

# Post-filtering of DCT Coded Images Using Fuzzy Blockiness Detector and Linear Interpolation

Hak-Choong Kim, Oğuzhan Urhan, *Member, IEEE* and Tae-Gyu Chang, *Member, IEEE*

**Abstract** — *Post-filtering is an effective tool for improvement of encoded image and video quality at low bit-rates. Some consumer electronics devices such as mobile phones apply excessive compression to meet limited bandwidth requirements. Thus, some annoying visual artifacts occur in the decoded image/video. This paper presents a deblocking method based on fuzzy logic to alleviate one of the most common visual artifacts (i.e. blocking) encountered in heavily compressed images. The proposed approach takes intensity difference and variance of pixels at the block boundaries into account in a fuzzy manner to decide amount of blocking effect. Once the proposed approach decides the type of the blockiness, a simple interpolation according to the strength is carried out. Experimental results show the effectiveness of the proposed approach<sup>1</sup>.*

**Index Terms** — **Post-filtering, deblocking detector, fuzzy blockiness detector, JPEG.**

## I. INTRODUCTION

Block transform based image and video coding is widely used in many standard such as JPEG [1], H-261 [2], MPEG-2 [3], and H.264/AVC [4]. These standards make use of discrete cosine transform (DCT) which is known to have good energy compaction properties and various efficient hardware/software implementations. However, DCT coded images suffer from some visual artifacts in the case of high compression. Blockiness is the main visual artifact in DCT based image coding. This problem arises due to inadequate amount of DCT coefficient when low bit rate compression is aimed. In this case, a few DCT coefficients are encoded to meet limited bandwidth or storage requirements. Thus, some blocks might have uniform intensity values and some discontinuities become visible between these blocks.

Many approaches are proposed in the literature to reduce the blocking artifact of DCT based image coding (i.e. JPEG) for a given bit budget. Some approaches present certain modifications in the transform. For example, in [5] warped discrete cosine transform (WDCT) which modifies the transform according to input signal properties is presented to

improve the performance. An important advantage of this method is that it can be implemented using existing hardware or software DCT implementations in contrast to the interleaved block transform [6] and combined transform [7]. Another group of approaches aims to make some modification on the quantization scheme. For example, performance of baseline JPEG can be improved using human visual system based quantization table design [8] and optimal quantization matrix design [9]. Recently proposed approaches in [10, 11] show that the bit-plane based efficient coding of DCT coefficients provides better performance than JPEG2000 [12] which uses wavelet transform, and significantly outperforms the baseline JPEG.

Post-filtering is an important tool to improve visual quality of DCT-based coded images without making significant changes in neither encoder nor decoder. These approaches mainly focus on the alleviation of the blocking effect itself. An iterative algorithm based on projection on convex sets (POCS) is proposed to reduce the blocking effects in [13] for instance. Another POCS based approach in [14], which enables faster implementation, uses a new smoothness constraint set and an improved quantization constraint for the performance enhancement. The method proposed in [15] for example applies directional 1-D filtering for edge regions and uses 2-D adaptive average filtering for flat areas in order to reduce the blocking effect while retaining edges. Based on the same concept, the deblocking method proposed in [16] basically classifies image regions as smooth, intermediate and complex and carries out suitable filtering according to the complexity of the region. The latest state of the art video coding standard H.264/AVC also uses an adaptive deblocking filter to improve visual quality of image frames at low bit-rates [17]. A frequency-domain DCT technique has been presented in [18] for the detection and reduction of the blocking artifacts. An optimal post-processing filter is also proposed in [19] assuming available information about the input spectrum to reduce the blocking artifacts.

## II. LOW-BIT REPRESENTATION MOTION ESTIMATION APPROACHES

The approach presented in this paper consists of two stages. In the first stage, the amount of blockiness at the block boundaries for each pixel is obtained using a fuzzy logic based detector. This novel detector successfully determines the amount of blockiness considering intensity change at the block boundary and variance of pixels at both sides of the block

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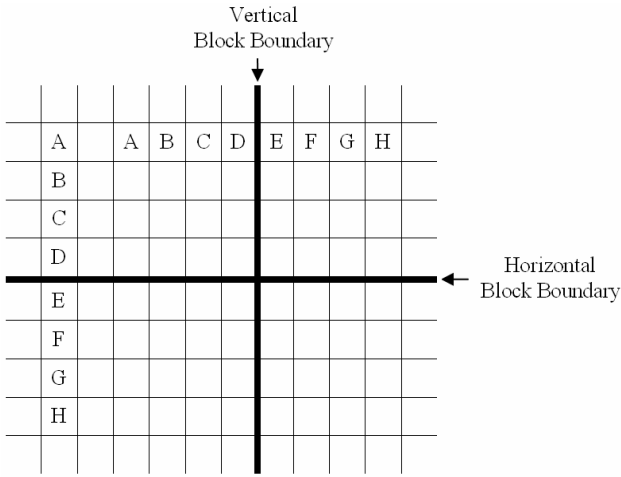


Fig. 1. Pixels at the block boundaries.

boundary. Next, different kinds of filtering are carried out in accordance with the property of the pixels to be filtered. Simple 1-D linear interpolation is utilized at this stage to enable faster implementation.

#### A. Fuzzy Blockiness Detector

Fuzzy logic has various applications in image processing such as edge detection [20], image denoising [21], and image sequence stabilization [22], since it provides an effective way to deal with non-linear systems. The reader is referred to [23] for detailed applications of fuzzy logic in image processing. In the first step of fuzzy logic based systems, i.e., in fuzzification, real world input variables are transformed to fuzzy values employing input membership functions. Then, fuzzy inference engine provides a fuzzy output based on the rule-base. Defuzzification is the last stage of this process which converts obtained results in the previous stage into real world variables using output membership functions for each output. Input/output variables, membership functions, and rule base should be carefully chosen in order to obtain better performance from a fuzzy logic based system. For the further details of fuzzy logic the reader is referred to [24].

Blocking artifact is observed mainly when the amount of DCT coefficients is insufficient. In this case, image blocks have uniform intensity values which may lead abrupt intensity transitions between neighbor image blocks. Based on these observations, two important indicators of blocking artifact can be used in a blockiness detection system. First one is the intensity difference at block boundary i.e., the difference between  $D$  and  $E$  labeled pixels in Fig. 1. The other one is the intensity change between pixels in a block. The second indicator can be simply evaluated using block gradients. For example in [16] the gradients are compared with a threshold and then the number of pixels above the threshold is used to decide the activity of the region. After the region type is determined an appropriate filter is selected and applied in association with the strength of the blockiness (difference between  $D$  and  $E$  pixels) and the value of the quantization parameter.

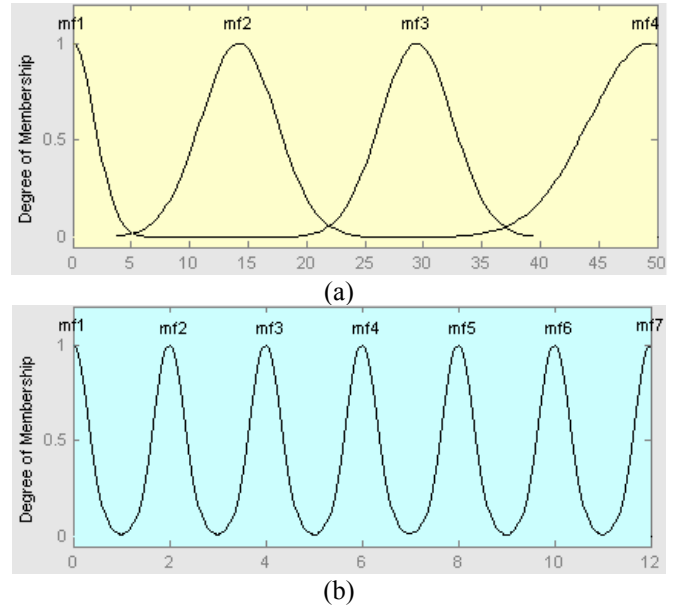


Fig. 2. Membership functions of input and output parameters. (a) MF of input parameters, (b) MF of output parameter.

In the proposed fuzzy logic based blockiness detector we defined three input variables to determine the amount of blockiness as follow:

$$\begin{aligned}
 I1 &= \text{abs}(D - E) \\
 I2 &= \text{var}(\{A, B, C, D\}) \\
 I3 &= \text{var}(\{E, F, G, H\})
 \end{aligned} \tag{1}$$

The first input parameter is the absolute difference between  $D$  and  $E$  labeled pixels which indicates the blockiness amount. The other two inputs are variance values of the left and right sides (or up and down sides) at a block boundary, respectively. These three inputs are utilized to determine uniform intensity for a block. The output of the proposed fuzzy detector indicates the type of spatial filtering to be applied. We used Gaussian membership functions for both input and output parameters. Membership functions (MFs) of input and output parameters are given in Fig 2. As seen in this figure, we have four MFs for input variables in the range from 0 to 50 whereas seven MFs for output parameters. Four MFs of input parameters correspond to low, low medium, medium-high, and high cases of the inputs, respectively.

The rule base is defined in Table 1 according to our observations and tests. For rule 1, output MF is set to mf1 (note that this situation corresponds no filtering case) since the intensity difference is low. In the case of rule 2 and 3 output MF is again set to mf1 because we have low/medium difference but higher variance within the blocks, which means there is no blockiness. For rule 4, we have high difference at the block boundary and variance values not mf1 (not low). This case also does not contain blockiness effect but may be an edge at block boundary. For rules 5 to 7 we have some intensity difference at the block boundary, but the variances are not low, so the output MF value is set to mf2. In this case

a slight filtering may be carried out. I1 is not mf1 (not low) in rules 8 to 12. Therefore, we may have blockiness effect for certain values of I2 and I3. In the case of rule 8, I2 is not low while I3 is low. So, we can say that there is some blockiness at the right (or down) side. The rule 9 is similar to the rule 8 and in this case there is some blockiness at the left (or up) side. For rules 10 to 12 the difference is not low and the variances at blocks are decreasing. This means that we have increasing blocking effect through rule 10 to 12. Therefore the amount of filtering should be increased for these cases.

TABLE I. RULE BASE OF PROPOSED FUZZY BLOCKINESS DETECTOR

| Rule Number | I1      | I2      | I3      | Output |
|-------------|---------|---------|---------|--------|
| 1           | mf1     | None    | none    | mf1    |
| 2           | mf2     | mf3     | mf3     | mf1    |
| 3           | mf2     | mf4     | mf4     | mf1    |
| 4           | mf4     | Not mf1 | not mf1 | mf1    |
| 5           | mf2     | Not mf1 | not mf1 | mf2    |
| 6           | mf3     | Not mf1 | not mf1 | mf2    |
| 7           | mf4     | Not mf1 | not mf1 | mf2    |
| 8           | not mf1 | Not mf1 | mf1     | mf3    |
| 9           | not mf1 | mf1     | not mf1 | mf4    |
| 10          | not mf1 | mf3     | mf3     | mf5    |
| 11          | not mf1 | mf2     | mf2     | mf6    |
| 12          | not mf1 | mf1     | mf1     | mf7    |

### B. Linear Interpolation

Fuzzy blockiness detector described above gives important information about the strength and type of the blockiness effect. In the interpolation stage we should change pixel values at the block boundaries according to the blockiness information. We applied different kinds of filtering for each output MF cases. The filtering equations associated with the outputs of the fuzzy blockiness detector are given in (2) where  $Dif$  equals to  $D - E$ .

$$\begin{aligned}
 & \left\{ \begin{array}{l} A = A - Dif / 8; B = B - Dif / 6; \\ C = C - Dif / 4; D = D - Dif / 2; \\ E = E + Dif / 2; F = F + Dif / 4; \\ G = G + Dif / 6; H = H + Dif / 8; \end{array} \right. \\
 & \left\{ \begin{array}{l} B = B - Dif / 6; C = C - Dif / 4; \\ D = D - Dif / 2; E = E + Dif / 2; \\ F = F + Dif / 4; G = G + Dif / 6; \end{array} \right. \\
 & \left\{ \begin{array}{l} C = C - Dif / 4; D = D - Dif / 2; \\ E = E + Dif / 2; F = F + Dif / 4; \end{array} \right. \\
 & \left\{ \begin{array}{l} C = C - Dif / 5; D = D - Dif / 3; \\ E = E + Dif / 3; \end{array} \right. \\
 & \left\{ \begin{array}{l} D = D - Dif / 3; E = E + Dif / 3; \\ F = F + Dif / 5; \end{array} \right. \\
 & \left\{ \begin{array}{l} D = D - Dif / 4; E = E + Dif / 4; \end{array} \right.
 \end{aligned} \tag{1}$$

When we assess these filtering cases together with the rule base given in Table 1 we can see that the strength of smoothing (number of pixels to be filtered) increases when we have significant amount of blockiness whereas we do not perform any filtering if there is no blockiness effect.

## III. EXPERIMENTAL RESULTS

We compared the proposed post-filtering approach with the methods presented in [16] and [17] to obtain both objective (peak signal to noise ratio - PSNR) and subjective (visual) results. The Lena, Barbara, Peppers, Goldhill, and Boats images of size  $512 \times 512$  pixels are used in the comparison. Table 2 to 6 show PSNR results of the baseline JPEG, the methods proposed in [16] and [17], and the proposed method as well. Quality parameter (QP) starts from zero, which means maximum compression.

TABLE II. PSNR COMPARISON OF PROPOSED POST-FILTERING METHOD FOR "LENA" IMAGE.

| QP | Bit-rate (bpp) | JPEG PSNR (dB) | [16] PSNR (dB) | [17] PSNR (dB) | Proposed PSNR (dB) |
|----|----------------|----------------|----------------|----------------|--------------------|
| 0  | 0.1335         | 24.25          | 25.53          | 25.52          | 25.73              |
| 5  | 0.1732         | 27.33          | 28.31          | 28.30          | 28.53              |
| 10 | 0.2455         | 30.41          | 30.99          | 31.08          | 31.29              |
| 15 | 0.3079         | 31.95          | 32.30          | 32.43          | 32.58              |
| 20 | 0.3634         | 32.96          | 33.18          | 33.33          | 33.40              |
| 25 | 0.4144         | 33.70          | 33.83          | 33.99          | 34.00              |
| 30 | 0.4626         | 34.28          | 34.34          | 34.51          | 34.45              |

TABLE III. PSNR COMPARISON OF PROPOSED POST-FILTERING METHOD FOR "BARBARA" IMAGE.

| QP | Bit-rate (bpp) | JPEG PSNR (dB) | [16] PSNR (dB) | [17] PSNR (dB) | Proposed PSNR (dB) |
|----|----------------|----------------|----------------|----------------|--------------------|
| 0  | 0.1693         | 22.38          | 23.11          | 23.16          | 23.33              |
| 5  | 0.2113         | 24.05          | 24.40          | 24.53          | 24.63              |
| 10 | 0.3155         | 25.79          | 25.95          | 26.01          | 26.19              |
| 15 | 0.4159         | 27.16          | 27.25          | 27.30          | 27.46              |
| 20 | 0.5080         | 28.34          | 28.39          | 28.46          | 28.54              |
| 25 | 0.5902         | 29.39          | 29.41          | 29.50          | 29.42              |
| 30 | 0.6641         | 30.32          | 30.34          | 30.42          | 30.18              |

TABLE IV. PSNR COMPARISON OF PROPOSED POST-FILTERING METHOD FOR "PEPPERS" IMAGE.

| QP | Bit-rate (bpp) | JPEG PSNR (dB) | [16] PSNR (dB) | [17] PSNR (dB) | Proposed PSNR (dB) |
|----|----------------|----------------|----------------|----------------|--------------------|
| 0  | 0.1367         | 24.29          | 25.68          | 25.73          | 25.91              |
| 5  | 0.1766         | 27.16          | 28.21          | 28.33          | 28.39              |
| 10 | 0.2463         | 30.13          | 30.77          | 30.89          | 30.90              |
| 15 | 0.3067         | 31.53          | 31.94          | 32.06          | 32.02              |
| 20 | 0.3604         | 32.43          | 32.69          | 32.83          | 32.76              |
| 25 | 0.4143         | 33.05          | 33.20          | 33.37          | 33.25              |
| 30 | 0.4620         | 33.53          | 33.62          | 33.79          | 33.64              |

TABLE V. PSNR COMPARISON OF PROPOSED POST-FILTERING METHOD FOR "GOLDHILL" IMAGE.

| QP | Bit-rate (bpp) | JPEG PSNR (dB) | [16] PSNR (dB) | [17] PSNR (dB) | Proposed PSNR (dB) |
|----|----------------|----------------|----------------|----------------|--------------------|
| 0  | 0.1255         | 23.74          | 24.79          | 24.80          | 24.95              |
| 5  | 0.1710         | 26.16          | 26.99          | 27.00          | 27.05              |
| 10 | 0.2655         | 28.65          | 29.08          | 29.12          | 29.20              |
| 15 | 0.3598         | 29.95          | 30.20          | 30.26          | 30.36              |
| 20 | 0.4448         | 30.87          | 31.01          | 31.10          | 31.17              |
| 25 | 0.5218         | 31.56          | 31.62          | 31.74          | 31.78              |
| 30 | 0.5904         | 32.10          | 32.12          | 32.24          | 32.24              |



Fig. 3. Deblocking result for a cropped part of Barbara image.

TABLE VI. PSNR COMPARISON OF PROPOSED POST-FILTERING METHOD FOR "BOATS" IMAGE.

| QP | Bit-rate (bpp) | JPEG PSNR (dB) | [16] PSNR (dB) | [17] PSNR (dB) | Proposed PSNR (dB) |
|----|----------------|----------------|----------------|----------------|--------------------|
| 0  | 0.1349         | 23.34          | 24.23          | 24.20          | 24.41              |
| 5  | 0.1838         | 26.03          | 26.73          | 26.70          | 26.91              |
| 10 | 0.2772         | 28.86          | 29.30          | 29.36          | 29.49              |
| 15 | 0.3574         | 30.36          | 30.63          | 30.71          | 30.79              |
| 20 | 0.4269         | 31.41          | 31.60          | 31.71          | 31.70              |
| 25 | 0.4904         | 32.20          | 32.33          | 32.45          | 32.37              |
| 30 | 0.5480         | 32.84          | 32.91          | 33.05          | 32.90              |

We have observed that the deblocking methods generally provide acceptable results up to 0.5 bpp (bit per pixel) rate. Therefore, we provide PSNR results up to QP=30.

These results show that the proposed method can improve the performance of JPEG compressed images up to 1.5 dB for low bit-rates whereas the gain is limited for higher bit-rates. The proposed method also provides better results when compared to the methods presented in [16] and [17].

The five cropped Barbara images in Fig. 3 correspond to the original image, the JPEG compressed image, the two deblocking filtered images using methods [16] and [17], and the deblocking filtered image of the proposed method, respectively. As seen from this figure the compressed image has significant blockiness. The methods presented in [16] and [17] can alleviate the blocking effect at the smooth areas but the blockiness is

visible at the textured areas. The proposed method on the other hand can successfully remove the blocking artifacts, even without introducing any noticeable blurring effect.

#### IV. CONCLUSIONS

A fuzzy logic based blockiness detector is combined with a linear interpolator in this work to alleviate blocking effects encountered in DCT compressed images. The fuzzy detector takes the difference at the block boundary and the variance of pixels into account to enable successful determination of the amount of blockiness. In the linear interpolation phase, an appropriate filter is selected and applied in accordance with the type of blockiness determined in the previous phase. Both objective and subjective experiments show effectiveness of the proposed approach. The proposed approach can be utilized in many consumer electronics devices such as mobile terminals that have limited bandwidth and therefore may suffer from blocking artifacts.

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