Loop-filtering and Post-filtering for Low Bit-rates Moving Picture Coding

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Abstract

The decompressed images from highly compressed data have noticeable image degradations such as blocking artifacts, corner outliers, and ringing noise, because most image coding standards quantize the DCT coefficients of 8×8-pixel blocks independently. A loop-filtering algorithm and a post-filtering algorithm, which can reduce the quantization effects, are described, and the performances of both algorithms are compared with respect to the image quality, the computational complexity, and the compressed bit rates. Both the loop-filtering algorithm and the post-filtering algorithm reduce the quantization effects adaptively by using both DCT domain analysis and temporal information.

1. Introduction

Most video compression standards, including ITU-T H.263 [1-2] and MPEG-4 [3], use a block-based discrete cosine transform (DCT) and a block-based motion compensation (MC). The 8×8 block-based DCT scheme, which is used to pack information into a few transform coefficients, takes advantage of the spatial correlation property of images. However, this block-based coding induces the well-known blocking artifacts, corner outliers, and ringing noise, particularly, when the image is highly compressed. The blocking artifacts are the grid noise along the block boundaries in a relatively homogeneous area. Corner outliers occur at the corner points of the 8×8 blocks, and the ringing noise is due to truncation of the high-frequency coefficients by quantization.

The loop-filtering methods have been proposed for low bit-rates moving picture coding to reduce the blocking artifacts [4]. The method has simply used 3-tab low pass filter (LPF) of (1,14,1) in order to reduce blocking artifacts at the block boundary. However, (1,14,1) filter is too weak to reduce the blocking artifacts even if PSNR can be improved. Several post-filtering algorithms have been proposed to reduce the quantization effects of block-based coding [5-6]. Such algorithms can enhance the PSNR and the subjective image quality significantly. However, the main drawback of these post-processing methods is their computation complexity for their real implementation.

In this paper, a loop-filtering method and a post-filtering method [7] with low computation complexity are described and applied to TMN10 (H.263+) [2]. The two methods are compared with respect to the computation complexity, the image quality, and the compressed bit rates.

2. The flags of blocking artifacts and ringing noise

In order to perform an efficient reduction of the quantization effects and to reduce the number of computations in H.263+, two kinds of 8×8 block-based flags are defined; the blocking flags and the ringing flag. The blocking and the ringing flags are extracted from each 8×8 block of the INTRA macroblock in DCT domain. Also, the flags of each block in the INTER macroblock are calculated from both the residual signal in DCT domain and the flags of the reference macroblocks pointed by the corresponding motion vectors. Although the blocking flags for both the loop-filtering and post-filtering methods are extracted in the same way, the deblocking algorithm of the loop-filtering method is slightly different from that of the post-filtering method. The ringing flags for loop-filtering and post-filtering methods are extracted in a different way but the same deringing filter is applied to both filtering methods. The post-filtering is applied only to the decoded image so that it is not applied to the encoder. However, the loop-filtering is applied to the reconstructed image which is used as a reference image for motion estimation and compensation, so that it is required both in the encoder and the decoder. In the loop-filtering method, the motion estimation and compensation are performed to the filtered reference frame. Therefore, the motion vectors and the compressed bit rates can be changed from those without loop-filtering, whereas the post-filtering method does not affect the motion vectors and bit rates.

In INTRA macroblock, the distribution of the inverse quantized coefficients (IQC), which is the DCT coefficients after inverse quantization, is investigated.

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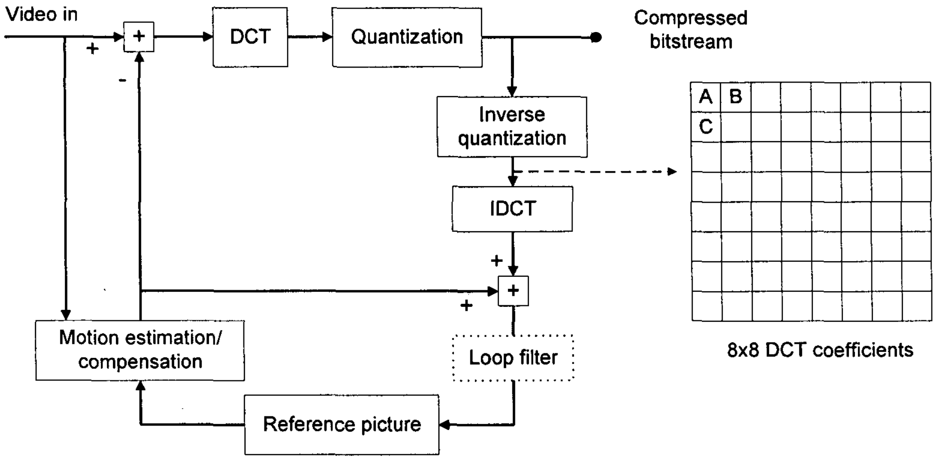

Figure 1. Encoder block diagram of H.263+ and 8×8 block of DCT coefficients after inverse quantization.

Figure 1 shows the encoder block diagram of the base line H.263. In the 8×8 inverse quantized block of Fig. 1, the coefficients of A, B, and C are used for deciding the blocking and the ringing flags.

When only the coefficient in position A of 8×8 DCT block has a non-zero value, a block having only a DC component can induce horizontal and vertical blocking artifacts. In this case, both the horizontal blocking flag (HBF) and the vertical blocking flag (VBF) of the block are set to "1". When only the coefficients in the top row of the 8×8 inverse quantized block have non-zero values, this block may induce vertical blocking artifacts between the current block and the vertically adjoining blocks, so the VBF is set to "1". When only the coefficients in the far-left column have non-zero values, this block may induce horizontal blocking artifacts between the current block and the horizontally adjoining blocks, so the HBF is set to "1".

The ringing flag (RF) is composed of RF0 and RF1. The RF0 is set to "1" if any non-zero DCT coefficients exist in positions other than A, B, and C of 8×8 DCT block in Fig. 1. The high-frequency coefficients mean that the block includes image edges. Therefore, the block can produce the ringing noise around the image edges due to the truncation of the high-frequency coefficients. These three flags of HBF, VBF, and RF0 are stored in three bits for each block. No additional calculation is required to extract the flags. The flag information can be extracted in decoder at the same way.

In INTER macroblock, the HBF and the VBF of current inter block can be calculated by a bit-wise AND operation on the HBF and the VBF of the reference blocks, respectively. In this case, the AND operation is performed for only the reference blocks which are overlapped by the motion-estimated block with the overlapped regions wider than one pixel. In the loop-filtering method, the quantization effects can be reduced by only weak filter because the reference image is already filtered. Therefore, the RF0 and the RF1 of INTER blocks in the loop-filtering are derived in the different way from those in the post-filtering. In the loop-filtering method, the RF0 of the current block is set to "1" if only the DC component of IQC of the residual signals is non-zero. The RF0 is used to decide the deblocking filters for the INTER blocks. The RF1 of the current block is set to "1" if any AC components of IQC of the residual signals is non-zero. This decision procedure for RF is applied to both the encoder and the decoder in the same way. The RF is not propagated from the reference frame in the loop-filtering method. In the post-filtering method, the RF1 of the current block is set to "1" if any AC component of IQC of the residual signals is non-zero. The RF0 of a block which has the 8×8 prediction mode in H.263+ is also set to "1". If the RF0 is still "0" after the above decision, the RF0 of the current block can be calculated by a bit-wise OR operation on the RF0 of the overlapped reference blocks for which the overlapped regions are wider than one pixel.

3. The proposed filtering methods

3.1 Deblocking filter

One-D LPF to reduce the blocking artifacts is performed strongly or weakly, depending on the blocking flags, on the horizontal block boundary and on the vertical block boundary. The proposed deblocking algorithm does not require image-edge detection, which requires a large number of computations, because it utilizes the block-based blocking flags obtained in Section 2. For the current 8×8 block, B_i, and an horizontal adjoining block, B_j, the blocking artifact reduction is performed for the block boundary between B_i and B_j.

Deblocking filter in loop-filtering: Horizontal deblocking filtering of loop-filtering method can be summarized as follows:

In INTRA frame, if RF0 of B_i and RF0 of B_j are both 0 and HBF of B_i and HBF of B_j are both 0, strong deblocking filtering is performed. Otherwise, weak filtering is performed. In INTER frame, if B_i and B_j are both "*Not coded*" block, no filtering is performed. If RF1 of B_i is 0 and both B_i and B_j are "*INTRA_BLOCK*" and both HBF of B_i and HBF of B_j are 1, or if RF1 of B_i is 0 and both RF0 of B_i and RF0 of B_j are 1 and both HBF of B_i and HBF of B_j are 1, strong deblocking filtering is performed. Otherwise, weak filtering is performed, in which "*NOT coded*" means skipped macroblock and "*INTRA_BLOCK*" is a block in INTRA macroblock. As explained in Section 2, RF1 of I (Intra) frame is not always used because I frame is only composed of INTRA macroblock.

Deblocking filter in post-filtering: Horizontal deblocking filtering in the post-filtering can also be summarized as follows:

In INTRA frame, post-filtering is performed in the same way as loop-filtering. In INTER frame, If RF1 of B_i is 0 and both HBF of B_i and HBF of B_j are 1, strong deblocking filtering is performed. Otherwise, weak filtering is performed.

The strong deblocking filtering in both the loop-filtering and the post-filtering is a convolution process with 7-tap coefficients (1,1,1,2,1,1,1) for six pixels on the horizontal block boundary. However, the weak filtering for the post-filtering is different from that of the loop-filtering. Four pixels on block boundary are smoothed in the post-filtering if the difference between two pixels on the block boundary is smaller than QP [7], whereas two pixels C and D on the block boundary are replaced as $C=C+(D-C)/4$ and $D=D-(D-C)/4$ in loop-filtering if $|D-C|$ is smaller than QP, where the parameter QP is the quantization parameter of H.263.

The deblocking filtering of the proposed loop-filtering and post-filtering methods changes the pixel values on the block boundary in order to reduce the 1-D artificial discontinuity. Vertical filtering is performed in the same way as horizontal filtering. The proposed deblocking algorithm, which can be implemented in hardware by block-based parallel processing, requires only shift and addition operations for strong filtering and weak filtering.

3.2 Compensation of corner outliers

Corner outlier compensation is only performed in INTRA frame. A corner outlier [7] is characterized by a pixel which is either much larger or much smaller than its neighboring pixels in the corner point of an 8×8 block of the decompressed image. When a dark-gray region is distributed over four blocks and one or two pixels of the dark-gray region are located in the corner points of neighboring blocks, the corner points can be distorted by quantization of the DCT coefficients. This point is called a corner outlier. In order to reduce the corner outlier, the corner outlier must be detected and compensated for [7].

3.3 Deringing filter for reducing ringing noise

Prior to applying the deringing filtering for each block, the RF's are investigated. Deringing filtering in the loop-filtering and the post-filtering can also be summarized as follows:

Deringing filtering in loop-filtering:

```
if( $B_i$ ==NOT coded)      No filtering;
if( INTRA frame )
    if( RF0 of $B_i$ ==1) filtering;
    else                  filtering;
if( INTER frame)
    if( $B_i$ ==INTRA_BLOCK) filtering;
    else
        if( $B_i$ ==INTER4V_BLOCK ) filtering;
        else{ if( RF1 of $B_i$ ==1 ) filtering;
                else        No filtering;
        }
```

Deringing filtering in post-filtering:

```
if( RF0 of $B_i$ ==1|| RF1 of $B_i$ ==1)    filtering;
else        No filtering;
```

The deringing filtering consists of two processes of edge detection and 2-D signal adaptive filtering (2-D SAF). In order to prevent the image details from being distorted by filtering, simple edge detection is performed before filtering. Edge detection and 2-D SAF are applied to an 8×8 block assigned for deringing filtering in order to reduce the ringing noise [7].

4. Simulation results

The simulation was performed with unrestricted motion estimation, advanced prediction mode, advanced INTRA coding mode and a TMN8 rate control of H.263+ TMN10 (H.263 version 2) [3]. QCIF image sequences, each of which had 300 frames, were used for this simulation. Each sequence was compressed with the scheme of I,P,P,P,P.... The computer simulations were carried out to demonstrate the performance of the proposed loop-filtering and post-filtering which reduces the blocking artifacts, corner outliers, and ringing noise. The total number of instructions and memory access statistics related with the run-time software and hardware complexity were calculated to evaluate the computation complexity on the Ultra Sparc machine.

Table 1 shows the PSNR and bit-rates of the TMN 10 only, TMN 10 with loop-filtering, and TMN 10 with post-filtering, where INTRA PSNR means the PSNR of the first frame and Avg. PSNR means the average PSNR of all decoded frames. The PSNR of the post-filtering algorithm is slightly better than both TMN10 decoder and TMN10 decoder with loop-filtering algorithm for most of the test sequences in Table 1. However, the loop-filtering algorithm produces lower bit rates than TMN10 encoder. The total number of instructions (in million instructions per second) and the total memory access statistics (in Mbytes per second) for each sequence are compared in Table 2. According to the comparison studies, the average number of instructions and the average memory access statistics of the loop-filtering are 22.8 percent and 23.8 percent of the post-filtering, respectively, which correspond to 35.8 percent and 33.8 percent of those of the TMN10 decoder, respectively. As an example, the number of instructions and the memory access statistics for the loop-filtering algorithm only in "Hall monitor" are 6.3 MIPS and 6.8 Mbytes/sec.

In subjective quality assessment, the loop-filtering and post-filtering methods show very similar results. A 120th-frame image of the "Hall Monitor" sequence is shown in Fig. 2. The original image, Fig. 2(a), was compressed with QP of 18, a frame rate of 7.5 Hz, and a spatial resolution of 176×144 (QCIF). The decompressed image is shown in Fig. 2(b). Both the loop-filtering in Fig. 2(c) and the post-filtering in Fig. 2(d) show better performance than Fig. 2(b).

5. Conclusions

The proposed loop-filtering and post-filtering methods reduce the quantization effects of the decompressed images by using flags and adaptive filters. The blocking and ringing flags of each block contribute to reducing the computational complexity of the loop-filtering algorithm. The motion vectors in the INTER frame are used to extract the blocking and the ringing flags. In this experiment, the loop-filtering method requires much low computation complexity in comparison with the post-filtering method.

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Bitrates, Size, Frame rates	Sequences	Fixed QP	A			B			C	
			INTRA PSNR (Y)	Avg. PSNR (Y)	bitrates (kbps)	INTRA PSNR (Y)	Avg. PSNR	bitrates (kbps)	INTRA PSNR (Y)	Avg. PSNR (Y)
10kbps, QCIF, 7.5Hz	Hall	18	31.29	30.10	9.534	31.65	30.31	9.438	31.67	30.33
	M & D	15	33.46	32.31	8.798	33.80	32.42	8.744	33.79	32.48
	Container	17	31.22	29.72	9.912	31.35	29.67	9.957	31.37	29.78
24kbps, QCIF, 10Hz	Hall	9	35.61	34.25	25.048	35.80	34.42	24.506	35.82	34.53
	M & D	8	37.11	35.33	22.941	37.21	35.32	23.050	37.20	35.44
	Container	9	35.06	33.29	26.233	35.16	33.30	26.027	35.18	33.40
	Silent voice	14	32.05	30.72	21.039	32.13	30.77	20.714	32.13	30.83

Table 1. Comparison of PSNR and bit rates of the TMN10 decoder only, the TMN10 decoder with loop-filtering, and the TMN10 decoder with post-filtering for the test sequences. Where A : TMN10 decoder, B : TMN10 decoder + loop filter, C : TMN10 decoder + post filter. Y represents the luminance signal.

Bitrates, Size, Frame rates	Sequences	Total Instructions (MIPS)			Memory Bandwidth (Mbyte/sec)		
		A	B	C	A	B	C
10kbps, QCIF, 7.5Hz	Hall monitor	28.59	**34.92**	63.79	33.69	**40.49**	69.63
	M & D	29.72	**37.28**	71.78	34.35	**42.61**	77.43
	Container	29.12	**36.19**	61.65	34.10	**41.78**	67.27
24kbps, QCIF, 10Hz	Hall monitor	39.22	**48.76**	93.97	46.22	**56.52**	102.82
	M & D	41.43	**58.79**	102.48	47.71	**66.41**	110.87
	Container	39.79	**51.45**	91.32	46.57	**59.23**	99.75
	Silent voice	41.09	**57.04**	114.75	47.28	**64.39**	123.64

Table 2. Comparison of the number of instructions per a second and the memory access statistics per a second for the TMN10 decoder only, the TMN10 decoder with loop-filtering, and the TMN10 decoder with post-filtering.


(a) (b) (c) (d)

Figure 2. The original 120th-frame image in the "Hall monitor" sequence and the loop-filtered and post-filtered image in the TMN10 decompressed image (fixed QP=18, 7.5 frame/sec, 24kbps): (a) Original image, (b) TMN10 decompressed image, (c) loop-filtered image, and (d) post-filtered image.