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A New and Efficient Method for Removal of High Density Salt and Pepper Noise through Cascade Decision Based Filtering Algorithm

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Abstract

In this paper, a new and efficient cascade decision based filtering algorithm for the removal of high density Salt and Pepper Noise in images is proposed. The proposed algorithm is a cascaded filter employing a Modified Decision Based Median Filter as its first stage of operation. The second stage involves a combination of a new algorithm that calculates mean of difference in neighborhood pixels and a Modified Unsymmetric Trimmed Mean Filter. The proposed algorithm when compared with existing non-linear filters such as Standard Median Filter (SMF), Adaptive Median Filter (AMF), Decision Based Algorithm (DBA), Progressive Switch Median Filter (PSMF), Modified Decision Based Algorithm (MDBA) and Modified Decision Based Unsymmetric Trimmed Median Filter (MDBUTMF) produces a better Peak Signal-to-Noise Ratio (PSNR) and Image Enhancement Factor (IEF) even at high density salt and pepper noise. The proposed algorithm is tested for different images and the results are compared with other filters. The proposed algorithm results better in terms of image restoration and quantitative measures.

Keywords: Cascaded Filters; Decision Based Filter; Trimmed Mean Filter; Median Filter

1. Introduction

Images are corrupted by Salt and Pepper noise during their transmission over channels due to faulty communication [1], [2]. Salt and Pepper noise is also known as Impulse Noise. The objective of Signal Processing is to remove randomly occurring salt & pepper noises without disturbing edges [3]. A large number of algorithms have been proposed to remove this noise while still trying to preserve image details.

Noise removal can be achieved by the use of linear filters which are favored due to their mathematical simplicity and the existence of unifying linear system theory. Most of the linear filters minimize the Mean

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Squared Error (MSE) criterion and it provides optimum performance if the noise is additive and Gaussian. However the problem with linear filter is that they fail when the noise is non-additive which results in unsuccessful removal of salt and pepper noise.

The best known and most widely used non-linear digital filters based on the order statistics [4] are median filters. Median filters are known for their capability to remove the salt and pepper noise while still preserving the edges. Standard Median Filter (SMF) replaces the value of a pixel by the median of the intensity levels in the neighborhood of that pixel [5]. The main disadvantage of this type of filter is that they only work for low noise densities. At high noise densities, SMF exhibits blurring for large window sizes and is unable to suppress noise for small window sizes [6] [7].

The Adaptive Median Filter is another type of non-linear median filter which performs well if the spatial density of the salt and pepper noise is not large. This filter identifies possible noisy pixels and replaces them using the median filters while leaving all other pixels unchanged. The advantage is that it seeks to preserve detail while smoothing non-impulse noise [5]. The Alpha Trimmed Mean Filter (ATMF) [4] and Alpha Trimmed-Midpoint Filter (ATMP) [1] are another type of commonly used non-linear filter. These filters are used to remove the salt and pepper noise in which the parameter 'α', called the trimming factor controls the number of value that are trimmed.

The Decision Based Algorithm (DBA) processes only the noisy pixel by identifying them by their intensity values. Generally the salt and pepper noise introduces pixels with intensities either minimum or maximum (0-255, 8-bit image) [8] [9]. The noisy pixel is replaced by the median/mean/mid-point value of the window or by its neighborhood values. For high density salt and pepper noise it might so happen that the replaced pixel (median/mean) might be a noisy pixel which does not help in suppression of noise.

The Modified Decision Based Algorithm (MDBA) is a derivative of DBA where the median/mean/midpoint is calculated by eliminating the entire noisy pixels from the window. During high density salt and pepper noise the MDBA fails when all the pixels in the window are noisy pixels.

The Progressive Switching Median Filter (PSMF) [10] is a modified form of the basic switching median filter. The detection and removal of salt and pepper noise are recursively done in two separate stages. This filter provides improved filtering performance than most of the median filters but it has a very high computational complexity due to its recursive nature.

The Modified Decision Based Unsymmetric Trimmed Median Filter replaces the noisy pixel by the trimmed median value (excluding the minimum and maximum intensities in the window) when other pixel values, 0's and 255's are present in the window. When all the pixel values surrounding the noisy pixel in the window are either 0 or 255 the noise pixel is replaced by the mean value of all the elements present in the current window.

In order to compensate for the above shortcomings of each filter, a new cascaded filter is proposed in this paper which removes the noise as high as possible, without blurring the image and retaining as much sharp edges as possible. The proposed algorithm contains a modified decision based filter followed by a new algorithm that calculates the noisy pixel replacement. The difference between the edges along different directions in the window is calculated and then there mean is generated. Now the maximum difference between two edges along the prescribed directions (Fig. 2) is found. The lowest edge intensity in this difference is added with the mean which becomes the replacement for the noisy pixel. This proposed algorithm shows better results when compared with other non-linear filters in terms of Peak Signal-to-Noise Ratio (PSNR), Mean Square Error (MSE) and Mean Absolute Error (MAE). Also the proposed algorithm is tested on different images and their respective PSNR are found and compared with those of other standard non-linear filters. The Sec. 2 of this paper describes the proposed algorithm followed by the Sec. 3 describing the Simulation results which compares the performance of our proposed algorithm with that of other standard algorithms. This is followed by Conclusion in Sec. 4 and References.

2. Proposed Algorithm

This section describes the proposed algorithm by breaking it down to stages.

2.1. Modified Decision Based Median Algorithm (MDBMA)

The first stage of the proposed algorithm is the modified decision based median algorithm. The algorithm for MDBMA is as follows:

Step 1: A 2D 3x3 window is selected. Let P_{xy} be the processing pixel which lies at the center of the window.

Step 2: If $P_{xy} > 0$ and $P_{xy} < 255$ then P_{xy} is a noise-free pixel. It is not processed.

Step 3: Else P_{xy} is replaced by the median of the window excluding the 0's and 255's, if any present in the window.

Step 4: Move the 3x3 window to the next pixel.

Step 5: Repeat steps 2 to 4 for every pixel in the entire image. The output of the MDBMA is obtained for further processing. Figure 1 shows the structure of MDBMA.

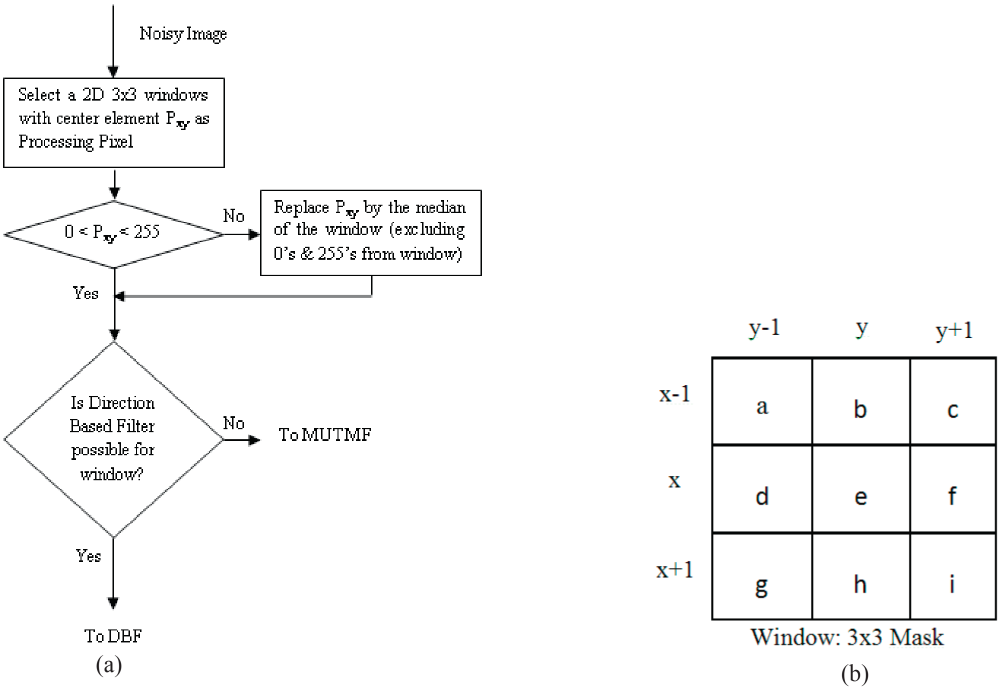


Fig. 1.(a) Structure of MDBMA; (b) 3x3 Masking Window centred on P_{xy}

2.2. Direction Based Filter (DBF)

This is the second stage of the proposed algorithm. The output of MDBMA is fed into this filter. We select a 3x3 window surrounding our processing pixel P_{xy} (Fig. 1(b)). Here it finds the mean of the edge intensity differences along the four directions as shown in Fig 2. The edge difference along a particular direction is taken if and only if both the edges have intensities not equal to '0' or '255'. If a case appears where all the four differences cannot be calculated the decision is made to use the modified unsymmetric trimmed mean filter (MUTMF) for that processing pixel.

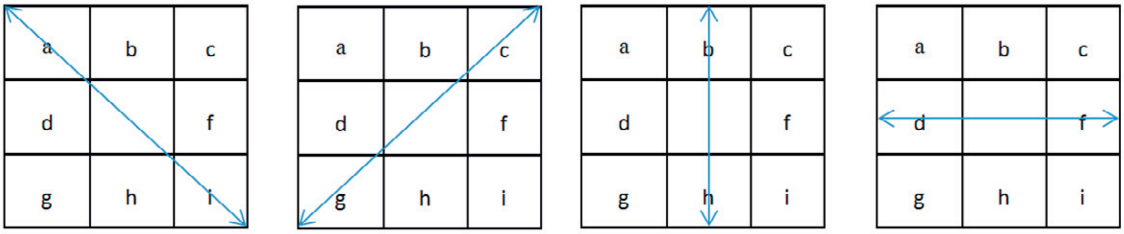
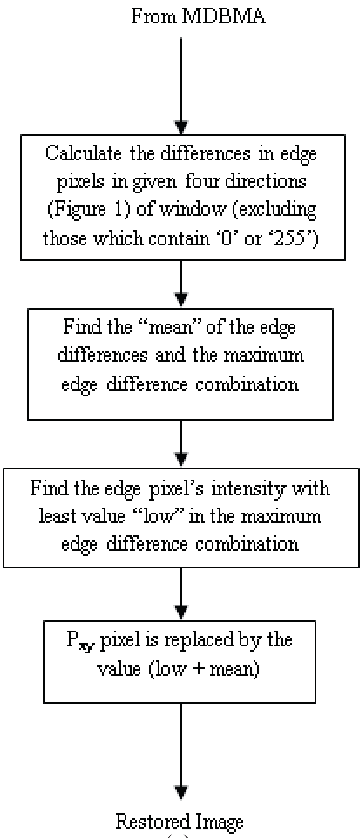


Fig. 2.Four directions in Direction Based Filter (DBF)

Once it is found in which direction the maximum edge difference occurs, the intensities of both the edge pixels are compared and the lowest one is found out. This lowest edge intensity is added with the mean of the difference to give the replacing value of the processing pixel.



(a)

Let P_{xy} be the Processing Pixel

w = | a-i |

x = | c-g |

y = | b-h |

z = | d-f |

m = mean (w,x,y,z)

q = max (w,x,y,z)

if q = = w

    low = min (a,i)

else if q = = x

    low = min (c,g)

else if q = = y

    low = min (b,h)

else

    low = min (d,f)

$\mathbf{P_{xy}}$ = low + m

(b)

Fig. 3.(a) Structure of DBA; (b) Step Wise Calculations of DBA

Figure 3(a) shows the structure of DBA. Figure 3(b) shows the step by step calculations involved in finding the restored value of P_{xy}. The process is repeated for each pixel in the entire image. The output of this filter gives rise to the restored image pixels.

2.3. Modified Unsymmetric Trimmed Mean Filter (MUTMF)

This MUTMF acts as a second stage of our proposed algorithm when the Direction Based Algorithm fails to act for a processing pixel. Figure 4 shows the structure of MUTMF. The algorithm for MUTMF works as follows:
Step 1: A 2D 3x3 window is selected with the processing pixel at its center.
Step 2: All the elements are transferred into a 1D array.
Step 3: All ‘0’ and ‘255’ are eliminated from the 1D array.
Step 4: If the length of the 1D array is equal to 0. The window size is increased (3x3 to 5x5, 5x5 to 7x7 and so on). Steps 2-4 are repeated again in case of increase in window size.
Step 5: The processing pixel P_{xy} is assigned a new value which is the mean of the 1D array.
Step 6: Move to the next pixel and repeat steps 1-5 for every pixel in the entire image.
The output of this filter gives us the final pixel values after restoration.

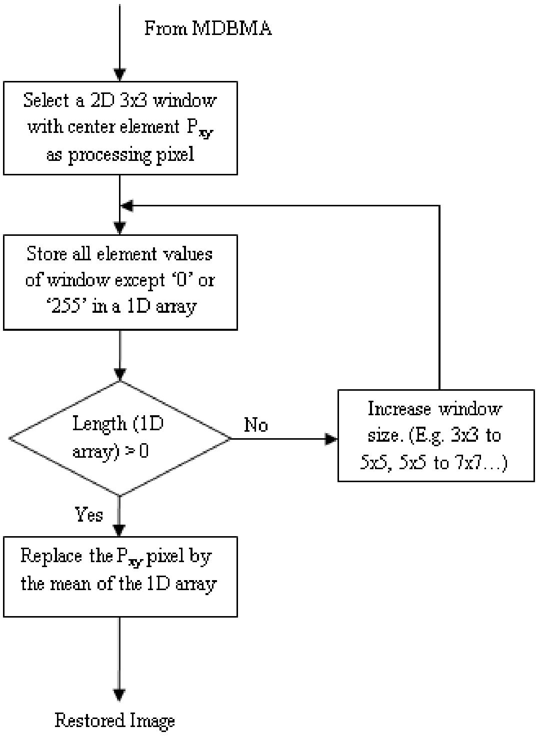


Fig 4.Structure of MUTMF

2.4. Cascaded Filter

The MDBMA is superior to the SMF because it only removes the corrupted pixels. Although the drawback is that in case of high density salt and pepper noise it is unable to remove the corrupted pixels. To overcome this drawback we cascade this filter with another filer for better performance. The second stage filter consists of a new algorithm that uses direction based difference method to calculate the restoration value for the noisy pixel. This filter also has a drawback that it cannot work on high density noise for which we connect a modified unsymmetric trimmed mean filter which finds the mean of the window excluding the noise pixels. In case this 3x3 window has no noise free pixel the window expands in size and keeps on growing until it finds a noise free pixel in its window. This cascaded configuration yields the highest PSNR and lowest MAE and MSE compared to the other filters as shown from Table 1 to Table 4. In case of IEF at high noise density (above 70%) the proposed algorithm produced the highest IEF when compared to other algorithms.

The following section provides the simulation results of the proposed algorithm and compares it with other standard algorithms.

1. Simulation Results

The proposed algorithm was mainly tested using 512×512, 8 bits/pixel image "Lena" (Grayscale). The algorithm was also tested upon two other images, both 512×512, 8-bits/pixel grayscale image "Baboon" and "Cameraman". The performance of the algorithm was tested by applying various intensities of salt and pepper noise. The results were compared with standard filters namely standard median filter (SMF), adaptive median filter (AMF), progressive switching median filter (PSMF), decision based algorithm (DBA), modified decision based algorithm (MDBA) and modified decision based unsymmteric trimmed median filter (MDBUTMF). Each time the test image "Lena" is corrupted by salt and pepper noise of different noise densities ranging from 10% to 90% with a step size of 10%. Each corrupted image is passed through different filters and the proposed algorithm and performance is compared by the following parameters such as peak signal-to-noise ratio (PSNR), mean absolute error (MAE), mean square error (MSE) and image enhancement factor (IEF). Also the test images "Cameraman" and "Baboon" are corrupted by 70% salt and pepper noise and the proposed algorithm's performance is compared with those of the other standard filters mentioned above. Table 1 to Table 4 lists the performance measurement parameters PSNR, MAE, MSE & IEF against various level of noise density. Table 5 lists the performance of proposed algorithm and other algorithms for different images at 70% noise density. Table 6 and 7 provides the result for different images such as "Cameraman" and "Real" (image taken by Webcamera) for different noise densities (30%, 60%, 90%). All the filters were designed in MATLAB 7.6 and the default window size taken is 3x3 unless otherwise stated.

$$PSNR = 10\log_{10}\left[\frac{255^2}{\frac{1}{MN}\sum_i\sum_j(r_{ij}-x_{ij})^2}\right]$$

$$MAE = \frac{1}{MN}\sum_i\sum_j(r_{ij}-x_{ij})$$

$$MSE = \frac{1}{MN}\sum_i\sum_j(r_{ij}-x_{ij})^2$$

$$IEF = \frac{\sum_i\sum_j(\eta_{ij}-r_{ij})^2}{\sum_i\sum_j(x_{ij}-r_{ij})^2}$$

Where,

PSNR	Peak Signal to Noise Ratio
MAE	Mean Absolute Error
MSE	Mean Square Error
IEF	Image Enhancement Factor
MxN	Image Size
r_{ij}	Original Image
x_{ij}	Restored image
η_{ij}	Noisy Image

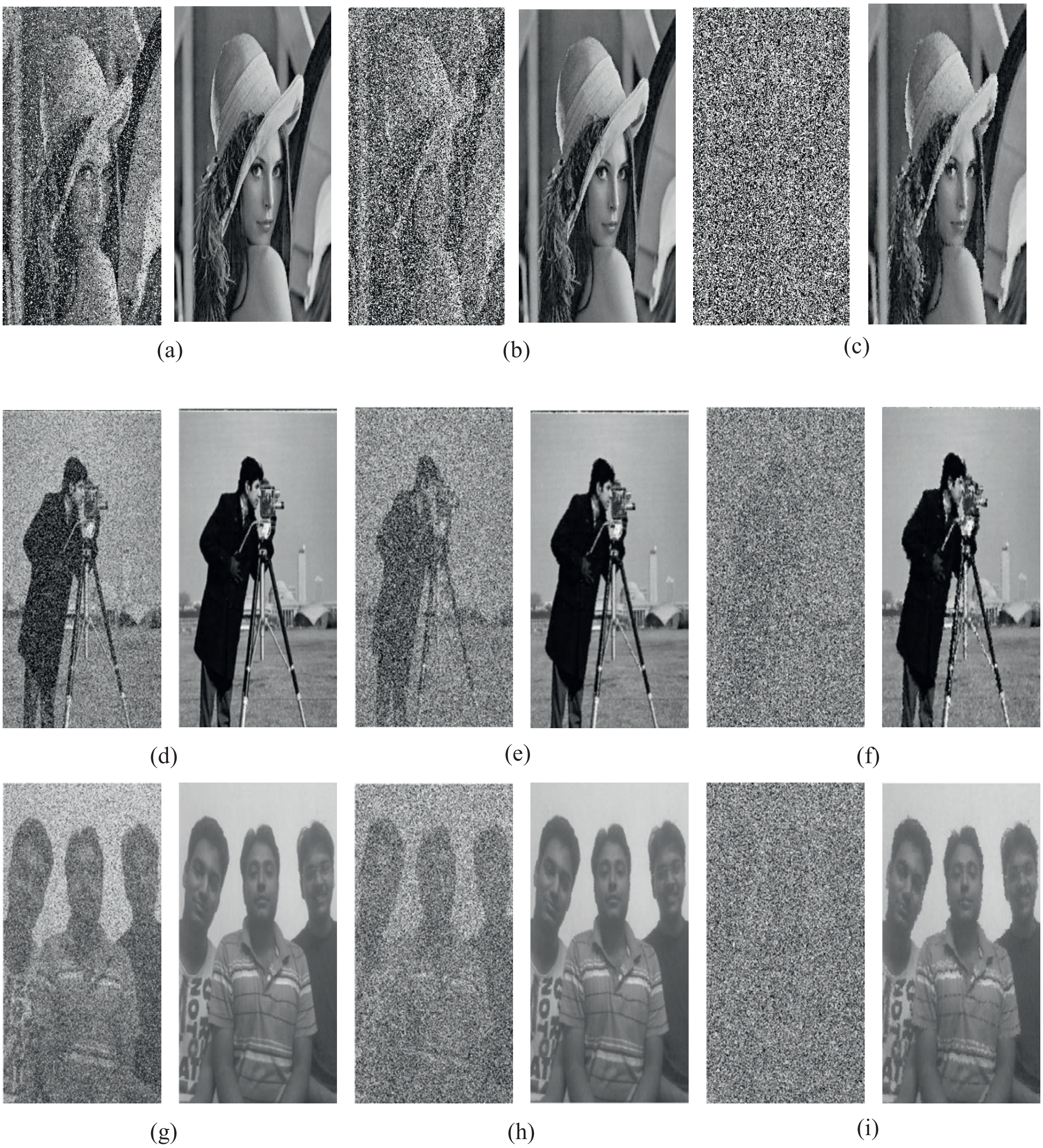


Fig. 5.Simulation Results on different images for different noise densities (a) “Lena” Image with 30% noise and its restored image; (b) “Lena” Image with 60% noise and its restored image; (c)) “Lena” Image with 90% noise and its restored image; (d)) “Cameraman” Image with 30% noise and its restored image; (e)) “Cameraman” Image with 60% noise and its restored image; (f)) “Cameraman” Image with 90% noise and its restored image; (g) “Real” Image with 30% noise and its restored image; (h) “Real” Image with 60% noise and its restored image; (i) “Real” Image with 90% noise and the restored image;

Table 1.Comparitive Results of various filters in terms of PSNR for “Lena” image.

Noise Density	SMF	AMF	DBA	PSMF	MDBA	MDBUTMF	PA
10%	33.72	28.43	36.4	30.22	36.94	37.91	41.87
20%	29.69	27.4	32.9	28.39	32.69	34.78	38
30%	24.03	26.11	30.15	25.52	30.41	32.29	35.75
40%	19.03	24.4	28.49	22.49	28.49	30.32	33.83
50%	15.45	23.36	26.41	19.13	26.52	28.18	32.1
60%	12.44	20.6	24.83	12.1	24.41	26.43	30.62
70%	10.09	15.25	22.64	9.84	22.47	24.3	28.86
80%	8.19	10.31	20.32	8.02	20.44	21.7	26.93
90%	6.69	7.93	17.14	6.57	17.56	18.4	24.61

Table 2.Comparitive Results of various filters in terms of MSE for “Lena” image.

Noise Density	SMF	AMF	DBA	PSMF	MDBA	MDBUTMF	PA
10%	31.2	93.34	14.89	61.81	13.15	10.52	4.32
20%	89.5	118.32	33.35	94.2	35	21.63	10.31
30%	277	159.25	62.81	182.42	59.16	38.37	17.33
40%	832	236.09	92.06	366.5	92.06	60.4	26.93
50%	1968	299.97	148.62	794.47	144.9	98.87	40.12
60%	3800	566.34	213.83	4009.4	235.54	147.93	56.48
70%	6569	1941.24	354.06	6746.52	368.19	241.59	84.55
80%	9977	6054.52	604.06	10258.41	587.59	439.62	132.16
90%	14185	10473.22	1256.26	14490.39	1140.46	939.89	219.99

Table 3.Comparitive Results of various filters in terms of MAE for “Lena” image.

Noise Density	SMF	AMF	DBA	PSMF	MDBA	MDBUTMF	PA
10%	2.74	4.99	2.18	2.31	1.96	1.72	0.36
20%	3.4	5.53	3.05	3.07	2.87	2.68	0.8
30%	5.06	5.85	3.72	5.17	3.36	3.27	1.27
40%	9.1	6.1	4.4	10.57	4.12	4.06	1.81
50%	16.39	6.49	5.19	19.36	4.91	4.83	2.41
60%	28.92	6.71	6.2	32.25	5.98	5.85	3.14
70%	46.68	7.37	7.78	51.73	7.46	7.29	4.06
80%	70.01	8.59	11.01	73.15	10.82	10.77	5.34
90%	96.98	11.5	27.89	98.13	27.56	27.41	7.31

Table 4.Comparitive Results of various filters in terms of IEF for “Lena” image.

Noise Density	SMF	AMF	DBA	PSMF	MDBA	MDBUTMF	PA
10%	10.36	23.2	171.63	171.63	422.58	648.98	471.26
20%	28.17	37.76	207.31	207.31	377.42	568.43	392.48
30%	30.02	42.57	190.92	190.92	324.74	590.83	356.65
40%	23.12	40.98	143.49	143.49	275.24	424.18	312.12
50%	11.72	36.11	62.98	62.98	217.18	345.13	261.93
60%	6.73	25.21	6.61	6.61	175.89	261.66	222.36
70%	3.31	7.89	3.28	3.28	129.65	171.69	172.65
80%	2	2.91	1.98	1.98	73.24	101.72	122.78
90%	1.37	1.31	1.37	1.37	33.33	34.23	82.35

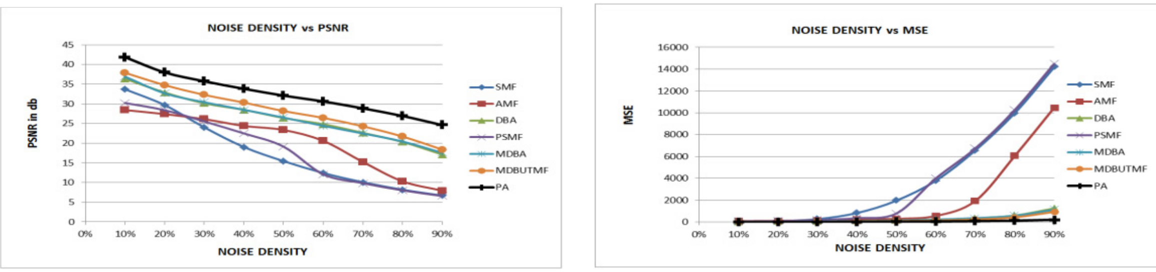


Fig. 6.(a) Comparison graph of Peak Signal to Noise Ratio (PSNR) at different noise densities for “Lena” image ;(b) Comparison graph of Mean Square Error (MSE) at different noise densities for “Lena” image

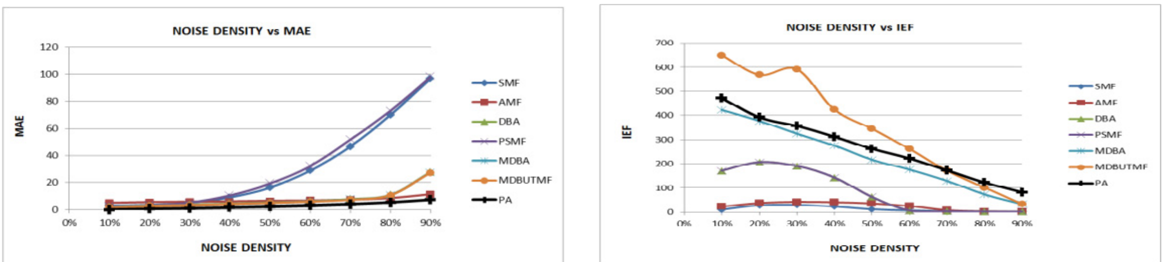


Fig. 7.(a)Comparison graph of Mean Absolute Error (MAE) at different noise densities for “Lena” image;(b) Comparison graph of Image Enhancement Factor (IEF) different noise densities for “Lena” image

Table 5.Comparision results of PSNR values of different test images at 70% noise density

Test images	SMF	AMF	PSMF	DBA	MDBA	MDBUTMF	PA
Cameraman	9.46	13.93	9.47	20.84	19.97	22.52	25.55
Lena	9.93	15.25	9.84	22.64	22.47	24.3	28.86
Baboon	10.11	14.86	10.05	22.35	20.54	23.8	23.91

Table 6.Results for different noise densities obtained for “Cameraman” Image. (Fig.6 (d-f))

Noise Density	MAE	MSE	IEF	PSNR
30%	1.2774	40.3738	150.3142	32.0698
60%	3.2481	135.0239	90.3219	26.8267
90%	7.3899	405.5216	44.9323	22.0507

Table 7.Results for different noise densities obtained for “Real” Image. (Fig.6 (g-h))

Noise Density	MAE	MSE	IEF	PSNR
30%	0.5598	4.2337	1315.2	41.8636
60%	1.4304	15.4709	724.1381	36.2334
90%	3.44	61.1860	274.1756	30.2643

4. Conclusion

A new improved algorithm has been proposed that increases the efficiency of the removal of salt and pepper noise. Results of this algorithm exhibit better performance in comparison with SMF, AMF, PSMF, DBA, MDBA and MDBUTMF in terms of higher PSNR, MSE and MAE. The proposed algorithm also shows consistent and stable performance across a wide span of noise densities varying from 10%-90%. The proposed algorithm shows better image enhancement factor (IEF) for salt and pepper noise of density more than 70%. As a future work the proposed algorithm can be further improved by implementation of de-blurring techniques, use of neural networks or fuzzy logic for improving the restoration outputs and also to remove other types of noise such as speckle noise, random noise, Rayleigh noise, Gaussian noise, etc.

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