Enhanced Block-Based Adaptive Loop Filter with Multiple Symmetric Structures for Video Coding

Hahyun Lee, Sung-Chang Lim, Haechul Choi, Seyoon Jeong, Jongho Kim, and Jin Soo Choi

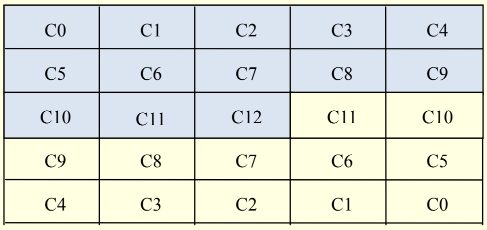
In this letter, we present an enhanced block-based adaptive loop filter (E-BALF) with multiple filter symmetric structures. The E-BALF adapts various filter symmetric structures in a rate-distortion optimization sense, reflecting the statistical properties of each image in a video sequence. Experimental results show that the proposed method achieves a reduction in the Bjøntegaard delta (BD)-bitrate by an average of 9.60% compared with Joint Model 11.0 of H.264/AVC. Compared to the state-of-the-art BALF, a reduction of up to 1.13% in BD-bitrate is achieved.

Keywords: Wiener filter, adaptive loop filter.

I. Introduction

Recently, the ISO/IEC JTC1/SC29 WG11 Moving Picture Experts Group (MPEG) started the development of a new video coding standard, called High-Performance Video Coding (HVC) [1]. The ITU-T Q.6/SG16 Video Coding Experts Group (VCEG) has also released a draft call for proposals for a next-generation video coding project [2]. These groups are urgently encouraging new video coding algorithms [3] for new video coding standards.

Since 2005, VCEG has been mainly focused on improving coding efficiency and computational complexity. To evaluate contributed video coding tools and integrate promising ones, a Key Technical Area (KTA) has been developed as a software platform, which is based on the Joint Model (JM) reference software of H.264/AVC. During the KTA exploration stage, Chujoh and others [4], [5] proposed a block-based adaptive loop filter (BALF) to improve coding efficiency. The BALF applies an adaptive Wiener filter, a well-known optimal linear filter to deal with a picture corrupted by Gaussian noise, distortion, and blurring. The adaptive Wiener filter is applied to a deblocked picture that is obtained after the deblocking filter process to reduce distortion between the original and deblocked pictures. Moreover, a picture filtered by BALF can be used as a reference picture for incoming pictures in decoding order. In general, the optimal filter coefficients of the Wiener filter are calculated by minimizing the mean square error between the original input pixels and deblocked pixels. The BALF decides the optimal block size, dividing a picture into block sizes such as 8×8, 16×16, 24×24, 32×32, 48×48, 64×64, 96×96, or 128×128, and sends a flag on a block basis to indicate whether a block is filtered or not [4]. In [5], the tap length of a Wiener filter can be selected from a 5×5, 7×7, or 9×9 tap on a slice basis. For example, in the case of a 9×9 tap length of a Wiener filter, 81 filter coefficients have to be transmitted to the decoder side. Transmitting such an amount



C0	C1	C2	C3	C4
C5	C6	C7	C8	C9
C10	C11	C12	C11	C10
C9	C8	C7	C6	C5
C4	C3	C2	C1	C0

Fig. 1. Example of 5×5 Wiener filter with central symmetric structure.

Manuscript received Nov. 30, 2009; revised Apr. 28, 2010; accepted May 18, 2010.

This work was supported by the IT R&D program of MKE/KCC/KEIT [KI001932, Development of Next Generation DTV Core Technology], Rep. of Korea.

Hahyun Lee (phone: +82 42 860 6138, email: hanilee@etri.re.kr), Sung-Chang Lim (email: sclim@etri.re.kr), Seyoon Jung (email: jsy@etri.re.kr), Jongho Kim (email: pooney@etri.re.kr), and Jin Soo Choi (jschoi@etri.re.kr) are with the Broadcasting & Telecommunications Convergence Research Laboratory, ETRI, Daejeon, Rep. of Korea.

Haechul Choi (email: choihc@hanbat.ac.kr) was with the Broadcasting & Telecommunications Convergence Research Laboratory, ETRI, Daejeon, Rep. of Korea, and now is with the Division of Information Communication & Computer Engineering, Hanbat National University, Daejeon, Rep. of Korea.

doi:10.4218/etrij.10.0209.0487

of side information for each slice could degrade the coding efficiency. In an adaptive interpolation filter (AIF), which also uses the Wiener filter to improve the coding efficiency, the filter coefficients are reduced under the assumption that statistical properties of the image signal are symmetrical. Similar to the AIF, the BALF uses this assumption to reduce the filter coefficients. In the BALF, the filter coefficients are symmetric with respect to the center point as shown in Fig. 1. In Fig. 1, the shaded letters are only transmitted to the decoder side.

II. Proposed Methods

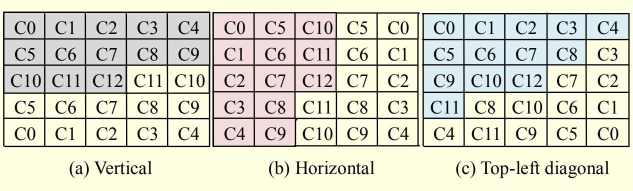
Note that the assumption of symmetry can provide a good trade-off between the accuracy of a loop filter and the overhead bits used to transmit the filter coefficients. However, since the statistical properties of the video sequence can vary spatially or temporally, a fixed single symmetry assumption would not be appropriate for every frame in a video sequence. For example, some frames in a video sequence may contain relatively complex scenes that hold neither vertical nor horizontal symmetry, whereas the scenes in other frames are well characterized by one of either symmetry type. For this reason, in addition to the central symmetric structure described in Fig 1, we define three more filters with different symmetric structures to reflect the varying statistical properties of a video sequence. In detail, the following filter symmetric structures are used in the proposed method.

- Filter with vertical symmetry. Here, we assume that an image signal has only vertical symmetry, but no horizontal, top-left diagonal, central, or other symmetries.
- Filter with horizontal symmetry. Here, we assume that an image signal has only horizontal symmetry, but no vertical, top-left diagonal, central, or other symmetries.
- Filter with top-left diagonal symmetry. Here, we assume that an image signal has only a top-left diagonal symmetry, but no vertical, horizontal, central, or other symmetries.

Figure 2 illustrates examples of 5×5 Wiener filters each with a vertical, horizontal, or top-left diagonal symmetric structure. In Fig. 2, the letter on each position represents a filter coefficient index. The indices with the same letter share the same filter coefficient. In the proposed method, symmetric structure and filter coefficients are selected on each slice to capture the characteristics of each frame in a video sequence so that the error between the original frame and filtered reconstructed frame could be further minimized.

In order to determine the optimal filter symmetric structure for a frame among multiple filters, the rate-distortion (RD) optimization is used.

$$J = D_{\mathrm{F}} + \lambda \times R_{\mathrm{F}},$$



C0	C1	C2	C3	C4
C5	C6	C7	C8	C9
C10	C11	C12	C11	C10
C5	C6	C7	C8	C9
C0	C1	C2	C3	C4

(a) Vertical

C0	C5	C10	C5	C0
C1	C6	C11	C6	C1
C2	C7	C12	C7	C2
C3	C8	C11	C8	C3
C4	C9	C10	C9	C4

(b) Horizontal

C0	C1	C2	C3	C4
C5	C6	C7	C8	C3
C9	C10	C12	C7	C2
C11	C8	C10	C6	C1
C4	C11	C9	C5	C0

(c) Top-left diagonal

Fig. 2. Examples of 5×5 Wiener filters each with a vertical, horizontal, or top-left diagonal symmetric structure.

where the D_{F} is a distortion measured by the mean square error between the original and filtered frames, λ is the Lagrange multiplier, and R_{F} denotes generated bits for filter coefficients, filter symmetry structure indicator, and control flags for BALF. The filter coefficients and filter symmetric structure resulting in minimum RD cost, J, are selected as the optimal filter coefficients and filter symmetric structure.

The proposed method consists of the four steps below.

Step 1. The filter coefficients for each filter symmetric structure are obtained by solving the Wiener-Hopf equations.

Step 2. The block-based filtering process using the filter coefficients for each symmetric structure obtained in the Step 1 is performed. The filtering process is based on the BALF.

Step 3. The RD cost is calculated for each filter symmetric structure.

Step 4. The filter symmetric structure resulting in the minimum RD cost is selected as the optimal filter symmetric structure. Then, the optimal filter symmetric structure and its coding results are stored.

III. Experimental Results

The proposed method is implemented on KTA software version 2.2r1 and compared with JM11.0 of H.264/AVC. Three 720p (1280×720) and two 1080p (1920×1080) sequences are used for the experiment under a VCEG common test condition [6]. One hundred and forty-five frames of 720p and 121 frames of 1080p sequences are coded using hierarchical B prediction structures. To see the improvement of the proposed method, we computed the Bjøntegaard delta

Table 1. Four filter symmetric structures and assigned filter modes used in proposed method.

Symmetric Structure	Mode
Central	0
Vertical	1
Horizontal	2
Top-left diagonal	3

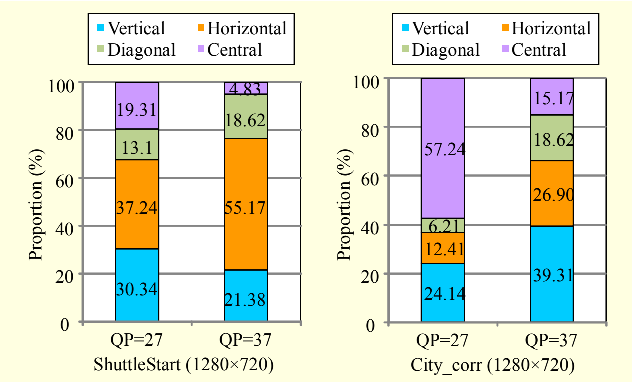


Fig. 3. Proportion of filter symmetric structures.

Table 2. Experimental results of JM11.0 and proposed method.

Sequence	QP	JM11.0		Proposed method		BD-bitrate (%)	BD-PSNR (dB)
		Bitrate (kbps)	PSNR (dB)	Bitrate (kbps)	PSNR (dB)		
City _corr (720p)	22	10197.26	38.51	9471.41	38.8	–10.06	0.33
	27	3196.8	36.25	3159.92	36.58		
	32	1331.94	33.48	1329.97	33.76		
	37	705.67	30.36	711.52	30.62		
Shuttle Start (720p)	22	1489.45	43.52	1412.24	43.70	–8.29	0.23
	27	571.02	41.67	562.36	41.87		
	32	280.89	39.54	283.41	39.82		
	37	143.34	37.27	151.25	37.57		
Jets (720p)	22	1813.84	41.39	1745.00	41.51	–7.50	0.20
	27	632.06	40.10	623.77	40.27		
	32	346.93	38.23	345.27	38.44		
	37	211.98	35.93	213.03	36.21		
Traffic (1080p)	22	5283.5	41.18	5238.83	41.33	–4.13	0.20
	27	2581.61	38.03	2560.80	38.2		
	32	1319.61	34.88	1316.93	35.07		
	37	710.94	31.84	713.26	32.02		
Sun flower (1080p)	22	2932.06	43.57	2823.66	44.20	–18.00	0.79
	27	1412.12	41.71	1387.91	42.38		
	32	763.73	39.23	741.57	39.94		
	37	475.13	36.32	444.97	36.92		

(BD)-bitrate and BD-PSNR [7], which provided a relative gain between the two methods by measuring the average difference between the two RD-curves. For the experiment, four types of filter symmetric structures, shown in Table 1, were used. First, we investigated the percentage of the filter symmetric structures. As shown in Fig. 3, after we applied three more filters, a large percentage of central symmetric structure was moved to newly added symmetric structures. We found that the selection percentage of each symmetric structure relies on characteristics of a video sequence. Table 2 shows the experimental results of H.264/AVC JM11.0 and the proposed method for various sequences. Table 3 shows the coding performance comparison between the BALF and the proposed method. The average BD-bitrate reduction of the proposed method and BALF is 9.60% and 8.83% in comparison with H.264/AVC JM11.0, respectively. Note that a 0.77% reduction of the average BD-bitrate is achieved by the proposed method relative to the BALF. The computational overhead (ΔEnc/ΔDec) of the proposed method is also tabulated in Table 3. In comparison with the BALF, the computational complexity in the encoder increased by an average of 10% due to the added symmetric structures. However, since the data path of each symmetric structure is independent, the parallel implementation can be adopted to make the computational complexity level of the proposed method similar to the BALF. On the other hand, the decoder has almost the same computational complexity as the BALF.

Table 3. Coding performance comparison between BALF vs. proposed method.

Sequence	BALF		Proposed method		ΔBD-bitrate (%)	ΔBD-PSNR (dB)	ΔEnc (%)	ΔDec (%)
	BD-bitrate (%)	BD-PSNR (dB)	BD-bitrate (%)	BD-PSNR (dB)				
City_corr	–9.84	0.33	–10.06	0.33	–0.22	0.00	7.65	–0.87
ShuttleStart	–7.16	0.21	–8.29	0.23	–1.13	0.02	11.76	–0.59
Jets	–6.60	0.18	–7.50	0.20	–0.90	0.02	10.61	–1.32
Traffic	–3.63	0.17	–4.13	0.20	–0.50	0.03	10.45	–3.24
Sunflower	–16.92	0.77	–18.00	0.79	–1.08	0.02	10.00	–0.34

IV. Conclusion

In this letter, we have presented an enhanced block-based adaptive loop filter that uses multiple filters with different symmetric structures. The proposed method selects an optimal filter symmetric structure on a slice basis in an RD sense to exploit the varying statistical properties of video sequences. The experimental results show that the proposed method achieves up to an 18% reduction in BD-bitrate when compared to H.264/AVC. It also shows a better compression performance compared with the BALF.

In future work, we will apply the proposed method to the quadtree-based adaptive loop filter [8].

References

[1] ISO/IEC JTC 1, "Draft Call for Proposals on High-Performance Video Coding (HVC)," Doc.N10926, Oct. 2009.

[2] ITU-T SG16, "Draft Call for Proposals for Next-Generation Video Coding Standardization," TD152(PLEN/16), Nov. 2009.

[3] J. Lee et al., "Intra-Mixture Prediction Mode and Enhanced Most Probable Mode Estimation for Intra Coding," *ETRI J.*, vol. 31, no. 5, Oct. 2009, pp. 610-612.

[4] T. Chujoh et al., "Block-Based Adaptive Loop Filter," ITU-T SG16/Q.6 Doc. VCEG-AI18, July 2008.

[5] T. Chujoh et al., "Improvement of Block-based Adaptive Loop Filter," ITU-T SG16/Q.6 Doc. VCEG-AJ13, Oct., 2008.

[6] T.K. Tan, G. Sullivan, and T. Wedi, "Recommended Simulation Common Conditions for Coding Efficiency Experiments Revision 4," ITU-T SG16/Q.6 Doc. VCEG-AJ10r1, July 2008.

[7] G. Bjøntgaard, "Calculation of Average PSNR Differences between RD-Curves," ITU-T SG16 Q.6 VCEG, Doc. VCEG-M33, 2001.

[8] T. Chujoh, N. Wada, and G. Yasuda, "Quadtree-Based Adaptive Loop Filter (QALF)," IUT-T SG16/Q.6 Doc. COM16-C181-E, Jan. 2009.