A Fuzzy Switching Median Filter for Highly Corrupted Images

R.Pushpavalli* & G.Sivarajde**

*Research Scholar, ECE dept. Department, Pondicherry Engineering College, Puducherry, India.
**Professor, ECE dept. Department, Pondicherry Engineering College, Puducherry, India.

Abstract: In this paper, fuzzy based switching median filtering technique is proposed for enhancing highly corrupted digital images. This filter is obtained in two steps; in first step fuzzy decision rule is applied to detect the impulse noise on input image (noisy image). In second step, noisy pixels are removed using decision based filters. The performance of the proposed filter is compared with other existing filters and shown to be more effective in terms of eliminating impulse noise and preserving edges and fine details of digital images.

Index Terms- Fuzzy logic, Impulse Noise, Membership function and Nonlinear Filter

I. INTRODUCTION

Removal of noise is one of the challengeable tasks in image processing. Commonly, linear techniques are used because linear filters are easy to implement and design. Further, they are optimal among the class of all filtering operations when the noise is additive and Gaussian [1-3]. However, if the images are contaminated by impulse noise, these assumptions are not satisfied. Thus the linear filters deteriorate severely. To address these issues, a large number of nonlinear methods had been investigated [4, 5]. The most popular nonlinear filter is the median filter; it is computationally efficient and has proved extremely successful for removing noise of impulsive nature. Unfortunately, it suffers from the fact that the signal details become blurred.

To overcome these problems, Existing switching-based median filters had been investigated [6-16]. However these are commonly found to be non-adaptive to noise density variations and prone to misclassifying pixel characteristics at high noise density interference. To overcome these, it is investigated to study and examine new decision based filtering schemes [17-25]. The decision based filtering procedure consists of the following two steps: (i) an impulse detector that classifies the input pixels as either corrupted pixels or uncorrupted pixels, (ii) a noise removal filter that aims to restore those pixels that are classified as corrupted pixels. These techniques aim to achieve optimal performance over the entire image. A good noise filter is required to satisfy two criteria, namely, suppressing the noise and preserving the useful information in the signal.

Fuzzy switching median filters have been investigated to satisfy the above mentioned criteria [26-30]. In many image-processing applications, expert knowledge is used to overcome the difficulties (e.g. object recognition, scene analysis). Fuzzy set theory and fuzzy logic offer powerful tools to represent and process human knowledge in the form of fuzzy if-then rules. On the other side, many difficulties in image processing arise because the data/tasks/results are uncertain. This uncertainty, however, is not always due to the randomness but to the ambiguity and vagueness. Beside randomness which can be managed by probability theory can distinguish between three other kinds of imperfection in the image.

Fuzzy filters eliminate impulse noise satisfactorily. Even though, these are commonly found to be non-adaptive to noise density variations and prone to misclassifying pixel characteristics. In order to address the above mentioned issues, a new fuzzy switching filter is proposed. In this paper, gradient vector is determined between noisy image and two decisions based nonlinear filters separately for impulse detection. In addition to this, fuzzy gradient is calculated. Impulse detection is obtained using fuzzy IF-THEN rule and detected impulse noise is eliminated using two decision based filters. The proposed filter exhibit superior performance in terms of impulse noise detection and reduction than the other existing filtering techniques. The newly proposed fuzzy switching filter is a powerful tool for knowledge representation and processing and it can manage the vagueness and ambiguity efficiently.

In this paper, noise model and two special of decision based filters are explained for clarity of work and then the proposed filter is explained. In section2, noise model is described. Section 3, described the image denoising. In section 4, proposed filtering algorithm is discussed. Section 5 discusses the experimental results. Conclusion is drawn in section 6.

II. NOISE MODEL

Fundamentally, there are three standard noise models, which model the types of noise encountered in most images; they are additive noise, multiplicative noise and impulse noise. Digital image are often corrupted by salt and pepper noise (or impulse noise). Impulse noise is considered for proposed work. For images corrupted by salt-and-pepper noise (respectively fixed-valued noise), the noisy pixels can take only the maximum and the minimum values (respectively any random value) in the dynamic range. In other words, an image containing salt-and-pepper noise will have dark pixels in bright region and bright pixels in dark regions. A digital image function is given by $f(i,j)$ where (i,j) is spatial coordinate and f is intensity at point(i,j). let $f(i,j)$ be the original image, $a(i,j)$ be the noise image version and η be the noise function, which returns random values coming from an arbitrary distribution. Then the additive noise is given by the equation (1)

$$a(i,j) = f(i,j) + \eta(i,j) \qquad (1.1)$$

Impulse noise is caused by malfunctioning pixels in camera sensors, dead pixels, faulty memory locations in hardware, erroneous transmission in a channel, analog to digital converter, malfunctioning CCD elements (i.e. hot and dead pixels) and flecks of dust inside the camera most commonly cause the considered kind of noise etc. It also creeps into the images because of bit errors in transmission, faulty memory locations and erroneous
switching during quick transients. Two common types of impulse noise are the salt and pepper noise and the random valued noise. The proposed filter first detects the Salt and pepper noise present in digital images in very efficient manner and then removes it. As the impulse noise is additive in nature, noise present in a region does not depend upon the intensities of pixels in that region. Image corrupted with impulse noise contain pixels affected by some probability. The intensity of grayscale pixel is stored as an 8-bit integer giving 256 possible different shades of gray going from black to white, which can be represented as a [0,*L*-1] (*L* is 255) integer interval. In this paper the impulse noise is considered. In case of images corrupted by this kind of salt and pepper noise, intensity of the pixel A_{ij} at location (i,j) is described by the probability density function given by the following equation (2)

$$f(A_{ij}) = \begin{cases} p_a & for \quad A_{ij} = a \\ 1-p & for \quad A_{ij} = Y_{ij} \\ p_b & for \quad A_{ij} = b \end{cases} \qquad (1.2)$$

where *a* is the minimum intensity (dark dot); *b* is the maximum intensity (light dot); p_a is the probability of intensity (a) generation; p_b is the probability of intensity (*b)* generation; *p* is the noise density, and Y_{ij} is the intensity of the pixel at location (i,j) in the uncorrupted image. If either p_a or p_b is zero the impulse noise is called unipolar noise. If neither probability is zero and especially if they are equal, impulse noise is called bipolar noise or salt-and-pepper noise.

III. IMAGE DENOISING

In this section, two special classes of decision based filtering techniques are described. Nonlinear Filter (NF) is used to preserve the edge region of the digital image and homogeneous region is preserved using New Tristate Switching Median Filter (NTSSMF). These are explained in subsection 3.1 and 3.2.

3.1 Nonlinear Filter

The filtering technique explained in this section detects the impulse noise in the image using a decision mechanism. The corrupted and uncorrupted pixels in the image are detected by comparing the pixel value with the maximum and minimum values in the selected window. If the pixel intensity lies between these minimum and maximum values, then it is an uncorrupted pixel and left undisturbed. If the value does not lie within the range, then it is a corrupted pixel and is replaced by the median pixel value or already processed immediate neighboring pixel in the current filtering window. Consider an image of size N×N having 8-bit gray scale pixel resolution. The steps involved in detecting the presence of an impulse or not are described as follows:

Step 1) A two dimensional square filtering window of size 3 x 3 is slid over a highly contaminated image.

Step2) The pixels inside the window are sorted out in ascending order.

Step3) Minimum, maximum and median of the pixel values in the processing window are determined.

Step 4) If the central pixel lies between minimum and maximum values, then it is detected as an uncorrupted pixel and the pixel is left undisturbed. Otherwise, it ibis considered a corrupted pixel value. In the present case, the central pixel value 0 does not lie between minimum and maximum values. Therefore, the pixel is detected to be a corrupted pixel.

Step 5) The corrupted central pixel is replaced by the median of the filtering window, if the median value is not an impulse. If the median value itself is an impulse then the central pixel is replaced by the already processed immediate top neighboring pixel in the filtering window. In the present case, the median value is also an impulse and therefore, the pixel is replaced by its already processed top neighboring pixel value. Then the window is moved to form a new set of values, with the next pixel to be processed at the centre of the window. This process is repeated until the last image pixel is processed.

3.2 New Tristate Switching Median Filter

Decision based median filter, called new *tri-state median* (TSM) filter, is proposed and discussed in this section. Impulse noise detection is realized by an impulse detector, which takes the outputs from the ***DBMF-1*** [20] and ***DBMF-2*** [21] filters and compares them with the origin or center pixel value within the filtering window on given contaminated digital image in order to make a tri-state decision. The switching logic as shown in Fig. 2 is controlled by a threshold T (T = 24; [0 - 255] for gray-scale images).

IV. PROPOSED ALGORITHM

The filtering technique proposed in this paper detects the impulse noise on the image using a fuzzy decision rule. An image gradient vector is determined between central pixel from an input image and filtered output image for two decision based filters. These gradient vectors are given by the following equation:

$$\nabla(k,l)D1 = YNF(i,j) - A(i,j) \;\; with k, l \in \{-1,0,1\} \qquad (4.1)$$

$$\nabla(k,l)D2 = YNTSSMF2(i,j) - A(i,j) \;\; with k, l \in \{-1,0,1\} \qquad (4.2)$$

where, $\nabla_{(k,l)}D_1$ is gradient vector between original pixel value and nonlinear filter (NF), $\nabla_{(k,l)}D_2$ is gradient vector between input pixel value and New Tristate Switching Median filter (NTSSMF) output, A(i,j) is the Noisy image, Y_{NF}(i,j) is the nonlinear filtered (NF1) output, Y_{NTSSMF}(i,j) is the New Tristate Switching Median (NTSSMF) output.

The proposed filtering algorithm is applied on noisy image and is described in steps as follows:

Step 1) A two-dimensional square filtering window of size 3 x 3 is slid over the noisy image.

Step 2) As the window move over the noisy image; at each point, the central pixel inside the window is checked whether it is a corrupted pixel or not. If the pixel is an uncorrupted one, it is left

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undisturbed and the window is moved to the next position. On the other hand, if the pixel is detected as a corrupted one, the filtering procedure is performed by following the further steps described below.

Step3) Determine gradient vector between central pixels from filtered image and processing pixels from noisy image (i.e. input image)

Step4) Fuzzy IF THEN rule is applied for impulse noise detection and noisy pixels are replaced by two decision based filters. Then the window is moved to form a new set of values, with the next pixel to be processed at the centre of the window. This process is repeated until the last image pixel is processed.

In this paper, fuzzy gradient ($\nabla_{(k,l)} D_F$) is obtained by fuzzy set and is used for impulse detection. This gradient $\nabla_{(k,l)} D_F$ is used to determine if a central pixel switching the filtering window is corrupted with impulse noise or not, because if this gradient is small then It is good indication of noise free pixel. Suppose if gradient is medium then the processing pixel is either an edge pixel or noisy pixel. If gradient is large then it is an indication of noisy pixel.

Finally, fuzzy gradient value is used to detect the impulse noise. The proposed fuzzy switching median filter is constructed using Sugeno fuzzy system, Gauss membership function with 3 input, two input variables and 9 fuzzy rules. Noisy pixels are detected by the following fuzzy rules:

IF D_1 is low AND D_2 is medium THEN $\nabla_{(k,l)} D_F$ *is high*

IF D_1 is medium AND D_2 *is high* THEN $\nabla_{(k,l)} D_F$ *is low*

IF D_1 *is high* AND D_2 *is low* THEN $\nabla_{(k,l)} D_F$ is medium

IF D_1 *is low* AND D_2 is medium THEN $\nabla_{(k,l)} D_F$ *is high*

IF D_1 is medium AND D_2 *is high* THEN $\nabla_{(k,l)} D_F$ *is low*

IF D_1 *is high* AND D_2 *is low* THEN $\nabla_{(k,l)} D_F$ is medium

IF D_1 *is low* AND D_2 is medium THEN $\nabla_{(k,l)} D_F$ *is high*

IF D_1 is medium AND D_2 *is high* THEN $\nabla_{(k,l)} D_F$ *is low*

IF D_1 *is high* AND D_2 *is low* THEN $\nabla_{(k,l)} D_F$ is medium

Here, Low, medium and high are the nondeterministic features, these terms can be represented as fuzzy sets. Fuzzy sets can be represented by membership function. These membership functions are described by the following fig.1.

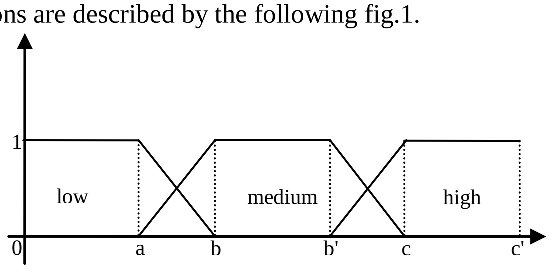

Fig.1 Membership function low, medium and high respectively

These functions represents all possible gradient values in the range of 0 to 255 and membership degree is represented in the range of 0 to 1 (i.e. $\in [0,1]$). A membership degree indicates the degree in which a certain gradient value matches the predicate. If the gradient value has membership degree one for the fuzzy set high, it means that it is large for noisy pixels, low for noise free pixels and medium for noisy/edge pixels.

Fuzzy rule contains some conjunctions and disjunctions. In fuzzy logic, AND operator is used for conjunctions and OR used for disjunctions. These three membership function depend on the parameters 0-a, b-b' and c-c'. According to the following observations these parameters values are determined.

1) Gradient value $\nabla_{(k,l)} D_1$ or $\nabla_{(k,l)} D_2$ *lie in the interval [0-45] indicates* the noise free pixels and nonedge pixels. So these pixels are categorized as noise free pixels and there is no uncertainty is happen, resulting in a zero membership degree in the fuzzy set.

2) Gradient value $\nabla_{(k,l)} D_1$ or $\nabla_{(k,l)} D_2$ *lie in the interval [45-125] indicates* the noisy pixels and edge pixels. So these pixels are categorized as either noisy pixels or edge pixels. Here, some kind of uncertainty is expressed by membership degrees in fuzzy set(lies in the interval [0-0.5].

3) Gradient value $\nabla_{(k,l)} D_1$ or $\nabla_{(k,l)} D_2$ *lie in the interval [125-255] indicates* the noisy pixels. So these pixels are categorized as noisy pixels. In this case, membership degree in the fuzzy set is one.

In fig.1 the membership degree is represented for noise free pixel in the range of [0-a], noisy or edge pixels are represented in the range of [b-b'] and noisy pixels are represented in the range of [c-c']. Based on image quality only, the membership degree and fuzzy gradient value is chosen. After choosing the membership degree and $\nabla_{(k,l)} D_F$ value, activation degree is calculated for fuzzy IF-THEN rule. This activation degree indicates the low, medium and large $\nabla_{(k,l)} D_F$ value for impulse noise detection on digital images.

Finally, the detected impulse noise is replaced by either DBF1 or DBF2. If the indentified pixel is either noisy or edge pixels then it is replaced by DBF1 and otherwise it is a corrupted one and is replaced by DBF2.

V. SIMULATION RESULTS

The filtering technique is tested using 3 x 3 windows with Lena image of size 256 x 256. In this paper, Lena image is used as a test images. In order to analyze the performance of the proposed filter approach, the performance evaluation factors like Peak Signal to Noise Ratio (PSNR) is used. This performance evaluation is based on threshold values and noise levels. Filter has higher PSNR values are considered to be superior filter in terms of noise elimination and restoration of image features. A Fuzzy Switching Median Filtering Scheme (FSMF) is quantitatively evaluated using objective measures are defined as:

$$PSNR = 10\log_{10}\left[\frac{255 * 255}{MSE}\right] \quad (5)$$

where $$MSE = \frac{\Sigma \left| X(i,j) - F(i,j) \right|^2}{row * col} \quad (5)$$

(i,j) denotes the number of rows and columns in the image data, *X(i,j)* represents the pixel intensities of the original image at the position of *X(i,j), F(i,j)* represents the output intensities in the filtered image at the position of (i,j). The proposed filter has very good subjective improvements for lower level of mixed impulse noise (i.e. fine details preservation of the image).

The enhancement result for the corrupted 'Lena' image by different level of impulse at suitable threshold has been estimated. The estimated values are tabulated and are given in the Table1. Figure 2 graphically illustrates the objective improvement of the proposed filter with respect to other switching schemes and this fuzzy filter exhibit good performance when images are corrupted up to 70% of noise. In order to prove the effectiveness of this filter, existing filtering techniques are experimented and compared with proposed filter for visual perception and subjective evaluation on Lena image including the standard medians filter (MF), the Weighted median filter (WMF), Centre weighted median filter (CWMF), the Tristate median filter (TSMF), New impulse detector (NID), Multiple decision based switching median filter (MDBSMF), Improved decision based algorithm (IDBA), New tristate switching median filter (NTSMF), Nonlinear filter (NF) and the proposed filter in Fig.2.

Fig.2 Subjective Performance comparison of proposed filter with other existing filters on test image Lena (a) Noise free images, (b) image corrupted by 70% impulse noise, (c) images restored by MF, (d) images restored by WMF, (e) images restored by CWMF, (f) images restored by TSMF, (g) images restored by IDBA, (h) images restored by NFT, (i) images restored by NTSSMF, (j) image restored by MSSMF, (k) image restored by FUF and (l) images restored by the proposed filter

TABLE.1
PSNR values obtained using proposed filter and compared with different filtering techniques on Lena image corrupted with various densities of impulse noise

Filtering Techniques	10	30	50	70	90
MF	31.74	23.20	15.28	9.98	6.58
WMF	23.97	22.58	20.11	15.73	8.83
CWMF	28.72	20.28	14.45	10.04	6.75
TSMF	32.89	24.96	16.82	11.33	7.58
IDBA	36.5	29.72	26	23.5	19.3
FUF	36.34	32.12	27.39	18.59	9.32
NFT	39.30	32.70	27.73	23.73	17.69
TSSMF	42.57	35.38	29.34	19.52	10.13
MSSMF	47.58	36.34	30.24	24.93	19.42
FUF	36.45	32.12	27.39	18.59	11.56
Proposed filter	48.39	39.72	33.82	28.42	20.12

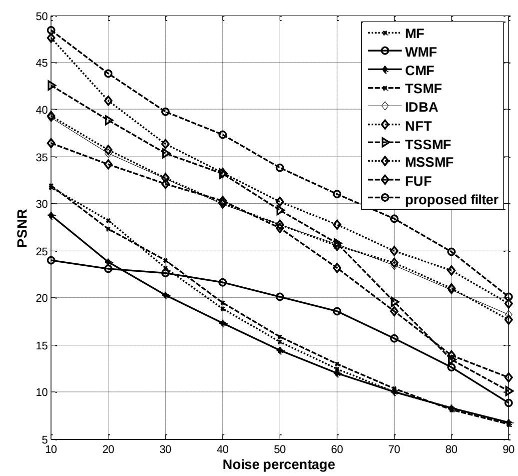

Fig.3 PSNR obtained using proposed filter on Lena image corrupted with different densities of impulse noise and compared with other existing filtering techniques

Figure 3 illustrates the subjective performance for human visual perception. The performance of this filter is evaluated using various impulse corruption ratios from 10% to 90% with suitable threshold. This filter has better performance than the other filtering schemes for the noise densities up to 70%. It shows that the better performance in removing impulse noise from digital images without distorting the useful information in the image.

Digital images are nonstationary process; therefore depends on properties of edges and homogenous region of the test images, each digital images having different quantitative measures. Fig.4

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illustrate the subjective performance of the fuzzy filtering technique on four test images like Baboon, Lena, Pepper and Rice images: noise free image in first column, images corrupted with 70% impulse noise in second column, Images restored by proposed Filtering technique in third column. This depicts properties of digital images. Performance of quantitative analysis is evaluated and is summarized in Table.2.

Table 2. PSNR values obtained by applying proposed filtering technique on different test images corrupted with various densities of impulse noise

Noise %	Baboon	Lena	Pepper	Rice
10	42.67	48.39	51.03	46.44
20	38.02	43.83	46.78	44.60
30	33.56	39.72	43.00	41.24
40	31.89	37.33	39.74	37.50
50	28.90	33.82	36.39	34.02
60	26.35	31.05	34.05	32.67
70	23.27	28.42	31.61	29.45
80	19.76	24.92	27.32	25.45
90	17.92	20.12	24.96	22.77

Fig.4 Performance of test images: First column represents original images, second column represents images corrupted with 70% of noise and third column represents images enhanced by proposed filter

The proposed filter is graphically illustrated in Fig.5. This qualitative and quantitative measurement shows that the proposed filtering technique outperforms the other filtering schemes for noise densities up to 70%. Since there is an improvement in PSNR values of all images up to 70% while compare to PSNR values of conventional filters output.

The qualitative performance of Pepper and Rice images are better than the other images for the noise levels ranging from 10% to 70%. But for higher noise levels, the Pepper image is better. The Baboon image seems to perform poorly for higher noise levels. Based on the intensity level or brightness level of the image, it is concluded that the performance of the images like pepper, Lena, Baboon and Rice will change. Since digital images are nonstationary process. The quantitative performance of Pepper and Rice images are better than the other images for the noise levels ranging from 10% to 70%. The proposed filtering technique is found to have eliminated the impulse noise completely while preserving the image features quite satisfactorily. This novel filter can be used as a powerful tool for efficient removal of impulse noise from digital images without distorting the useful information in the image and gives more pleasant for visual perception.

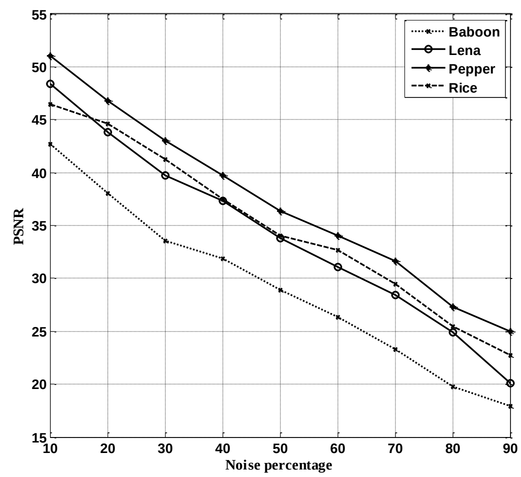

Fig. 5 PSNR obtained by applying proposed filtering technique for different images corrupted with various densities of impulse noise

In image processing, some objective quality criteria are usually used to ascertain the goodness of the results (e.g. the image is good if it possesses a low amount of fuzziness indicating high contrast). The human observer, however, does not perceive these results as good because their judgment is subjective. This distinction between objectivity and subjectivity is the first major problem in the human machine-interaction. Another difficulty is the fact that different people judge the image quality differently. This inter-individual difference is also primarily due to the aforesaid human subjectivity.

VI. CONCLUSION

In this paper, the efficiency of this fuzzy filtering technique is examined and is well suited for digital images when the images are contaminated by impulse noise up to 70%. Since the fuzzy based impulse noise detection mechanism can accurately detect the corrupted pixels on digital image and are replaced with the estimated central noise-free ordered median value from decision based median filter. Based on the expert knowledge and fuzzy if then rules, misclassification is avoided. Simulation results show that the filtering technique has better performance in terms of both quantitative and qualitative measurements.

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