A Novel Type-2 Fuzzy Directed Hybrid Post-Filtering Technique for Efficient JPEG Image Artifact Reduction

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Abstract: - Image and video compression becomes very popular and intense field in recent decades, due to their fast and quality communication demand. To cope up with the high speed communication demand of image and videos, over the communication channel, higher compression (ie. low bit rate compression) is now preferred at the cost of quality degradation. Currently JPEG and JPEG2000 are the most popularly used codec's for achieving quality image compression. Practically, on the low bit rate compression, it has been observed that, the JPEG standard compressed images suffer from multifarious visual distortions. To address this problem effectively, this paper proposed an innovative type-2 fuzzy directed hybrid post filtering technique, which is framed to suppress the artifacts generated in JPEG compressed images at low bit rate compression. The proposed technique addresses all three types of JPEG compressed image artifacts: blocking, edges blurring, and aliasing. Furthermore the proposed technique is structured with two stages, to enhance the quality of JPEG compressed images. The first stage, removes blocking artifacts using boundary smoothing and guided filtering techniques. The second stage reduces blurring and aliasing around the edges through type-2 fuzzy directed local edge regeneration. To prove higher efficiency of proposed work, a complete comparative performance evaluation with other existing JPEG artifact removal techniques, has also presented. This extensive performance analysis includes visual quality assessment of post-filtered images along with subjective quality assessment on the basis of, Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE). Performance evaluation illustrates that the, proposed approach is efficient, provides PSNR improvement of approximately 1 dB along with higher reduction in MSE values as compared to state of the art algorithms for all the bit-rate compressions.

Key-Words: - JPEG image artifact removal, blocking artifacts; edge artifacts, type-2 fuzzy logic, local edge regeneration, PSNR, MSE.

1 Introduction

Image compression is, fundamentally, a process of representing an image with fewer amounts of bits as compare to original image. Various standards have been developed time to time for achieving good quality image compression, most popular, relying on the transform domain lossy compression strategy. Block Discrete Cosine Transform (BDCT) [1] -[4] is the most accepted and extensively used transform based lossy compression technique in image compression standards, owing to its optimum energy compaction property and ease of implementation, hence adopted by Joint Photographic Experts Group (JPEG) for JPEG standard development [5]. For the JPEG image compression, one of the widely recognized practical limitation is that, at low bit rates, the compression leave discontinuities of intensities among adjacent blocks (named as blocking artifacts). JPEG compression also leads to further visual artifacts such as degraded textures, blurring, and distortion of the edges. Altogether, decreasing the bit rate will increase the severity and the dominance of these visual artifacts.

Over the past decades, abundant algorithms have been proposed to enhance the visual quality of JPEG compressed images by attempting to remove the artifacts. Two techniques are generally adopted: encoder-based methods and post-processing based methods. The encoder based techniques work by making modifications to the encoder, such as transform-domain methods [8]-[10], interleaved block transforms [11], and interactive methods [12], lapped transform [13], combined transform [14], or wavelet based filtering [15]. However the drawback of this process is a deviation from the rules of the JPEG standard.

Post-processing relies improvement of the visual quality by removing artifacts through processing of the image after decoding. This process does not require any modifications to the available JPEG encoder or decoder, and can thus be used on existing JPEG images. Post-processing can generally be divided into spatial-domain techniques [16] -[23], DCT-domain techniques [24] -[29], Projections onto Convex Sets (POCS) [30]-[34], and block-shift filtering [35] -[44].

The spatial-domain techniques process the JPEG image based on some past knowledge and information about the original image, such as intensity smoothness or block boundaries of images. For instance, Reeve and Lim proposed a symmetric two-dimensional Gaussian spatial filtering method to reduce the blocking artifacts [16]. Other methods of spatial-domain techniques are also reported in the literature, based on gradients/thresholds and the histogram which first classify the blocks as ei ther high frequency or low frequency, followed by filtering to remove artifacts [18]-[23].

In DCT-domain post processing algorithms, blocking artifacts is reduced by direct alteration of DCT coefficients. For example, Jeon and Jeong proposed a post processing method to reduce discontinuities of pixel values over block boundaries by compensating for the loss of coefficients accuracies in the transform domain [26]. Then Zeng proposed a DCT-domain method for blocking reduction by applying a zero-masking to the DCT coefficients of some shifted image blocks. However, a loss of edge information caused by the zero-masking scheme can be noticed in his method [27]. On continuation Chen et al. proposed an algorithm based on three filtering modes in terms of the activity across block boundaries. They considered the masking effect of the human visual system and integrated adaptive filtering into the de-blocking process [28].

There are also some methods which use both spatial domain and DCT domain approaches. Singh et al. proposed an adaptive post filtering algorithm to remove blocking artifacts [29]. They classify the boundary regions between the blocks as smooth, non-smooth, or the intermediate regions. Then, blocking artifacts in the smooth and non-smooth regions are removed by modifying selected DCT coefficients while an edge preserving smoothing filter is applied to the intermediate regions. In addition, there are typical post-processing iterative methods based on the theory of projection onto convex sets (POCS) [30] and a m aximum a posterior probability approach [31]. Reeve and Lim introduced a method based on the theory of POCS and proposed a post-processing technique to reduce blocking artifacts in JPEG images [35]. The major drawback of this approach is the high computational complexity.

Block shift filtering is an adaptive filtering algorithm for reducing image artifacts [43]-[44]. Some algorithms have been proposed which attempt to reduce blockiness by using a quad-tree (QT) decomposition and block-shift filtering [35]-[38]. Luo and Ward proposed an adaptive approach which reduced blocking artifacts in both the domains [41]. For smooth regions, this method took advantage of the fact that the original pixels in the same block provide continuity. Zhai et al. proposed algorithms to preserve the image's details and reduce the effect of quantization noise [43]-[44]. They integrated QT decomposition with the block shift filtering.

Although previous algorithms can effectively suppress blockiness, JPEG images suffer from more than just blocking. At low bit rates, the compressed image also suffers from blurring and aliasing artifacts around the edges. Some authors have taken deblocking further and shown attempts to pay off for degraded textures in the compressed image [15], [43], [44]. Nevertheless, this method does not address blurring and aliasing around the edges. Recently Golestaneh et al. proposed a single technique to enhance the quality of the image via two stages [51]. First, they removed blocking artifacts via boundary smoothing and guided filtering. Then, they reduced blurring and aliasing around the edges via a local edge regeneration stage. For detecting the strong edges, they used canny edge detection with Otsu's thresholding. The results of this technique have proven comparable performance compare to others, but not for all the bit rate compression.

The motivation for our work came from Golestaneh et al. [51] work, where, they have used canny edge detection technique along with Otsu's thresholding to detect important edges which are more likely similar to original raw image for local edge regeneration. The canny edge detection technique might be not so prominent on detection of such important edges in the presence of blocking and reigning artifacts, and may be a cause of artifact removal efficiency reduction. The presence of blocking and reigning artifacts actually creates imprecise environment for the detection of important edges, and creates ambiguousness between block boundaries and original raw image edges, to overcome this problem we propose interval type-2 fuzzy edge detection technique for important edge localization in presence of artifacts for efficient local edge regeneration and hence named as type-2 fuzzy directed local edge regeneration. Meanwise the basic aim is to exploit the higher imprecise condition handling capability of type-2 fuzzy sets and taking advantage of its capability to efficiently direct local edge regeneration process.

So broadly, in the present paper, we have proposed a technique to efficiently enhance the visual quality of JPEG images via a two-stage approach. The proposed algorithm removes blocking artifacts by using image smoothing [41] followed by guided filtering [45], and it reduces blurring and aliasing artifacts around the edges by means of type-2 fuzzy directed local edge regeneration. The major contribution of the proposed work is to develop a technique to enhance the quality of JPEG images not only by removing blocking artifacts, but also by reducing blurring and aliasing artifacts around the edges.

This paper is organized in the following three sections; the first section provides the details of the two stages of the proposed algorithm followed by the section 3, which comprises results and discussions. At the end, section 4 deals with the concluding remarks of the present work.

2 Proposed Type-2 Fuzzy Directed Hybrid Post-filtering Technique

The flow chart of proposed type-2 fuzzy directed hybrid post-filtering technique is shown in Fig. 1. In the proposed technique, given a JPEG image as the input, two stages are used to suppress the artifacts. The first stage is being designed to remove blocking artifacts. The second stage removes blurring and aliasing artifacts around the edges in an attempt to make the edges appear sharper.

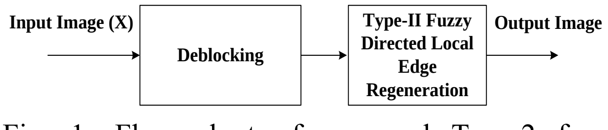


Fig. 1: Flow chart of proposed Type-2 fuzzy directed hybrid post-filtering technique.

2.1 Deblocking

A very eminent problem with JPEG images is blocking artifacts. This stage serves to remove blocking artifacts by smoothing the boundaries of blocks [41] and by using guided filtering [45]. The flow chart of this stage is shown in Fig. 2. At low bit rate compression, there exist discontinuities between block boundaries due to independent quantization. We first reduce discontinuities between the neighboring blocks by using the method presented by Luo and Ward for smooth areas [41].

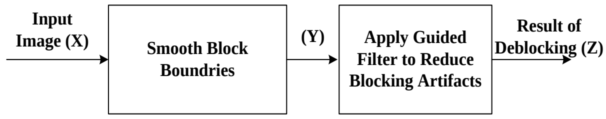


Fig.2 Flow chart of the deblocking stage.

As mentioned by Luo and Ward, their method for smooth areas first identifies pairs of neighboring blocks whose shared boundary is not due to a genuine change in the intensities at that position. This condition satisfies if: (1) the two blocks share similar horizontal/vertical frequency properties and (2) a third block centered on the boundary is otherwise quite smooth. After determination of such blocks, the block to block discontinuities are suppressed via DCT-based filtering, i.e., via strategic blending of the DCT coefficients of the two blocks and of the third block encompassing the boundary so as to remove blockiness but not introduce artifacts. By operating only on blocks which satisfy the above two criteria, the technique avoids modifying strong textures and edge regions, and thus attempts to preserve important information, true edges, and textures in the image.

After reducing the discontinuities between block boundaries, we apply a guided filter proposed by He and Tang on the image to reduce the blocking artifacts [45]. The guided filter has two parameters: ϵ and α. The parameter ϵ is a regularization parameter and α specifies the local window radius. Rising ϵ and α usually results in more smoothing. Decreasing these parameters generally results in images which might still contain visible blocking artifacts. Following the same technique used by Golestaneh et al. [51], we select the ϵ parameter of the guided filter based on the JPEG quality factor (Q). To determine ϵ, relationship given in ref. 51, has been used,

$$\epsilon = 0.0067Q^{-0.7891} - 0.0003 \quad \text{... (1)}$$

We also choose α empirically $\alpha = 4$, which generally yields good results across a wide variety of images. However, the selection of this value is not critical, the results are very close when α is chosen within a $\pm 20\%$ range.

2.2 Type-2 Fuzzy Directed Local Edge Regeneration Technique

In this second and final stage, we use local area information in an attempt to regenerate the edges and thus remove these edge artifacts. The flow chart of this stage is shown in Fig. 3. Let Z denotes the output result of the deblocking stage.

At this stage, Golestaneh et al. [51] have utilized canny edge detection along with Otsu's thresholding to detect the strong edges. To improve the edge detection capability in this work, we have used type-2 fuzzy edge detection system to compute the strong and important edges. On utilizing the proposed type-2 fuzzy edge detection technique, not only improves the edge detection capability to detect strong and important edges, but also saves lots of computation as compare to the canny edge operator. Consequently, use of the proposed edge detection modification provides us real strong edges as compare to Golestaneh et al. [51] and hence provides improvement in PSNR and MSE. The modeling of proposed type-2 fuzzy edge detection (T2FLSED) technique is given in the next subsection. Let denote an edge pixel value which is detected by T2FLSED and is located at the positions *i* and *j*. We determine which area around the edges is more similar to the edge pixel by applying the following equation:

$$d_{left} = \left| Z(i,j) - \frac{Z(i,j-1)+Z(i,j-2)}{2} \right| \quad \text{... (2)}$$

$$d_{right} = \left| Z(i,j) - \frac{Z(i,j+1)+Z(i,j+2)}{2} \right|$$

In Eq. 2, we chose to compare the edge pixel against the average of the two pixel values to the left and right. In this equation, d_{left} represents the difference between the edge pixel $Z(i,j)$ and the average of the two pixels horizontally to the left. Also, d_{right} represents the difference between the edge pixel $Z(i,j)$ and the average of the two pixels horizontally to the right. After computing d_{left} and d_{right}, if $d_{left} < d_{right}$, this signifies that the left side of the edge pixel is more similar to the edge pixel than the right side. In the following equation, we take the benefit of the area which is similar to the edge pixel to improve the edge pixel:

$$Z(i',j') = \frac{Z(i'+1,j')+Z(i',j'-1)+Z(i'+1,j'-1)+4Z(i',j')}{7} \quad \text{... (3)}$$

For the edge pixel itself,

$$Z(i,j) = \frac{Z(i+1,j-1)+Z(i,j-1)+Z(i+1,j)+Z(i,j)}{4} \quad \text{... (4)}$$

In Eqs. 3 to 4, the algorithm begins by improving the pixels near the center pixel. Eq. 3 describes the regeneration of the pixels neighboring the center block. The algorithm then uses these improved pixel values to enhance the center block. Specially, Eq. 4 uses the average of regenerated pixels as well as the previous value of the edge pixel to regenerate the edge pixel.

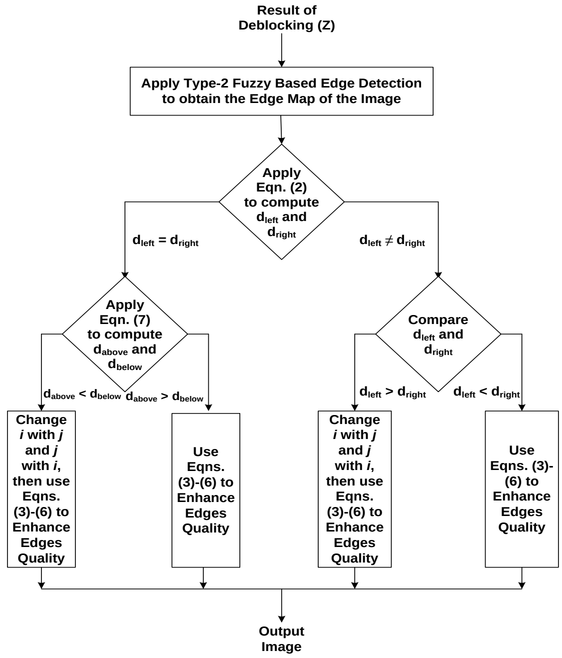


Fig. 3. Flow chart of proposed Type-2 fuzzy based local edge-regeneration stage.

The next step is to reduce aliasing and blurring artifacts on the other side. By using the following equation, we regenerate pixels which are slightly further away from the edge.

$$Z(i',j') = \frac{Z(i'-1,j')+Z(i',j'+1)+Z(i'-1,j'+1)}{3} \quad \text{...(5)}$$

$$Z(i',j') = \frac{Z(i'-1,j')+Z(i',j'+1)+Z(i'-1,j'+1)+4Z(i',j')}{7} \quad \text{...(6)}$$

In Eqs. 5 and 6, by using the average of the pixels on the side which is different from the edge pixel, we just regenerate pixels around the edges and reduce the aliasing and blurring to make the edge appear highly sharper. First, by using Eq. 5, we regenerate neighboring pixels; next, by using Eq. 6, we regenerate selected pixels to make the area around the edge more smooth. Eqs. 3 to 6, are applied to all edge pixels identified by the type-2 fuzzy edge detection system.

In Eq. (2), after calculating d_{left} and d_{right}, if $d_{right} < d_{left}$, this signifies that the right side of the edge pixel is more similar to the edge pixel than the left side. In this condition, the equations are similar to Eqs. 3 to 6, except that *i* is replaced with *j* and *j* is replaced with *i*, resulting in a 180 degree rotation in the image plane of the regeneration pattern about $Z(i,j)$. We chose the basic structure for Eqs. 3 to 6 due to its relative simplicity and its ability to operate effectively on all edge orientations.

If $d_{left} = d_{right}$, it means that the edge is horizontal. As a result, we use the following equation to compute the side which is similar to the edge pixel:

$$d_{above} = \left| Z(i,j) - \frac{Z(i-1,j)+Z(i-2,j)}{2} \right| \quad \text{... (7)}$$

$$d_{below} = \left| Z(i,j) - \frac{Z(i+1,j)+Z(i+2,j)}{2} \right|$$

In Eq. (7), d_{above} represents the difference between the edge pixel $Z(i,j)$ and the average of the two pixels vertically above. Also, dB_{elow} represents the difference between the edge pixel $Z(i,j)$ and the average of the two pixels vertically below. If $d_{above} > dB_{elow}$, this signifies that the region below the edge pixel is more similar to the edge pixel than the region above. Therefore, we use Eqs. 3 to 6 for the pixels to enhance the edge quality. On the other hand, if $d_{above} < dB_{elow}$, it means that the region above is more similar to the edge pixel than the region below. In this case, we use Eqs. 3 to 6 after changing *i* with *j* and *j* with *i*.

2.3 Type-2 Fuzzy Logic

This subsection is intended to briefly describe type-2 fuzzy sets and their corresponding membership functions. If for a type-1 membership function, as in Fig. 4, we blur it to the left and to the right, as illustrated in Fig. 5, then a type-2 membership function is produced.

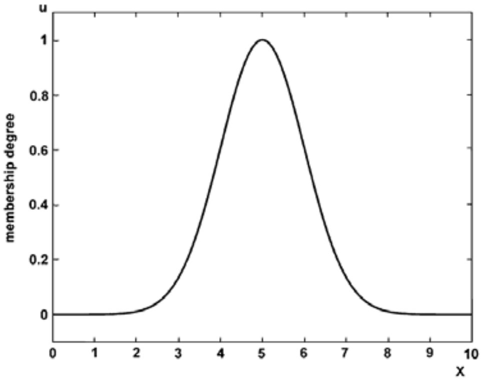


Fig. 4: An example of a type-1 membership function

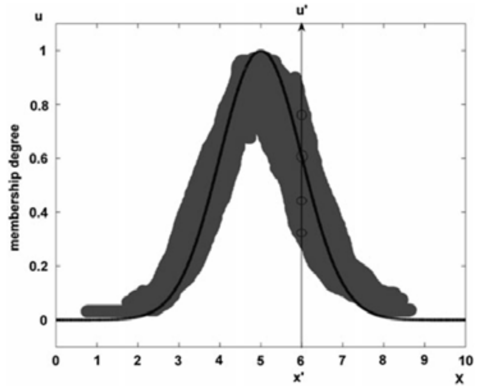


Fig. 5: Blurred type-1 membership function

In this case, for a specific value x', the membership function (u'), takes on different values, which are not all weighted the same, so we can assign membership grades to all of those points.

By doing this for all $x \in X$ we form a three-dimensional membership function (a type-2 membership function), which characterizes a type-2 fuzzy set [52]. A type-2 fuzzy set $\tilde{A}$ is characterized by the membership function:

$$\tilde{A} = \{((x,u), \mu_{\tilde{A}}(x,u)) \mid \forall x \in X, \forall u \in J_x \subseteq [0,1]\} \quad \dots(8)$$

In which $0 \le \mu_{\tilde{A}}(x,u) \le 1$. In fact $J_x \subseteq [0,1]$ represents the primary membership of x, and $\mu_{\tilde{A}}(x,u)$ is a type-1 fuzzy set known as the secondary set. Hence, a type-2 membership grade can be any subset in [0,1], the primary membership, and corresponding to each primary membership, there is a secondary membership (which can also be in [0,1]) that defines the possibilities for the primary membership. Uncertainty is represented by a region, which is called the footprint of uncertainty (FOU). When $\mu_{\tilde{A}}(x,u)=1, \forall u \in J_x \subseteq [0,1]$, we have an interval type-2 membership function, as shown in Fig. 5. The uniform shading for the FOU represents the entire interval type-2 fuzzy set and it can be described in terms of an upper membership function $\bar{\mu}_{\tilde{A}}(x,u)$ and a lower membership function $\underline{\mu}_{\tilde{A}}(x,u)$.

A fuzzy logic system (FLS) described using at least one type-2 fuzzy set is called a type-2 FLS. Type-1 FLSs are unable to directly handle rule uncertainties, because they use type-1 fuzzy sets that are certain (viz, fully described by single numeric values). On the other hand, type-2 FLSs are useful in circumstances where it is difficult to determine an exact numeric membership function, and there are measurement uncertainties [52].

A type-2 FLS is characterized by IF–THEN rules, where their antecedent or consequent sets are now of type-2. Type-2 FLSs, can be used when the circumstances are too uncertain to determine exact membership grades such as when the training data is affected by noise. Similarly, to the type-1 FLS, a type-2 FLS includes a fuzzifier, a rule base, fuzzy inference engine, and an output processor, as we can see in Fig. 6, for a Mamdani model. The output processor includes type-reducer and defuzzifier; it generates a type-1 fuzzy set output (from the type-reducer) or a number (from the defuzzifier) [52].

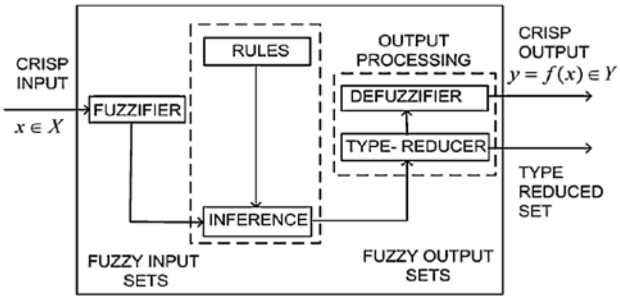


Fig. 6: Type-2 fuzzy logic system

2.4 Proposed Type-2 fuzzy Edge Detection

The beauty of this proposed work is the utilization of the imprecise condition handling capability of the fuzzy logic to design an efficient edge detection technique. An edge is a boundary between two uniform regions. We can detect an edge by comparing the intensity of neighbouring pixels.

However, because of uniform regions are not crisply defined, small intensity differences between two neighbouring pixels do not always represent an edge. Instead, the intensity difference might represent a shading effect. The fuzzy logic approach for image processing allows using membership functions to define the degree to which a pixel belongs to an edge or a uniform region.

The type-2 fuzzy edge detection (T2FLSED) technique designed relies on the image gradient to locate breaks in uniform regions. Hence the first step is to calculate the image gradient along the x-axis and y-axis. Next step is to design the directional fuzzy edge detector by defining appropriate membership functions and rule base system. For the efficient detection of image edges two input variables have been used, namely 'Ix' and 'Iy'. The output variable of proposed T2FLSED system is indicated as 'Iout', which provides edges of the input image. F ig. 7 shows the plot of membership functions (mf) for input and output variables of designed T2FLSED system.

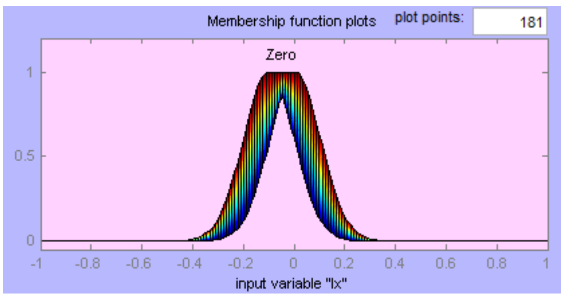


Fig. 7 (a): Plot of mf for first input Ix.

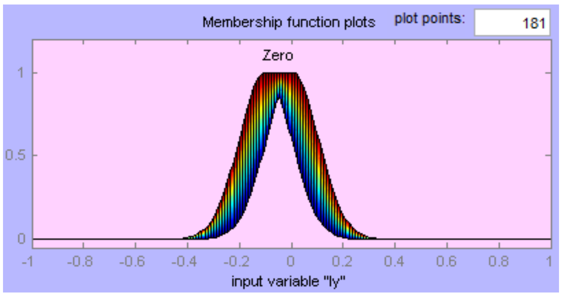


Fig. 7 (b): Plot of mf for second input Iy.

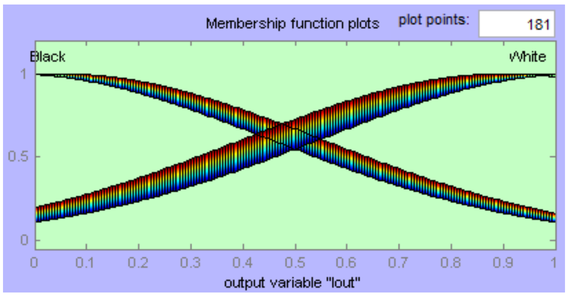


Fig. 7 (c): Plot of mf for output variable Iout.

The rule base designed is:

1. If (Ix is zero) and (Iy is zero) then (Iout is white) (1)
2. If (Ix is not zero) or (Iy is not zero) then (Iout is black) (1)

Finally the layout of the developed T2FLSED FIS is shown in Fig.8.

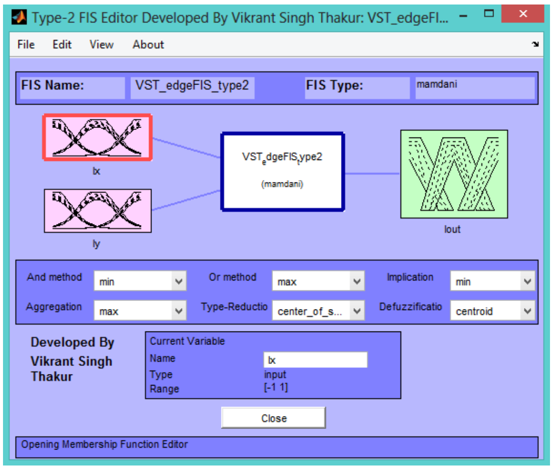


Fig. 8: Layout of developed T2FLSED FIS.

3 Results and discussion

The proposed work has been successfully implemented and tested on MATLAB 2012(b). Simulation is carried out to compare the proposed type-2 fuzzy directed hybrid post-filtering technique (T2FLSEDHPFT) to other state of the art techniques. Total four images of size 512 × 512 as shown in Fig. 9, are used for testing purpose.

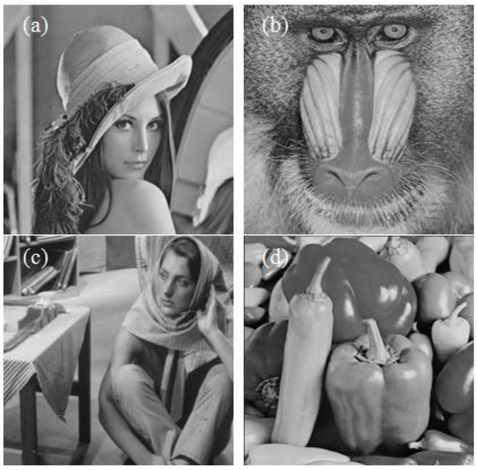


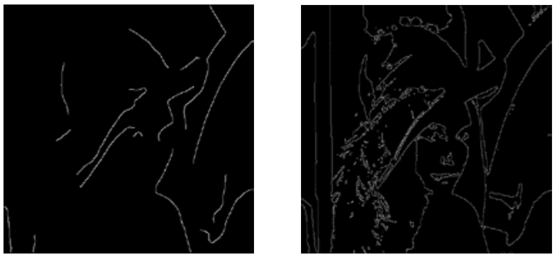
Fig. 9 Four 512 × 512 test images: (a) Lena, (b) baboon, (c) Barbara and (d) peppers.

Now Fig. 10 shows the results obtained for the algorithm given by Golestaneh et al. [51] and proposed T2FLSEDHPFT technique of this paper. The PSNR value obtained for “Lena” image with JPEG compressed is 30.4112 after post filtering with technique of Golestaneh et al. [51], it comes out 30.628 and with our proposed technique the PSNR value obtained is 31.3552.

Notice that the results of Golestaneh et al. [51], exhibit very slight PSNR improvement, whereas the proposed technique shows higher PSNR improvement, of approximately 1 dB. This improvement is due to the higher efficiency of proposed type-2 fuzzy edge detection (T2FLSED) technique for detection of strong and important edges of JPEG compressed image.

Fig. 10: (a) Shows the JPEG compressed “Lena” image for Q = 10 and bpp = 0.24, (b) the result of Golestaneh et al. [51] technique. (c) The result of our proposed T2FLSEDHPFT technique. For ease of examination, closeups of Fig. 10(a), 10(b) and 10(c) are provided in Figures 10(d), 10(e) and 10(f).

Fig. 11 shows the comparison of canny edge detection used by Golestaneh et al. [51] and T2FLSED edge detection used in the proposed work.



(a) Edge output of Ref. 51. (b) Edge output of proposed technique

Fig.11: Comparison of edge detection capability.

The PSNR and MSE values obtained after JPEG image artifacts removal, using proposed type-2 fuzzy directed hybrid post-filtering technique (T2FLSEDHPFT) and other state of the art techniques for all the test images shown in Fig. 9, have been tabulated in Table 1 and Table 2 respectively.

Table 1: Comparison of PSNR (dB) for various post-processing techniques applied to different JPEG images.

Images	Bitrate (bpp)	JPEG	Ref. 15	Ref. 41	Ref. 43	Ref. 44	Ref. 51	Proposed T2FLSEDHPFT
Lena	0.17	27.3	28.13	27.5	28.5	28.3	28.3	**28.77**
	0.24	30.4	30.99	30.3	31.1	31.2	30.7	**31.46**
	0.31	31.9	32.42	31.6	32.6	32.6	32.6	**32.91**
Baboon	0.26	21.5	21.79	21.6	22	22	22.05	**22.17**
	0.46	23.4	23.53	23.3	23.7	23.6	23.7	**23.8**
	0.62	24.5	24.56	24.3	24.7	24.6	24.6	**24.72**
Barbara	0.23	24.5	24.38	24	24.9	24.9	24.9	**27.32**
	0.35	26.3	26.02	25.7	26	26.1	26.4	**28.103**
	0.45	27.6	27.33	26.9	27.8	27.3	27.6	**29.87**
Peppers	0.21	28.2	28.27	27.6	28.6	28.3	29.1	**30.43**
	0.31	30.7	30.91	30.1	30.9	30.9	31.3	**32.44**
	0.38	31.9	32.14	31.4	32.2	32.1	32.3	**33.22**

Table 2: Comparison of MSE values for various post-processing techniques applied to different JPEG images.

Images	Bitrate (bpp)	JPEG	Ref. 15	Ref. 41	Ref. 43	Ref. 44	Ref. 51	Proposed T2FLSEDHPFT
Lena	0.17	121.08	100.02	115.63	91.85	96.18	96.18	**86.31**
	0.24	59.30	51.77	60.68	50.48	49.33	55.34	**46.46**
	0.31	41.98	37.25	44.99	35.73	35.73	35.73	**33.27**
Baboon	0.26	460.34	430.61	449.86	410.28	410.28	405.58	**394.53**
	0.46	297.22	288.46	304.14	277.38	283.84	277.38	**271.07**
	0.62	230.72	227.55	241.59	220.33	225.47	225.47	**219.32**
Barbara	0.23	230.72	237.18	258.87	210.42	210.42	210.42	**120.53**
	0.35	152.43	162.58	175.02	163.34	159.62	148.96	**100.64**
	0.45	113.00	120.25	132.76	107.91	121.08	113.00	**67.00**
Peppers	0.21	98.42	96.85	113.00	89.76	96.18	80.00	**58.89**
	0.31	55.34	52.73	63.54	52.85	52.85	48.20	**37.07**
	0.38	41.98	39.73	47.11	39.18	40.09	38.29	**30.98**

Now for clear visualization of obtained results for all the techniques included in this paper, Fig. 12 to Fig. 15 s hows the bar chart of obtained PSNR values, plotted against various Bits per pixel (bpp) for all the four test images separately.

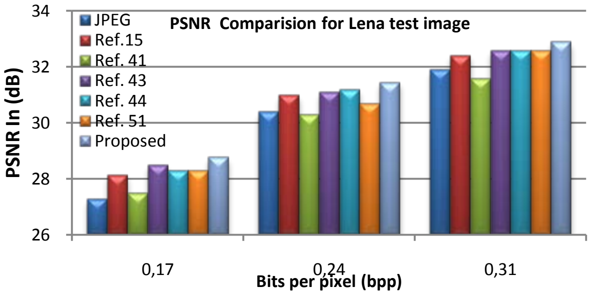


Fig. 12: PSNR comparison plot for test image “Lena”.

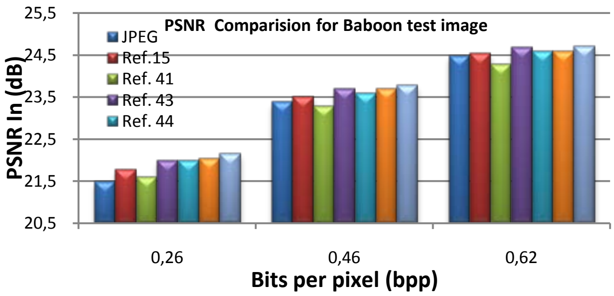


Fig. 13: PSNR comparison plot for test image “Baboon”.

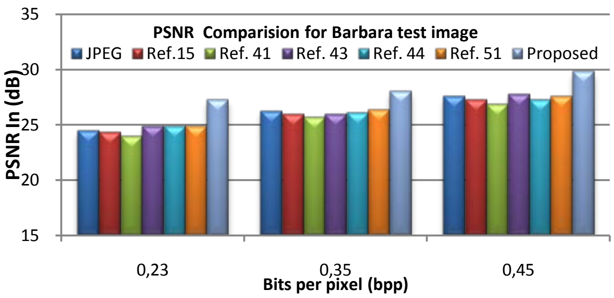


Fig. 14: PSNR comparison plot for test image “Barbara”.

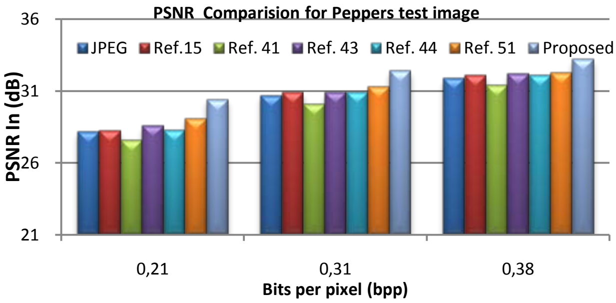


Fig. 15: PSNR comparison plot for test image “Peppers”.

From all the above PSNR plots it is clearly evident that, the proposed type-2 fuzzy directed hybrid post-filtering technique (T2FLSEDHPFT), provides highest PSNR among all the available state of the art techniques. Furthermore, it is also observable that the proposed edge detection system based on type-2 fuzzy set theory, efficiently detects the strong and important edges in the presence of blocking and reigning artifacts and hence provides, efficient solution of the local edge regeneration based on edge detection strategy.

3 Conclusions

In this paper a novel type-2 fuzzy directed hybrid post-filtering technique (T2FLSEDHPFT) has been proposed and successfully implemented in MATLAB 2012 (b).

The proposed work is basically intended to provide modification of the available JPEG artifact reduction technique via local edge regeneration developed by Golestaneh et al. [51]. The modification proposed, particularly deals with the replacing canny edge detection technique by type-2 fuzzy based edge detection technique, to efficiently detect strong and important edges of JPEG images in the presence of blocking and reigning artifacts toward achieving efficient enhancement in the visual quality of JPEG images.

The proposed algorithm addresses all the three types of artifacts which are prevalent in JPEG images through two stage hybrid post filtering. First, it reduces blocking artifacts by smoothing boundaries of blocks via guided filtering, and then improves the edges of the image by performing type-2 fuzzy directed local edge regeneration. The obtained result clearly signifies the efficient performance of the proposed algorithm against several well-known JPEG artifact removal methods. Moreover comparative performance evaluation shows that, for all the test cases proposed algorithm provides maximum PSNR and minimum MSE values as compared to state of the art algorithms and hence efficient to reduce the JPEG image artifacts.

In addition to this, by the development of the proposed work we have achieved improvement in PSNR values in the range of 0.5 to 1 dB as compare to other available techniques.

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