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High Density Impulse Noise Detection using Fuzzy C-means Algorithm

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ABSTRACT

A new technique for detecting the high density impulse noise from corrupted images using Fuzzy C-means algorithm is proposed. The algorithm is iterative in nature and preserves more image details in high noise environment. Fuzzy C-means is initially used to cluster the image data. The application of Fuzzy C-means algorithm in the detection phase provides an optimum classification of noisy data and uncorrupted image data so that the pictorial information remains well preserved. Experimental results show that the proposed algorithm significantly outperforms existing well-known techniques. Results show that with the increase in percentage of noise density, the performance of the algorithm is not degraded. Furthermore, the varying window size in the two detection stages provides more efficient results in terms of low false alarm rate and miss detection rate. The simple structure of the algorithm to detect impulse noise makes it useful for various applications like satellite imaging, remote sensing, medical imaging diagnosis and military survillance. After the efficient detection of noise, the existing filtering techniques can be used for the removal of noise.

Keywords: Clustering, impulse noise, noise detection, noise removal, peak signal to noise ratio and mean square error

1. INTRODUCTION

Impulse noise is generally introduced into images while transmitting and acquiring them over an unsecure communication channel. In the case of satellite or TV images it can be caused through atmospheric disturbances. In other applications, it can be caused by strong electromagnetic fields, transmission errors, etc. Images play an important role in extracting hidden information in the field of satellite imaging, remote sensing and military surveillance. Raw images received from satellite, radar, space probes and aircrafts can be corrupted by impulse noise. The intensity of impulse noise has the tendency of being either relatively high or relatively low. Thus, it could severely degrade the image quality. The human visual system is very sensitive to the amplitude of noise signals, thus noise in an image can result in a subjective loss of information. Therefore, Image denoising is one of the most important preprocessing steps in fields such as defence and security applications, astronomy, medical imaging, and forensic science, where high quality imaging is needed for analysing images of unique events.

Various techniques have been introduced in the literature to filter images corrupted by impulse noise, including non-linear, fuzzy and combined filters. Conventional median filter[1] is the most popular and earliest method to remove noise at low noise densities. At high noise level, the edge details of the original image are not preserved as it processes each pixel regardless it is a noisy or noise-free. Proper detection of corrupted pixels increases the performance of the median filter. In order to overcome this problem, an impulse noise detection mechanism prior to filtering is employed in several algorithms, for example, tri-state median filter (TSM)[2], an efficient edge-preserving algorithm (EEP)[3], fuzzy switching median filter (FSM)[4], noise adaptive fuzzy switching median filter (NAFSM)[5], a highly effective impulse noise detection algorithm (HEIND)[6], Contrast enhancement-based filter (CEB)[7], Modified decision based unsymmetrical trimmed median filter algorithm (MDBUTM)[8] and A new adaptive switching median (ASWM) Filter[9].

In the detection phase, different methods based on thresholding, histogram based and clustering are used. Each has their own limitations and advantages, but clustering technique yields much better results. Clustering is a grouping of large sets of data into clusters of smaller sets of similar data. Various algorithms present in literature have incorporated different clustering techniques such as modification of advanced boundary discriminative noise detection algorithm (MDBDND)[13], efficient techniques for denoising of speckle and highly corrupted impulse noise images (ETDS)[14] and removal of high-density salt-and-pepper noise in images with an iterative adaptive fuzzy filter using alpha-trimmed mean[10]. Various clustering techniques are present which can be used depending on the type of data to be classified and as per requirement of the procedure.

Clustering techniques can be divided into two main categories. First is Hard clustering, in which for the whole data different clusters are formed such that each data belongs exclusively to one cluster. It has a well defined physical boundary which is incorporated in various state of the art algorithms like boundary discriminative noise detection

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algorithm (BDND)[11], HEIND[6], etc.

Second is Fuzzy clustering. It is also known as Soft clustering in which data elements can belong to more than one cluster depending upon the membership function associated with the data item. Fuzzy clustering is employed in several techniques and yields better results in the presence of outliers.

Fuzzy c-means (FCM) is one of the most frequent methods of clustering. It has robust framework and basis of several clustering techniques. In this paper, FCM is incorporated in the two detection stages to detect the location of noisy pixels. Noise free pixels are left unchanged and only noisy pixels are restored. The proposed algorithm is intuitive and has a simple structure.

The main focus of the proposed work is the efficient detection of impulse noise. Once the noisy pixel is detected, the subsequent noise can be removed by various existing techniques such as switching median filters.

Extensive simulation results show that it outperforms various existing techniques. It yields better quantitative as well as qualitative results in terms of peak signal to noise ratio (PSNR) and mean square error (MSE). Finer details of the image are preserved even at high noise level.

2. PROPOSED ALGORITHM

The efficient removal of impulse noise mainly depends on the detection phase. The detection method of the proposed algorithm efficiently identifies the location of noisy pixels, so that the false alarm rate and miss detection rate are minimised.

Using clustering, the high intensity and low intensity noisy pixels are grouped separately. The rest of the pixels belongs to the noise free group. Fuzzy c-means (FCM) is one of the most common techniques used to cluster data. This method was developed by Dunn[15] in 1973 and improved by Bezdek[16] in 1981 and it is frequently used in pattern recognition. In this paper, FCM is incorporated in both the detection stages.

2.1 Fuzzy C- Means Algorithm

Fuzzy clustering is employed in various algorithms for the classification of image data. The main advantage of fuzzy clustering over hard clustering is that it allows each pattern to belong to more than one cluster on the basis of membership function or varying degrees of certainty. Fuzzy C-Means is one of the popular fuzzy clustering algorithm. It provides the best result for overlapped data set.

The main purpose of FCM is to minimise the following objective function:

$$J_m = \sum_{i=1}^{N} \sum_{j=1}^{C} u_{ij}^m \left\| x_i - c_j \right\|^2 \ , 1 \le m \le \infty \tag{1}$$

where m is the fuzziness index, which is any real number greater than 1(usually 2); u_{ij} is the degree of membership of x_i in the cluster j; x_i is the i^{th} data of d-dimensional measured data; N is the number of data; C is the number of clusters; c_j is the d-dimension center of the cluster, and $\left\|x_i - c_j\right\|^2$ is the Euclidean distance between i^{th} data and j^{th} cluster center.

This algorithm assigns membership value to each data point x_i corresponds to each cluster center c_j on the basis of distance between the cluster center and the data point. This distance is the Euclidean distance between i^{th} data and j^{th} cluster center. More the data is near to the cluster center more is its membership towards the particular cluster center. After each iteration, membership u_{ij} and cluster centers c_j are updated by:

$$u_{ij} = \frac{1}{\sum_{k=1}^{c} \left(\frac{\left\| x_i - c_j \right\|}{\left\| x_i - c_k \right\|} \right)^{\frac{2}{m-1}}} \tag{2}$$

where $$c_j = \frac{\sum_{i=1}^{N} u_{ij}^m \cdot x_i}{\sum_{i=1}^{N} u_{ij}^m} \tag{3}$$

This iteration will stop when $\max_{ij} \left\{ \left| u_{ij}^{(k+1)} - u_{ij}^{(k)} \right| \right\} < \varepsilon$ where ε a termination criterion between 0 and 1 and k is the iteration number.

The *FCM* algorithm can be summarized as follows:

(a) Initialize $U = \left[u_{ij} \right]$ matrix, $U^{(0)}$

(b) At *k*-step: calculate the centers vectors $C^{(k)} = \left[c_j \right]$ with $U^{(k)}$

(c) Update $U^{(k)}$, $U^{(k+1)}$

(d) If $\left\| u_{ij}^{(k+1)} - u_{ij}^{(k)} \right\| < \varepsilon$ then STOP; otherwise return to step (b).

The advantage of using fuzzy c-means is that it gives the best result for overlapped data in the form of pixels in images and comparatively better than other existing algorithms such as k-means algorithm.

2.2 Impulse Detection

In this technique for noise removal, the detection of impulse noise is done in two stages. Double stage detection efficiently locates the noisy pixels and does not alter the value of noise free pixels.

Stage I

1. Select a window size of 21 × 21 which is centered on each pixel of an image.
2. Let the central pixel at which window is centered be $p(i, j)$ Using FCM algorithm, divide the neighborhood values of the central pixel into three clusters.
3. Let the three clusters formed after applying FCM be A, B and C. After the formation of clusters find the maximum value present in each cluster respectively.
4. In a 21×21 window there will be 441 values. The FCM algorithm divides these values unsupervisely into three clusters. Let the three maximum values present in the three clusters be M1, M2 and M3.
5. The three maximum values from each cluster are sorted in ascending order, such that M1 < M2 < M3.
6. Using the following equation, check whether the central pixel $p(i, j)$ is noisy or noise-free.

$$p(i, j) = \begin{cases} \text{pepper noise}: \text{ if } p(i, j) \le M1 \\ \text{noise free} \quad : \text{ if M1} < p(i, j) \le M2 \\ \text{salt noise} \quad : \text{ if M2} < p(i, j) \le M3 \end{cases} \tag{4}$$

Pixels in the cluster having the minimum, maximum value i.e. M1 are lowest intensity pixels which contain the Pepper noise. The cluster has the maximum value of a pixel, i.e. M3 are highest intensity pixels which contain Salt noise. The third maximum value M2 lies in the middle range intensity values. The cluster having the maximum value as M2 is considered as Noise free cluster.

1. If the pixel lies in a noise free cluster, it is left unaltered.
2. If the pixel is noisy it is processed again in the second detection stage.

Stage II

3. Now change the window size to 7 × 7.
4. Repeat Steps 2) to 6) in the same way.
5. If the pixel is detected as a noisy pixel in the second detection stage also, it is marked as noisy pixel else noise free.

The algorithm flow chart is given in Fig. 1.

Restoration of noisy pixels is performed using the well known conventional median filter[1]. Median value for neighboring pixels within the window of size 7 × 7 is computed and is used to replace the noisy pixel value.

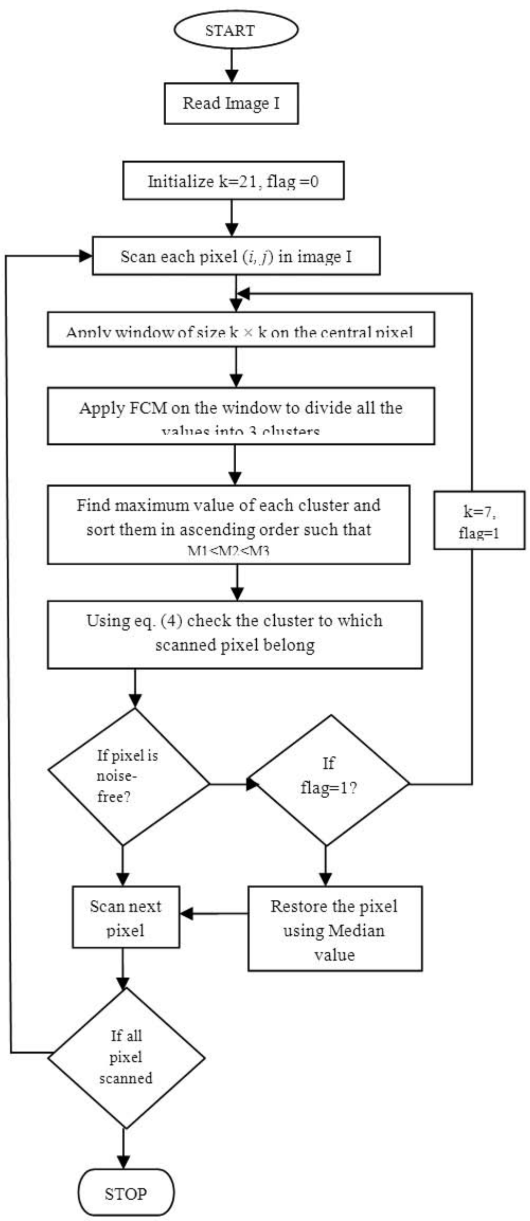


Figure 1. Algorithm flowchart.

2.3 Illustration

For better understanding of the proposed algorithm, an illustration of the work is presented as:

Instead of using a window size of 21×21 in the first detection Stage, working of algorithm is explained using a window size of 7×7.

All the 49 values of the window of size 7×7 are sorted in ascending order and using FCM algorithm they are divided into three clusters.

Cluster A = {72, 77, 81, 87, 87, 97, 99, 104, 113, 116, 117, 119, 119, 125, 132, 136, 141,145, 155, 155, 156, 163}

Cluster B = {255, 255, 255, 255, 255, 255, 255}

Cluster C = {0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 24, 29, 39, 46, 46, 49, 54, 54, 64}

The maximum value for each cluster is computed and sorted in ascending order such that M1< M2< M3*:*

M1= 64, M2=163, M3= 255

From Fig. 1, Pixel under consideration is $p(i, j) = 0$. Using Eqn. (4),

$$p(i,j) = \begin{cases} \text{pepper noise : if } p(i,j) \le 64 \\ \text{noise free : if } 64 < p(i,j) \le 163 \\ \text{salt noise : if } 163 < p(i,j) \le 255 \end{cases} \quad (5)$$

From Eqn. (5) it is clear that 0 belongs to the cluster having Pepper noise. Therefore, it will be processed again in the second detection stage using a window of size 7×7 in the same manner as illustrated above. If the pixel is again detected as noisy, it will be restored using median filter.

After arranging all the pixel values of the 7×7 window in ascending order, Median value is computed as:

{0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 24, 29, 39, 46, 46, 49, 54, 54, 64, 72, 77, 81, 87, **87**, 97, 99,104, 113, 116, 117, 119, 119, 125, 132, 136, 141, 145, 155, 155, 156, 163, 255, 255, 255,255, 255, 255, 255}

The median value of the selected window of size 7×7 is computed as 87. For the restoration of the pixel value in Fig. 2, the central pixel 0 is replaced by computed median value 87.

The selection of restoration method can be performed according to the application of images using several methods present in literature. For example, the value of detected noisy pixel value '0' in Fig. 1 is restored by mean filter as "97". Another technique used to restore the detected noisy pixel is MDBUTM filter algorithm[8]. The combination of restoration method of MDBUTM and detection method of the proposed algorithm provided satisfactory results at various noise levels. In future the work can be expanded to better restoration of pixels after efficient detection using proposed algorithm.

Experimental results and comparison with existing techniques, exhibits that the proposed detection algorithm detects noise in a more effective manner. It even outperforms the recent techniques such as, CEB filter[7], MDBUTM filter[8], a new ASWM filter[9], improved decision-based detail-preserving variation method for removal of random-valued impulse noise[12], removal of high and low density impulse noise from digital images using non linear filter[17], high-density impulse noise removal using FMM[18], etc.

49	87	155	255	54	64	81
24	255	132	163	0	255	0
46	39	145	0	156	119	0
87	46	141	0	155	255	117
113	104	77	125	0	136	116
0	0	99	72	119	255	255
0	0	255	0	97	54	29

(a)

49	87	155	255	54	64	81
24	255	132	163	0	255	0
46	39	145	0	156	119	0
87	46	141	87	155	255	117
113	104	77	125	0	136	116
0	0	99	72	119	255	255
0	0	255	0	97	54	29

(b)

Figure 2. (a) 7 × 7 window and (b) Restored value of noisy pixel.

3. EXPERIMENTAL RESULTS

Comparison of the proposed algorithm is performed with some existing techniques to demonstrate its effectiveness. For the performance analysis, two similarity measures the mean square error (MSE) and peak signal to noise ratio (PSNR) are selected. Lower MSE values provide better results.

$$MSE(f,I)=\frac{\sum_{z=1}^{3}\sum_{x=1}^{L}\sum_{y=1}^{M}\left[I(x,y,z)-f(x,y,z)\right]^2}{3\times L\times M} \quad (6)$$

where L and M are Image dimensions, $I(x, y, z)$ is the pixel value of the restored image and $f(x, y, z)$ is the pixel value of the original image.

PSNR (peak signal to noise ratio) is inversely related to MSE as*:*

$$PSNR(f,I)=10\log\left(\frac{1}{MSE(f,I)}\right) \quad (7)$$

Higher the value of PSNR better is the similarity between the original image and reconstructed image. From Table 1 and Table 2, it is clear that our proposed algorithm is a novel filter for images corrupted with high noise density.

Table 1. Comparison of PSNR values for 'Lena' image

	Noise percentage (%)			
Method	**10**	**20**	**30**	**40**
ASWM	33.01	33.57	33.02	32.22
FSM	36.08	34.11	32.41	31.30
NAFSM	37.09	34.52	32.49	31.41
CEB	39.05	37.56	35.42	32.87
HEIND	39.65	38.57	37.41	35.87
EEP	40.26	38.95	37.39	35.03
MDBU	40.76	39.06	36.01	33.21
Proposed Algorithm	41.93	40.67	39.14	37.90

Table 2. Comparison of MSE values for 'Lena' image

	Noise percentage (%)			
Method	**10**	**20**	**30**	**40**
ASWM	26.26	28.53	32.40	38.96
FSM	12.30	12.56	14.25	15.02
NAFSM	12.60	25.25	37.13	47.83
CEB	25.20	26.60	27.80	29.41
HEIND	38.60	37.90	37.17	36.15
EEP	30.60	32.55	37.42	45.67
MDBU	11.90	14.94	19.41	22.56
Proposed Algorithm	5.68	6.93	7.91	10.53

Miss detection (MD) and false alarm (FA) rates are computed for more reliability of the proposed algorithm (PA). One of the simplest methods to compute MD and FA rates is a difference based method. Noise matrix is generated by the estimation of differences between the noisy matrix and original matrix. There is absolute correct detection when a center pixel is noisy as shown in Fig. 3(i). '1' in the noise flag matrix marks the center pixel as noisy candidate, whereas '0' marks the central pixel as uncorrupted.

False Alarm occurs when a center pixel is not noisy and

(i) Absolute correct detection

(a)

233	245	202
224	255	223
200	197	207

(b)

233	245	202
224	225	223
200	197	207

(c)

0	0	0
0	30	0
0	0	0

(d)

0	0	0
0	1	0
0	0	0

(ii) False alarm (FA)

(a)

233	245	202
224	225	223
200	197	207

(b)

233	245	202
224	225	223
200	197	207

(c)

0	0	0
0	0	0
0	0	0

(d)

0	0	0
0	1	0
0	0	0

(iii) Miss detection (MD)

(a)

233	245	202
224	255	223
200	197	207

(b)

233	245	202
224	225	223
200	197	207

(c)

0	0	0
0	30	0
0	0	0

(d)

0	0	0
0	0	0
0	0	0

Figure 3. (a) Noisy image matrix, (b) original image matrix, (c) difference matrix, and (d) noise flag matrix.

value ‘1’ is marked at its location in the noise flag matrix. It is illustrated in Fig. 3(ii). Miss detection is present when a center pixel is noisy and value ‘0’ is marked at its location in the noise flag matrix. It is illustrated in Fig. 3(iii).

The advantage of proposed algorithm is that its performance is not degraded with increasing noise level. It can easily handle high noise levels up to 80 per cent. The application of FCM helps to classify the salt and pepper noisy pixels separately in an efficient manner. This in turn improves our detection process. The algorithm uses the median value of the selected window to restore the detected pixel. If the detected pixel is an edge pixel, which might be uncorrupted, then it will be restored by the median value of the selected window which in turn will be equal to 0 or 255 only. It gives low miss detection rates as well as false alarm rates as shown in Table 3. The feasibility of the proposed algorithm is also observed from visual results at various noise levels. To assess the image results, the standard gray scale test image ‘Lena’ of size 512× 512 is used.

Figure 4, using MATLAB Results of different filters, including proposed algorithm, is presented at a noise level of 30 per cent. From the figure, it is also observed that the quality of restored image using our technique is better than the quality of restored images using other existing algorithms. Our algorithm preserves more edge details and fine details present in the image.

From Fig. 5, it is derived that our algorithm performance is not degraded with increasing percentage of noise density. For the better reconstruction of image it provides high PSNR values and lower MSE values as compared to existing techniques in literature at different noise densities. Some more results are incorporated for image ‘mandril’ in Fig. 6 at noise levels of 30 per cent, 40 per cent, and 50 per cent, respectively.

Some more results of the proposed algorithm are provided for image ‘mandril’ in Fig. 6 at noise levels of 30 per cent, 40 per cent, and 50 per cent, respectively. The PSNR and MSE values for different images after applying the proposed algorithm are presented in Table 4.

Table 3. Comparison of MD and FA values for ‘Lena’ image

	Miss detection (MD)			False alarm (FA)		
Noise %	MDBU	EEP	Proposed algorithm	MDBU	EEP	Proposed algorithm
20	0	0	0	0	0	0
40	0	0	0	2	0	0
60	21	6	0	8	5	4
80	30	11	2	10	9	7

Table 4. PSNR and MSE values for different images using proposed algorithm

Noise percentage (%)	30		40		50	
Image	PSNR	MSE	PSNR	MSE	PSNR	MSE
Mandril	34.68	22.11	33.52	28.89	32.48	36.66
Pirate	37.59	11.32	36.35	15.04	34.84	21.29
Woman blonde	37.91	10.34	36.92	13.19	35.89	16.89
Living room	36.59	14.24	35.46	18.49	33.96	26.09

4. CONCLUSION

In this paper, an efficient detection scheme for impulse noise is presented. The performance of the algorithm is not degraded with increasing percentage of noise density. The detection phase is divided into two stages. It is iterative and minimises the false alarm rate as well as zero miss detection rates. The application of FCM to detect the noisy pixels makes this algorithm a novel technique. By extensive simulation results and comparison with other filters, it is observed that the proposed algorithm outperforms several methods. After efficient detection of noise any restoration technique present in the literature can be incorporated. In future the work can be expanded by incorporating better restoration technique along with the efficient detection scheme presented in the paper. It is easy to understand as it has an uncomplicated structure and intuitive in nature.

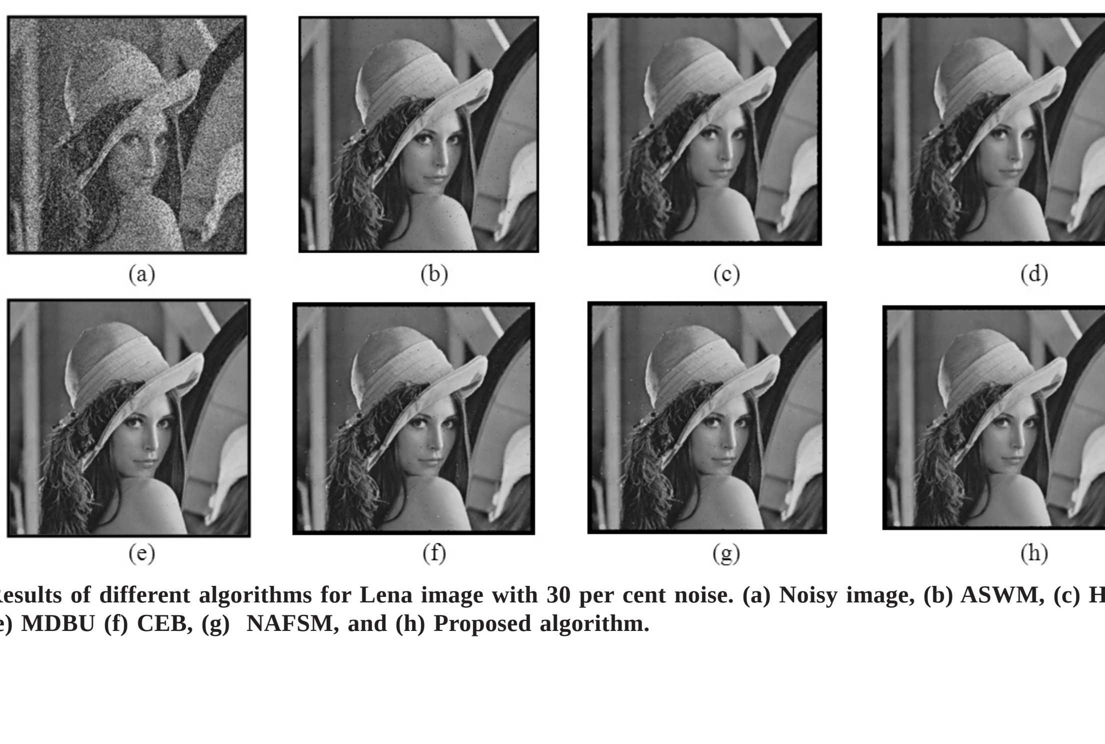
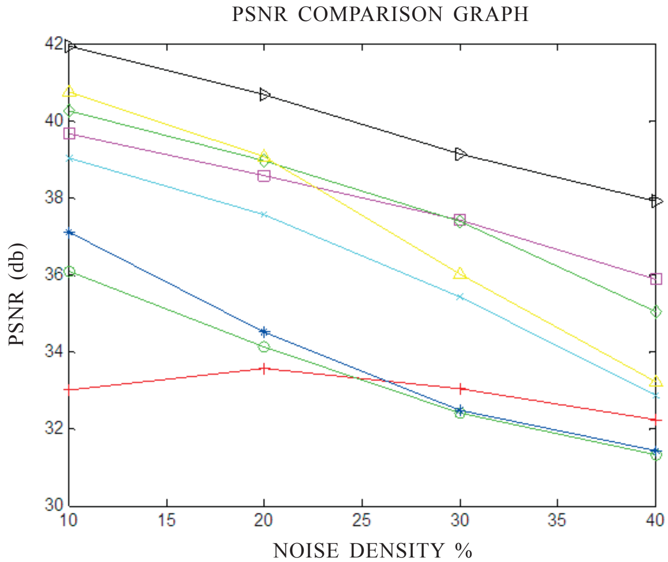
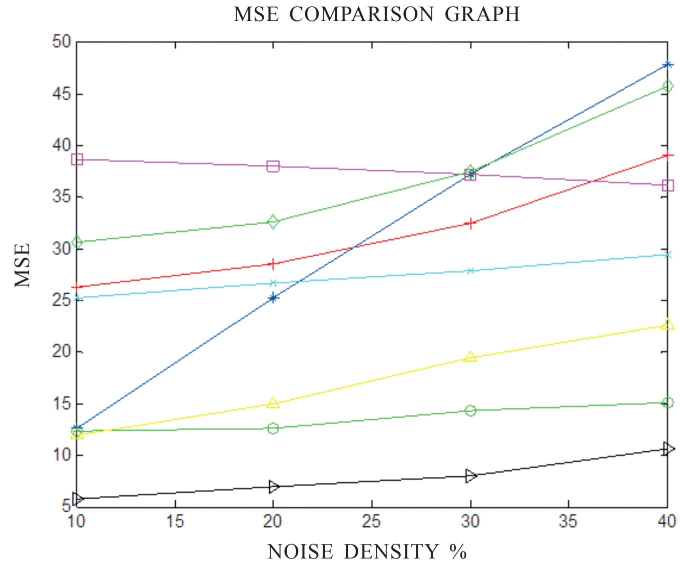


Figure 4. Results of different algorithms for Lena image with 30 per cent noise. (a) Noisy image, (b) ASWM, (c) HEIND, (d) EEP, (e) MDBU (f) CEB, (g) NAFSM, and (h) Proposed algorithm.



(a)



(b)

Figure 5. (a) PSNR comparison graph and (b) MSE comparison graph at different noise densities for 'Lena' image.

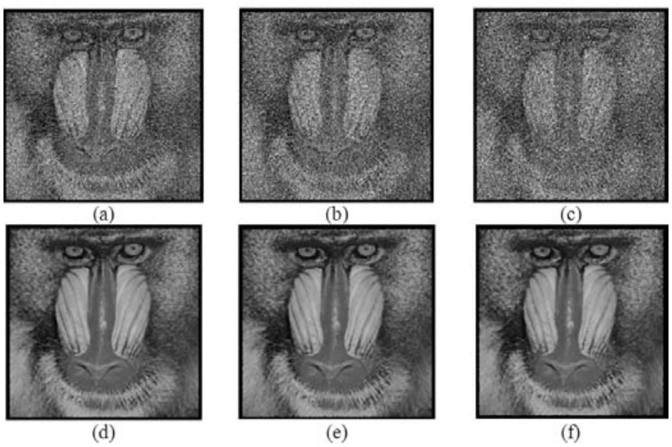


Figure 6. Results for 'Mandril' image (a) Image with 30% noise (b) Image with 40% noise (c) Image with 50% noise (d) Removed noise image (30%) (e) Removed noise image (40%) (f) Removed noise image (50%).

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Under his valuable guidance the work has been implemented.