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Reduction of Salt and Pepper Noises from a Degraded Image Based on Fuzzy Techniques

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Abstract

Objectives: The present paper is concerned for removing the salt and pepper noises along with preserving the edge details of images from the degraded images. There are different techniques are available in literature for it with some merits and demerits. **Methods:** To overcome the demerits of some existing methods, we have presented a new technique based on fuzzy logic. The suggested technique is able to describe in two phases. In first phase, centroid defuzzification method is critically used for reducing the Salt and pepper noises and in second phase some techniques are used to preserve the different tiny edges of the degraded images. **Findings:** The proposed method tested and compared with some existing methods for 8-bit images of different percentage of noises. It gives the satisfactory result in terms of PSNR values and also preserved the different tiny edges. Here edges are computed by means of canny edge detector. **Application:** The suggested method can be applied to find the features of the images in medical imaging and in different industry.

Keywords: Canny Edge Detector, Centroid Method, Fuzzy Logic, Membership Function, Salt and Pepper Noise

1. Introduction

In today's information-driven society various multimedia items, like text, image, audio and video are generated or captured, manipulated and transmitted in digital form. The quality of the multimedia items like images may be degraded due to the presence of noises at the time of acquisition, processing or transmission. Now-a-days, to get back the original images or near to the original images certain techniques are available. Most of these techniques are well appreciated. In response to the demand, almost every year, the different techniques are introduced by different researchers. Still, it is not sufficient to meet the satisfactory requirement. Noise means, true pixel values of image are replaced or modified by different intensity values. The central objective of noise removal technique is to remove or reduce the visibility of noise from the corrupted image by smoothing the entire image. After application of the above method some information of the image can be reduced such as edges, low contrast, fineness etc. Based on characteristic of noises, different noises are available such as a) Impulse noise b) Additive Noise c) Multiplicative Noise.

1.1 Various Sources of Noises in Images

Noise can be introduced in the images at the time of capturing and/or processing and/or broadcast. During image acquisition or processing or transmission, several factors[1-3] are responsible for introducing noises in the image. Here we mention some of the source of noises for digital images:

- The sensor (imaging) may be affected by atmospheric turbulence during image acquisition.
- Due to temperature of the sensor may corrupt the image.
- Insufficient Light, improper opening and closing of the shutter and misfocus of the lens may also corrupt the image.

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- Due to presence of dust particles on scanner screen may also degrade the image.
- Interference of transmission channel may also degrade image.

1.2 Types of Noise

Depending on the types of disturbance, the noise can affect the image to different extent at the time of handling the image. To remove noise from the corrupted image we have to identify the types of noise followed by certain noise removal technique. Some common types of noises are listed as follows:

A. Impulse Noise

Due to malfunctioning of sensor cell of camera, sharp and sudden change of image signal or faulty memory locations in hardware, dust particle present[2,4-9] impulse noise is introduced in image.

It replaces the original gray values of the given image at different positions. The impulse noise is classified as 'salt and pepper', 'random-valued' respectively. If corrupted one takes either '0' or '255' for 8-bit images, then it is termed as salt and pepper. Whereas random valued noise, the noisy pixels can take any random integer value in the dynamic range. The probability density function of impulse noises as shown below. The graphical representation of it as displayed in Figure 1.

$$P(z)=\begin{cases} p_a & \text{if } z=a \\ p_b & \text{if } z=b \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

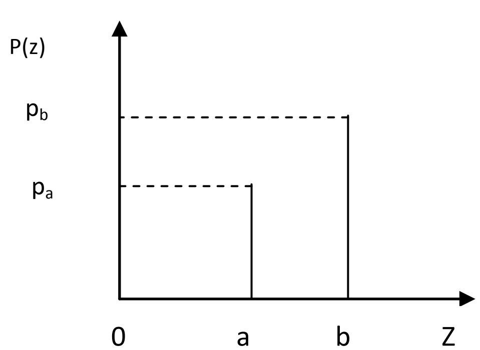

Figure 1. Probability Density Function of impulse noise.

p_a is probability of occurrence of 'a' i.e. $P(Z=a)=p_a$

B. Gaussian Noise

It is uniformly distributed over the image. The Gaussian noise is an additive noise. Here the actual pixel of images are added with randomly distributed Gaussian noise value[2,6,42]. The pdf of Gaussian distributed noise is given by

$$\mathrm{F}(x)=\frac{1}{\sqrt{2\pi\sigma^2}}e^{\frac{-(x-m)^2}{2\sigma^2}} \tag{2}$$

Here 'm' represents the average of the noises. σ represents standard deviation of noise. The graphical representation of it as displayed in Figure-2. There are different filters are available to reduce the Gaussian noise. However, such filter can reduce not only Gaussian noise but also some image details remove.

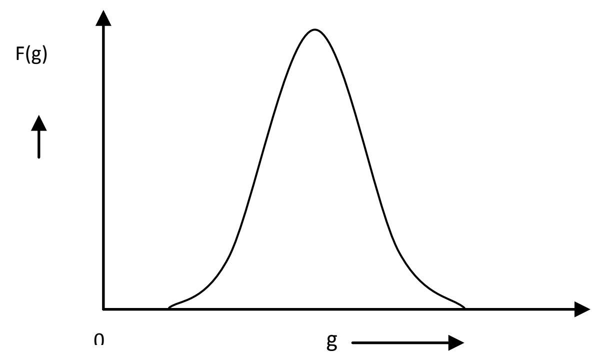

Figure 2. Probability Density Function of Gaussian noise.

C. Poisson Noise

Due to statistical quantum fluctuation, some noise may be introduced in the lighter parts of an image. The detection of photon can be considered as independent events. It follows a random temporal distribution. So, photon counting can be considered as a Poisson process. Therefore, the number of photons N measured over a time interval t by a sensor element described by the discrete probability mass function (pmf) as follows:

$$P(N=k)=\frac{e^{-\lambda t}(\lambda t)^k}{k!} \tag{3}$$

The λ indicates average number of photons/time. It is proportional to incident scene irradiance. The above distribution is a Poisson distribution with parameter λt. The Poisson distribution counts the expected number of photons in a unit interval of time. The Poisson noise is a multiplicative noise. We know that, E [N] = Var [N] = λ [for Poisson distribution], which imply that it is signal dependent and its standard deviation grows with the square root of the signal.

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ -1 & -1 & 4 & -1 & -1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} -1 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & 4 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Figure 3. Laplacian operator.

1.4 Different Methods for Noise Removal

An image can be degraded by various factors at the time of handling the image. The noise decreases the visual performance and computerized analysis. The visual performance and/ or computerized processing are improved by removing the noise from the corrupted image. There are different techniques are available to reduce the different noises. Some of them are listed below for salt and pepper noise.

1.4.1 Standard Median Filter

The standard median (SM) filter[2,10-14] tries to restore middle pixel by median of window (of size 3x3, 5x5 etc generally, if the middle pixel is either '0' or '255'.

1.4.2 Weighted Median Filter

In weighted median filter method[10-16], sort the pixels of the window (of size w×w(=p)). Let it be x(1) ≤ x(2) ≤ · · · ≤ x(p) and the corresponding weights are a(1), a(2), · · · , a(p). Then find i* such that following inequality must be satisfied:

$$a_{i^*} + \sum_{i=1}^{i^*-1} a_{(i)} \geq \sum_{i=i^*+1}^{p} a_{(i)} \qquad \sum_{i=1}^{i^*-1} a_{(i)} \leq \sum_{i=i^*+1}^{p} a_{(i)} + a_{i^*} \tag{4}$$

Then, x(i*) can be considered as weighted median value of weighted median filter. Then replace the central pixel by the weighted median value.

1.4.3 Center-Weighted Median(CWM) Filter

The CWM filter[11,12,14,17-20] tries to give more weight to central pixel. The central pixel is assigned a weight, i.e., w (0, 0) = 2y + 1 where y ≥ 0, and, for non-central pixel assigned a weight is 1 i.e., w(i,j) = 1 for i, j ≠ 0, y is a nonnegative integer. The current filter under discussion is controlled by two parameters, namely, the size of the window and the weights of the central pixel.

1.4.4 Switching Median Filter

The switching median filter[10,12] method, four 1-D Laplacian operators are used. These four operators are shown in the Figure 3. These four operators are more responsive to edges in different direction. First of all, switching median filter computes r_{ij} for each Laplacian operators by the following formula[21]. $r_{ij}=\min\{|x_{ij}\otimes K_p|:p=1,2,3,4\}$ Here ⊗ is represent the convolution operation.

If r_{ij} is large then current pixel can be considered as a noise. I fit is small then it can be considered as a noise-free. So, whether the pixel is corrupted or not, it is decided by a threshold value (T).

1.4.5 Tri-State Median Filter

The tri-state median[8] filter is the combination of SM filter and CWM filter. The central pixel of the window may be noise free or noisy (corrupted, or probably uncorrupted). Based on it, the tri-state median filter has three states. The state s∈{0,1,2} if s=0 (noise free) then central pixel is unchanged. If s=1, (noisy) then the central pixel is replaced by SM filter output. If s=2, (probably uncorrupted) then central pixel is replaced by CWM filter output. The block diagram of tri-state median filter method along with threshold calculation is shown in Figure 4.

$$Y_{ij}^{TSM} = \begin{cases} Y_{ij}^{SM}, & T < d_2 \\ Y_{ij}^{CWM}, & d_2 \leq T < d_1 \\ X_{ij}, & T \geq d_1 \end{cases}$$

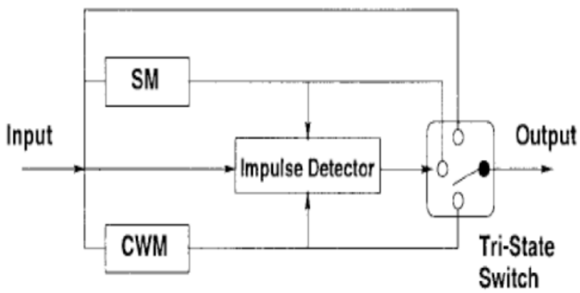

Figure 4. Tristate Median Filter.

1.4.6 Progressive Switching Median Filter (PSMF)

The presentfilter[12,21,22] is used to remove salt and pepper noise from corrupted image. Here, first check central pixel of specified window is corrupted or not. Corrupted value is replaced by median of that window. If the calculated median value is again corrupted then increases the size of the window until get the correct median value. Then left the central pixel as it is if it is not corrupted.

1.4.7 Signal-Dependent Rank-Ordered Mean(SD-ROM) Filter

In this methods[5,7,10,23,24], first checked the central pixel of specified window is corrupted or not. If it is corrupted then a new value is estimated based on rank order mean of that window for the central pixel, otherwise left as it.

1.4.8 Adaptive Center Weighted Median (ACWM) Filter

It can remove the drawbacks of CWM and switching median filters. In this method input data are clustered by SQ method. It provides in fix threshold for all images. Modified adaptive center weighted median (MACWM) filter is used from Fuzzy clustering method (FCM) data[17,20,25-29].

1.4.9 Boundary Discriminative Noise Detection Filter (BDND)

In Boundary Discriminative Noise Detection Filter (BDND)[26,28,30,31] methods tries to implement in two steps. In step 1, image is classified into three groups based on their intensity values using the concept of Fuzzy logic. It is basically a noise detection step. Pixels having lower (0) and higher (255) intensity are considered as noisy pixels. In step 2, replace the corrupted pixel step by step by median of uncorrupted pixels. If the number of corrupted pixel is less than 50% of that window, then step 2 is applicable, otherwise increase the window size in all directions (if Possible). The experimental result shows the effectiveness of the BDND filter even if the noise density is high in term of PSNR.

1.4.10 Fuzzy Inference Ruled by Else-Action (FIRE)

The FIRE filter[32,33] was introduced by Russo in the year 1996. Russo suggested a technique to reduce salt and pepper noise using fuzzy rules and employing fuzzy sets. Based on fuzzy membership values, filter under discussion; calculate the degree of noisiness of each pixel. Some pixels are modified by some rectification process based on their degree of noisiness in that window. The filter under discussion is incompetent to eliminate noise of degraded image at the edges.

1.4.11 LUO

The LUO method [35]tries to eliminate impulse noises from the degraded images. It is an efficient detail-preserving approach to remove impulse noises from degraded images. It is described in two steps. In step 1, detect the middle pixel of specified window is noisy or not. It is done by the concept of alpha-trimmed mean. In step 2: If middle one is corrupted then it is replaced by the weighted average of true value and median of its local window[34,35].

1.4.12 Directional Weighted Median Filter (DWM)

The present filter[36,37] under discussion tries to remove impulse noises from a degraded image using direction based method. DWM impulse detector calculates the sum of weighted differences between the present pixel or current intensity value and its neighbors aligned for each direction within the filtering window of size 5. It is called as direction index. Then calculate the minimum of all direction indexes, if the value is small then the present pixel is considered as noise free or edge pixel. If the value is large (≥ threshold value) then the current pixel is considered as noisy pixel. If the central pixel is identified as noisy then the central pixel under discussion is replaced by the yield of the renowned weighted median filter, otherwise central pixel under discussion left as it is.

To remove the impulse noises, different methods [36]have been developed based on fuzzy concept also. Despite availability of so many filtering methods, there is scope to improve upon the de-noised image by suggesting new filters. With the presently available filters some information is removed along with noise. To overcome this problem we have suggested remarkable approach for image de-noising with fuzzy filtering technique. It preserves almost all types of edges and does de-noising as well.

2. Proposed Method

In the proposed method, centroid defuzzification method[38,39] is used for defuzzification purpose to reduce the impulse noises. To preserve different tiny edges of the corrupted image a technique[29] is used and it is critically handled. The newly designed filter is explained in two phases. In Phase I, tried to remove the impulse noise using centroid defuzzification method. In phase II, tried to preserve the actual image information or in other words, preserve the different edges of the image. The phase I and phase II are discussed as follows:

Phase I

At the time of capturing or processing or transmitting the images, some noises are introduced in the captured image due to malfunctioning of camera's sensor cells, faulty memory locations in hardware, sharp and sudden change of image signal or dust particle present in the transmission medium. For removing the impulse noise (here Salt and Pepper) from the corrupted image we pursue the succeeding steps:

Step 1: Initially apply median filter around a corrupted pixel. Let the input and output are x(i,j) & y_1(i,j) respectively of filter under discussion. The result of the current filter is given by:

$$y_1(i,j) = \text{median}\{x(i\text{-}s;\ j\text{-}t) : \forall(s,t) \in W\} \tag{5}$$

and here we consider

$$W = \{(s, t): -1 \le s, t \le 1\} \tag{6}$$

Step 2: All the neighborhoods of the central pixel of W are arranged in non decreasing manner depending on intensity values.

Step 3: Now calculate the membership value of each pixel of W based on some membership function[38,40,41], which have the following properties.

- The highest and lowest gray values of the W have zero membership value.
- The mean gray value of the window W of size w × w has 1(one) membership value.

Based on the above properties, the membership function is also defined and presented in Figure-5.

$$\mu(x;\alpha,\beta,\gamma)=\begin{cases} 0 & \text{if } x \le \alpha \\ \dfrac{(x-\alpha)}{(\beta-\alpha)} & \text{if } \alpha < x \le \beta \\ 1-\dfrac{(x-\beta)}{(\gamma-\beta)} & \text{if } \beta < x \le \gamma \end{cases} \tag{7}$$

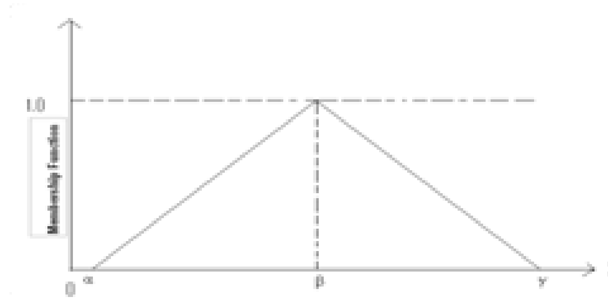

Figure 5. Graphical representation of membership function.

Step 4: Now calculate the crisp value of the membership values of all the pixels of W based on centroid defuzzification method[26,27,38,40,41]. The outcome of centroid defuzzification method *($y_2(i,j)$)* at the position *(i,j)* is defined as follows**:**

$$y_2(i,j) = \frac{\sum_x x\mu_x(i,j)}{\sum_x \mu_x(i,j)} \tag{8}$$

Here 'x' represents pixel values at (i,j) and $\mu_x(i,j)$ represent membership value of 'x' at (i,j).

Phase II

After application of phase I, on the corrupted images, some noises would be reduced. Here some image details also removed along with noises (0 or 255). The salt and p epper noises are represented by '0' and '255', so all '0' and '255' will be removed after application of the phase I; even of those were not noises. For estimating the actual data or near to the actual data we pursue the following steps:

Step 1: For the corrupted central pixel compute *p(i,j)* and *q(i,j)*as follows[29]:

$$p(i,j) = |f(i,j) - \text{median}\{Lf(i,j)\}| \quad (9)$$

Here $L(f(i,j))$ is the 8-neighborhood of point (i,j).

$$q(i,j) = \frac{|f(i,j) - f_{c1}(i,j)| + |f(i,j) - f_{c2}(i,j)|}{2} \quad (10)$$

where

$$f_{c1}(i,j) = \underset{\forall i,j \in W}{\text{1st-min}} \{|\, f(i,j) - L(f(i,j))\,|\} \quad (11)$$

$$f_{c2}(i,j) = \underset{\forall i,j \in W}{\text{2nd-min}} \{|\, f(i,j) - L(f(i,j))\,|\}$$

Then rearrange p(i,j) and q(i,j) in ascending order for all i,j.

Step 2: Compute the weight $w(i,j)$ based on $p(i,j)$ and $q(i,j)$ such that $w(i,j) = F(p(i,j), q(i,j))$ i.e.

$$w(i,j) = 1 - \frac{p(i,j) + k_1}{p(i,j) + q(i,j) + k_2} \quad (12)$$

Here k_1 and k_2 are real values, which quantifies by the quality of input images. For each pixels of the specified window have the weight w(i,j). Calculate w by the following formula:

$$w = \max\{w(i,j): i,j = 0,1,2,\ldots w \times w\}. \quad (13)$$

Step 3: If $y_1(i,j) \neq y_2(i,j)$ then

$$y_3(i,j) = w^* y_1(i,j) + (1 - w)^* y_2(i,j) \quad (14)$$

Else $\quad y_3(i,j) = y_1(i,j)$

Step 4: Continue the above process for all pixels of given degraded images.

The present technique is illustrated as below:

Consider a 3×3 window of the given corrupted image as shown in the Figure-6. Here central pixel is noisy (i.e. 0). Here we consider a suitable membership function, based on it construct the membership value for each pixel as shown in the table 1 and graphically presented in Figure-7.

Now we calculate y_2(i,j) using centroid method. In the Table 2, the centroid of each sector is calculated of a graph of membership function. So, the calculated value for $\sum_x x\mu(i,j)$ = 2858.328857 and the calculated value for

$\sum_x \mu(i,j)$ = 42.02631 Therefore, $y_2(i,j)$ = 68 [Selected value in phase I]

Based on equation (9), (10) and (12), weight w(i,j) can be calculated as follows:

Therefore w= 0.956522 using eq.(13) (as shown in the Table 3). Therefore y_3(i,j) = 82. The Figure 8 shows the selected pixel of the given test image after phase-I where as Figure-9 shows the selected pixel of the given image after phase-II.

83	113	71
99	0	58
112	92	47

Figure 6. Original value: 0 Mean value: 75 Median value $y_1(i,,j)$: 83.

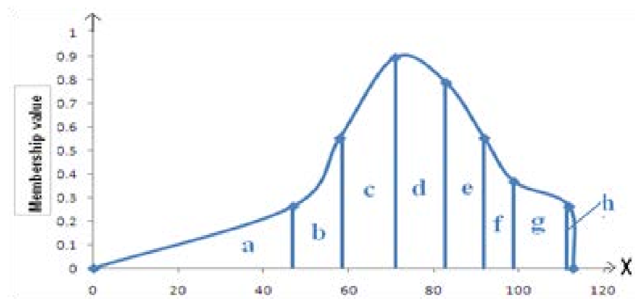

Figure 7. Graphical representation of membership function.

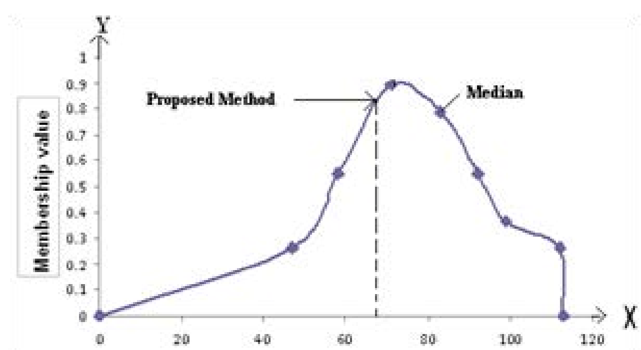

Figure 8. Graphical representation of selected.

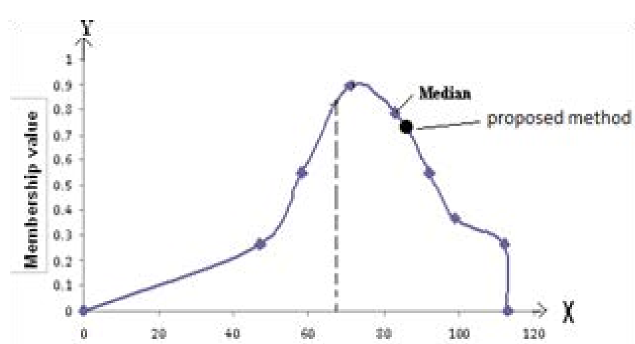

Figure 9. Graphical representation of selected pixel.

Table 1. Membership values of each pixel of the given corrupted image

Sorted order	0	47	58	71	83	92	99	112	113
Membership value	0.00	0.26	0.55	0.89	0.79	0.55	0.37	0.26	0.00

Table 2. Centroid of each sector of graph as presented in Figure 7

Sector Name	Area	Centroid of the sector
a	6.184211	23
b	4.486842	52
c	9.407894	64
d	10.105263	77
e	6.039474	87
f	3.223684	95
g	2.565789	105
h	0.013158	112

3. Experimental Result

The proposed method is tested for some 8-bit standard images of different noise levels. Here size of the window is 3×3. The output of the newly proposed filter is tested against the original one. The experimental result shows the success of our newly described filter. It effectively reduces the salt and pepper noises. The performance of newly designed algorithm is calculated with the help of PSNR[2,6] values. It is defined as follows:

$$\text{PSNR} = 10\log_{10}\left(\frac{\sum_k 255^2}{\sum_k (d(k)-y(k))^2}\right) \tag{15}$$

Here all the symbols bear the usual meaning. Figure-10 shows the set of original images whereas Figure-11 shows the corresponding noisy (with 5% salt and pepper) images. The output of the proposed method is shown in the Figure-13 of noisy images as shown in the Figure-11. The experimental results are also compared with other existing method as shown in the Figure-12. It is also compared with other methods (SM, FIRE, BDND, LUO, and DWM) in tabular form in the Table-4.

The newly described filter is also preserved the different edges. It is measured by canny edge detector.

Table 3. Calculation of weights

p(i,j)	0	9	12	16	25	29	30	36	83
q(i,j)	7	7.5	8	10	10.5	12	12.5	17.5	52.5
w(i,j)	0.956	0.207	0.509	0.388	0.388	0.328	0.202	0.472	0.330

Figure 10. Original Images: a) Lena b) Girl c) Hair d) Field e) paddy f) Aish.

Figure 11. Noisy Images: a) Lena b) Girl c) Hair d) Field e) paddy f) Aish.

Figure 12. Median based output: a) Lena b) Girl c) Hair d) Field e) paddy f) Aish.

Figure 13. Proposed method a) Lena b) Girl c) Hair d) Field e) paddy f) Aish.

Table 4. Comparative restoration results in PSNR of proposed method with some existing method for noisy (with 5% salt and pepper) images

Sl. No.	Images	SM	FIRE	BDND	LUO	DWM	Proposed Method
1	Lena	38.795	38.438	37.239	38.872	40.349	43.774332
2	Girl	43.664	43.239	44.389	44.879	45.397	49.988178
3	Field	35.284	38.083	38.896	40.209	41.387	49.370430
4	Hair	33.578	35.650	36.870	37.909	39.980	46.27762
5	Paddy	32.270	38.492	38.290	38.277	39.285	44. 832817
6	Aish	41.603	43.290	43.750	45.280	46.850	57.420597

It is compared with SM filter. The edge preservation of proposed method along with other median based method is presented in Table-5. The newly designed filter is tested for more than 1000 gray scale images. Here we displayed some of those 8-bit images. The proposed method is also tested for different percentage of noises as shown in the Table 6 for the test image as 'hair'. Based on the experimental result we can conclude that suggested method is better than other existing method in terms of PSNR values. Again we also observed that from the Table 6, the proposed method preserved more edges compare to other median based filter. The experimental result of newly designed technique is presented in the Figure-14 of 'hair images' (8-bit) in terms of PSNR values for different percentage of noises along with median filter. Along the x-axis, represent the percentage of noises and along the Y-axis, represent the PSNR value. The suggested method is improved the quality of images and it also preserved tiny edges.

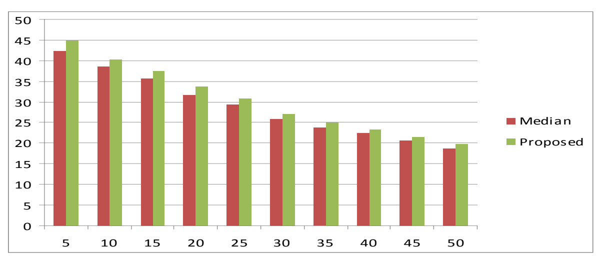

Figure 14. Comparative study of the proposed method with median based method.

Table 5. Comparative restoration results in edge count of the proposed method with median filter for noisy (with 5% salt and pepper)

Image Name	Actual edges in the original image	Number of edges for output of Median Filter	Number of edges for Proposed Filter Output
Lena	18904	21848	21889
Girl	15468	15481	15559
Hair	21864	21839	21863
Field	29855	29605	29719
Paddy	21329	21265	21389
Aish	11605	11601	11653

Table 6. Experimental result of the proposed method with different % of noise level for 'hair' images

Noise Percentage	Median Filter	Proposed Filter
5 %	42.55175	44.916355
10 %	38.80244	40.318722
15 %	35.74166	37.733429
20 %	31.76021	33.796974
25 %	29.41449	30.928938
30 %	25.98153	27.275433
35 %	23.94808	25.14379
40 %	22.5963	23.435760
45 %	20.67396	21.548168
50 %	18.77719	19.788691

4. Conclusion

Here, we have suggested for salt and pepper noise removal technique based on fuzzy logic from a degraded image. It removes the impulse noises and also preserved the different tiny edges. The technique under discussion is tested for different 8-bit corrupted (5%-50%) images. The experimental results of suggested filter gives satisfactory result in terms of PSNR values compare to other existing method. It gives visually and quantitatively better result compared to other existing methods, even with high noise levels. The output of proposed method gives more or less original image. This restoration of images can be applicable in different areas such as medical diagnostics.

5. References

1. Baudes A, Coll B, Morel JM. IEEE Conf. A non-local algorithm for noise Denoising, Computer Vision and Pattern Recognition, CVPR. 2005; 2:60-65.
2. Gonzalaz RC. Digital Image processing Prentice Hall, 2nd edition. 2008; p. 954. ISBN: 0-201-18075-8.
3. Jayaraman S, Esakkirajan S, Veerakumar T. Digital Image processing Tata McGraw Hill Education Private Limited. 2008; p. 554. ISBN N0: 0070144796.
4. Hamza A, Krim H. Image denoising Anon linear robust statistical approach. IEEE. Trans. Signal Processing. 2001; 49(2):3045-54.
5. Abreu E, Lightston M, Mitra SK. A New efficient Approach for the Removal of Impulse Noise from Highly corrupted Images IEEE Transaction on Image processing. 1996; 5(6):1012-25.
6. Boyat AK, Joshi BK. A Review Paper: Noise Models in Digital Image Processing. Signal & Image Processing: An International Journal (SIPIJ). 2015; 6(2):63-75.
7. Aizenberg I. Effective Impulse Detector Based on Rank-order Criteria IEEE signal processing Letters. 2004; 11(3):363-66.
8. Chen T, Ma KK, Chen LH. Tri-state median filter for image Denoising IEEE Trans. on Image Processing. 1999; 8(12):1834–38.
9. Murugan V, Avudaiappan TR, and Balasubramanian B. A Comparative Analysis of Impulse Noise Removal Techniques on Gray Scale Images. International Journal of Signal Processing, Image Processing and Pattern Recognition. 2014; 7(5):239-48.
10. Judith GMC, Kumarsabapathy N. Study and analysis of impulse noise reduction filter. Signal and Image Processing: An International Journal. 2011; 2(1):82-92.
11. Manivel K, Ravindran RS. A Comparative Study of Impulse Noise Reduction in Digital Images for Classical and Fuzzy Filters. International Journal of Engineering Trends and Technology (IJETT). 2013; 4(1):4584-89.
12. Yli-Harja O, Astola J, Neuvo Y. Analysis of the properties of median and weighted median filters using threshold logic and stack filter representation. IEEE Trans. Signal Processing. 1991; 39(2):395–410.
13. Chen T, Wu HR. Space variant median filters for the restoration of impulse noise corrupted images. IEEE Trans. on Circuits and Systems II: Analog and Digital Signal processing. 2001; 48(8):784–89.
14. Sun T, Neuvo Y. Detail-preserving median based filters in image processing. Pattern Recognition Letters. 1994; 15(4):341–47.
15. Jeong B, Lee YH. Design of weighted order statistic filters using the perceptron algorithm Non linear digital signal processing. IEEE winter Workshop. 1993; p. 3.1_1.1 - 3.1_1.6.
16. Jeong B, Lee YH. Design of Weighted order Statistic Filter Using the perceptron Algorithm. IEEE Trans. Signal Processing. 1994; 42(11):3264–69.
17. Ghandeharian B, Hadi S. Modified, Adaptive center weighted median filter for up pressing impulse noise in images. International Journal of Research in Applied Sciences. 2009; 1(3):218-27.
18. Ko SJ, Lee YH. Center weighted median filters and their applications to image enhancement. IEEE Trans. Circuits and Systems. 1991; 38(9):984–93.
19. Lin TC, Yu PT. A new adaptive center weighted median filter for suppressing impulsive noise in images. Information Sciences. 2007; 177(4):1073-87.
20. Chen T, Wu HR. Adaptive impulse detection using center-weighted median filters. IEEE Signal Processing Letters. 2001; 8(1):1–3.
21. Zhang S, Karim MA. A new impulse detector for switching median filters. IEEE Signal Processing Letters. 2002; 9(11):360–63.
22. Wang Z, Zhang D. Progressive Switching Median Filter for

removal of Impulse Noise from highly corrupted Images. IEEE transaction on circuits and systems–II Analog and digital Signal Processing. 1999; 46(1):78-80.

23. Abreu E, Mitra SK. A signal-dependent rank ordered mean SD-ROM filter: A new approach for removal of impulses from highly corrupted images, IEEE ICASSP. 1995; 95(4):2371-74.
24. Somasundram K, Shanmugavadivy P. Adaptive iterative order Statistics Filter. ICGST-GVIP Journal. 2009; 9(4):23-32.
25. Hwang H, Haddad RA. Adaptive Median filters: New algorithms and results. IEEE transaction on Image Processing. 1995; 4(4):499-502.
26. Jagadish H, Pujar P. Robust Fuzzy Median Filter for Impulse Noise Reduction of Gray Scale Images. World Academy of Science, Engineering and Technology. 2010; p. 1-5.
27. Arakawa K. Median filters based on fuzzy rules and its application to image restoration. Fuzzy Sets and Systems. 1996; 77(1):3-13.
28. Lee CS, Kuo VK, Yu PT. Weighted Fuzzy mean filters for Image processing. Fuzzy Sets Sys. 1997; 89(2):157-80.
29. Yazdi S, Homayouni F. Impulsive Noise Suppression of Images Using Adaptive Median Filter. International Journal of Signal Processing, Image Processing and Pattern Recognition. 2010; 3(3):1-12.
30. Verma OP, Singh S. A Fuzzy Impulse Noise Filter Based on Boundary Discriminative Noise Detection. J. Inf. Process Syst. 2013; 9(1):89-102.
31. Shalimettilsha S, Kumar RPA. A New Proposed Modification on the BDND Filtering Algorithm for the Removal of High Density Impulse Noise. Int. Journal of Engineering Research and Applications. 2014; 4(4):306-08. ISSN: 2248-9622.
32. Lakshimiprabha S. A new method of image Denoising based on fuzzy logic. International Journal of Soft Computing. 2008; 3(1):74-77.
33. Lin TC, Yu PT. Partition fuzzy median filter based on fuzzy rules for image restoration. Fuzzy Sets and Systems. 2004; 147(1):75–97.
34. Mohan R. Image Denoising Methods: A Survey. International Journal of Advanced Research in Computer and Communication Engineering. 2014; 3(8):7808-12.
35. Brar AK, Wasson V. Image Denoising Using Improved Neuro-Fuzzy Based Algorithm: A Review. International Journal of Advanced Research in Computer Science and Software Engineering. 2014; 4(4):1072-75. ISSN: 2277 128X.
36. Mondal JK, Mukhopadhyay S. A Novel Directional Weighted Minimum Deviation (DWMD) Based Filter for Removal of Random Valued Impulse Noise. Burdwan, West Bengal, India: Proceedings of ICCS. 2010; p. 1-7.
37. Dong Y, Xu S. Beijing: School of Mathematical Sciences, Peking University: A New Directional Weighted Median Filter for Removal of Random-Valued Impulse Noise. 2007; 14(3):193-96. 100871.
38. Zimmermann HJ. Allied Publishers Limited: Fuzzy Set Theory and its Applications, 2nd edition. 1996; p. 203-40. ISBN 978-94-010-0646-0.
39. Ross TJ. Wiley: Fuzzy logic with Engineering Applications, 2nd edition. 2009. ISBN: 978-0-470-74376-8.
40. Konar A. New York: Springer: Computational Intelligence. 2015. ISBN 978-3-540-27335-6.
41. Bezdek JC. Norwell: Kluwer Academic Publishers: Pattern Recognition with Fuzzy Objective Function Algorithms. 2013. ISBN: 0306406713.
42. Jea-Gu Lee, Byung-Kwan Kim, Sung-Bong Jang, Seung-Ho Yeon, Young Woong Ko. Accuracy Enhancement of RSSI-based Distance Estimation by Applying Gaussian Filter. Indian Journal of Science and Technology. 2016 May; 9(20). DOI: 10.17485/ijst/2016/v9i20/94675.