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A New Hybrid Post-Filtering Technique for Efficient JPEG Artifacts Reduction

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***Abstract*—The Joint Photographic Expert Group (JPEG) is the most popular lossy image compression standard owing to its simple structure and economical hardware implementation. However, at the low bitrate compressions, the JPEG standard suffers from the highly visible blocking artifacts, which is the primary reason behind its poor compression performance. In order to efficiently address this issue, this paper forwards a new hybrid post-filtering technique for the JPEG blocking artifacts reduction. The proposed hybrid technique is a proper fusion of iterative steering kernel regression-based filtering and the guided image filtering techniques. Numerous tests have been carried out to validate the blocking artifacts reduction capability of the proposed hybrid technique against the state-of-the-art techniques. The resultant findings confirm that the proposed hybrid technique offers a noteworthy reduction in the JPEG artifacts as compared to the available techniques.**

***Index Terms*— JPEG image artifact removal, blocking artifacts, steering kernel filtering, guided image filtering, PSNR.**

I. Introduction

The ultimate aim of the lossy image compression techniques is to represent the input image with the fewer bits as compared to the original image. Thus, the lossy techniques make a loss of information at the time of compression to facilitate the transmission of images over the band-limited channel. In the past, numerous international standards have been established to full-fill the good quality compression demand of images. Among, the existing standards, the most popular is the JPEG standard, which is a block-based coding technique that utilizes Discrete Cosine Transform (DCT) [1]-[4] for the energy compaction followed by the quantization and entropy coding. Usually, at the medium and the higher bitrate image compression, the JPEG standard provides good quality compression, but on the lower bitrates side, it often suffers from the strong blocking artifacts. Meanwhile, as the bitrate decreases further, the JPEG compression also demonstrates the other visual artifacts such as degraded textures, blurring, and distortion of the edges [5].
Therefore, numerous techniques have been developed in the past to enhance the visual quality of JPEG compressed images by the removal of the compression artifacts. The existing JPEG artifacts reduction techniques can be divided into two categories viz. (1) Encoder-based techniques, and (2) Post-processing

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based techniques. The encoder-based techniques rely on the modifications of the encoder structure, like transform domain techniques [8]-[10], interleaved block transforms [11], interactive methods [12], lapped transform [13], combined transform [14], or wavelet transform based filtering [15]. However, the major disadvantage of all these techniques is that they generate deviation from the rules of the JPEG standard. Conversely, the Post-processing techniques rely on the improvement of the visual quality of JPEG compressed images by removing the artifacts through the processing after JPEG decoding. Therefore, these techniques do not require modifications on the existing JPEG encoder or decoder, and hence can be directly utilized with the existing JPEG standard. The Post-processing can be sorted into four main categories such as (1) Spatial-domain techniques [16]-[23], (2) DCT-domain based techniques [24]-[29], (3) Projections onto Convex Sets (POCS) based techniques [30]-[34], and (4) the block-shift filtering techniques [35]-[44].

Recently in 2014, Golestaneh et al. proposed a technique to enhance the quality of the JPEG image via two stages [45]. First, they have removed the blocking artifacts using boundary smoothing and guided filtering. Subsequently, they have reduced aliasing and blurring across the edges using a local edge regeneration method. The result of this technique was comparable to the others, but its performance is not uniform for all types of test images over different bitrates.

Therefore, this paper presents a new hybrid post-filtering technique to achieve better JPEG artifacts reduction at low bitrates uniformly for different types of JPEG images. The proposed hybrid technique utilizes two level artifacts suppression strategy. In the first level iterative steering kernel regression-based filtering is utilized, and in the second stage guided image filtering technique is used for the efficient JPEG artifacts reduction.

The complete organization of this paper is as follows; Section 2 describes the basic details of the proposed hybrid post-filtering technique, Section 3, presents the results and discussions followed by Section 4, which presents the conclusion of this work.

II. Proposed Hybrid Post-Filtering Technique

The simple flow chart depiction of the proposed hybrid post-filtering technique is depicted in Fig. 1. The proposed hybrid technique accepts a JPEG compressed image as the input and then applies a two-stage blocking artifacts reduction strategy. The first stage is being designed to initially remove the blocking artifacts using iterative steering kernel-based filtering [46]. The second stage removes other visual artifacts using guided image filtering [47].

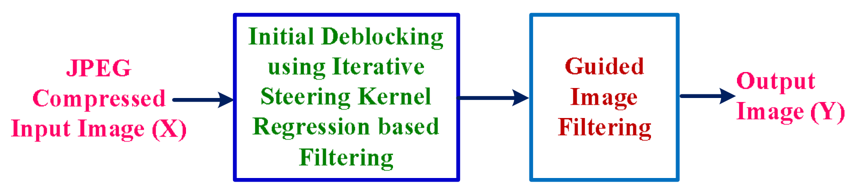


Figure 1. Flow chart of the proposed hybrid post-filtering technique

A. Iterative Steering Kernel Regression-based Filtering

The kernel regression-based filtering is the non-parametric estimation of the implicit model which is referred as the regression function [48]. In simple form, the 2-D kernel regression function can be defined as:

$$y_i = z(x_i) + \varepsilon_i; \qquad i = 1, 2, \cdots P \tag{1}$$

Where, $Z(\cdot)$ is the regression function and $\varepsilon_i s$is the independent and identical zero mean values, $x_i s$ are the data sample values and $y_i s$ are the measured data values. We can now simply provide a local level expansion of the above regression function as:

$$z(x_i) = z(x) + \{\nabla z(x)\}^T (x_i - x) + \frac{1}{2} vec^T \{Hz(x)\} vec\{(x_i - x)(x_i - x)^T\} + \cdots \tag{2}$$

Where, ∇ and H are the gradient and hessian (or also known as smoothing matrix) operators, and $vec(\cdot)$ is the vectorization operator. Further, considering the symmetry property of the Hessian matrix, (2) can be simply rewritten as,

$$z(x_i) = \beta_0 + \beta_1^T (x_i - x) + \beta_2^T vec\{(x_i - x)(x_i - x)^T\} + \cdots \tag{3}$$

By comparison of (2) and (3), we have $\beta_0 = z(x)$, which is the pixel value of interest, and

$$\beta_1 = \nabla z(x) = \left[\frac{\partial z(x)}{\partial x_1}, \frac{\partial z(x)}{\partial x_2}\right]^T \tag{4}$$

$$\beta_2 = \frac{1}{2}\left[\frac{\partial^2 z(x)}{\partial x_1^2},\ 2\frac{\partial^2 z(x)}{\partial x_1 \partial x_2},\ \frac{\partial^2 z(x)}{\partial x_2^2}\right]^T \tag{5}$$

Usually, the data-adapted kernel regression can be simply framed by an optimization problem given as [46],

$$\min_{\{\beta_n\}} \sum_{i=1}^{P}\left[y_i - \beta_0 - \beta_1^T(x_i - x) - \beta_2^T vec\left\{(x_i - x)(x_i - x)^T\right\} - \cdots\right]^2 \cdot K_{adapt}(x_i - x, y_i - y) \tag{6}$$

Where, K_{adapt} is a data-adapted kernel function. Now, in the case of steering kernel regression, the kernel function takes the following form,

$$K_{adapt}(x_i - x, y_i - y) \equiv K_{H_i^{steer}}(x_i - x) \tag{7}$$

where, H_i^{steer} is the data-dependent full matrices known as steering matrices and given by,

$$H_i^{steer} = h\mu_i C_i^{-\frac{1}{2}} \tag{8}$$

Where h is the global smoothing parameter, μ_i is a scalar that captures (usually set to 1) the local density of the data and $C_i s$ are the covariance matrices [46].

Finally, a simple block diagram representation of the iterative steering kernel-based filtering technique is shown in Fig. 2 in which u denotes the iteration number.

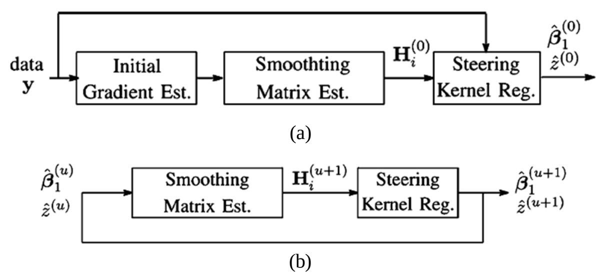


Figure 2. Simple block diagram of the iterative steering kernel regression [46]. (a) Initialization. (b) Iteration

B.Guided Image Filtering

The guided image filtering technique is a popular edge-preserving based image smoothing technique [47]. The basic mathematical description of guided image filtering technique is as follows: Let us denote the guidance image, input and output image of the filter as I, p and q respectively. Then the linear model of guided image filter can be given by [47]:

$$q_i = a_k I_i + b_k; \quad \forall i \in \omega_k \tag{9}$$

Where, i is the selected pixel index, k denotes the index of local window whose radius is r. The minimization of reconstruction error between p and q takes the following form [47]:

$$a_k = \frac{\frac{1}{|w|}\sum_{i \in \omega_k} I_i p_i - \mu_k \overline{p}_k}{\sigma_k^2 + \varepsilon} \tag{10}$$

$$b_k = \overline{p}_k - a_k \mu_k \tag{11}$$

Where, σ_k and μ_k are the variance and the mean value of I in window k, ε is a parameter that controls the smoothness degree. With this, the final filtered output of guided image filter is given by,

$$q_i = \bar{a}_i I_i + \bar{b}_i \quad (12)$$

Where, $\bar{a}_i$ and $\bar{b}_i$ are the average value of a and b respectively on the square window ω_i which is centered at position i.
From (9) to (12), we can easily analyze that, the guided image filter has two parameters: ε and r. The parameter ε is a regularization parameter and r specifies the radius of local window. To determine ε we have directly adopted the following relationship given by Golestaneh et. al. [45],

$$\varepsilon = 0.0067Q^{-0.7891} - 0.0003 \quad (13)$$

Next, for the proposed work we have taken r empirically equal to 1.

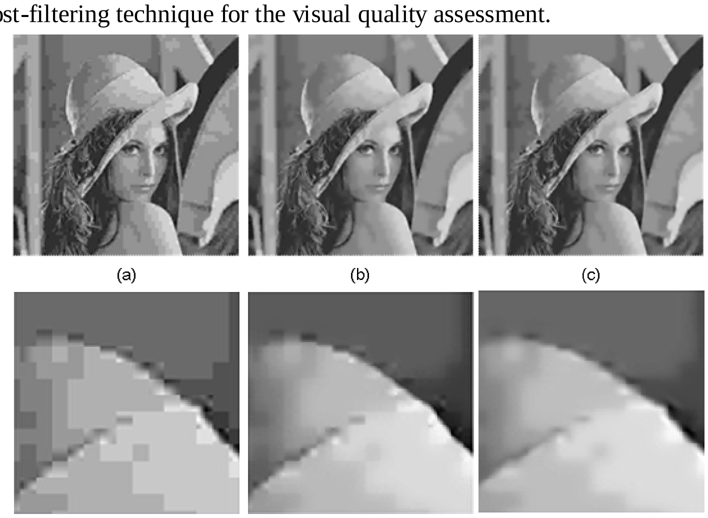
III. Results and Discussion

This section presents an extensive performance evaluation of the Proposed Hybrid Post-Filtering (PHPF) technique on the ground of visual quality assessment of filtered output images and the objective quality criteria PSNR. All the experiments have been performed on the MATLAB 2014b software platform for two standard test images Lena.png and Peppers.png, each of dimension 512×512 with 8-bit precision. The test images are shown in Fig. 3. In order to perform proper comparative testing of the proposed technique, both the test images are first individually compressed by JPEG standard on different quality values and then the blocking artifacts have been filtered by the proposed and other existing techniques.

(a (b

Figure 3. Two test images of size 512 × 512 (a) Lena.png, (b) Peppers.png

Figure 4 depicts the results obtained for the first test image Lena after JPEG standard compression, after filtering from the artifacts reduction technique developed by Golestaneh et al. [45] and after filtering from the proposed hybrid post-filtering technique for the visual quality assessment.



(a) (b) (c) (d) (e) (f)

Figure 4. (a) Shows the JPEG compressed "Lena" image for Q = 5 and bpp = 0.17, (b) obtained result of Golestaneh et. al. [45] technique. (c) Obtained result of the proposed hybrid post-filtering technique. For ease of visual examination, close-ups of Fig. 4(a), 4(b) and 4(c) are provided in figures 4(d), 4(e) and 4(f) respectively

From Fig. 4, we can clearly observe that at the 0.17 bpp bitrate, the JPEG compressed image contains strong visual blocking artifacts (Fig 4 (a) and (d)). On the same bitrate, the recent technique developed by Golestaneh et al. [45] shows less blocking artifacts than the JPEG compressed image (Fig. 4 (b) and (e)). Whereas, on the bitrate compression the obtained image from the proposed hybrid post-filtering technique exhibit much fewer artifacts compared to the filtering technique of Golestaneh et al. [45].

Furthermore, in order to make a robust remark about the comparative artifacts reduction capability of the proposed hybrid technique, the PSNR values obtained for the proposed technique and other existing techniques for both the test images at different bitrate compressions are tabulated in Table I.

TABLE I. COMPARISON OF PSNR (IN DB) FOR VARIOUS POST-PROCESSING TECHNIQUES APPLIED TO THE TEST IMAGES

Images	**Bitrate (bpp)**	**JPEG**	**Ref. 15**	**Ref. 41**	**Ref. 43**	**Ref. 44**	**Ref. 45**	**Proposed Hybrid Post-Filtering Technique**
Lena	0.17	27.3	28.13	27.5	28.5	28.3	28.3	**28.82**
	0.24	30.4	30.99	30.3	31.1	31.2	30.7	**31.49**
	0.31	31.9	32.42	31.6	32.6	32.6	32.6	**32.80**
Peppers	0.21	28.2	28.27	27.6	28.6	28.3	29.1	**30.42**
	0.31	30.7	30.91	30.1	30.9	30.9	31.3	**32.54**
	0.38	31.9	32.14	31.4	32.2	32.1	32.3	**33.14**

From the PSNR values tabulated in Table I, it is clearly evident that the proposed hybrid post-filtering technique offers the highest PSNR amongst all the state of the art JPEG artifacts reduction techniques. Hence, the proposed technique provides higher removal of JPEG artifacts from the JPEG compressed images as compared to other existing techniques.

IV. CONCLUSIONS

In this paper, a new hybrid post-filtering technique for the efficient JPEG image artifacts reduction has been developed and successfully implemented in MATLAB 2014(b). The proposed hybrid technique is basically a fusion of the two different filtering techniques. Hence, it is a two-stage artifacts reduction strategy, in which the initial filtering is provided by the iterative steering kernel-based technique and further artifacts reduction is achieved by the guided image filtering.

The comparative JPEG artifacts reduction performance of the proposed technique against the state of the art filtering techniques has been properly analyzed for the two different test images on various bitrates. The obtained results validate that the proposed hybrid post-filtering technique provides higher artifacts reduction as compared to the existing artifacts reduction techniques.

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