 and Group 2) of 16 bands each as shown in Figure 6.

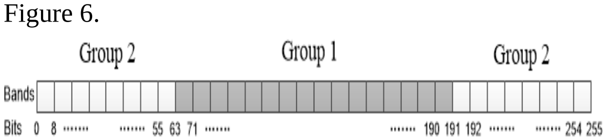

Figure 6. Categorization of samples into bands

EO assigns the offset to the samples according to four 1-D classification of 3 consecutive samples with 'c' as current sample and n_0, n_1 as neighboring samples as shown in Figure 7.

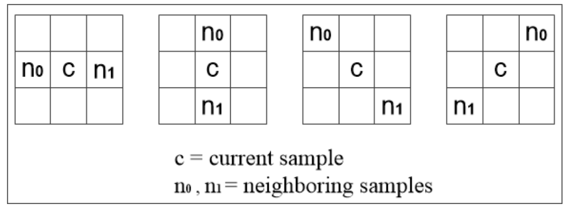

Figure 7. Possible consecutive samples arrangement

The sample 'c' is modified according to the conditions given in flow chart of Figure 8.

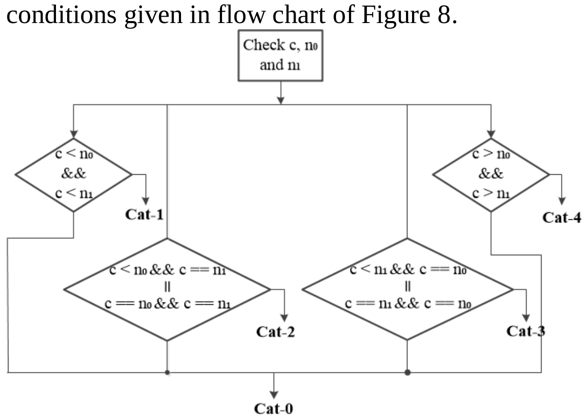

Figure 8. Categorization in EO

The offset calculated by the filter will be assigned according to various categories. For cat-1 and cat-2, the positive offset results in smoothing while the negative offset in sharpening of edges. In cat-3 and cat-4, positive and negative offset work oppositely in comparison to cat-1 and cat-2. The task of EO in HEVC is smoothing so positive offsets for cat-1, cat-2, and negative offset in cat-3, cat-4 will be used. Cat-0 results in no SAO filtering for samples.

4. Simulation Results

HEVC reference software (HM-9.2) is used for the simulations (Reference software, 2013). We have used 480p (832 x 480), 720p (1280 x 720) and 1080p (1920 x 1080) HD test sequences providing wide range of slow and fast moving frames. The 480p sequences taken are BASKETBALL DRILL, PARTY SCENE, KEIBA and RACE HORSES while 720p sequences are FOUR PEOPLE, KRISTEN AND SARA, JOHNNY AND DUCKS TAKEOFF and 1080p sequences used are BASKETBALL DRIVE, CACTUS, BLUE SKY and PEDESTRIAN AREA (Test Sequences, 2013). Fifty (50) frames of each sequence having frame rate of 30 fps have been taken into account for testing purpose. First the various resolution high definition test video sequences are encoded by disabling in-loop filter and then encoded using in-loop filter.

Table 1 describes the objective comparison of with and without HEVC in-loop filter for different QP values using various 1080p, 720p and 480p high definition test video sequences. It is observed that Peak to Signal Noise Ratio (PSNR) using filter has a slight improvement in comparison to no filter with additional benefit of suppression of blocking artifacts. Figure 9 describes the subjective comparison of selected frames of various high definition test video sequences for without and with in-loop filter. The blocking artifacts seems to appear excessively where either the objects are fast moving or two objects are overlapping each other and also at edges. The most effected parts are highlighted with using rectangular boxes in Figure 9. It can be seen that HEVC in-loop filter can significantly suppress these blocking artifacts.

Table 1. Y-PSNR comparison of various high definition video test sequences with and without HEVC in-loop filter

Test Sequence	QP	PSNR (dB) Without Filter	PSNR (dB) With Filter	Difference (dB)	Test Sequence	QP	PSNR(dB) Without Filter	PSNR(dB) With Filter	Difference (dB)
Basketball Drive (1920X1080)	23	39.2922	39.3521	+0.0599	**Johnny (1280X720)**	23	42.5390	42.5947	+0.0557
	28	37.9177	37.9441	+0.0264		28	41.0200	41.0769	+0.0569
	33	36.1707	36.1863	+0.0156		33	39.1141	39.1717	+0.0576
	38	34.2335	34.2420	+0.0085		38	36.7591	36.8125	+0.0534
	43	32.0414	32.0333	+0.0081		43	34.1450	34.2208	+0.0758
Cactus (1920X1080)	23	37.9561	38.0544	+0.0983	**Ducks Takeoff (1280X720)**	23	36.5679	36.6915	+0.1236
	28	36.3222	36.3774	+0.0552		28	33.9405	34.0289	+0.0884
	33	34.3384	34.3932	+0.0548		33	31.2323	31.3123	+0.0800
	38	32.0986	32.1597	+0.0611		38	28.8306	28.8419	+0.0113
	43	29.7411	29.7793	+0.0382		43	26.4732	26.4739	+0.0007
Blue Sky (1920X1080)	23	42.8562	42.9409	+0.0847	**Basketball Drill (832X480)**	23	39.8258	39.9856	+0.1598
	28	40.7149	40.7947	+0.0798		28	36.7910	36.9121	+0.1211
	33	38.1364	38.1997	+0.0633		33	33.9836	34.1040	+0.1204
	38	35.3527	35.4047	+0.0520		38	31.5013	31.6586	+0.1573
	43	32.4441	32.4561	+0.0120		43	29.1629	29.2303	+0.0674
Pedestrian Area (1920X1080)	23	41.7079	41.7820	+0.0741	**Party Scene (832X480)**	23	37.2671	37.3530	+0.0859
	28	39.8925	39.9365	+0.0440		28	33.5471	33.6342	+0.0871
	33	37.6639	37.7151	+0.0512		33	30.2540	30.3434	+0.0894
	38	35.3275	35.3561	+0.0286		38	27.2838	27.3813	+0.0975
	43	32.7794	32.7889	+0.0095		43	24.5222	24.5754	+0.0532
Four People (1280X720)	23	42.2759	42.3754	+0.0995	**Keiba (832X480)**	23	39.0232	39.1227	+0.0995
	28	40.2455	40.3632	+0.1177		28	36.1653	36.2234	+0.0581
	33	37.7356	37.8745	+0.1389		33	33.3188	33.3861	+0.0673
	38	34.9069	35.0159	+0.1090		38	30.7667	30.8031	+0.0364
	43	31.8686	31.9031	+0.0345		43	28.2876	28.3436	+0.0560
Kristen &Sara (1280X720)	23	42.2759	42.9933	+0.7174	**Race Horses (832X480)**	23	37.6224	37.7066	+0.0842
	28	40.2455	41.1473	+0.9018		28	34.3575	34.4520	+0.0945
	33	37.7356	38.8687	+1.1331		33	31.4717	31.5570	+0.0853
	38	34.9069	36.2455	+1.3386		38	28.8053	28.8626	+0.0573
	43	31.8686	33.4140	+1.5454		43	26.5043	26.5229	+0.0186

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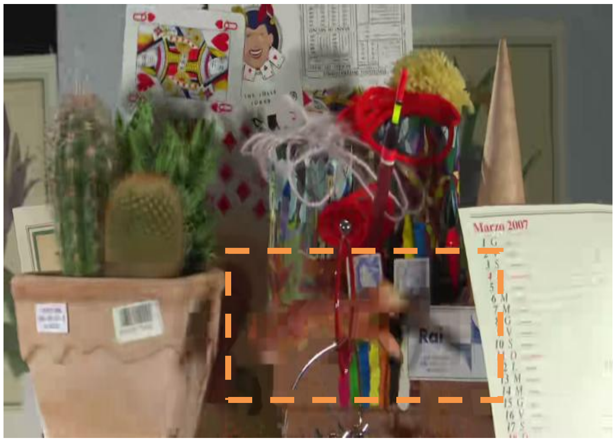

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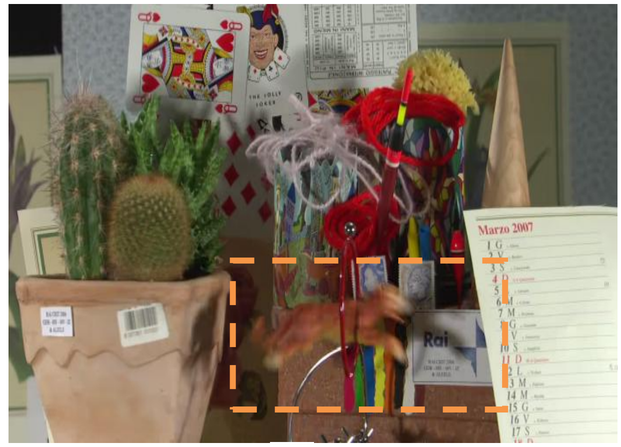

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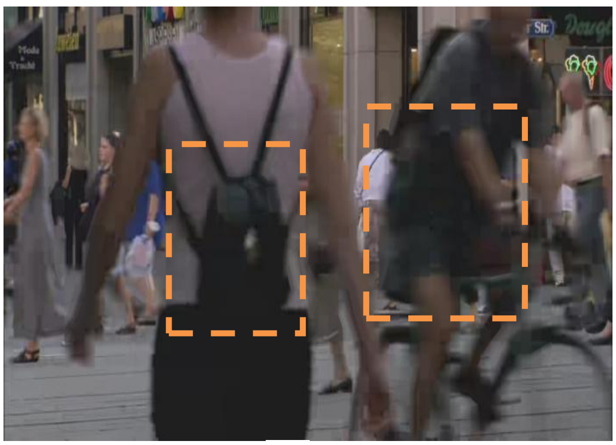

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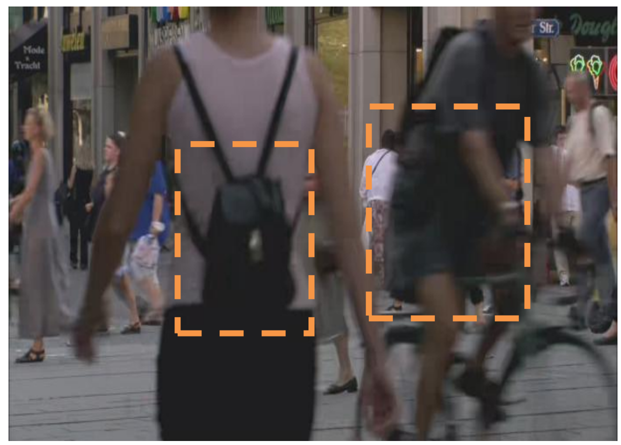

(b)

(a)

(b)

Figure 9. Subjective comparison of various high definition video sequences (a) without filter (b) with in-loop filter