Modified Histogram Based Fuzzy Filter

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Abstract. In this paper, a fuzzy based impulse noise removal technique has been proposed. The proposed filter is based on noise detection, fuzzy set construction, histogram estimation and fuzzy filtering process. Noise detection process is used to identify the set of noisy pixels which are used for estimating the histogram of the original image. Estimated histogram of the original image is used for fuzzy set construction using fuzzy number construction algorithm. Fuzzy filtering process is the main component of the proposed technique. It consists of fuzzification, defuzzification and predicted intensity processes to remove impulse noise. Sensitivity analysis of the proposed technique has been performed by varying the number of fuzzy sets. Experimental results demonstrate that the proposed technique achieves much better performance than state-of-the-art filters. The comparison of the results is based on global error measure as well as local error measures i.e. mean square error (MSE) and structural similarity index measure (SSIM).

Keywords: Image restoration, fuzzy logic, structural similarity index, impulse noise.

1 Introduction

Image restoration is an important branch of image processing, which deals with the reconstruction of images by removing noise and blurriness, and making them suitable for human perception. Images can become corrupted during any of the acquisition, pre-processing, compression, transmission, storage and/or reproduction phases of processing [1],[2]. Spatial image restoration technique can be divided into two broad categories namely conventional and blind image restoration techniques [3]. Information about the degradation process is generally known in case of conventional image restoration techniques. This known information can be used in developing a model which is further used to restore the corrupted image back to its original form. Conventional techniques are used to solve motion blur, system distortions, geometrical degradations and additive noise problems.

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Recently, more focus has been placed on the blind image restoration [3], where the image has to be restored directly from the degraded image without any prior knowledge about the degradation process. Main objectives in developing blind image restoration technique are to remove noise along with preserving the image details. Smoothing a region of the degraded image might destroy an edge and/or texture information while sharpening edges might lead to amplification of unnecessary noise. In the sequel, we present a spatial image restoration technique which is based on histogram statistics and fuzzy logic to remove impulse noise along with edge preservation.

A number of approaches have been developed for the impulse noise removal. Tukey [4], Astola et al. [5], and Pitas et al. [6] have used median filtering to remove impulse noise. It has been observed that the median based filter cannot give good results when noise rate is high. Furthermore, number of fuzzy based image restoration techniques has been developed for impulse noise removal. For instance, the histogram based fuzzy filter (HFF) [7], novel fuzzy filter (NFF) [8] and genetic based fuzzy image filter (GFIF) [9] are the examples of the most recent fuzzy filters. HFF is able to outperform the rank-order filter (such as median filter) for the whole range of the corruption rate ranging from 0.1 to 0.9 without any training. NFF gives superior performance than the median filter for highly corrupted images, however it does not preserve the image details well. NFF also uses histogram of the original image or image database to find the fuzzy parameters, which shows that it is not a pure blind technique. GFIF performs well for the whole range of corrupted images but the major drawback of GFIF is its extensive training as well as original image or image database is required to calculate the fuzzy sets.

In this paper, we propose a modified histogram based fuzzy filter (MHFF) to remove impulse noise from low as well as highly corrupted images.The proposed filter consist of noise detection, fuzzy set construction through fuzzy number construction algorithm, histogram estimation and fuzzy filtering process. Experimental results show that MHFF gives much better results than state-of-the-art fuzzy based filters as well as median filter for impulse noise removal. Main Contribution of the proposed technique includes:

- It is a pure blind image restoration technique which gives better results than state-of-the-art filters without any training.
- Proposed technique uses the fuzzy number construction algorithm[8] instead of principle of histogram potential[7] to construct fuzzy sets.
- Sensitivity analysis of the proposed technique is performed by varying the number of fuzzy sets.

The rest of the paper is organized as follows. In section 2, system architecture of the MHFF is presented. Section 3 presents the fuzzy filtering process. Fuzzy set construction has been discussed in section 4. Experimental results and sensitivity analysis of the proposed technique are described in section 5. Finally conclusion is drawn in section 6.

2 System Architecture of the MHFF

In this section, system architecture and its working are presented. Block diagram of the system is shown in figure 1. In the first step, set of noisy pixels N_{pixels} are detected using noise detection process. To determine N_{pixels} , noise detection process scan the image using a window of size 3x3 from left to right and top to bottom. The central pixel of the sub-image will belong to the set N_{pixels} if it is minimum, maximum, less than some threshold T or greater than 1-T. The set of noisy pixels and the corrupted image histograms are used to estimate the histogram of the original image using the following equation.

$$H_{est}(i) = \frac{H_{corr}(i) - H_{noisy}(i)}{\sum\limits_{g=0}^{255} (H_{corr}(g) - H_{noisy}(g))} \tag{1}$$

where H_{corr} and H_{noisy} are the histograms of the corrupted image and set of noisy pixels respectively. H_{est} represent the estimated histogram of the original image. We have considered 8-bit gray scale images so gray level ranges from 0 to 255.

Estimated histogram of the original image is used to construct fuzzy sets. MHFF is designed to create five fuzzy membership functions namely very dark (vdk), dark (dk), medium (md), bright (br) and very bright (vbr). Therefore, each intensity pixel under the considered window is treated as the fuzzy variable with membership degree in the fuzzy set vdk, dk, md, br and vbr. Membership functions identify the degree of brightness for each input pixel. Following equation shows the trapezoidal shaped membership function used in MHFF [11].

$$f_A(x) = \begin{cases} 0, & x < a_A \\ \frac{(x-a_A)}{(b_A-a_A)}, & a_A \le x < b_A \\ 1, & b_A \le x < c_A \\ \frac{(d_A-x)}{(d_A-c_A)}, & c_A \le x < d_A \\ 0, & x \ge d_A \end{cases} \tag{2}$$

The trapezoidal function of fuzzy set A ε *vdk, dk, md, br, and vbr.* This fuzzy set is denoted by the parameters $\left[a_A \; b_A \; c_A \; d_A \right]$ Section 3 presents the details about the calculation of these parameters through fuzzy number construction algorithm [8].

3 Fuzzy Filtering Process

Fuzzy sets (Section 4) and estimated histogram are used in fuzzy filtering process. Fuzzy filtering process consists of fuzzification, de-fuzzification and predicted intensity calculation processes. These components of fuzzy filtering process are described one by one as follows:

Fuzzification. A window of size 3x3 is used to scan the image from left to right and top to bottom. In each window where the central pixel is detected noisy by the noise detection process is considered as the candidate for fuzzy filtering process. In the first step, each pixel under the candidate window is considered as a fuzzy variable and its degree of brightness is calculated using fuzzy membership functions. This process of calculating the degree of membership is known as fuzzification process.

Defuzzification. In this step, all the outputs from the previous step belonging to each membership function are separately used for defuzzification. Resultantly, the outputs of this step will be five crisp values, calculated using equation 3 [11].

$$D_A = \begin{cases} \frac{\sum_{i=1}^{9} f_A(x_i)*x_i}{\sum_{i=1}^{9} f_A(x_i)} & if \sum_{i=1}^{9} f_A(x_i) > 0 \\ 0 & otherwise \end{cases} \tag{3}$$

where D_A represents output of the defuzzification process associated with fuzzy membership function having fuzzy set A ε *vdk, dk, md, br, and vbr.* This fuzzy set is denoted by the parameters $\left[\, a_A \; b_A \; c_A \; d_A \,\right]$ where x_i denotes the corresponding pixel value $i = 1, 2, \ldots, 9$ where $f_A(x_i)$ represent the membership degree of x_i in fuzzy set A.

Predicted Intensity Process. Finally in order to choose best estimate of the corrupted pixel under the considered window, predicted intensity is computed. It is calculated using the mean of the non-noisy pixels under the 3x3 pixel window as shown in figure 1.

4 Fuzzy Set Construction

The proposed technique uses the fuzzy number construction algorithm [8] instead of using the principle of histogram potential [7] to calculate the parameters of the trapezoidal fuzzy membership functions. Estimated histogram of the original image and the number of fuzzy sets to be constructed are given as input to the algorithm. This algorithm gives the parameters of the fuzzy sets as output.

In this paper, we use the luminance fuzzy variables with five linguistic terms. The fuzzy sets for an image include very dark (vdk), dark (dk), medium (md), bright (br) and very bright (vbr). These fuzzy sets can be represented by the following equation.

$$\left.\begin{array}{r} vdk = \left[\, a_{vdk} \; b_{vdk} \; c_{vdk} \; d_{vdk} \,\right] \\ dk = \left[\, a_{dk} \; b_{dk} \; c_{dk} \; d_{dk} \,\right] \\ md = \left[\, a_{md} \; b_{md} \; c_{md} \; d_{md} \,\right] \\ br = \left[\, a_{br} \; b_{br} \; c_{br} \; d_{br} \,\right] \\ vbr = \left[\, a_{vbr} \; b_{vbr} \; c_{vbr} \; d_{vbr} \,\right] \end{array}\right\} \tag{4}$$

The detailed algorithm for constructing the fuzzy sets can be found in [9].

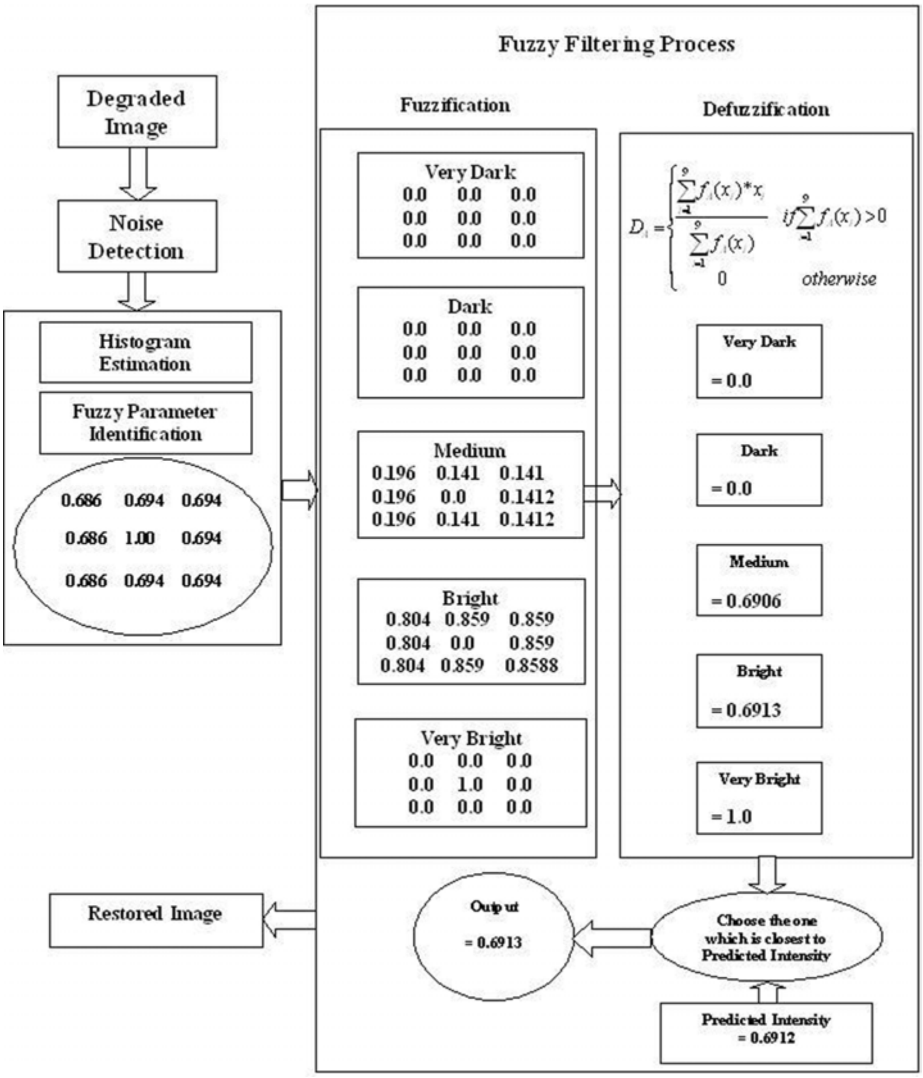

Fig. 1. Block Diagram of MHFF

5 Experimental Results and Sensitivity Analysis

In order to test the quality of the proposed technique, we compare MHFF with the other state-of-the-art filtering techniques such as HFF, NFF and median filter. The quantitative measures used for comparison are mean square error (MSE) and structural similarity index measure (SSIM) [10]. Representative results for a typical "Lena" image are shown in table 1, where the image is corrupted with impulse noise (salt and pepper) with noise level ranging from 0.1 to 0.9.

Table 1. Comparison of de-noising methods for Lena image degraded with salt and pepper noise having corruption rate varying from 0.1 to 0.9

Method	Quality measure	Noise Corruption Rate								
		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
NFF	MSE	40.6	59.6	82.4	125.17	222.04	561.7	1475.9	4964.3	13655
	SSIM	0.9	0.8	0.8	0.79	0.72	0.58	0.38	0.16	0.05
HFF	MSE	85.2	89.2	101.5	119	177.82	375.61	1095.1	3382.3	8899.2
	SSIM	0.8	0.8	0.8	0.84	0.8	0.69	0.44	0.19	0.06
MF	MSE	68.1	133.2	325.8	1028.4	2210.2	4326	7597.7	11509	16342
	SSIM	0.8	0.8	0.7	0.49	0.28	0.15	0.07	0.04	0.02
MHFF	MSE	31.1	39.1	52.5	74.91	135.99	333.28	999.51	3185	8379.3
	SSIM	0.9	0.9	0.9	0.91	0.86	0.75	0.48	0.21	0.06

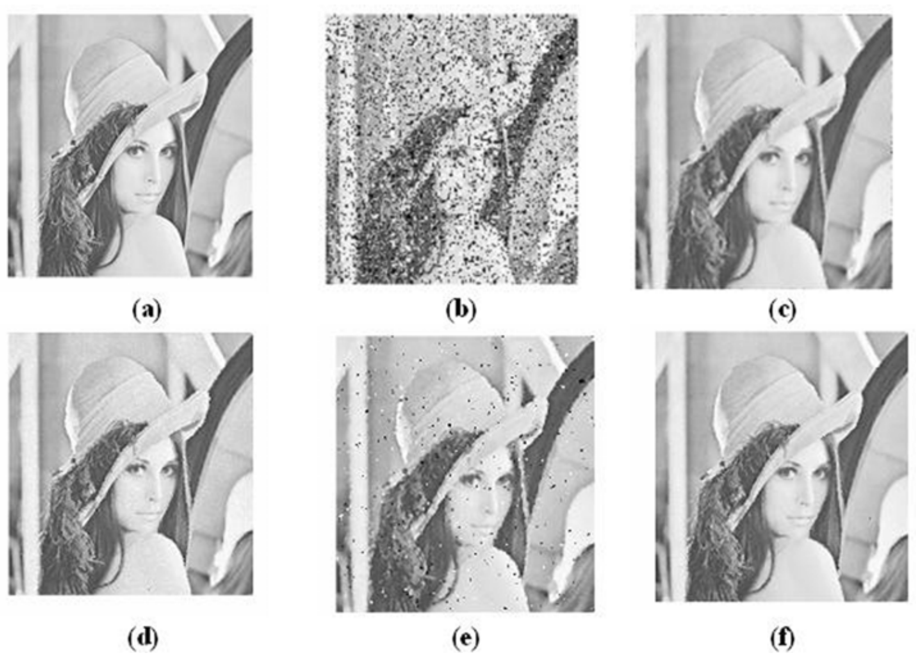

Fig. 2. (a) Original Lena image (b) Image corrupted with 30% impulse noise (c) After the HFF method (MSE=101.59)(d) After NFF method (MSE=82.48) (e) After MF method (MSE=325.82) (f) After the proposed MHFF method (MSE=52.52)

Results show that the MHFF gives much better results for low as well as highly corrupted images.

Visual performance of MHFF is shown in figure 2, which shows that the proposed technique (Fig. 4(f)) removes the impulse noise and preserves the image details better than the other competitive techniques. Sensitivity analysis of the

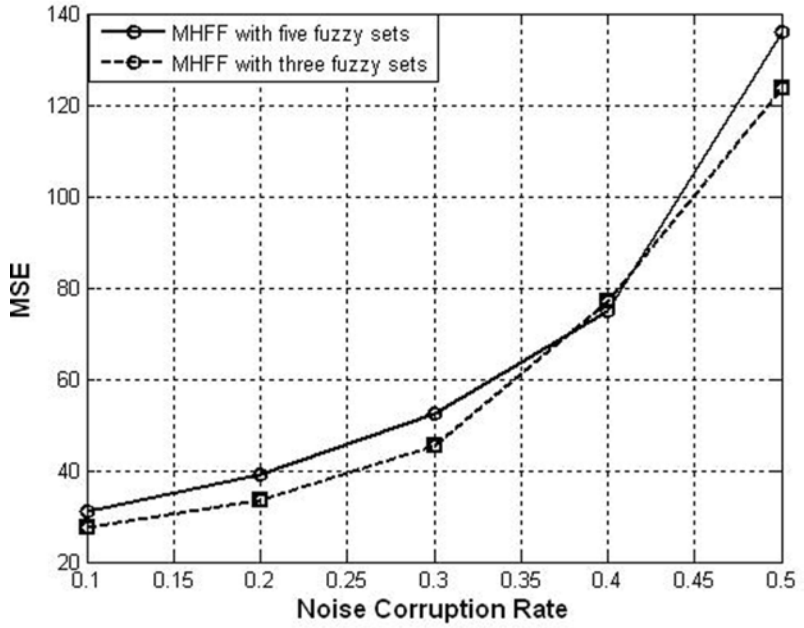

Fig. 3. Sensitivity Analysis of the proposed technique based on number of fuzzy sets

proposed technique is performed on the basis of number of fuzzy sets constructed through fuzzy number construction algorithm. Figure 3 compares the MHFF results with three and five fuzzy sets. It can be seen that MHFF with five fuzzy sets gives better performance but difference is quite less which shows that the proposed technique is robust against number of fuzzy sets used.

6 Conclusion

In this paper, a modified histogram based fuzzy filter (MHFF) is introduced. MHFF consists of noise detection, histogram estimation, fuzzy set construction and fuzzy filtering process. From the experimental results, we observed that the proposed filter gives much better results than the other filtering techniques. Sensitivity analysis of MHFF is also presented in this paper which is based on varying the number of fuzzy sets. In sensitivity analysis it has been proved that MHFF with five fuzzy sets gives better results than having three fuzzy sets but the difference is quite less which shows the robustness of the proposed technique against the number of fuzzy sets used. In future, we will extend this technique for uniform impulse noise removal.

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