Combined Fuzzy Logic and Unsymmetric Trimmed Median Filter Approach for the Removal of High Density Impulse Noise

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Abstract: - In this paper, a combined fuzzy logic and unsymmetric trimmed median filter approach is proposed to remove the high density salt and pepper noise in gray scale and colour images. This algorithm is a combination of decision based unsymmetrical trimmed median filter and fuzzy thresholding technique to preserve edges and fine details in an image. The decision based unsymmetric trimmed median filter fails if all the elements in the selected window are 0's or 255's. One of the possible solutions is to replace the processing pixel by the mean value of the elements in the window. This will lead to blurring of the edges and fine details in the image. To preserve the edges and fine details, the combined fuzzy logic and unsymmetric trimmed median filter approach is proposed in this paper. The better performance of the proposed algorithm is demonstrated on the basis of PSNR and IEF values.

Key-Words: - Fuzzy logic, Fuzzy threshold, Salt and Pepper noise, Decision based Unsymmetric Trimmed Median Filter, Membership function, Noise reduction.

1 Introduction

Digital images are contaminated by impulse noise during image acquisition or transmission due to malfunctioning pixels in camera sensors, faulty memory locations in hardware, or transmission in a noisy channel. Salt and pepper noise is one type of impulse noise which can corrupt the image, where the noisy pixels can take only the maximum and minimum gray values in the dynamic range. The linear filter like mean filter and related filters are not effective in removing impulse noise. Non-linear filtering techniques like Standard Median Filter (SMF), Adaptive Median Filter (AMF) are widely used to remove salt and pepper noise due to its good denoising power and computational efficiency [1]. SMF is effective only at low noise densities. Several methods have been proposed for removal of impulse noise at higher noise densities [2-5]. The window size used in these methods is small which results in minimum computational complexity. However, small window size leads to insufficient noise reduction. Switching based median filtering has been proposed as an effective alternative for reducing computational complexity [6]. Recent methods like Decision Based Algorithm (DBA), Modified Decision Based Algorithm (MDBA), are one of the fastest and efficient algorithms capable of impulse noise removal at noise densities as high as 80% [7-8]. A major drawback of this algorithm is streaking effect at higher noise densities. To overcome this drawback, Modified Decision Based Unsymmetric Trimmed Median Filter (MDBUTMF) is used to remove salt and pepper noise at very high densities as 80 -90% [9]. In this algorithm, at high noise density, the processing pixel is replaced by the mean value of elements within the window. This will lead to blurring of fine details in the image. To avoid this problem, we have introduced fuzzy thresholding is used to preserve the edges and fine details in this paper. Already several fuzzy filters for noise reduction have been developed like weighted fuzzy mean filter and the iterative fuzzy control based filter [10-11]. These filters are removing the salt and pepper noise at medium noise variance 50-60%. Hence, we have proposed a new algorithm is the combination of fuzzy logic and unsymmetric trimmed median filter in this paper. This algorithm gives better performance than the existing algorithms.

The organization of the rest of this paper is as follows: In the next section, the proposed algorithm is described in detail. In section 3, some experimental results are presented with discussion.

Finally, the concluding remarks are given in section 4.

2 Proposed Algorithm

2.1 Fuzzy Sets and Fuzzy Rules

A Fuzzy set theory is a generalization of classical set theory that allows membership degree between zero and one, thus a more gradual transition between belonging to and not belonging to [12]. A fuzzy set F in the universe X is characterized by an $X \rightarrow [0, 1]$ mapping μ_F, which assigns with every element x in X a degree of membership $\mu_F(x) \in [0,1]$ in the fuzzy set F. In our problem, the Fuzzy membership function is defined based on the number of zeros or 255s in the selected window. For the current pixel within the processing window, the function F(x) is defined as per equation (1):

$$F(x) = \{F_0, F_{255}\} \quad (1)$$

F_0 = Number of zeros in a selected window

F_{255} = Number of 255s in a selected window

Let $\mu_F(x) \in [0,1]$ is the membership function of F(x). The fuzzy rule enacted for the proposed algorithm is summarized below:

Rule 1: if F_0 is Large Negative (LN) or F_{255} is Small Positive (SP) then $\mu_F(x)$ is Very Low (VL).

Rule 2: if F_0 is Negative (N) then $\mu_F(x)$ is Low (L).

Rule 3: if F_{255} is Large Positive (LP) or F_0 is Small Negative (SN) then $\mu_F(x)$ is Very High (VH).

Rule 4: if F_{255} is Positive (P) then $\mu_F(x)$ is High (H).

With these rules the fuzzy membership function is defined as:

$$\mu_F(x) = \begin{cases} \text{std}(X) & \text{if } F_0 \geq Th_1 \\ \text{std}(X) \times \left(\dfrac{F_0}{F_{255}}\right) & \text{if } Th_2 < F_0 < Th_1 \\ \text{mean}(X) & \text{if } F_{255} \geq Th_1 \\ \text{mean}(X) \times \left(\dfrac{F_{255}}{F_0}\right) & \text{if } Th_2 < F_{255} < Th_1 \end{cases} \quad (2)$$

Where, X is the selected neighboring pixel elements, 'std' stands for standard deviation, mean represents average value of the selected window elements. Th_1 and Th_2 are predefined thresholds such that if F_0 is greater than Th_1, the pixel belong to lower gray level, if F_0 is greater than Th_2 and less than Th_1 then the pixel belong to medium gray level, if the F_{255} is greater than Th_1, the pixel belong to very high gray level and if the F_{255} is greater than Th_2 and less than Th_1 then the pixel belong to higher gray value. The membership function defined as per equation (2) is used to replace the noisy pixel. The graphical representation of the membership function is shown in figure 1.

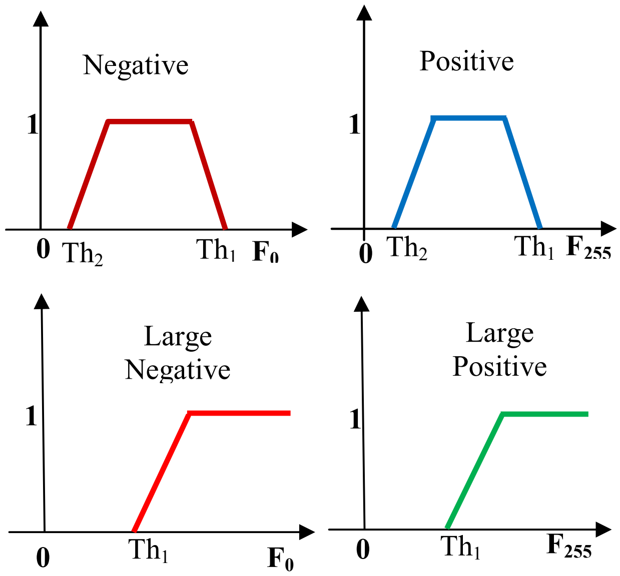


Fig.1 Membership functions

The threshold value Th_1 and Th_2 are selected based on the following fact:

Case 1: The selected window size is 3 X 3, which implies that the number of elements within the window is 9. In the selected window, the number of '0s' is more than number of '255s' means that '0s' should have occurred a minimum of 5 times. The same logic holds well if number of '255s' is greater than number of '0s' within the window. This enabled us to select the threshold value Th_2 as 4.

Case 2: In the selected 3 X 3 window, most frequent occurrence of '255' or '0' means it should have occurred more than 5, this enabled us to fix the threshold Th_1 as 6.

Case 3: The extreme case is all the pixels within the selected window are either '0' or '255'. In such case, the processing pixel is replaced by the average of the two extreme gray levels which is 128.

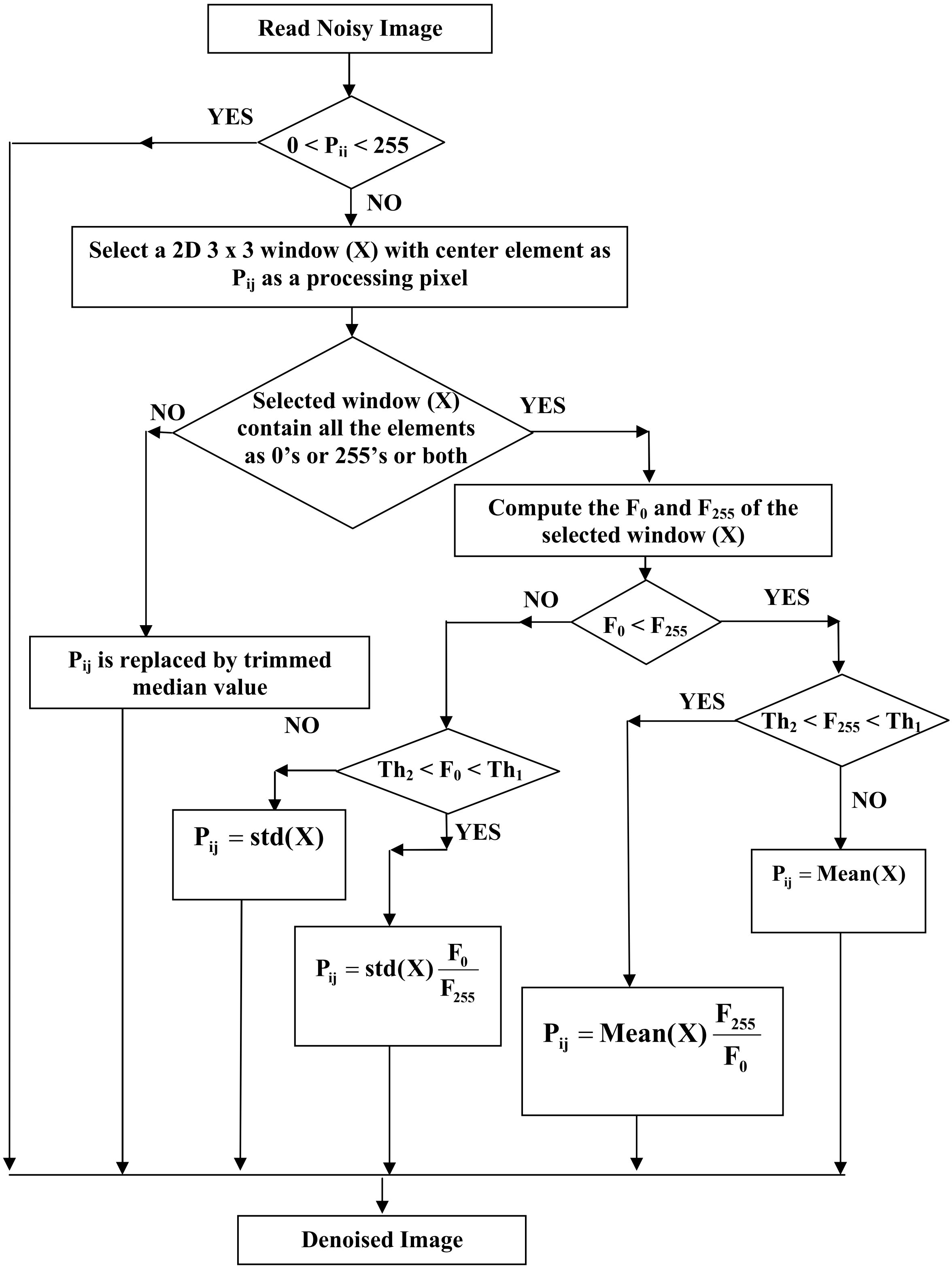


Fig.2 Flowchart of the proposed algorithm

2.2 Algorithm for Combined Fuzzy logic and Decision Based Unsymmetric Trimmed Median Filter

The proposed algorithm combines Fuzzy logic with Decision based Unsymmetric Trimmed Median Filter to process the image which is highly corrupted by impulse noise. The algorithm starts with the detection of impulse noise. That is, if the processing pixel lies within the maximum and minimum gray level values, then it is noise free pixel, it is left unchanged. If the processing pixels take the maximum or minimum gray level then it is noisy pixel which is processed by the proposed algorithm. The steps followed in the proposed algorithm are given below:

Step 1: Select 2-D window of size 3 x 3. The processing pixel is denoted as P_{ij}.

Step 2: If $0 < P_{ij} < 255$ then P_{ij} is a noise free pixel and its value is unaltered.

Step 3: If $P_{ij} = 0$ or $P_{ij} = 255$ then P_{ij} is a noisy pixel then apply the proposed algorithm to the processing pixel.

Step 3a: In the selected window (3 x 3) if all the elements are not 0's and 255's, then replace P_{ij} with the trimmed median value [8].

Step 3b: If the selected window contain all the elements as 0's and 255's, then four possible combinations defined based on impulse noise density using fuzzy rule are Very High, Very Low, Low and High. Here 'Very High' refers to frequent occurrence of 255 and 'Very Low' corresponds to frequent occurrence of gray level '0'. Then replace the processing pixel by fuzzy membership function output value as given in the flow chart shown in figure 2.

Step 4: Repeat steps 1 to 3 until all the pixels in the entire image are processed.

3 Experimental Results

The performance of the proposed algorithm is tested with different gray scale and colour images. The noise variance is varied from 50% to 95%. For implementing our algorithm, we have used MATLAB 7 on a 2.80 GHz Pentium R processor with 1 GB of RAM. The performances of the proposed algorithm are quantitatively measured by the Peak Signal to Noise Ratio (PSNR) and Image Enhancement Factor (IEF) as defined in (3) and (5) respectively.

$$\text{PSNR in dB} = 10\log_{10}\left(\frac{255^2}{\text{MSE}}\right) \quad (3)$$

$$\text{MSE} = \frac{\sum_i \sum_j (Y(i,j) - \hat{Y}(i,j))^2}{M \times N} \quad (4)$$

$$\text{IEF} = \frac{\sum_i \sum_j (\eta(i,j) - \hat{Y}(i,j))^2}{\sum_i \sum_j (\hat{Y}(i,j) - Y(i,j))^2} \quad (5)$$

where MSE stands for Mean Square Error, M x N is size of the image, Y represents the original image, $\hat{Y}$ denotes the denoised image and η represents the noisy image. The PSNR values of the proposed algorithm are compared against the existing algorithms by varying the noise variance from 50 to 95% and are given in table 1 and table 2. From the table 1, it can be evident that the PSNR value of the proposed algorithm is better than the existing algorithm at high noise densities above 85% for Lena gray scale image. The PSNR value for Bird color image is tabulated in table 2. From the table 2, it can be observed that the performance of the proposed algorithm is better than the existing algorithms at high noise densities. Not all the elements in a selected 3 x 3 window is 255s or zeros at medium noise density. Hence, the proposed algorithm is almost same PSNR value against MDBUTMF at medium noise density.

A plot of PSNR against noise density for Bird image is shown in figure 3. From the figure, it shows that the performance of the proposed algorithm is better than existing algorithms like SMF, AMF, PSMF, DBA, and MDBA at all the noise densities. But the performance of the proposed algorithm is on par with MDBUTMF at high noise densities in the range from above 85%.

The proposed algorithm is also quantitatively measured with image enhancement factor (IEF) and the results are given in table 3 and 4. From the table 3, it indicates that the result of proposed algorithm is better than the existing algorithm for Bird image at all noise densities. In table 4, shows the IEF values for different noise removal filters for Lena gray scale image against noise variance. From the table, it can be concluded that the performance of the proposed algorithm outperforms the existing algorithms. A plot of IEF against noise variances for Lena (Colour) image is shown in figure 4. From the figure, it is possible to observe that the performance of the proposed algorithm is better than the existing algorithms.

The results for 256 x 256 Lena (Gray) image for 90% salt and pepper noise is shown in figure 5. From this figure, the result of proposed algorithm is better than the existing algorithms.

The proposed algorithm is also tested for colour images like Lena and Bird. The noise densities chosen are 80% and 85% for Lena and Bird image respectively. The performance comparison of the proposed algorithm with the existing denoising algorithms for Lena and Bird images are shown in Fig. 5 and 6 respectively.

Table 1 Comparison of PSNR Values of Different Denoising Algorithms for Lena (Gray) Image at Different Noise Variances

Noise Variance in %	PSNR in dB						
	SMF	AMF	DBA	MDBA	PSMF	MDBUTMF	Proposed
50	14.9272	20.4015	26.4631	26.5412	19.1503	28.3928	**28.4078**
60	12.1984	18.5184	24.7147	24.7816	12.1167	26.4464	26.4464
70	9.9129	14.7210	22.6817	22.6920	9.8510	24.3478	24.3478
75	9.0455	13.1944	21.3631	21.4160	8.9901	22.9436	**23.0083**
80	8.0648	11.1912	20.2687	20.4259	8.0239	21.6736	**21.6833**
83	7.6323	10.3147	19.6345	19.7652	7.5989	20.9792	**20.9847**
85	7.3363	9.7593	19.1350	19.3407	7.3087	20.0751	**21.0451**
87	7.0972	9.1269	18.6138	18.8324	7.0736	19.5279	**20.3779**
90	6.5705	8.1315	17.2801	17.5021	6.5530	17.8250	**18.6454**
92	6.3185	7.4783	16.1166	16.4760	6.3057	17.2588	**17.8188**
95	6.0450	6.7748	15.2274	15.3765	6.0371	15.5949	**16.0433**

Table 2 Comparison of PSNR Values of Different Denoising Algorithms for Bird Image at Different Noise Variances

Noisy Variance in %	PSNR in dB						
	SMF	AMF	DBA	MDBA	PSMF	MDBUTMF	Proposed
50	15.1090	21.6495	27.9952	28.0598	15.0979	29.6445	29.6445
60	12.3321	18.9457	26.2009	26.2883	12.3094	27.9243	27.9305
70	10.0573	15.3018	24.3741	24.4529	10.352	26.0343	26.0343
75	9.0421	13.3949	23.1798	23.3175	9.0223	24.6220	24.6463
80	8.1877	11.5321	22.0689	22.2200	8.1724	23.4187	23.4263
83	7.7238	10.5100	21.3575	21.4089	7.7110	22.4370	22.4412
85	7.3986	9.8080	20.5674	20.6662	7.3869	21.9253	**22.5310**
87	7.1028	9.1859	20.5043	20.5067	7.0930	21.3661	**21.9854**
90	6.6709	8.2715	19.3082	19.4191	6.6642	20.1227	**20.8403**
92	6.4796	7.7104	18.4734	18.5799	6.4740	19.4691	**19.9800**
95	6.1076	6.8456	17.2971	17.1939	6.1045	17.9607	**18.2770**

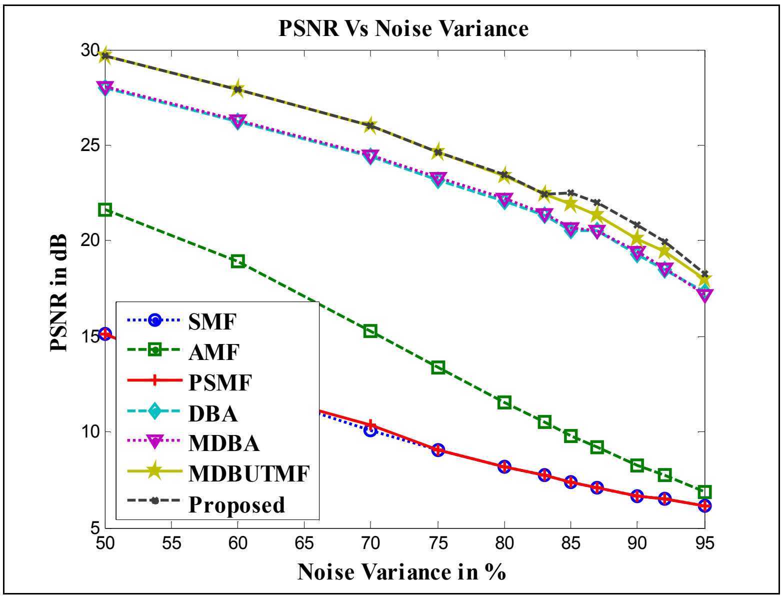


Fig.3 Performance plot of PSNR Vs Noise Variance for Bird image

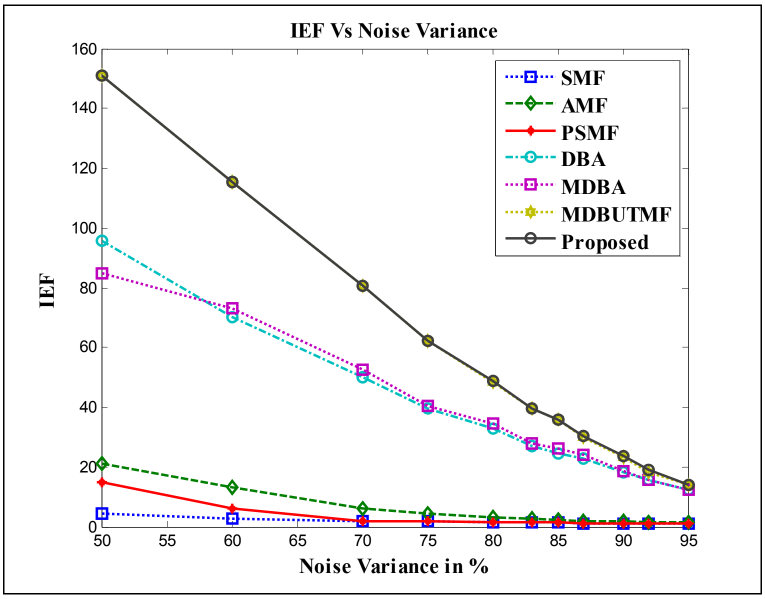


Fig.4 Performance plot of IEF Vs Noise Variance for Lena colour image

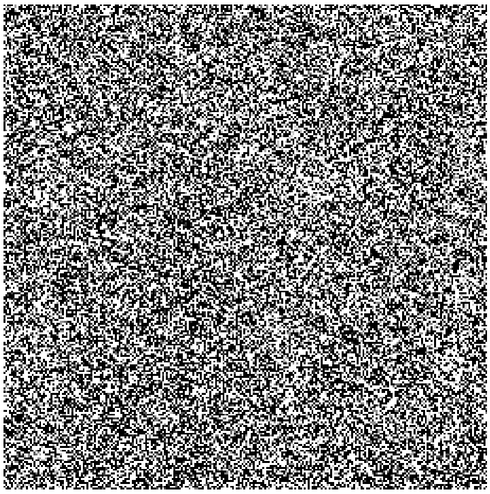
Table 3 Comparison of IEF Values of Different Denoising Algorithms for Bird Image at Different Noise Variances

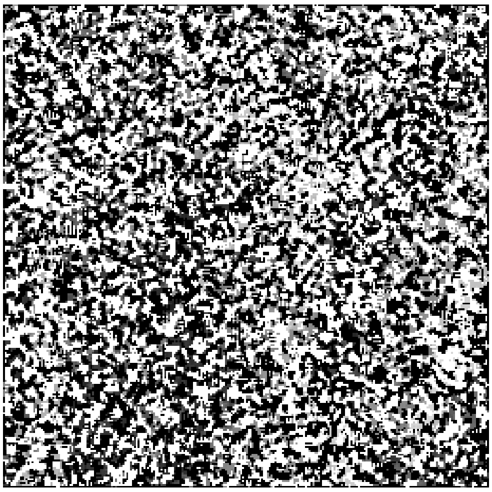
Noisy Variance in %	IEF						
	SMF	**AMF**	**DBA**	**MDBA**	**PSMF**	**MDBUTMF**	**Proposed**
50	4.5274	20.4157	87.993008	89.3008	4.5160	128.7132	**128.7132**
60	2.8628	13.1456	69.7698	71.1900	2.8480	103.7601	**103.9101**
70	1.9795	6.6225	53.5081	54.4718	1.9694	78.4735	**78.4735**
75	1.6808	4.5866	43.6093	45.0280	1.6731	60.9093	**60.9496**
80	1.4726	3.1842	36.0840	37.3087	1.4675	49.3198	**49.3969**
83	1.3716	2.6071	31.6849	32.0719	1.3676	40.7024	**40.7325**
85	1.3063	2.2768	27.3397	27.9532	1.3028	37.5901	**39.6511**
87	1.2471	2.0156	27.4426	27.3634	1.2443	33.5496	**35.6841**
90	1.1732	1.6970	21.5782	22.1455	1.1714	26.1706	**28.2693**
92	1.1395	1.5140	18.2713	18.6003	1.1380	23.0314	**26.0839**
95	1.0818	1.2828	14.3923	14.1028	1.0810	16.8653	**19.9203**

Table 4 Comparison of IEF Values of Different Denoising Algorithms for Lena (Gray) Image at Different Noise Variances

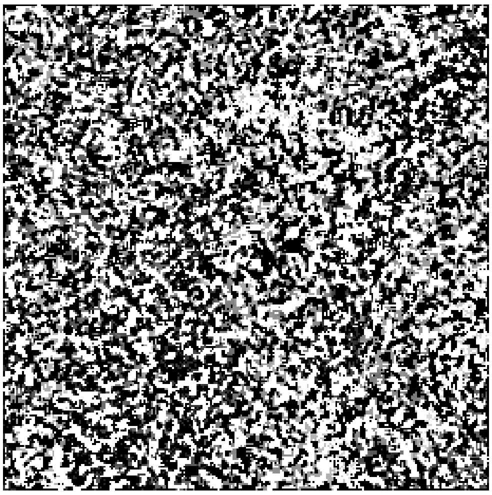
Noisy Variance in %	IEF						
	SMF	**AMF**	**DBA**	**MDBA**	**PSMF**	**MDBUTMF**	**Proposed**
50	4.3104	16.4254	65.3164	65.8853	12.3237	90.5976	90.5976
60	2.7501	10.8710	48.9681	50.3341	2.6981	75.4184	75.4184
70	1.9758	6.0015	35.8214	36.5141	1.9483	53.8612	54.0493
75	1.6975	4.3508	30.3591	32.3520	1.6773	43.1974	43.3067
80	1.4489	3.0681	26.7365	27.2315	1.4362	35.9322	35.9322
85	1.3186	2.2791	17.9403	19.6185	1.3101	25.4881	27.4881
87	1.2515	2.0148	17.4121	18.1795	1.2445	21.8846	23.8889
89	1.2008	1.7646	15.7212	16.2870	1.1953	18.5897	20.5918
90	1.1712	1.6830	13.2768	13.5976	1.1662	16.2066	19.2066
92	1.1404	1.5110	11.7434	12.2735	1.1365	13.8987	15.8992
95	1.0831	1.2904	8.9319	9.7995	1.0810	9.4691	10.4703

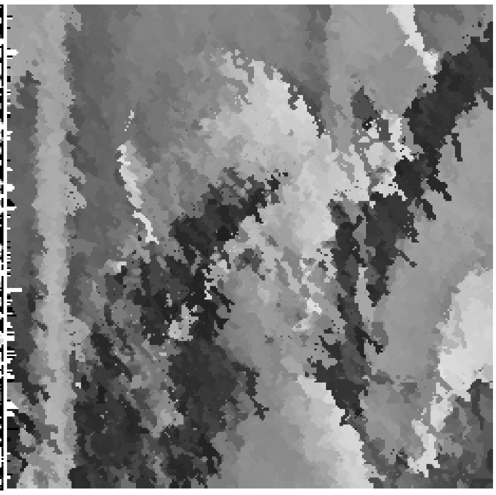

(a) Original

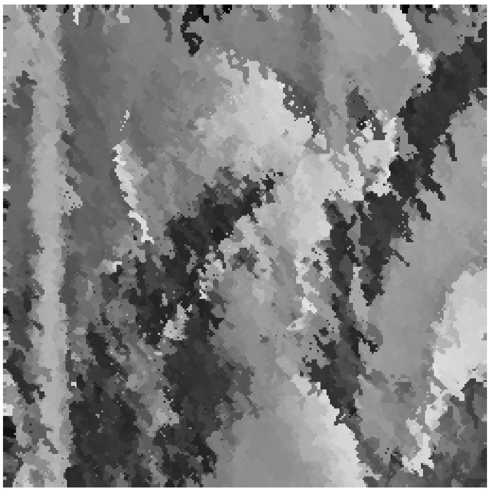

(b) Noisy 90%

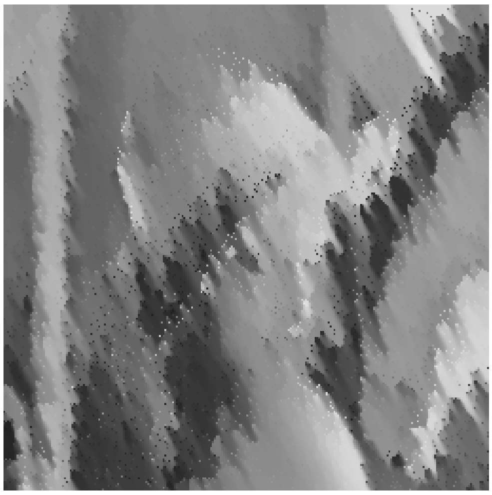

(c) SMF


(d) AMF


(e) PSMF


(f) DBA


(g) MDBA


(h) MDBUTMF

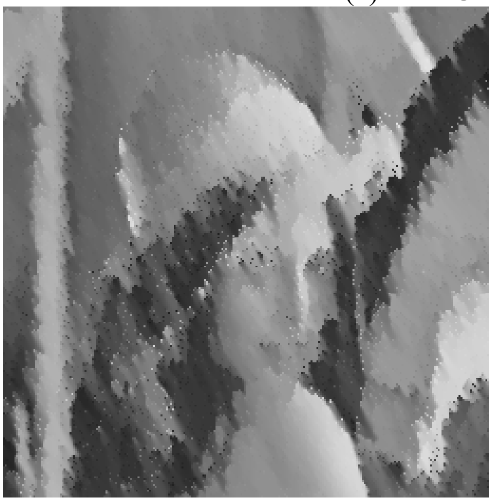
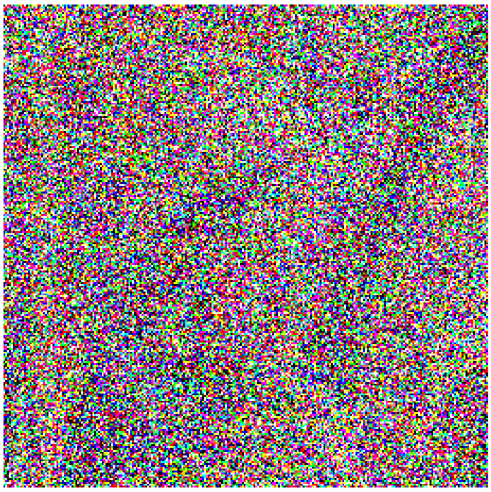
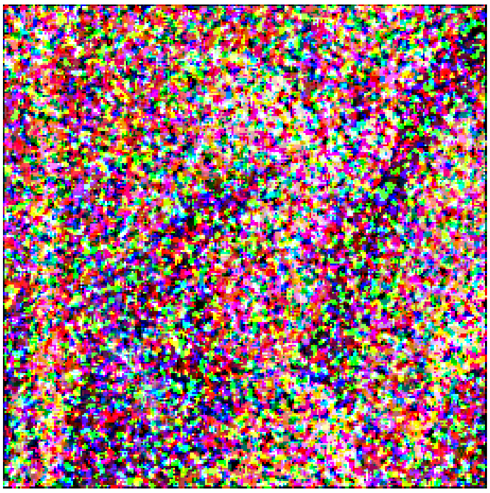
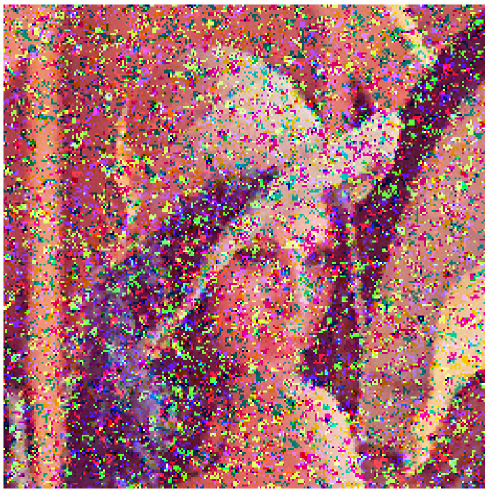

(i) Proposed

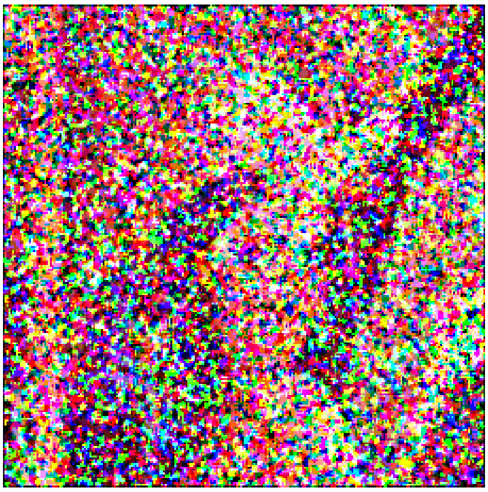
Fig.5 Results of various noise removal algorithms for Lena (Gray) image

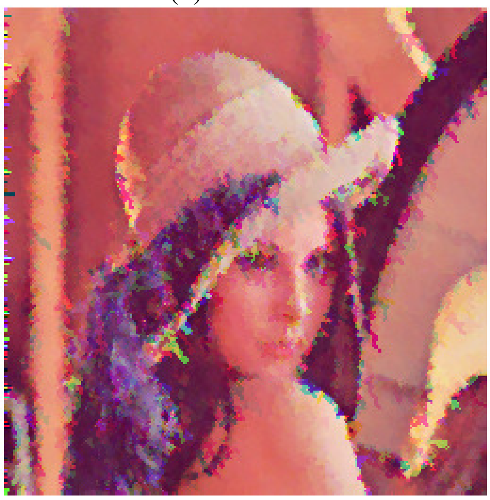

(a) Original

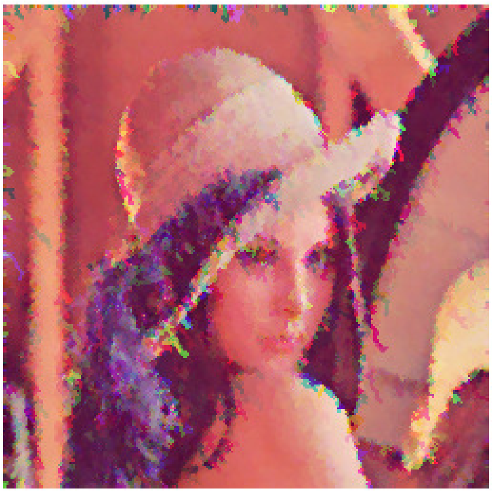

(b) Noisy 80%

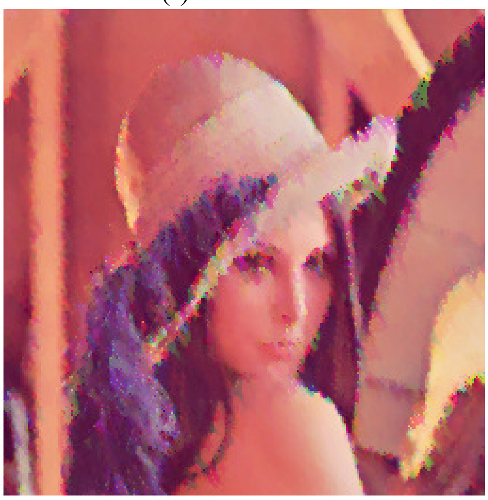

(c) SMF

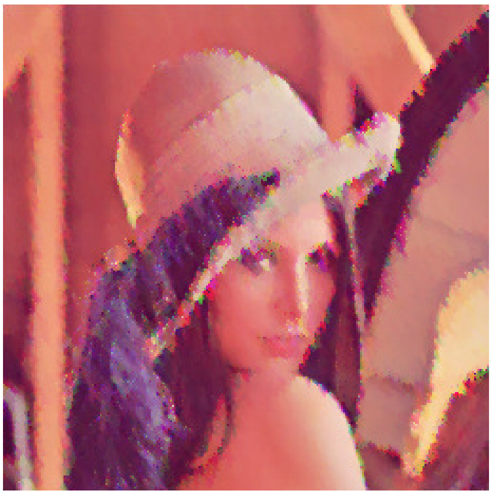

(d) AMF


(e) PSMF


(f) DBA

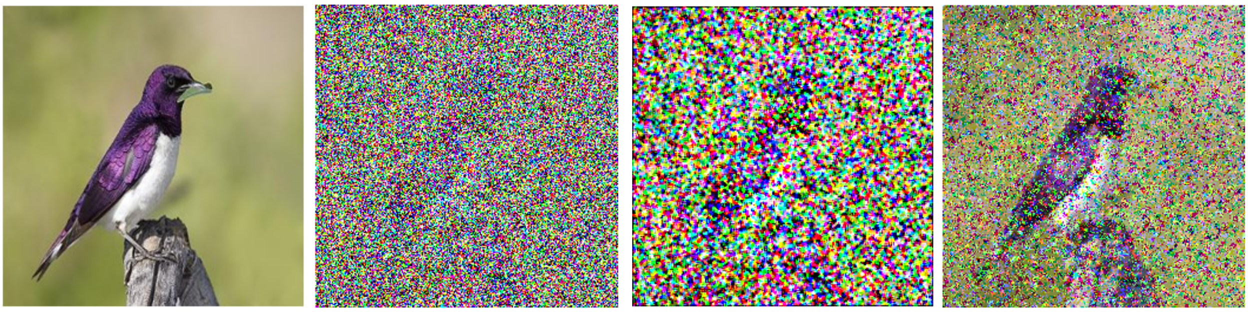

(g) MDBA


(h) MDBUTMF

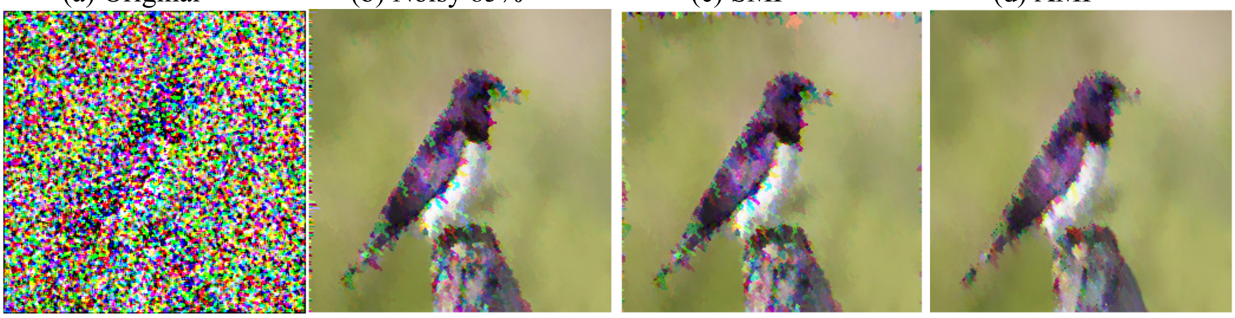


(i) Proposed

Fig.6 Results of various noise removal algorithms for Lena (Colour) image



(a) Original (b) Noisy 85% (c) SMF (d) AMF



(e) PSMF (f) DBA (g) MDBA (h) MDBUTMF

(i) Proposed

Fig.7 Results of various noise removal algorithms for Bird image

4 Conclusion

In this paper, a new algorithm is proposed to remove high density salt and pepper noise in an image. At high noise density, fuzzy logic based decision is taken to minimize the impact of salt and pepper noise. The fuzzy rule derived in the proposed method is simple and easier to implement. The algorithm is tested against different grayscale and colour images. The proposed algorithm gives better performance in comparison with existing impulse noise removal algorithms in terms of PSNR and IEF.

References:

[1] T. S. Huang, G.J. Yang, and G. Y. Tang, Fast two dimensional median filtering algorithm, *IEEE Trans. Acoustics, Speech, Signal Process.,* Vol.32, No.1, 1979, pp.13-18.

[2] N. C. Gallagher, and G. L. Wise, A Theoretical Analysis of the Properties of Median Filters, *IEEE Trans. Acoustics, Speech and Signal Processing*, Vol.29, 1981, pp.1136-1141.

[3] R.H. Chan, C.W. Ho, and M. Nikolova, Salt-and-pepper noise removal by median type noise detectors and detail preserving regularization, *IEEE Trans. Image Processing*, Vol.14, No.10, 2005, pp.1479-1485.

[4] T. A. Nodes and N. C. Gallagher, Median Filters: Some Modifications and their properties, *IEEE Trans. Acoustics, Speech and Signal Processing*, Vol.30, 1987, pp.739-746.

[5] E. Abreu, M. Lightstone, S. K. Mitra and K. Arakawa, A New Efficient Approach for the Removal of Impulse Noise from Highly Corrupted Images, *IEEE Trans. Image Processing,* Vol.5, No.6, 1996, pp.1012-1025.

[6] P. E. Ng and K.-K. Ma, A switching median filter with boundary discriminative noise detection for extremely corrupted images, *IEEE Trans. Image Processing*, Vol.15, No.6, 2006, pp.1506–1516.

[7] K. S. Srinivasan and D. Ebenezer, A new fast and efficient decision-based algorithm for removal of high density impulse noises, *IEEE Signal Processing Letters*, Vol.14, No.3, 2007, pp.189–192.

[8] M. S. Nair, K. Revathy and R. Tatavarti, Removal of Salt and Pepper Noise in Images: A New Decision Based Algorithm, *Proceedings of the International Multi Conference of Engineers and Computer Scientists 2008 (IMECS 2008),* Vol. I, 2008, pp.19-21.

[9] S. Esakkirajan, T. Veerakumar, A. N. Subramanyam and C. H. PremChand, Removal of High Density Salt and Pepper Noise Through Modified Decision Based Unsymmetric Trimmed Median Filter, *IEEE Signal Processing Letters*, Vol.18, No.5, 2011, pp.287-290.

[10] C.-S. Lee, Y.H. Kuo, and P.T. Yu, Weighted fuzzy mean filters for image processing, *Fuzzy Sets Syst.*, Vol.89, No.2, 1997, pp.157–180.

[11] F. Farbiz and M. B. Menhaj, *Fuzzy Techniques in Image Processing*. New York: Springer-Verlag, 2000.

[12] W. Siler and J. J. Buckley, *Fuzzy Expert Systems and Fuzzy Reasoning*, John Wiley & Sons, Inc, 2005.