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Pattern Analysis Through Edge for the Reduction of Artifact of Decompressed Image in DCT Domain

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Abstract: In this paper, we present a simple and effective approach for measurement of blocking artifact with optimal 2-D step function. First, a simple edge detection technique is designed for the measurement of blocking artifacts. Based on the visibility of blocking artifact in the edge image, optimal 2-D step function is chosen. In frequency domain, blocking artifact reduction algorithm is designed to extract all the parameters needed to detect the presence of blocking artifacts and replace optimal step function with ramp function by changing the coefficient of first row of horizontal blocks with the coefficient of shifted block. The proposed technique is experimented on various standard benchmark images and found to have improvement in the perceptual quality of the JPEG compressed images after removal of blocking artifact with the proposed method.

Keywords: Blocking artifact, DCT, Edge detection, Step function.

I. INTRODUCTION

Over the past several years, research has been applied to the problem of alleviating blocking artifact in Block Discrete Cosine Transform (BDCT) [10] [15] coded image. The BDCT is commonly used transform technique for image compression standards such as JPEG [11] for still images, MPEG [13] for moving pictures and H.263 [13] for videophone / teleconference due to its compaction property and ease of implementation. In a typical DCT compression scheme [3], each (8×8) block is transformed into frequency domain, quantized with a predefined quantization table, entropy encoded and then transmitted. At high compression ratio of the independent processing of the blocks [31] which does not take into account the existing correlations among pixels of adjacent blocks, there exists degradation in the visual quality of reconstructed image. As a result, one of the most noticeable degradation [28] is the "blocking artifacts" [2] [30] which appears as a direct result of the coarse quantization [29] of the coefficients and compression at low bit rate. These artifacts appear as a regular pattern of visible block boundaries. Hence, it is desirable to measure such artifacts and reduce the visibility of blocking effects in decompressed image.

To reduce compression artifacts in both spatial and frequency domain, various techniques are commonly adopted. They are pre-processing and post-processing techniques. Pre-processing technique [16] [18-20] makes changes in the compression encoder and post-processing technique [14] [15] [22] has been applied for improving visual quality by removing artifact on decompressed image. Post-processing techniques gather a lot of attention since the technique takes advantage of having decoded image as input and is compatible with decoding standards. M. Y. Shen *et al.* [22] categorized the post processing technique to reduce artifact in two different viewpoints, viz. image enhancement and image restoration. The image enhancement approaches aim at improving the perceived visual quality subjectively and the image restoration approaches deal with the post processing as an image recovery problem.

Various research [5-8] [12] [17] over the past several years have been reported by modeling the blocking artifact as 2-D step function and takes a measure to reduce artifact in spatial and DCT domain. In [5], Bing Zeng recognized that visible boundaries between two adjacent blocks in the coded image are primarily oriented along the horizontal and vertical directions, and thus modeled the blocking artifact as 2-D step block [21] and introduced the shifted block between two adjacent blocks. By applying zero masking technique to the DCT coefficients of some shifted image blocks, some of the AC coefficients are dropped and obtained better result in low bit rate images. Also, it is observed that, it reduces the blocking artifacts but the loss of edge information caused by zero masking can be noticed. Ramamurthi *et al.* [4] introduced a non linear space-variant filtering to reduce "staircase noise" and "grid effects" [1], based on human visual system in different direction and reduced the blocking artifact. Byeungwoo Jeon *et al.* [6] measure the block discontinuity as the sum of squared pixel differences over the four block boundaries and recover the DCT coefficient lost during network transmission by maximally smoothening the transition pixel over block boundaries and optimized with filtering approach. Tao Chen *et al.* [27] measured the activity of block and approximated the activity as the sum of its AC coefficient energy and experimented with adaptive filter [32] with less computation burden. Shizhong Liu *et al.* [24-25] have first described a DCT-domain method for the blind measurement of blocking artifacts, with Human Visual System (HVS) as parameter. It operates in DCT domain by adapting to the local measured visibility of the blocking artifacts at each block edge. Jagroop Singh *et al.* [17] introduced a filter that removes the blocking artifact, simultaneously preserving the image detail with minimum loss of image content by using shifting method only in the region to be filtered. It enhances the subjective as well as objective detail of the given image. F. Pan *et al.* [9] presented an algorithm for measuring blocking artifacts in images and videos. Instead of using the traditional pixel discontinuity along the block boundary, blocking artifacts are measured using directional information of edges [34]. It does not need the exact location of the block boundary thus is invariant to the displacement, rotation and scaling of the images.

Later, to overcome the loss of edge detail, a DCT-domain blind measurement [24-26] [33] is adopted by replacing 2-D step function with linear function. In this paper,a new edge detection technique is proposed for the measurement of blocking artifact with modified 2-D step function. We propose a model for the reduction of blocking artifact using ramp function in DCT domain, we also show how to modify transform coefficient to reduce blocking artifact.

The rest of the paper is organized as follows: In Section II, the description of DCT mathematical model is presented. In Section III, a simplified method for detecting edge from a compressed image for the measurement of blocking artifact is proposed. The proposed blocking artifact reduction algorithm is presented in Section IV. Standard performance measurement is given in Section V. Section VI presents the comparison of result of proposed algorithm with existing post-processing method. And lastly, Section VII presents the concluding remarks.

II. DISCRETE COSINE TRANSFORM

In this paper, we are focusing on the reduction of blocking artifacts in transform domain. For images, the intensity of pixel available in spatial domain is transformed into amplitude of a unique cosine function by using DCT transformation. DCT used in image coding includes block based transform, which converts image elements to DCT coefficients. Forward DCT transform F(u,v) at co-ordinate u and v respectively, represents the transform coefficient for each (N x N) block. It achieves very good energy compaction and coefficient decorrelation. It is defined as:

$$F(u,v)=\frac{2}{N}\cdot C(u)C(v)\left[\sum_{x=0}^{N-1}\sum_{y=0}^{N-1}f(x,y)\cos\frac{(2x+1)\cdot u\pi}{2N}\cos\frac{(2y+1)\cdot v\pi}{2N}\right] \tag{1}$$

for u=0,…..,N-1 and v=0,…..,N-1

where N=8 and $C(k)=\begin{cases}-\frac{1}{\sqrt{2}}, \text{ fork} = 0\\ 1, \text{ otherwise}\end{cases}$

By analyzing the transform coefficient, it is learnt that each coefficient reflects some particular features of the image f(*x,y*), where x and y are the coordinates in vertical and horizontal directions respectively. In order to get the pixel from transform coefficient value, Inverse DCT transform is used as given in (2)

$$f(x,y)=\frac{2}{N}\left[\sum_{u=0}^{N-1}\sum_{v=0}^{N-1}C(u)C(v)F(u,v)\cos\frac{(2x+1)\cdot u\pi}{2N}\cos\frac{(2y+1)\cdot v\pi}{2N}\right] \tag{2}$$

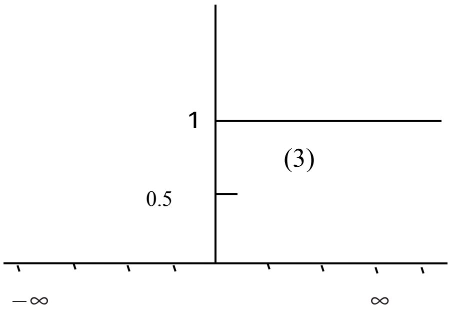
for x=0,…..,N-1 and y = 0,…..,N-1 where N=8

Thus, modeling the artifact in DCT domain is easy and manipulating the transform coefficient value, results into reduction of artifact as described in Section IV. The coefficient of F(u,v), where u=v=0 represents DC coefficient of each block which is relatively large in magnitude, and the AC terms become lower in magnitude as they move farther from the DC coefficient. This means that by performing the DCT on the input data, we have concentrated the representation of the image in the upper left coefficients of the output matrix, with the lower right coefficients of the DCT matrix containing less useful information.

III. A NEW EDGE DETECTION TECHNIQUE FOR MEASUREMENT OF BLOCKING ARTIFACT

Edges can be modeled according to their intensity profiles i.e. step edges, whose intensity abruptly changes from one value, to one side of discontinuity, to a different value on the opposite side. Discontinuity [23] [35] generally occurs between two regions having almost constant but different grey levels. To facilitate the analysis we first consider, one-dimensional edge profiles using step function u(t) that represents region of discontinuity at t, which occurs due to independent processing of each block in compressed domain.

$$u(t)=\begin{cases}1, & t>0\\ 0, & t<0\\ \frac{1}{2}, & t=0\end{cases} \tag{3}$$



And, in this transformation, 1, 0, $\frac{1}{2}$ are defined as constant amplitude at various value of t. But through amplitude scaling, only the quadrature axis values are modified i.e. magnitude of the signal changes, with no effects on the horizontal axis values or periodicity of signals. By the properties of signal operations, 1-D step function s(t) is defined as:

$$s(t) = \beta.u(t) \text{ where } \beta = 1, \frac{1}{2}, \frac{1}{4}, \frac{1}{8}, \frac{1}{16} \tag{4}$$

Here, β represents the amplitude of step function at the point of discontinuity. Similarly, two-dimensional function s(x,y) as defined in (5), represents constant cross-section in horizontal and vertical direction. Zero crossing property of step function, highlights the region of rapid intensity change and therefore can be used for edge detection. Zero crossing looks for point in an image, where the sign of the function is getting changed. Such points often occur at edges in images; this means that there is a reasonably sharp edge between two regions of uniform but different intensities and thus s(x,y) is defined as.

$$s(x,y) = \begin{cases} -\beta.u(t), \text{ for } x = 0,1,2,3\ ; y = 0,1,2,\ldots\ldots N-1 \\ \beta.u(t), \text{ for } x = 4,5,6,7\ ; y = 0,1,2,\ldots\ldots N-1 \end{cases} \tag{5}$$

where u(t) is equal to at the point of discontinuity as defined in (3) and β can be taken from (4) and (N x N) represents size of block. Thus in order to measure the blocking artifact as an edge using 2-D step function, s(x,y) is modeled as in (5), where positive values represent just to one side of the edge and negative value just to the other side of the edge.

With varying amplitude of 'β' as ±0.5/ ±0.25/ ±0.125/ ±0.0625/±0.03125 of 2-D step function s(x,y) as defined in equation (5) is formulated as the blocking artifact detection method via proposed edge detection technique. For an image, first derivative is implemented using the magnitude of gradient and hence can be used to detect an edge. The gradient represents an intensity which points in the direction of greatest change. To measure the rate of change of intensity in horizontal and vertical direction, each (8 x 8) block is convolved with 2-D step function s_h(x,y) and s_v(x,y) as defined in (6) and (7) respectively and measures the rate of change of intensity in horizontal (g_h) and vertical direction (g_v) respectively.

$$s_h(x,y) = \begin{cases} -\beta.u(t), \text{ for } x = 0,1,2,3 \text{ and } y = 0,1,2\ldots\ldots..7 \\ \beta.u(t), \text{ for } x = 4,5,6,7 \text{ and } y = 0,1,2,\ldots\ldots..7 \end{cases} \tag{6}$$

$$\text{And, } s_v(x,y) = \begin{cases} \beta.u(t), \text{ for } y = 0,1,2,3 \text{ and } x = 0,1,2\ldots\ldots..7 \\ -\beta.u(t), \text{ for } y = 4,5,6,7 \text{ and } x = 0,1,2,\ldots\ldots..7 \end{cases} \tag{7}$$

The larger the value of β, the more seriousness of visibility of the blocking artifact. Hence, it is identified that blocking artifact visibility is directly proportional to amplitude value of β. Thus, measuring blocking artifacts using relevant step function should prove correct for judging the visibility of the blocking artifacts. The algorithm for the measurement of blocking artifact, using edge detection technique is as follows.

Algorithm for the Measurement of Blocking Artifact Using Edge Detection

Input: Input image with pixel value (0-255), compressed at low bit per pixel (512 x 512).

Output: Edge image (512 x 512).

```
Begin
Step 1: Read input image I.
Step 2: Partition the image I into blocks $I_B$ of size (8 x 8).
Step 3: Initializes$_h$(x,y) and $s_v$(x,y) as given in (6) and (7)
        respectively, for varying amplitude of β as given in
        Section III.
Step 4: For each block $I_B$
    (a) Compute $g_h$ and $g_v$ by convolving $s_h$ and $s_v$ with $I_B$
        respectively.
    (b) Calculate gradient magnitude(G) as:
        $G = \sqrt{g_h^2 + g_v^2}$
Step 5: Form an output Image with gradient magnitude.
End
```

The proposed edge detection technique with varying amplitude β of s(x,y), using gradient method is viable enough to measure the optimal 2-D step function and thus results into reduction of blocking artifact. Having identified the discontinuity in the neighboring blocks and measured with gradient magnitude, a blocking artifact reduction system is proposed and the same is described in next Section.

IV. PROPOSED BLOCKING ARTIFACT REDUCTION SYSTEM

In this paper, a new technique is proposed with DCT for reducing the blocking effects. Since, blocking effects occurring in the horizontal and vertical directions generally have no difference in principle, we describe the proposed algorithm for measuring horizontal blocking artifacts.

Given a BDCT compressed image distorted by independent identically distributed Gaussian noise, model each block as constant block with zero mean and unknown variance. Consider two adjacent (N x N) blocks a1 and a2, with average values μ_1 and μ_2 respectively, where $\mu_1 \neq \mu_2$. Thus we model these two blocks as follows:

$$a1 = \mu_1 + \varepsilon_1 \text{ and } a2 = \mu_1 + \varepsilon_2$$

where, ε_1 and ε_2 are modeled as white noise. When the corresponding DCT blocks a1 and a2 are quantized and compressed at low bit per pixel, it reduces the effect of ε_1 and ε_2 and as a resulting 2-D step function become visible between a1 and a2. Based on this observation, we form a shifted block b as shown in Fig. 1.

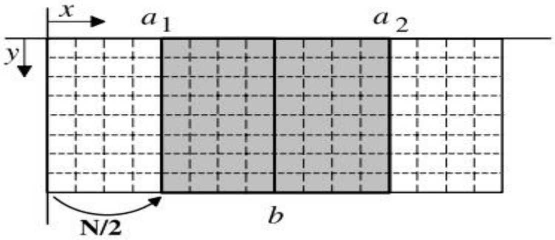


Fig. 1: Graphical Explanation of a1, a2 and b

Fig. 1 shows that block b is right-shifted by N/2 pixels from a1. Block b includes the right half of a1 and the left half of a2. If any blocking artifact is introduced between a1 and a2, the pixel values in b will be abruptly changed. By modeling the abrupt change in b, we can measure the blocking artifacts. Then shifted block b can be modeled as:

$$b(x,y) = \mu + \beta.s(x,y) \quad \text{for } x,y = 0,\ldots\ldots\ldots 7 \tag{8}$$

where, μ is the average value of block b and β represents amplitude of 2-D step function s as given in (4). To reduce the effect of blocking artifact in shifted block b, ramp function is introduced to replace the 2-D step block 's' with ramp function 'τ'. Thus the modified shifted block $\hat{b}$ can be modeled as:

$$\begin{aligned}\hat{b}(x,y) &= b(x,y) + \beta.\ \tau(x,y) - \beta.s(x,y)\\ &= b(x,y) + \beta.(\tau(x,y) - s(x,y)) \text{ for } x,y=0,\ldots\ldots.7\end{aligned} \tag{9}$$

Since discontinuity occurs at intersection point of each block and thus defined 1-D step block as $dis\,(x) = x - \left(\frac{N-1}{2}\right)$ for x = 0,1,…….7, where, N represents the block size. Using the optimal amplitude of β as obtained in Section III, ramp function can be defined as $\tau(x) = \dfrac{x}{\text{Slope of shifted block}}$ for each *dis*(x) of adjacent shifted blocks (see Fig. 1). 2-D 8 x 8 linear block can be constituted by τ (x,y) = τ (x) where, x = 0,1,2,……7, y = 0,1,…….7, where magnitude of 2-D step block is constant in the vertical direction and anti-symmetric in the horizontal direction.

The proposed algorithm can be implemented in DCT domain without using the original image. For the sake of explanation, we consider the measurement in the horizontal direction of blocking artifacts only. In block based transform coding, an image is composed of non-overlapping (N × N) blocks and thus, fast DCT domain algorithm [24] is followed for each shifted block as follows:

Based on definition of orthogonal matrix, let us define two matrices q1 and q2 as follows:-

$$q1 = \begin{bmatrix} 0 & 0 \\ I & 0 \end{bmatrix} \quad q2 = \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix}$$

where, q1*q2 = I and I is identity matrix and 0 is zero matrix of 4x4. Thus the shifted block B is implemented in DCT domain as:

$$\begin{aligned}B &= B1Q1 + B2Q2\\ &= \frac{1}{2}\left[(B1+B2)(Q1+Q2)+(B1-B2)(Q1-Q2)\right]\end{aligned} \tag{10}$$

Where, B, B1, B2, Q1, Q2 are the DCT of b, a1, a2, q1, q2 respectively.

Let $\lambda = [\lambda_0,\ldots\ldots\ldots,\lambda_7]$ be the vector of the first row of DCT transform of τ, which has only four non-zero elements in the first row i.e. $\lambda_0 = \lambda_2 = \lambda_4 = \lambda_6 = 0$ due to anti symmetric property of τ in the horizontal direction. Define a vector $\delta = \lambda - V$ where V is the vector of first row of the (8 x 8) DCT transform of 2-D step function s and $\hat{B}$ will be the modified shifted block. Modification of shifted block in DCT domain is given by:

$$\hat{B}(0,v) = B(0,v) + \beta.(\lambda_v - V_v)$$

where, v = 0,1,2,……,7

$$\text{and} \quad \hat{B}(u,v) = B(u,v) \ \text{ for } u > 0,\ v = 0,\ldots\ldots 7 \tag{11}$$
$$\beta = B(0,1) + B(0,3) + B(0,5) + B(0,7)$$

where $\hat{B}$, is the (8 x 8) DCT transform of $\hat{b}$.

The block $\hat{B}$ is then used to update both B1 and B2 by using matrix multiplication as similar to (10). Since only the elements of the first row of B have been changed to obtain $\hat{B}$ in (11), it can be seen from (10) that the changes only affect the elements in the first row of B1 and B2. Therefore, a simple way to update the blocks B1 and B2 can be found. Let δ1 and δ2 be the delta vectors in B1 and B2, respectively. Then δ1 = δQ2 and δ2 = δQ1 are constant vector which can be pre-computed and stored. Finally blocks B1 and B2 are updated using (12) and (13) as follows:

$$B1(0,v) = B1(0,v) + \beta.\ (\delta 1)_v; \quad v=0,\ldots..,7 \tag{12}$$

$$B2(0,v) = B2(0,v) + \beta.\ (\delta 2)_v; \quad v=0,\ldots..,7 \tag{13}$$

Block boundary discontinuity is minimized by applying the changes in the coefficient in the shifted block by following the proposed technique. Similarly, vertical blocking reduction can be easily derived by symmetry.

V. Performance Measure

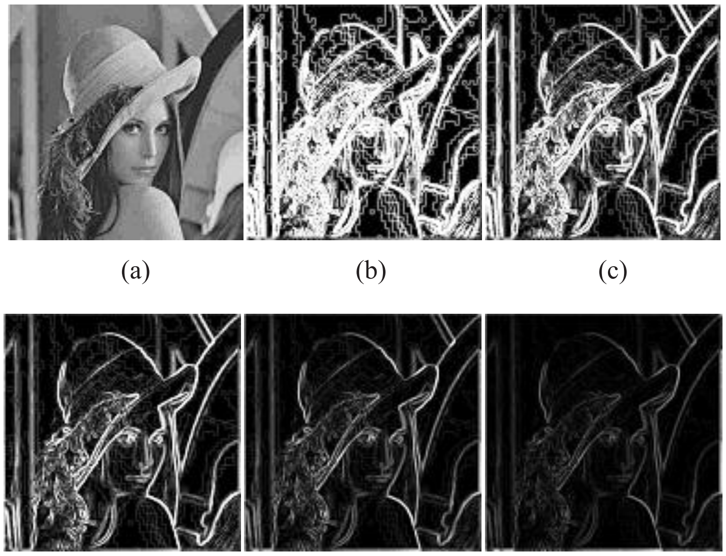
Peak Signal to Noise Ratio (PSNR) has been accepted as a widely used quality measurement unit in the field of image restoration in order to measure the objective quantitatively between the original and restored images. It is defined as:

$$PSNR = 10\log_{10}\frac{255^2}{MSE}\left(dB\right) \tag{14}$$

Where, MSE = $\frac{1}{MN}\sum_{i=1}^{M}\sum_{j=1}^{N}\left[I\left(i,j\right)-I'\left(i,j\right)\right]^2$, where MN represents the size of image and I and I′ represent an input image and output image respectively.

VI. Experimental Results

The proposed edge based measurement of blocking artifact is implemented and tested over hundred JPEG compressed images at varying bit per pixel from standard benchmark databases. As an example, Lena image of size (512 x 512) with pixel values (0-255) is shown in the Fig. 2 (a), compressed at 0.217 BPP. The input image is divided into blocks of size (8 x 8). For each block, convolve with 2-D step function as given in (5). The value of β is assigned to 0.5 or 0.025 or 0.125 or 0.0625 or 0.03125 to compute gradient magnitude and to measure the change of intensity as explained in Section III. Through gradient magnitude, edge has been detected and the results are shown in Fig. 2(b-f) for the input image Fig. 2(a).



(a) (b) (c)

(d) (e) (f)

Fig. 2: a) Original Lena Image Compressed with DCT at 0.217 BPP b) Result of Proposed Edge Detection Method when β = 0.5 c) when β = 0.025 d) when β = 0.125 e) when β = 0.0625 f) when β =0.03125

Based on experimental results, it is observed that the visibility of blocking artifact is reduced when $\lim_{\beta\to 0} s\left(x,y\right)$ i.e. β = ±0.03125 and thus can be considered as optimal constant value with reduced blocking artifact as shown in Fig. 2(e). In order to reduce blocking artifact in DCT-domain, experiments have been done as explained in Section IV. For experimental analysis, the same Lena image is considered. In DCT domain, blocking artifact reduction algorithm is designed to extract all the parameters needed to detect the presence of blocking artifacts and replace step function with ramp function by changing the coefficient of first row of horizontal blocks with the coefficient of shifted block as discussed in (12) and (13). The result of blocking artifact reduction with the proposed scheme on the Lena image shown in Fig. 2(a) is presented in Fig. 3.

Fig. 3: Result of Proposed Blocking Artifact Reduction Technique on the Image of Size (512 x 512) Shown in Fig. 2(a)

For performance evaluation of the proposed technique of the reduction of blocking artifact, objective measurement is evaluated using PSNR for differently coded images with equation (14). After post-processing using proposed method, resultant PSNR obtained is 31.34 for the image shown in Fig. 3. Similar, results were also reported in [24] and [26]. The perceptual quality of the five standard images such as Lena, Peppers, Cameraman, Barbara and Bafoon are examined by comparing the decompressed image, coded at different bit rates, with the proposed scheme. The measured PSNR for the images coded at various bit rates are tabulated in Table I.

TABLE I: PSNR VALUES OBTAINED FOR SAMPLE IMAGES WITH PROPOSED TECHNIQUE AND FOR DIFFERENT POST-PROCESSING TECHNIQUES

S.No.	Image	Bit Rate Per Pixel	Decoded Image	Method in [24]	Method in [26]	Proposed Method
1	Lena	0.208	28.81	29.27	28.95	30.80
2		0.217	30.62	30.27	30.89	31.34
3	Peppers	0.221	29.43	29.93	29.99	30.02
4		0.300	31.86	32.09	32.18	33.36
5	Cameraman	0.240	28.72	30.33	30.09	31.53
6		0.125	26.03	27.74	27.44	27.99
7	Barbara	0.24	27.43	27.68	27.00	27.79
8		0.56	30.90	31.05	31.21	31.32
9	Bafoon	0.304	27.22	28.54	28.00	28.92
10		0.622	31.45	32.08	31.60	32.40

VII. CONCLUSIONS

An attempt has been made in this paper to remove the annoying blocking artifacts from low-bit-rate JPEG compressed images. In the proposed technique, we propose a simple and effective approach for measurement of blocking artifact using edge detection with optimal 2-D step function. In [24] and [26], varying methods are used to reduce artifacts with fixed amplitude of step function for smooth, non-smooth and intermediate region of an image. Hence, losses of edges are noticed after post-processing. To overcome this drawback, a new edge based technique is designed for the measurement of blocking artifacts. Based on the visibility of blocking artifact in edge image, optimal 2-D step function is chosen. In frequency domain, blocking artifact reduction algorithm is designed to extract all the parameters needed to detect the presence of blocking artifacts and replace optimal step function with ramp function by changing the coefficient of first row of horizontal blocks with the coefficient of shifted block as discussed in (12) and (13). To demonstrate the performance of the proposed algorithm, PSNR is evaluated. It is found that there is an improvement in the perceptual quality of the JPEG compressed images after removal of blocking artifact by the proposed method. Due to the low computational requirement, the method can be integrated into real time image / video applications that process image / video in the DCT domain.

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