# A Deblocking Filter with Two Separate Modes in Block-Based Video Coding

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***Abstract*—This paper presents a method to remove blocking artifacts in low bit-rate block-based video coding. The proposed algorithm has two separate filtering modes, which are selected by pixel behavior around the block boundary. In each mode, proper one-dimensional filtering operations are performed across the block boundary along the horizontal and vertical directions, respectively. In the first mode, corresponding to flat regions, a strong filter is applied inside the block as well as on the block boundary because the flat regions are more sensitive to the human visual system (HVS) and the artifacts propagated from the previous frame due to motion compensation are distributed inside the block. In the second mode, corresponding to other regions, a sophisticated smoothing filter, which is based on the frequency information around block boundaries, is used to reduce blocking artifacts adaptively without introducing undesired blur. Even though the proposed deblocking filter is quite simple, it improves both subjective and objective image quality for various image features.**

***Index Terms*—Block-based coding, blocking artifacts, deblocking, postprocessing technique.**

## I. Introduction

TRADITIONAL block-based video coders such as H.261, MPEG-1, and MPEG-2 suffer from annoying blocking artifacts when they are applied in low bit-rate coding because interblock correlation is lost by block-based prediction, transformation, and quantization. In order to overcome the blocking artifact problem, various nonblock-based coding schemes have been proposed. Among them, the lapped orthogonal transform [1] and embedded zero-tree wavelet coding [2] have been proposed as a nonblock-based texture coding method, and warping prediction [3] and overlapped block motion compensation (OBMC) [4] have been proposed as a non block-based prediction method. Although these activities have drawn a lot of interest, recent international standards regarding low bit-rate video coding tend to adopt the block-based coding scheme as a baseline method considering performance, complexity, compatibility, market requirements, and so on. Therefore, as a postprocessing method, deblocking filtering is regarded as important due to improvement of visual quality in low bit-rate video coding. Even though the OBMC technique is adopted for deblocking in the recent low bit-rate video coder, H.263 [5], it cannot prevent the blocking artifacts caused by block-based texture coding and the artifacts propagated from the previous reconstructed frame. Therefore, additional postprocessing operations are required for better image quality.

Many deblocking schemes have been proposed in still image coding such as JPEG under the assumption that blocking artifacts are always located at block boundaries. In video coding, however, the blocking artifacts of the previous frame can be propagated to the current frame, and can be located at any position in a block due to motion-compensated prediction. Therefore, simple block boundary smoothing is not good enough to remove blocking artifacts appearing in video coding, so a more complicated scheme is needed. Iterative methods based on projection on a convex set [6], [7] may be a candidate algorithm. However, it is not adequate for real-time video coding due to its complexity. In contrast, a smoothing scheme based on edge information [8] may be easier to adapt to video coding. However, unlike a single still image, a video sequence consists of a set of image frames having various features, so it is hard to find a proper threshold value for each frame to make a good edge map in real time. Therefore, this scheme may suffer from inaccurate edge detection, which misinterprets blocking artifacts as edges or incurs undesirable blur.

In order to find an efficient deblocking filter, we investigate smoothing features in a video sequence in terms of the human visual system (HVS). According to these features across the block boundary, a deblocking filter with two separate modes is proposed. Each filter is a one-dimensional filter appropriate for real-time application. For the mode decision independent of artifact position, we examine the existence of the offset in the region rather than the existence of the edge around the block boundary. In a very smooth region with small dc-like offset, strong smoothing is applied inside the block as well as on the block boundary. In other regions, a sophisticated smoothing operation is applied to reduce blocking artifacts without introducing undesirable blur by using the frequency information around the block boundary. It has been shown that the proposed deblocking filter improves not only subjective image quality, but also objective image quality for various image features.

## II. Proposed Deblocking Filter

Based on three major observations, we propose a deblocking filter having two separate filtering modes. The proposed filter performs one-dimensional filtering along the boundaries of an $8 \times 8$ block (see Fig. 1). The filtering process consists of three major functional blocks, i.e., mode decision, filtering for the smooth region mode, and filtering for the default mode (see Fig. 2).

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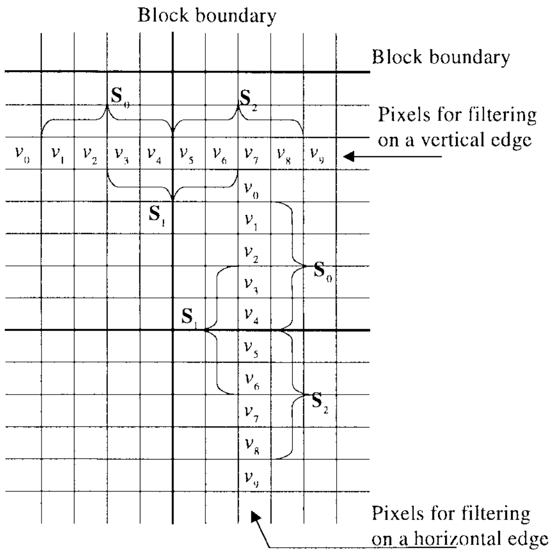



Fig. 1. 8 × 8 block boundaries.

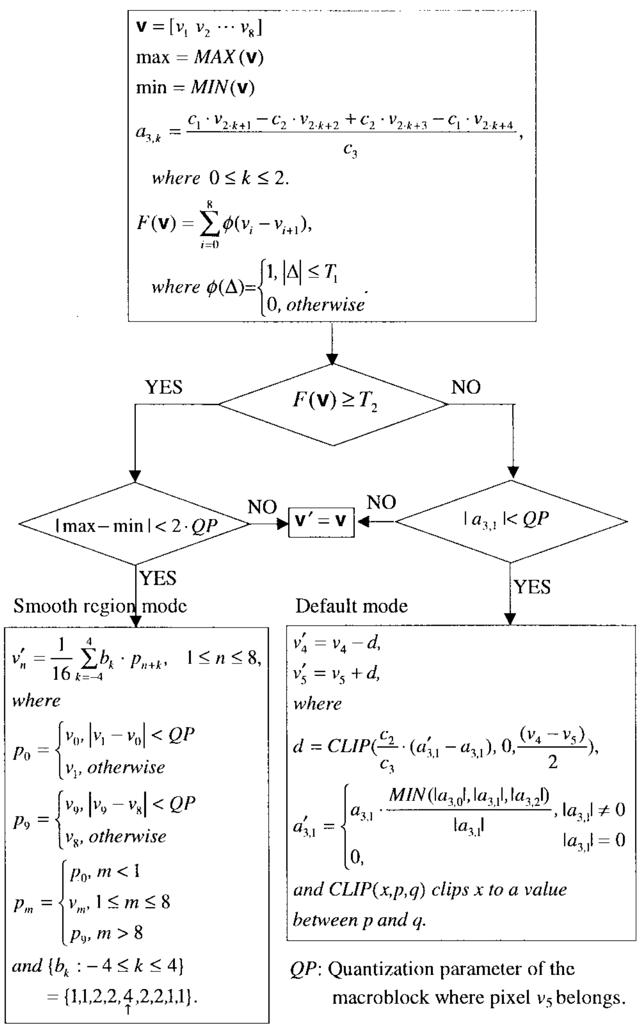



Fig. 2. Structure of the proposed deblocking scheme.

## A. Observations

A major operation of the deblocking filter is smoothing. But smoothing may introduce different effects according to local image characteristics across block boundaries. When we consider a smoothing operation to remove blocking artifacts in video coding, we find three interesting observations. First, the HVS is more sensitive to blocking artifacts in flat regions than in complex regions [9]. Therefore, a strong smoothing filter is required on those regions. In complex regions, however, smoothing of a few pixels around the block boundary is enough to achieve a desired deblocking effect. Second, smoothing operations tend to introduce more undesirable blur in complex regions than in flat regions. Hence, adaptive smoothing to preserve image details is desirable in complex regions. Third, because of motion compensation, blocking artifacts are propagated, and the propagated artifacts are more visible in flat regions than in complex regions. Therefore, smoothing in flat regions must cover the inside of a block as well as block boundaries.

From the observations above, it is found that the use of two separate filters depending on local image characteristics is preferable for effective deblocking. The filter for flat regions should provide a strong smoothing effect inside a block as well as on block boundaries. On the other hand, the filter for complex regions is required to work only on block boundaries. In the following discussions, the filtering modes for flat regions and for complex regions will be called a smooth region mode and a default mode, respectively.

## B. Mode Decision

To select a proper mode between the smooth region mode and the default mode, local image characteristics in the region are to be examined. In the proposed scheme, we examine the flatness of the region by using the following measurement:

$$F(\boldsymbol{v}) = \sum_{i=0}^{8} \phi(v_i - v_{i+1})$$

where

$$\phi(\Delta) = \begin{cases} 1, & |\Delta| \le T_1 \\ 0, & \text{otherwise.} \end{cases} \tag{1}$$

In (1), $T_1$ is set to a small value so that $F(\boldsymbol{v})$ may reflect the flatness of the local image across a block boundary. If $\boldsymbol{v}$ is dc like, $F(\boldsymbol{v})$ has a big value, larger than a certain threshold $T_2$. In that case, $\boldsymbol{v}$ is assigned to the smooth region mode, and strong smoothing is applied; otherwise, $\boldsymbol{v}$ is assigned to the default mode, and accurate and adaptive filtering is applied. Noticeable blocking artifacts may result from the concatenation of two flat regions with a small offset. In this case, the smooth region mode is selected because $F(\boldsymbol{v})$ still has a big value due to the two flat regions. It should be noticed that the value of $F(\boldsymbol{v})$ does not depend on the location of blocking artifacts since it is obtained from the difference values between neighboring pixels.

## C. Filtering in the Smooth Region Mode

In this mode, we apply a nine-tab smoothing filter (see Fig. 2) inside the block as well as on the block boundaries. To prevent real edges in the filtering region from smoothing, however, filtering is not performed when the difference

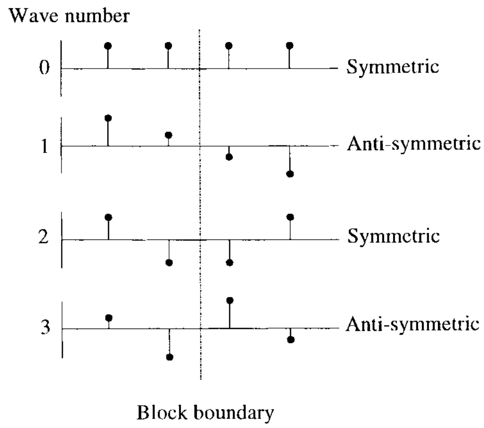



Fig. 3. DCT basis vectors for four points of $S_1$.

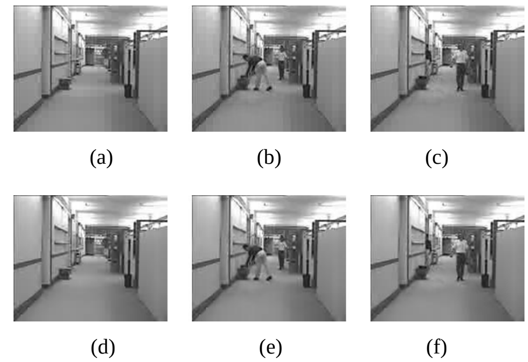



Fig. 4. Deblocking results for *Hall Monitor* sequence (QCIF, 10 kbits/s, 7.5 Hz). (a), (b), and (c) are the zeroth, one-hundred-twentieth, and two-hundred-fortieth reconstructed images, respectively. (d), (e), and (f) are deblocking results of (a), (b), and (c), respectively.

between the maximum value and the minimum value of $\boldsymbol{v}$ is larger than a certain value, $2QP$. Here, $QP$ is the quantization parameter of the macroblock to which pixel $v_5$ belongs. This is because the offset related to blocking artifacts is usually a small value, and is highly related to quantization parameter. In actual implementation, the 9-tab filtering can be simplified by using shift and addition operations only.

### D. Filtering in the Default Mode

As was mentioned, the default mode is applied on complex regions. In this mode, we smooth the two block boundary pixels $v_4$ and $v_5$ only, and use the four-point DCT as a frequency analysis tool to get the feature information of the pixel array. As shown in Fig. 1, if a four point pixel array $\boldsymbol{S}_1$ is located across the block boundary, four-point DCT basis vectors of $\boldsymbol{S}_1$ have symmetric and anti-symmetric properties around the center of four points, or the block boundary (refer to Fig. 3). We define $a_{0,1}, a_{1,1}, a_{2,1}$, and $a_{3,1}$ as the four-point DCT coefficients of $\boldsymbol{S}_1$. Then it is noticed that the high-frequency antisymmetric component $a_{3,1}$ is a major factor affecting the blocking artifact. This means that the proper adjustment of $a_{3,1}$ is directly related to the reduction of block discontinuity in the spatial domain. Thus, in this mode, the magnitude of $a_{3,1}$ is reduced by using a scaling factor $\mathrm{MIN}(|a_{3,0}|, |a_{3,1}|, |a_{3,2}|)/|a_{3,1}|$ whose value is between 0 and 1. The flatter the neighboring regions are, the smaller the scaling factor is. By doing this, the block boundary is smoothened in smooth regions and is not affected in complex regions so that undesirable blurring can be prevented. If the magnitude of $a_{3,1}$ is greater than a certain value (which is related to the quantization parameter), however, the filter is not applied to preserve the image details.

Refer to Fig. 2 for a detailed filtering procedure. Here, $[c_1, -c_2, c_2 - c_1]/c_3$ denotes a DCT kernel corresponding to the highest frequency component $a_{3,k}$. If we describe a four-point DCT/IDCT of $\boldsymbol{S}_1$ in matrix form, we have

$$\begin{bmatrix} a_{0,1} \\ a_{1,1} \\ a_{2,1} \\ a_{3,1} \end{bmatrix} = \begin{bmatrix} k_0 & k_0 & k_0 & k_0 \\ k_1 & k_3 & -k_3 & -k_1 \\ k_2 & -k_2 & -k_2 & k_2 \\ k_3 & -k_1 & k_1 & -k_3 \end{bmatrix} \begin{bmatrix} v_3 \\ v_4 \\ v_5 \\ v_6 \end{bmatrix} \tag{2a}$$

$$\begin{bmatrix} v_3 \\ v_4 \\ v_5 \\ v_6 \end{bmatrix} = \begin{bmatrix} k_0 & k_1 & k_2 & k_3 \\ k_0 & k_3 & -k_2 & -k_1 \\ k_0 & -k_3 & -k_2 & k_1 \\ k_0 & -k_1 & k_2 & -k_3 \end{bmatrix} \begin{bmatrix} a_{0,1} \\ a_{1,1} \\ a_{2,1} \\ a_{3,1} \end{bmatrix} \tag{2b}$$

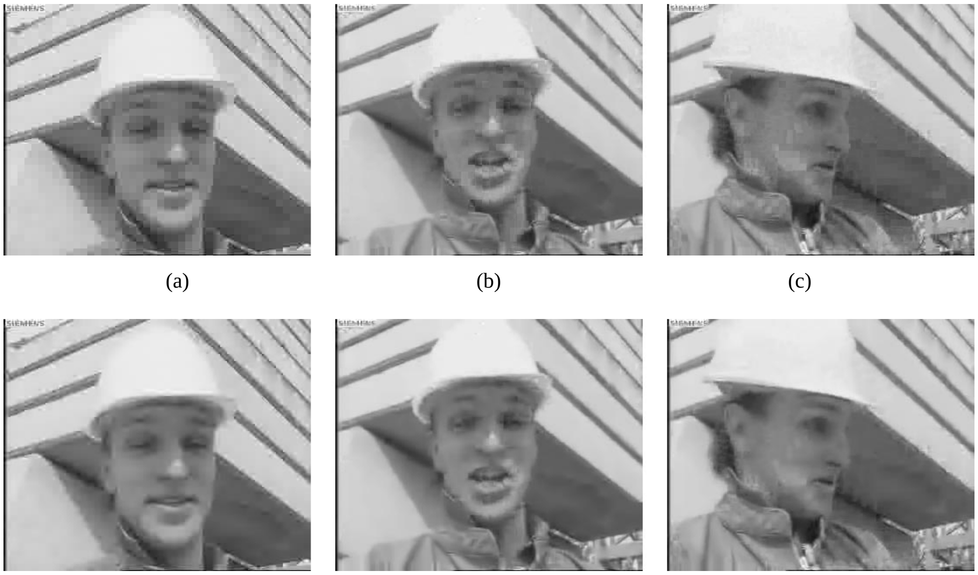
where

$$\begin{aligned} k_0 &= 0.5 \\ k_1 &= \frac{1}{\sqrt{2}} \cos\frac{\pi}{8} = \frac{c_2}{c_3} = 0.6533 \\ k_2 &= \frac{1}{\sqrt{2}} \cos\frac{\pi}{4} = 0.5 \\ k_3 &= \frac{1}{\sqrt{2}} \cos\frac{3\pi}{8} = \frac{c_1}{c_3} = 0.2706. \end{aligned}$$

New values of $v_4$ and $v_5$ due to the change of $a_{3,1}$ can be easily obtained without performing a full four-point IDCT. If $a_{3,1}$ increases by $\epsilon$, we can find that $v_4' = v_4 - k_1 \cdot \epsilon$ and $v_5' = v_5 + k_1 \cdot \epsilon$ from (2b). We should also note that the scaling of $a_{3,1}$ can be easily achieved without a dividing operation because the scaled value $a_{3,1}'$ is given as $\mathrm{SIGN}(a_{3,1}) \times \mathrm{MIN}(|a_{3,0}|, |a_{3,1}|, |a_{3,2}|)$. As shown in Fig. 2, the clipping operation is used to make sure that the magnitude of the gradient at the boundary is reduced without a change in direction. Therefore, the values of $v_4'$ and $v_5'$ always reside between 0 and 255.

## III. Experimental Results

Simulation is performed by using the MPEG-4 VM 5.0 coder for low bit-rate DCT-based video compression. The advanced prediction mode with 8 $\times$ 8 block motion vectors and the OBMC mode are turned on, and a fixed quantization parameter is used. The H.263 quantization method is adopted, and the motion search range is $[-16.0, 15.5]$. Various MPEG-4 test sequences are used for bit rates of 10, 24, 48, 112 Kbits/s, and 1 Mbit/s. Each test sequence has 300 frames, and only the first frame is coded as an intra frame. The components of the DCT kernel corresponding to $a_{3,k}, c_1, c_2$, and $c_3$ are approximated to 2, 5, and 8, respectively so that the filtering operation may require only integer multiplication and shift operations. And the threshold values of $T_1 = 2$ and $T_2 = 6$ are used. The proposed deblocking filter is applied for all of the block boundaries along the horizontal edges first, and then



(a) (b) (c)

(d) (e) (f)

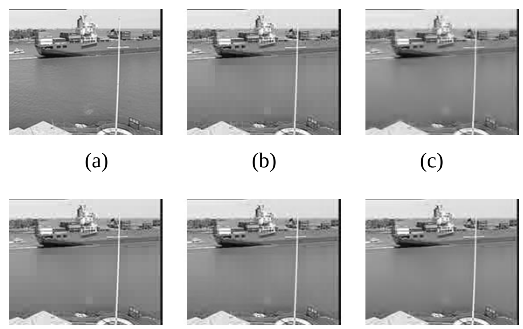
Fig. 5. Deblocking results for *Foreman* sequence (CIF, 112 kbits/s, 15 Hz). (a), (b), and (c) are the zeroth, eightieth, and one-hundred-sixtieth reconstructed images, respectively. (d), (e), and (f) are deblocking results of (a), (b), and (c), respectively.

TABLE I
PERFORMANCE EVALUATION OF THE PROPOSED DEBLOCKING FILTER IN TERMS OF PSNR

| *Condition* | *Sequence* | *QP* | *Bits* | *PSNR_Y* [dB] | | |
|---|---|---|---|---|---|---|
| | | | | Before filtering | After proposed filtering | |
| | | | | | Default mode only | Both modes |
| 10Kbps QCIF 7.5Hz | *Hall monitor* | 17 | 96583 | 30.04 | 30.27 | 30.37 |
| | *Container ship* | 17 | 93556 | 29.21 | 29.34 | 29.43 |
| | *Mother & daughter* | 15 | 95579 | 32.32 | 32.48 | 32.48 |
| 24Kbps QCIF 10Hz | *Hall monitor* | 9 | 236220 | 33.85 | 34.05 | 34.21 |
| | *Container ship* | 10 | 217480 | 32.36 | 32.47 | 32.54 |
| | *Mother & daughter* | 8 | 231791 | 35.20 | 35.36 | 35.37 |
| 48Kbps QCIF 10Hz | *Foreman* | 13 | 478108 | 30.91 | 31.03 | 31.06 |
| | *Coast guard* | 14 | 446028 | 29.01 | 29.05 | 29.09 |
| | *Silent voice* | 7 | 484656 | 34.30 | 34.46 | 34.49 |
| 48Kbps CIF 7.5Hz | *News* | 18 | 472973 | 31.20 | 31.37 | 31.40 |
| | *Mother & daughter* | 10 | 468027 | 36.06 | 36.23 | 36.18 |
| | *Hall monitor* | 12 | 458086 | 33.59 | 33.83 | 34.02 |
| 112Kbps CIF 15Hz | *News* | 11 | 1139868 | 34.00 | 34.17 | 34.26 |
| | *Foreman* | 30 | 1184538 | 28.25 | 28.34 | 28.35 |
| | *Coast guard* | 29 | 1172406 | 26.36 | 26.40 | 26.42 |
| 1Mbps SIF, 30Hz | *Stefan* | 13 | 9796735 | 29.00 | 29.07 | 29.12 |
| | *Mobile & Calendar* | 14 | 10259224 | 26.25 | 26.27 | 26.29 |

along the vertical edges. If a pixel value is changed by the previous filtering operation, the updated pixel value is used for the next filtering.

Figs. 4 and 5 show deblocking results for the *Hall Monitor* and *Foreman* sequences, respectively. Even though the OBMC technique is used in the video coder, blocking artifacts produced in low bit-rate coding are still objectionable. In addition, we can see the drift of the location of blocking artifacts, especially in the flat regions. As shown in Figs. 4 and 5, the proposed deblocking filter reduces blocking artifacts substantially, and still preserves edge details quite well. PSNR is also improved for all of the test sequences with 0.43 dB maximum in the *Hall Monitor* sequence (see Table I). These PSNR improvements demonstrate that the proposed filtering scheme is robust with respect to various image characteristics.



(a) (b) (c)

(d) (e) (f)

Fig. 6. Deblocking results for the decoded intra picture of the *Container Ship* sequence (QCIF, $QP = 17$). (a) Original. (b) No filtering. (c) POCS '92 [6]. (d) POCS '93 [7]. (e) VM 5.0 [10]. (f) Proposed method.

It is also interesting to note that each mode in the proposed filter contributes to PSNR improvements.

In order to compare the proposed algorithm with other existing postprocessing methods, we adopt well-known iterative deblocking schemes [6], [7] and a noniterative postfilter used in MPEG4 VM5.0 [10]. Since the first two schemes are for still images, all of the algorithms are applied to the decoded intra pictures (or still images) of test sequences. Fig. 6 shows deblocking results of the *Container Ship* sequence. Here, ten iterations were performed for the iterative schemes. As shown in the figure, the iterative filtering of [6] tends to blur the image at the expense of removing blocking artifacts, and the filtering of [7] and [10] provides higher resolution, but blocking artifacts are still visible in flat regions. In contrast, the proposed scheme adapts to various image features successfully, and removes noticeable blocking artifacts without degrading details. Table II shows that the PSNR of the proposed scheme is also superior to the other methods. We should mention that its superiority over the postfilter of VM 5.0 is maintained in video coding.

TABLE II
PERFORMANCE EVALUATION OF THE PROPOSED DEBLOCKING FILTER FOR INTRA FRAMES IN TERMS OF PSNR

| *Resol.* | *Sequence* | *QP* | *PSNR_Y* [dB] | | | | |
|---|---|---|---|---|---|---|---|
| | | | Before filtering | After filtering | | | |
| | | | | POCS'92 [6] | POCS'93 [7] | VM 5.0 [10] | Proposed |
| QCIF | *Hall monitor* | 17 | 30.69 | 30.00 | 30.87 | 30.99 | 31.13 |
| | *Container ship* | 17 | 30.12 | 29.19 | 30.17 | 30.30 | 30.44 |
| | *Mother & daughter* | 15 | 32.65 | 32.28 | 33.23 | 33.09 | 33.13 |
| QCIF | *Hall monitor* | 9 | 34.87 | 33.64 | 34.67 | 35.10 | 35.30 |
| | *Container ship* | 10 | 33.74 | 32.38 | 33.52 | 33.88 | 33.96 |
| | *Mother & daughter* | 8 | 36.09 | 35.17 | 36.42 | 36.38 | 36.44 |
| QCIF | *Foreman* | 13 | 32.08 | 31.54 | 32.68 | 32.48 | 32.56 |
| | *Coast guard* | 14 | 30.49 | 30.09 | 30.67 | 30.62 | 30.67 |
| | *Silent voice* | 7 | 35.12 | 34.14 | 35.21 | 35.33 | 35.35 |
| CIF | *News* | 18 | 31.82 | 30.92 | 32.24 | 32.19 | 32.26 |
| | *Mother & daughter* | 10 | 36.70 | 36.37 | 37.02 | 37.21 | 37.09 |
| | *Hall monitor* | 12 | 34.87 | 33.68 | 35.01 | 35.18 | 35.36 |
| CIF | *News* | 11 | 34.85 | 33.55 | 35.10 | 35.18 | 35.30 |
| | *Foreman* | 30 | 29.09 | 29.49 | 29.99 | 29.81 | 29.86 |
| | *Coast guard* | 29 | 27.16 | 27.10 | 27.49 | 27.44 | 27.49 |
| SIF | *Stefan* | 13 | 30.77 | 29.46 | 31.05 | 30.91 | 30.98 |
| | *Mobile & Calendar* | 14 | 28.00 | 26.53 | 28.09 | 28.07 | 28.13 |

## IV. CONCLUSIONS

A new deblocking filter has been proposed to remove the blocking artifacts in reconstructed video frames. In order to minimize the computational complexity, the filter is based on one-dimensional filtering with two separate modes. The selection of a proper mode and a corresponding filtering process provide the improvements of the PSNR as well as the subjective quality by reducing blocking artifacts without sacrificing image details. Because of its simple architecture, the proposed deblocking filter can be easily implemented in real-time applications.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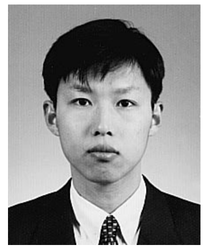

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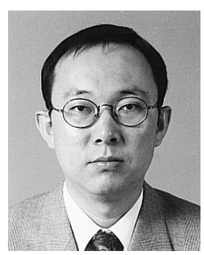

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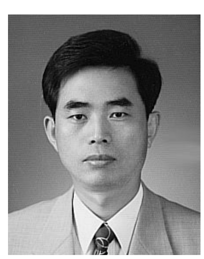

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