

Edge Preserving Fuzzy Filter for Suppression of Impulse Noise in Images

Isha Singh, Om Prakash Verma



Abstract — Impulse noise in images culminates to the loss of valuable information. This paper proposes an efficient fuzzy filter for suppression of impulse noise in images (EFFSIN). Firstly, impulse noise is effectively detected by the proposed algorithm with the utilization of Fuzzy C-Means (FCM) in two stages. Only legitimate pixels are restored after fair distinction of noisy pixel from edge pixel. Proper restoration of noisy pixel following effective detection by proposed work leads to low miss detection (MD) and false alarm (FA) rates. Simulation results depict the efficacy of the proposed filter with reference to peak-signal-to-noise ratio (PSNR) and structural similarity index measure (SSIM).

Index Terms — Impulse noise, Fuzzy filter, Noise suppression, Peak signal to noise ratio

I. INTRODUCTION

Impulse noise often degrades the images and ruin the valuable information present in an image. The quality of digital images is demolished by impulse noise at the time of procurement of images and their transposal. Faulty memory locations or impaired pixel sensors can result in images corrupted with impulse noise. Images acquired by low resolution digital cameras, scanned images and satellite images need to be processed before further use. Transmitted television signals are often affected by impulse noise and require processing. Impulse noise can either mark up the intensity values or mark the levels low, which can cause serious depletion in the quality of image. Thus noise removal is one of the most critical pre-processing operation, an image should undergo before further image analysis.

In literature, a variety of methods are present for removing impulse noise, broadly classified as linear and non-linear. Impulse noise is not adequately eliminated by linear filters as they tend to obscure the edges of an image. Then again, non-linear filters are more qualified for managing impulse noise because of their improved execution as for edge protection and noise suppression. Various traditional non-linear filters with fuzzy reasoning have risen in the previous couple of years. The application of fuzzy reasoning for the detection and impulse noise restoration is considered vital. Initially Bezdek and Castelaz [1] studied the fuzzy classifier for feature selection. The fuzzy set approach for

the enhancement of images was introduced by Pal and King [2]. They developed an algorithm for the progressive use of fuzzy operator [3].

Over the years, fuzzy based algorithms have shown various variations in their approach of working. Fuzzy mean filters are productive in their nature in terms of impulse noise removal [4-6]. Fuzzy logic used in concoction with the standard median filter have resulted in various efficient and more robust techniques as compared to fuzzy mean filters for impulse noise removal and detection [7-12].

Histogram of an image acts as an efficient tool for retrieving information. Histogram based fuzzy algorithms are also present in literature which works well for the assessment of impulse noise in images. J.H Wang et.al. suggested an algorithm developed by using a set of fuzzy membership functions with the initial parameters based on histogram of input image [13]. S. Schulte et.al. utilized the image histogram to find out impulse noise in color images [14]. In addition with the histogram, fuzzy K-means clustering along with fuzzy-support vector machine (FSVM) classifier is used in [15]. Many histogram-based fuzzy filters and fuzzy median filters perform effectively in terms of detection of impulse noise but proper restoration of noisy pixel is not achieved. It results in high false alarm (FA) rates. Edges present in an image are often detected as impulse noise which gives rise to greater miss detection (MD) rates.

In the recent years, various neuro-fuzzy filters along with evolutionary algorithms have evolved to deal with impulse noise and edge detection such as techniques based on Particle swarm optimization (PSO) [16,17], ant colony optimization [18] and bacterial foraging [19,20] by Verma et.al. Neuro-fuzzy filter with optimized intelligent water drop technique presented by Devi and Soranamageswari in [21] and many more. Neuro-fuzzy filters provide fair results but are complex in nature with increased computational time and cost.

Various algorithms are present in literature which are based on fuzzy logic in combination with other state-of-art filters to handle impulse noise. Each method has its own benefits and restrictions, but fuzzy clustering shows supremacy over other techniques due to its simple structure, less computation time and robust performance even in high noisy environment. Fuzzy C-Means (FCM) is among the popular sought algorithm utilized for grouping of information [22]. FCM is integrated for impulse noise detection by Singh and Verma in [23] which results in low miss detection rates and high PSNR values but false alarm rates are not decreased. After proper detection of noise, its subsequent restoration is important to get a high quality image.

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The proposed work also focuses on the efficient restoration of noisy pixel tampered with impulse noise ,after its double-stage detection using FCM algorithm. Experimental results depict that the proposed algorithm effectively suppress the impulse noise present in images thereby providing greater results with high PSNR rates,high structural similarity,low false alarm and low miss detection rates.

The paper is structured in various sections.Section II presents the proposed algorithm with illustration of work.Section III provides experimental results.Conclusion is given in Section IV and references at the end in Section V.

II. PROPOSED WORK

The basic characteristics of an image are impaired with the intrusion of impulse noise.Impulse noise is alias as Salt and pepper noise in literature.The original pixel values are altered by the extreme intensity values of the dynamic range usually 0 or 255.The proposed work is dynamic in nature which significantly removes impulse noise from images without compromising on the existing edge details.Even if the pixels are detected as noisy,algorithm performs restoration after checking whether the identified noisy pixel is impulse noise or an edge value whose true value is 0 or 255.This mechanism results in a potent algorithm with lower false alarm(FA) and miss detection(MD) values.

Fuzzy C-Means(FCM) is a widely recognized procedure for data clustering. This technique was introduced by Dunn[24] and Bezdek[25] further enhanced it.Since its invention,it is extensively used in various fields to classify data.It provides excellent results for overlapped data sets.FCM is employed in the detection phase twice for the grouping of pixels among three major categories i.e pepper noise,noise-free and salt noise.

A.Impulse Noise Detection

The proposed algorithm perfoms impulse noise detection in two phases.The initial phase attempts to detect noise on global basis therefore a bigger window size of 21×21 is used to extract relevant information from a noisy image.

Phase I

1. Center a 21×21 size window on every image pixel.
2. Pixel under inspection is referred as $v(l^i, l^j)$ i.e value at i^{th} location and j^{th} location in spatial domain.
3. FCM classify the adjacent 441 pixels unsupervisedly into three clusters.
4. Compute the the highest intensity value of pixel in each cluster respectively,denoted as H_1, H_2 and H_3 such that $H_1 < H_2 < H_3$.
5. Cluster with the highest intensity value as H_1 is labelled as "pepper noise",the group with H_2 as its highest value is termed as "noise-free" and H_3 belongs to "salt-noise" group.The following equation is used to evaluate that the pixel is affected with impulse noise or not.

$$v(l^i, l^j) = \begin{cases} \text{"pepper - noise"} : \text{if } v(l^i, l^j) \leq H_1 \\ \text{"noise - free"} : \text{if } H_1 < v(l^i, l^j) \leq H_2 \\ \text{"salt - noise"} : \text{if } H_2 < v(l^i, l^j) \leq H_3 \end{cases} \quad (1)$$

6. In case the pixel belongs to the "noise-free" group, it is not processed further and its original intensity value is retained,otherwise pixel is evaluated again in the second phase of detection.

Phase II

1. For the analysis of the noisy pixel on local basis ,window size is altered to 7×7.
2. FCM classify the adjacent 49 pixels unsupervisedly into three clusters.
3. Reiterate the steps 4) and 5) in the similar manner.
4. If $v(l^i, l^j)$ falls into "noise-free" group, it is considered as an uncorrupted pixel and no transition is made in its original value,otherwise the noisy pixel is restored.

B.Impulse Noise Restoration

An image is comprised of many fine details and sometimes the true value of a pixel or edge values are identified as noise.To minimize the false alarm and miss detection rates, it is important to differentiate between an edge pixel and noisy pixel. The double-phase analysis of a pixel by the proposed algorithm helps to identify the noise affected pixels in a more robust way.The proposed work also focuses on proper restoration of noisy pixels such that edges are preserved and an high quality image is perceived at the user end.For proper classification of noisy pixels from edge pixels, the following steps are performed at the restoration stage:

1. For a noisy pixel, consider the clusters generated by FCM with 7×7 window, having the highest intensity value of H_1 and H_3 respectively.
2. In each cluster, count the number of 0 and 255 respectively and its value is stored in a function denoted by "COUNT1" for number of 0 incase of "pepper-noise"and "COUNT2" for number of 255 incase of "salt-noise".
3. If $COUNT1 \leq 2$ or $COUNT2 \leq 2$ then the pixel under evaluation is considered as noisy and will be restored.
4. If $COUNT1 \geq 3$ or $COUNT2 \geq 3$ then take a 3 × 3 window placed on processing pixel to check if its a noisy pixel or an edge.
5. The following two cases are considered for image restoration by taking the eight adjacent pixels of the center pixel i.e N_8 into account :

Case I: If N_8 has all 0 or 255 then do not perform any restoration as it can be an edge value.

Case II: If N_8 has 0 or 255 greater than one then expand window size to 5 × 5 to check for any possible edge

v^{24}	v^9	v^{10}	v^{11}	v^{12}
v^{23}	v^8	v^1	v^2	v^{13}
v^{22}	v^7	v^0	v^3	v^{14}
v^{21}	v^6	v^5	v^4	v^{15}
v^{20}	v^{19}	v^{18}	v^{17}	v^{16}

figure 1: 5 × 5 window

Let the pixel under processing is " v^0 " as shown in fig 1.The adjacent pixels are denoted as v^1 to v^{24} .

The following rules are utilized to cross-check whether the pixel needs to be restored or not.

Rule 1:

IF (v^0 is NOISY) AND (v^2 and v^{12} are NOISY) AND (v^6 and v^{20} are NOISY) THEN (v^0 is EDGE)

Rule 2:

IF (v^0 is NOISY) AND (v^1 and v^{10} are NOISY) AND (v^5 and v^{18} are NOISY) THEN (v^0 is EDGE)

Rule 3:

IF (v^0 is NOISY) AND (v^8 and v^{24} are NOISY) AND (v^4 and v^{16} are NOISY) THEN (v^0 is EDGE)

Rule 4:

IF (v^0 is NOISY) AND (v^7 and v^{22} are NOISY) AND (v^3 and v^{14} are NOISY) THEN (v^0 is EDGE)

“NOISY” indicates the pixel value as 0 or 255. Noisy Pixel value should be either 0 in all cases or 255 during the complete analysis of pixel with above mentioned rules. Edges indicate the significant regional transitions of intensity values in an image. Constant occurrence of noisy pixels with same intensity value of either 0 or 255 imply the presence of a possible edge.

6. Pixel evaluated as “NOISY” via any of the rules stated in the preceding step is replaced with the median value of the 5x5 window and pixel evaluated as “EDGE” is not modified.

The separation of noisy pixels from possible edge pixels lowers the False Alarm rates and Miss detection rates by the proposed algorithm. It also increases the PSNR and SSIM values. The standard median filter [26] is a well known powerful filter in the area of image processing and is used for various applications including impulse noise removal. If used directly it can lead to loss of fine details/edges present in an image. The proposed work presents a sturdy technique which uses the median filter after the analysis of impulse noise in an image which enhances its performance.

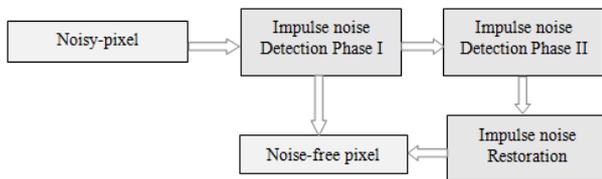


figure 2: Block Diagram of the Proposed Scheme
C.Exemplification of Proposed filter

An exemplification of the proposed work is presented for a more clear perception.

201	255	141	90	88	13	42
0	201	150	99	0	0	16
132	160	142	36	0	20	23
140	53	52	0	10	47	46
89	78	0	255	63	165	50
32	0	210	193	255	236	0
0	30	215	63	250	211	255

Pixel under investigation for impulse noise

figure 3: 7x7 window

A 7x7 window is used for demonstration of work instead of 21 x21 window for the first impulse noise detection phase for a crisp view. FCM classify the adjacent 49 pixels unsupervisedly in three clusters let Q,R and S.

$Q=\{193,201,201,210,211,215,236,250,255,255,255,255\}$

$R=\{78,88,89,90,99,132,140,141,142,150,160,165\}$

$S=\{0,0,0,0,0,0,0,0,0,10,13,16,20,23,30,32,36,42,46,47,50,52,53,63,63\}$

The highest value from each cluster is calculated and labeled as H_1, H_2 and H_3 such that $H_1 < H_2 < H_3$. Substitute the values of $H_1=63, H_2=165$ and $H_3=255$ in equation (1).

$$v(l^i, l^j) = \begin{cases} \text{"pepper - noise"}: & \text{if } v(l^i, l^j) \leq 63 \\ \text{"noise - free"}: & \text{if } 63 < v(l^i, l^j) \leq 165 \\ \text{"salt - noise"}: & \text{if } 165 < v(l^i, l^j) \leq 255 \end{cases} \quad (2)$$

It is depicted from the above equation that the pixel under processing is “pepper-noise”. Similarly, this pixel is again examined in the second detection phase with window size of 7x7, for the presence of impulse noise. Likewise it is discovered as a noisy pixel in second detection phase. For impulse noise restoration, consider the clusters with highest value of $H_1=63$ and $H_3=255$. The pixel is marked as “pepper-noise” therefore “COUNT1” is computed. COUNT1=9. In this case, COUNT1 ≥ 3, so 3x3 is centered on noisy pixel. According to step (5) case II of impulse noise restoration. the window is expanded to 5x5.

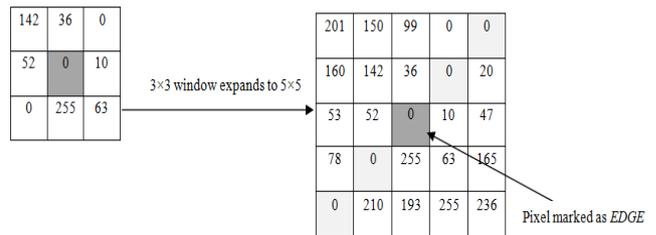


figure3:Expansion of window size and final result

Analysis for any possible edge is performed using Rule 1,2,3 and 4. Rule 1 is true for present pixel therefore, it is marked as EDGE and no restoration is done.

III. EXPERIMENTAL RESULTS

The proposed work abbreviated as EFFSIN is simulated for impulse noise of varying densities as well as examined in contrast with other state-of-art filters present in literature. The similarity measures employed for the performance evaluation of our work are Peak signal-to-noise ratio (PSNR) [27,28], structural similarity index (SSIM) [30], False alarm (FA) and Miss detection (MD) values [29].

PSNR (peak signal to noise ratio) is computed by:

$$PSNR(f, I) = 10 \log \left(\frac{1}{MSE(f, I)} \right) \quad (3)$$

I stand for the original image sequence, f stand for the filtered image sequence of N X M size. High value of PSNR indicates greater uniformity between noise-free image and restored image.

SSIM is calculated using the following equation:



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$$SSIM = \frac{(2\mu_I\mu_f + c_1) + (2\sigma_{If} + c_2)}{(\mu_I^2 + \mu_f^2 + c_1) + (\sigma_I^2 + \sigma_f^2 + c_2)} \quad (4)$$

c_1 and c_2 as constants to stabilize the division with weak denominator. $\mu_I, \mu_f, \sigma_I, \sigma_f$ and σ_{If} denotes the average intensity, standard deviation and cross-covariance values for images I and f , respectively. c_1 and c_2 have default values of $c_1 = (0.01 \times 255)^2$ and $c_2 = (0.03 \times 255)^2$.

Three comparison measurements to wit luminance(I), contrast(C) and structure(S) comparisons are performed between the two images of the same size. If $SSIM$ index results in a decimal value I , absolute structural similarity is implied between two images, whereas 0 indicates absence of structural similarity.

$$I(I, f) = \frac{2\mu_I\mu_f + c_1}{\mu_I^2 + \mu_f^2 + c_1} \quad (5)$$

$$C(I, f) = \frac{2\sigma_I\sigma_f + c_2}{\sigma_I^2 + \sigma_f^2 + c_2} \quad (6)$$

$$S(I, f) = \frac{\sigma_{If} + c_3}{\sigma_I\sigma_f + c_3} \quad (7)$$

$$c_3 = \frac{c_2}{2} \quad (8)$$

$SSIM$ is formulated as a weighted combination of above described comparative measures:

$$SSIM(I, f) = [I(I, f)^{\theta_1} \cdot C(I, f)^{\theta_2} \cdot S(I, f)^{\theta_3}] \quad (9)$$

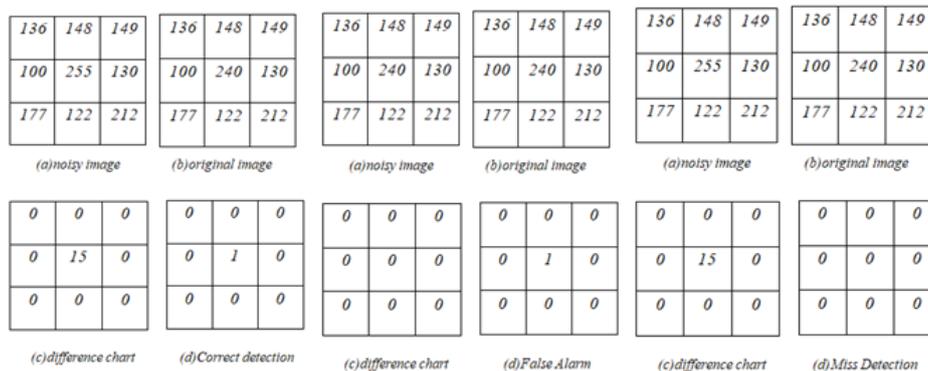


figure4: Difference based method for FA and MD

Table 1: PSNR and SSIM results for “Lena”

		Noise density%									
		10		20		30		40		50	
Method		PSNR	SSIM	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM
	FSM[8]		36.07	0.9117	34.12	0.9001	32.39	0.8541	31.27	0.7930	30.14

Variables θ_1, θ_2 and θ_3 define the relative importance of the three components. When $\theta_1, \theta_2, \theta_3 = 1$ and $c_1 = c_2$, $SSIM$ is deduced as in equation (4).

Apart from $PSNR$ and $SSIM$, the proposed algorithm has employed *False alarm (FA)* and *miss detection (MD)* rates as quality metrics. A difference based method[23] is used for the evaluation of FA and MD , which generates a noise chart on the basis of differences computed between noise chart and original image. Total correct detection, False alarm and Miss detection are shown in figure 4 where, ‘1’ in the noise chart indicates presence of noise, whereas ‘0’ imply noise free.

From figure 4, it is clear that False Alarm arises when a noise-free pixel is identified as noisy and marked as ‘1’ in the noise chart. Miss detection takes place when a noisy pixel is identified as noise-free and marked as ‘0’ is in the noise chart.

The standard gray scale test image ‘lena’ 512×512 is used for analysis of our work with other filters. Table 1 represents the analysis of $PSNR$ and $SSIM$ values for varying filters for impulse noise and our work. Table 2 provides $PSNR$ and $SSIM$ values by $EFFSIN$ for varying test images at 30% noise and there is illustration of FA and MD values in Table 3.

NAFSM[7]	37.07	0.9190	34.56	0.8925	32.05	0.7980	31.38	0.7806	30.31	0.7397
FSBH[15]	39.56	0.9501	38.75	0.9442	37.13	0.9231	35.76	0.9087	34.01	0.8709
AFSM[12]	40.60	0.9476	39.67	0.9402	38.22	0.8926	35.10	0.8862	34.65	0.8657
WAF[6]	32.92	0.7408	32.17	0.7309	31.81	0.7161	30.63	0.7037	30.04	0.7011
HDCNN[16]	40.27	0.9313	39.50	0.9156	37.66	0.9042	36.71	0.8887	36.11	0.8722
HDIND[23]	41.92	0.9551	40.58	0.9498	39.25	0.9402	37.89	0.9110	37.02	0.9079
EFFSIN	42.99	0.9715	41.76	0.9603	40.39	0.9373	39.66	0.9251	38.16	0.9115

Table 2: PSNR and SSIM results for various images using EFFSIN

Image name	PSNR	SSIM	PSNR	SSIM	PSNR	SSIM
Living room	38.79	0.8992	37.68	0.8876	38.48	0.9007
Woman Blonde	40.19	0.9237	39.70	0.9192	37.34	0.8998
Mandrill	35.87	0.8922	35.18	0.8910	34.47	0.8848
Pirate	39.96	0.9015	38.63	0.8993	38.48	0.9007
Cameraman	39.03	0.9067	37.81	0.8981	36.77	0.8837

Table 3: FA and MD values

Noise%	Miss detection(MD)				False Alarm(FA)			
	FSBH	AFSM	HDIND	EFFSIN	FSBH	AFSM	HDIND	EFFSIN
10	0	0	0	0	0	0	0	0
30	0	0	0	0	2	0	0	0
50	23	6	0	0	7	9	4	1
70	31	14	2	1	12	11	7	3
90	36	21	2	2	19	15	9	4

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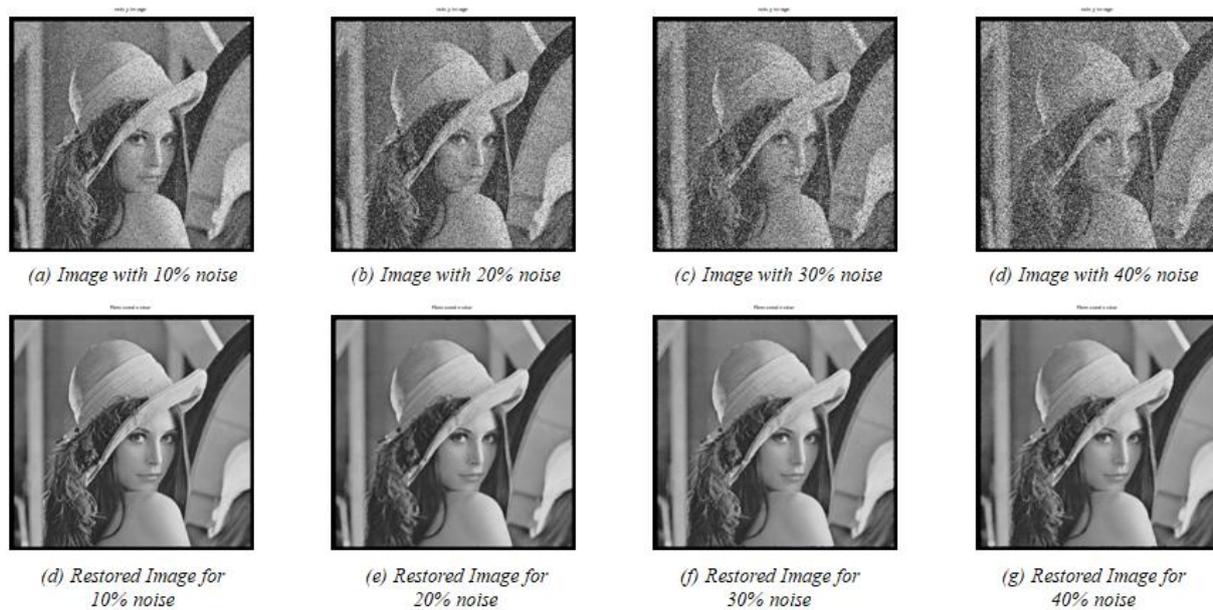


figure 5: Results for "Lena" image at different noise levels using EFFSIN

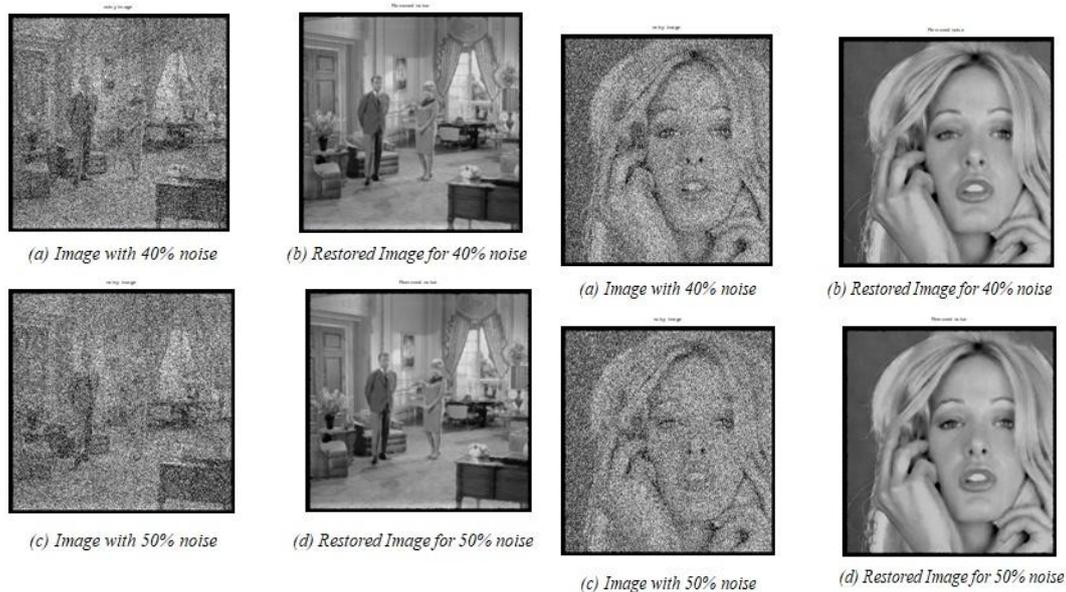


figure 6: Results for "Livingroom" image by EFFSIN

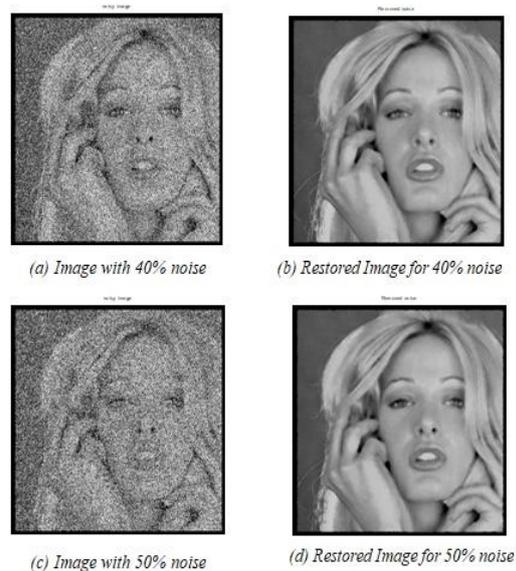


figure 7: Results for "Womenblonde" image by EFFSIN

From the analysis of mathematical data in Table 1, Table 2 and Table 3, it is clear that EFFSIN significantly surpasses the contemporary techniques available for impulse noise. There is notable improvement in the results of HDIND after the incorporation of edge detecting feature in the impulse restoration phase. The proposed filter confers consistent performance with varying amount of noise. The FA and MD values are reduced remarkably. HDCNN yields good PSNR and SSIM values but is complex in nature with high computation time. The proposed filter is elementary in nature with less computation time. WAF does not preserve the fine details of the image and provides low quantitative results. Similarly FSBH and AFSM do not reduce the FA and MD values. The proposed work is edge preserving in nature which provides relatively low False alarm rates and miss detection rates thereby improving the PSNR and SSIM values. It also gives efficient results for different test images.

The application of median filter after the assessment of possible edges has enhanced the quality of work. The qualitative results for "Lena" in "figure 5", "Livingroom" in "figure 6" and "Womenblonde" in "figure 7" display the high conduct of the proposed filter for differing levels of impulse noise. All the simulation results are derived using MATLAB.

IV. CONCLUSION

In this paper, an edge preserving algorithm for the suppression of impulse noise is introduced. The two phase impulse noise detection and proper impulse noise restoration with the evaluation of possible edges makes it a coherent technique for impulse noise suppression.

The extensive simulation results predict that the proposed work makes remarkable reduction in the False alarm rates. Moreover, it also excels quantitatively and qualitatively. An unequivocal approach of the proposed work enhances its performance with less computation time. The work can be extended further for impulse noise detection and restoration in color images and sequences.

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