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Probabilistic Decision Based Average Trimmed Filter for the Removal of High-Density Salt and Pepper Noise

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Abstract*: The paper focuses on the evacuation of salt and pepper noise from a contaminated image. A probabilistic decision based average trimmed filter (PDBATF) is proposed for both high and low noise density. The proposed algorithm addresses the issue related to even number of noise-free pixel in trimmed median filter for the calculation of processing pixel. The proposed average trimmed filter is incorporated for low noise density while the proposed patch else average trimmed filter is applied for high noise density. Finally, they are combined together to develop the proposed PDBATF. The proposed algorithm show an excellent noise removal capability compared to the recently developed algorithms in terms of peak signal to noise ratio, image enhancement factor, mean absolute error and execution time. It works very efficiently in de-noising contaminated medical images such as chest-x-ray and malaria-blood-smear.

Keywords* : Medical image de-noising; salt and pepper noise; noise removal; trimmed median filter; probabilistic approach;

I. INTRODUCTION

Digital Image Processing is a promising area of research [1] in the fields of electronics and communication engineering, consumer and entertainment electronics, control and instrumentation, biomedical instrumentation, remote sensing, robotics and computer vision and computer-aided manufacturing (CAM). The digital images are often corrupted by impulse noise because of transmission errors, malfunctioning pixel elements in the camera sensors, faulty memory locations, and timing errors in analog-to-digital conversion.

Noise removal is a noteworthy task in image processing. The quality of image pre-processing depends on the removal of the noise from the corrupted image without destroying the edges [2]. Impulsive noise is a type of noise which affect the most where the corrupted pixel may be replaced by the maximum or minimum value with a certain probability [3]. Numerous linear [4] and non-linear [5] filtering techniques have been proposed for noise reduction. Linear filters are not able to viably eliminate impulse noise as they tend to obscure the edges of an image. The conventional linear techniques are extremely basic in usage however they experience the ill effects of the loss of image details. They also don't perform well with the variation of signal-dependent noise. To conquer this constraint, nonlinear filters are proposed. Several nonlinear filters [4-5] dependent on Classical and fuzzy techniques have increased in a preceding couple of years. The Standard Median Filter (SMF) [4-5] is the basic non-linear filter developed which is the simple basic rank selection filter, used to remove impulse noise by processing the central pixel of the filtering window with the median value of the pixels contained within the window. SMF can extensively reduce impulse noise in an image. The uncorrupted pixel is likewise changed by the SMF. Many variations and improved strategies based on SMF is reported till date such as Adaptive Median Filter (AMF) [6] in which the size of the filtering window is adaptive in nature, and it depends on the number of noise-free pixels in the current filtering window, Adaptive Weighted Median Filter (AWMF) [7-8] where the weight of a pixel is decided on the basis of standard deviation in four-pixel directions (vertical, horizontal and two diagonals). The detection of the noisy pixel in an image contaminated by random-valued impulse noise, is increasingly troublesome in comparison with fixed valued impulse noise, as the gray value of a noisy pixel may not be substantially larger or smaller than those of its neighbors. Because of this reason, the conventional median-based impulse detection strategies don't perform well if there is an occurrence of random-valued impulse noise. Switching Median Filter (SMF) [9] which identifies noisy pixels, applied with AMF to develop Adaptive Switching Median Filter (ASMF) [10-11]. It computes the threshold value locally from the image pixel values in the sliding window. These filters work well in de-noising to a certain level of noise density but fail to perform for high noise density due to the use of basic median operations. One of the major concern is the time complexity with the above-reported algorithms. Thereby Trimmed Median Filter (TMF) [12] developed which removes the unwanted pixel elements before processing. In TMF, if the concerned processing pixel is noisy then the pixel elements with intensity value “0” and “255” is removed before applying the median approach. Several algorithms [6-12] are developed and reported with the application of TMF. In Alpha Trimmed Median Filter (ATMF) [12], trimming is symmetric which leads to blurring and loss of image details. This leads to the development of Un-symmetric Trimmed Median Filter (UTMF) [13] where the uncorrupted pixel elements are arranged in increasing or decreasing order in a selected window for the calculation of median after removing pixels with intensity value “0” and “255”.

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UTMF is applied in many state-of-the-art algorithms like Decision Based Un-symmetric Trimmed Median Filter (DBUTMF) [13], Modified Decision Based un-symmetric Trimmed Median Filter (MDBUTMF) [14], and Probabilistic Decision Based Filter (PDBF) [15]. DBUTMF is developed to overcome the drawback of decision based algorithm (DBA) [13] where the median value after calculation comes to be either "0" or "255". In such cases, DBA replaces processing pixel with a pixel value from the neighbor which leads to streaking effect [16]. DBUTMF [13] fails to operate when all the pixel elements are either "0" or "255" in a selected window which leads to the development of MDBUTMF [14]. MDBUTMF do not perform well in high noise density (ND) due to its fixed window size. Therefore PDBF is reported where TMF is utilized for low ND and a new technique called Patch Else Trimmed Median Filter (PETM) is incorporated for high ND. The algorithm works well in low as well as in high ND when the remaining noise free pixel (NFP) in the trimmed median filter is odd valued. It shows some blurring and loss of image information in case of even valued NFP. This particular issue motivated to develop the proposed Probabilistic Decision Based Average Trimmed Filter (PDBATF) to remove salt and pepper noise from a highly contaminated image. Here two new technique is proposed namely, proposed Average Trimmed Filter (ATF) and Patch Else Average Trimmed Filter (PEATF) to develop the proposed PDBATF. Proposed ATF is incorporated for low ND and proposed PEATF is utilized for high ND. Simulation results show that the proposed algorithm de-noise an image may it be a normal image or medical image contaminated with salt-and-pepper noise very efficiently and outperforms the recently reported State-of-the-art algorithm.

The rest of the paper is organized as follows. Section 2 discusses the complete procedure of the proposed PDBATF. Section 3 discusses the simulation results and section 4 concludes the paper.

II. PROPOSED ALGORITHM

The proposed PDBATF algorithm is developed by incorporating proposed ATF for low ND and PEATF for high ND. In order to establish various relationship, Z is considered as the original image of size m × n corrupted by noisy density (ND). NI is considered as the noisy image and Z_d be the de-noised image.

2.1. Proposed Average Trimmed Filter

With the application of TMF to de-noise an image, it works absolutely fine to retrieve the estimated original information in a selected window when the remaining NFP in the selected window is odd valued after removal of the intensity value "0" and "255". It simply sorts the remaining pixel elements and calculates the median value in order to replace the processing noisy pixel element. The situation becomes troublesome when the remaining NFP in the selected window is even valued. In such a case, after sorting of the pixel elements, the mean of the two center elements are calculated to replace the processing pixel. Mean of the center element is considered as an estimate of the original information. But the major concern with this approach is that the original information of the processing pixel may be at a far distance from the mean of the two center elements after application of the trimming. In most of the cases, it might not be able to estimate properly the original pixel intensity as only the two center elements are utilized to estimate the original processing pixel information. This leads to some probability of getting image detail loss and blur.

So, in order to resolve such an issue Average Trimmed Filter is proposed. The strategy of the proposed algorithm is as follows,

Case 1. Odd value of NFP.

In this case, noisy pixels are removed and the remaining NFP are sorted. Median will be the central element.

Case 2. Even value of NFP.

In this case, the same approach is followed until sorting. Then a probabilistic estimation strategy. Now the two center elements may or may not be adjacent to each other. So instead of taking the mean of the two center elements, the average of the remaining pixel elements is calculated to replace the processing pixel. It will minimize the distance to a maximum extent compared to the original pixel intensity.

The proposed ATF is shown in Algorithm 1 as follows:

Algorithm 1: Proposed ATF Algorithm

i. Select the window size of 3×3. Assume that the processing pixel is NI (i , j).

ii. **If** 0 < NI (i , j) < 255 then
 NI (i , j) is a NFP and its value is unchanged.
 End

iii. **If** NI(i , j)=0 or NI(i, j)=255 then
 NI (i, j) is a noisy pixel, then the probabilities are,
 If the considered window holds all the pixels as 0's and 255's, then
 NI (i , j) is replaced by the mean of the selected window.
 Else eliminate 0's and 255's from the considered window. Let the number NFP be p_1. Again two possibilities occur, they are,
 If p_1 is an odd number, then
 Sort and find the median value. Replace it with NI (i , j).
 Else Follow the below steps,
 1.Find the average of the remaining NFP.
 2.Replace the obtained average value with NI (i, j).
 End
 End
 End

iv. Repeat the same procedure from i to iii for all the pixels in the image.

2.2. Proposed Patch Else Average Trimmed Filter

This algorithm is proposed to de-noise an image contaminated with high ND. The Patch Median (PM) can be defined for a matrix of an odd size, as the pixel element obtained at the center of the matrix, after sorting the patch elements in rows and then columns or vice versa either in ascending or descending order. Single sample output is obtained by the Patch Median, whereas there is a probability that average output can be obtained in Trimmed Median. Proposed ATF along with PM is incorporated to develop the proposed PEATF. The proposed algorithm is shown in

Algorithm 2: Proposed PEITMF Algorithm

i. Find PM of the selected window.
ii. **If** obtained estimation is NFP then
  Consider this as the final estimate value
iii. **Else** find ATF
iv. **If** obtained estimation is NFP then
  Consider this as the final estimate.
v. **Else** increase the size of the window and go to step 1
  End
vi. Repeat the procedure till the noise free pixel is obtained and stop.

End

Algorithm 2.

2.3. Proposed Probabilistic Decision Based Average Trimmed Filter

In order to design the proposed PDBATF, proposed ATF and proposed PEATF is implemented considering the facts arrived from and above sections and from the referred literature [6-9] [11-13] are as follows:

1. Proposed ATF and proposed PEATF works approximately equivalent under ND 50%.
2. As the ND increase above 50%, proposed ATF lags behind proposed PEATF.
3. Switching strategy enhances the capability of the proposed algorithm.
4. With the increase in window size, undoubtedly noise removal capability will increase but with the loss of execution time.

The proposed PDBATF is set up and shown in flowchart 1.

III. SIMULATION RESULTS AND DISCUSSION

The proposed PDBATF are examined against some of the recently reported state-of-the-art algorithms like NAFSM-2010, MDBUTMF-2011, PDBF-2016, BPDF-2018 in terms of peak signal to noise ratio (PSNR), image enhancement factor (IEF), execution time (ET), mean square error (MSE) and mean absolute error (MAE). Standard grayscale images are collected from authentic standard image websites named imageprocessingplace.com and sipi.usc.edu. Images of Chest, Malaria-blood-smear, Lena, House, and Living-room are selected for the experiments. The images are of size 512 × 512. The experiments are conducted using Intel(R) Core(TM) i3-7200 central processing unit @ 2.30 GHz, 8 GB RAM with MATLAB R2013b environment.

The above-mentioned parameter can be defined as follows:

$$MSE = \frac{\sum_{i,j}^{m,n}\left(Z_{i,j} - Z_{d_{i,j}}\right)^2}{m \times n} \quad (1)$$

$$MAE = \frac{\sum_{i,j}^{m,n}\left(Z_{i,j} - Z_{d_{i,j}}\right)}{m \times n} \quad (2)$$

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

$$IEF = \frac{\sum_{i,j}^{m,n}\left(Z_{i,j} - NI_{i,j}\right)^2}{\sum_{i,j}^{m,n}\left(Z_{i,j} - Z_{d_{i,j}}\right)^2} \quad (4)$$

For better performance, the PSNR and IEF should be as high as possible, while the MSE, MAE, and ET should be as low as possible. ET is calculated using Matlab command “tic” and “toc”.

Table (1-4) shows the objective measures of the proposed PDBATF in comparison with the considered state-of-the-art while the graphical representation of the corresponding table is presented in Figure 4. It can be seen from Table 1 and figure 4(a) that IEF is comparably high using proposed PDBATF while MAE is comparatively less as can be seen in Table 2 and Figure 4(b) which confirms the superiority of the proposed algorithm. Table 3 and Figure 4(c) compares the proposed algorithm in terms of PSNR. It is analyzed and seen that the PSNR is better while de-noising an image using proposed PDBATF in comparison with the other reported state-of-the-art. The proposed algorithm has a better execution time compared to other algorithms except for PDBF as PDBF calculates the processing pixel using only one pixel for the odd valued case and two-pixel for even valued case while in case of the proposed algorithm it depends on the number of NFP for even valued case and same in the odd valued case. Figure 2 displays the visual representation of image Chest using considered state-of-the-art in comparison with the proposed PDBATF, while Figure 3 uses image House and Figure 5 uses image Malaria-blood-smear for the same. In Figure 2 it can be seen the proposed algorithm can detect the letter and circle clearly along with fine details of the image compared to other algorithms. While PDBF also shows a good de-noising capability but shows some blur in the image.

In Figure 3 and 5, it can be seen that the proposed algorithm retrieves the edges of the image better in comparison to PDBF and other algorithms in very high ND which confirms the outperformance of the proposed PDBATF.

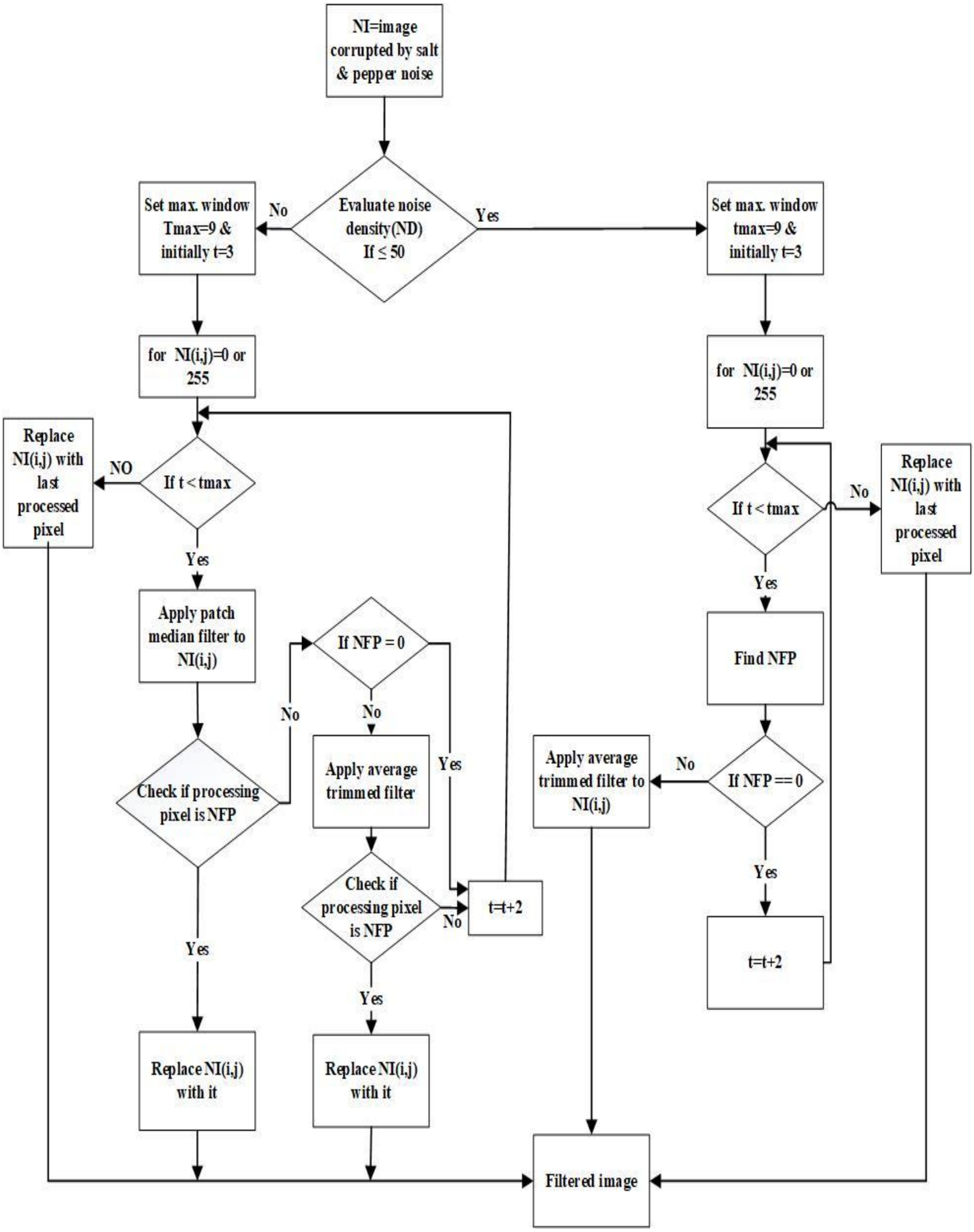

Figure 1 Flowchart of Proposed PDBATF

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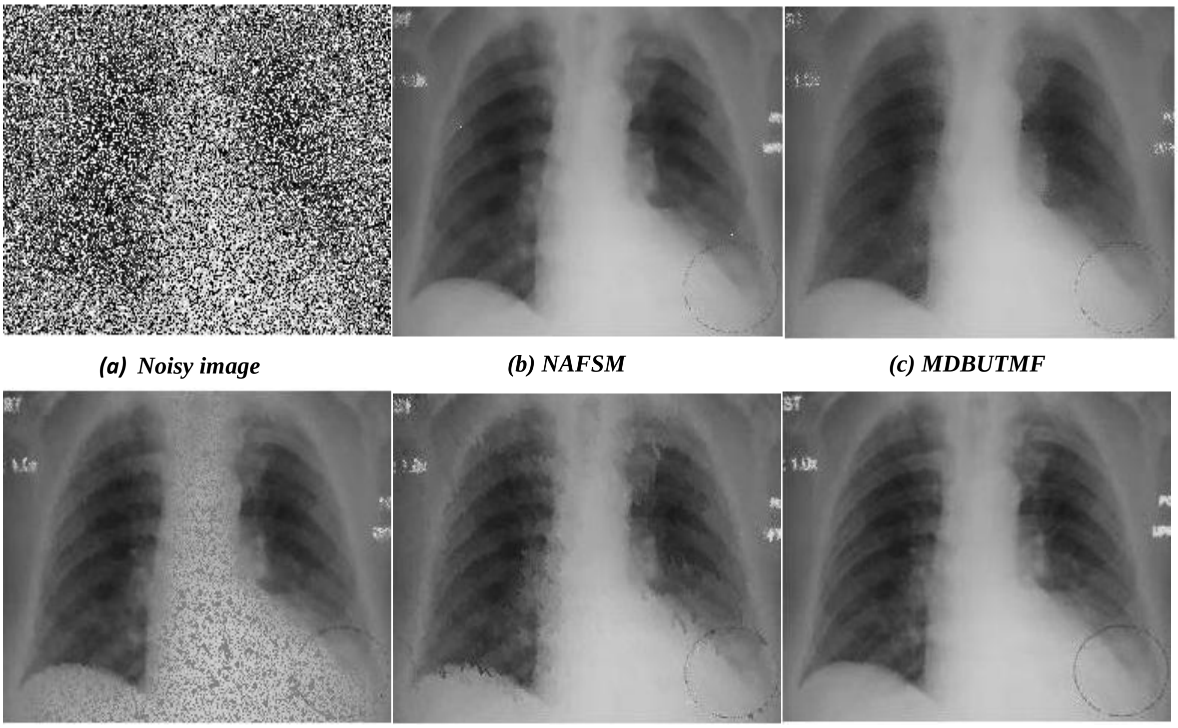

(a) Noisy image *(b) NAFSM* *(c) MDBUTMF*

(d) PDBF *(e) BPDF* *(f) Proposed PDBATF*

Figure 2 Visual comparison of the proposed PDBATF with considered algorithm using image Chest with ND 60%

ND	IEF				
in %	NAFSM-2010	MDBUT MF2011	PDBF-2016	BPDF-2018	Proposed PDBATF
10%	101.46	231.68	218.03	111.40	268.05
20%	95.36	226.22	188.12	94.38	248.45
30%	84.78	216.16	156.25	72.44	233.28
40%	77.75	191.66	127.01	55.45	198.05
50%	72.44	147.02	108.25	30.86	184.48
60%	62.93	97.55	84.38	23.43	152.50
70%	57.20	78.08	83.02	20.64	117.68
80%	50.02	47.40	79.22	18.46	96.08
90%	28.16	26.52	52.38	16.94	56.10

Table 1 Comparison of proposed PDBATF with the considered algorithm in context to IEF using Lena

ND	MAE				
in %	NAFSM-2010	MDBUT MF2011	PDBF-2016	BPDF-2018	Proposed PDBATF
10%	0.4436	0.462	0.426	0.361	0.3164
20%	0.8518	0.767	0.595	0.544	0.6291
30%	1.2956	1.174	1.145	1.039	0.9811
40%	1.894	1.777	1.594	1.489	1.4341
50%	2.653	2.653	3.156	2.996	1.9803
60%	3.997	3.246	4.155	5.353	2.9124
70%	4.156	5.246	4.553	6.246	3.6893
80%	5.156	8.397	4.907	9.246	4.9804
90%	8.246	12.246	6.156	14.246	6.1389

Table 2 Comparison of proposed PDBATF with the considered algorithm in context to MAE using Living room

ND		PSNR			
in %	NAFSM-2010	MDBUT MF2011	PDBF-2016	BPDF-2018	Proposed PDBATF
10 %	37.46	41.28	42.35	41.13	43.96
20 %	35.51	37.46	40.91	38.13	42.35
30 %	33.57	34.67	35.77	36.13	40.87
40 %	32.62	33.53	34.29	34.14	36.85
50 %	30.34	30.21	33.05	32.15	36.06
60 %	29.16	28.36	31.93	30.14	32.76
70 %	27.13	27.69	30.83	26.12	32.05
80 %	24.17	27.13	27.43	24.21	28.89
90 %	21.38	25.62	25.32	23.14	25.85

Table 3 Comparison of proposed PDBATF with the considered algorithm in context to PSNR using Chest

ND	ET				
in %	NAFSM-2010	MDBUT MF2011	PDBF-2016	BPDF-2018	Proposed PDBATF
10%	5.37	3.47	3.23	7.39	3.55
20%	6.10	4.66	2.94	8.17	3.59
30%	7.62	5.14	3.06	10.29	3.48
40%	8.66	5.47	3.69	13.17	4.11
50%	10.36	6.94	3.53	15.44	3.85
60%	11.60	7.36	3.96	18.33	4.28
70%	13.13	7.94	4.81	20.42	5.13
80%	14.00	8.68	5.89	21.01	6.29
90%	15.56	9.38	6.40	21.47	6.62

Table 4 Comparison of proposed PDBATF with the considered algorithm in context to ET using Malaria-blood-smear

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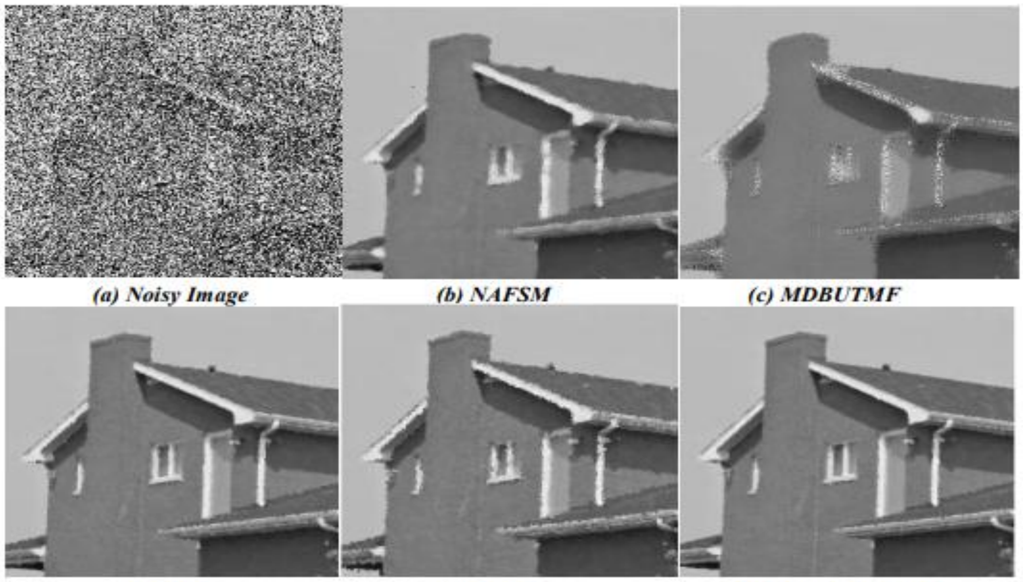
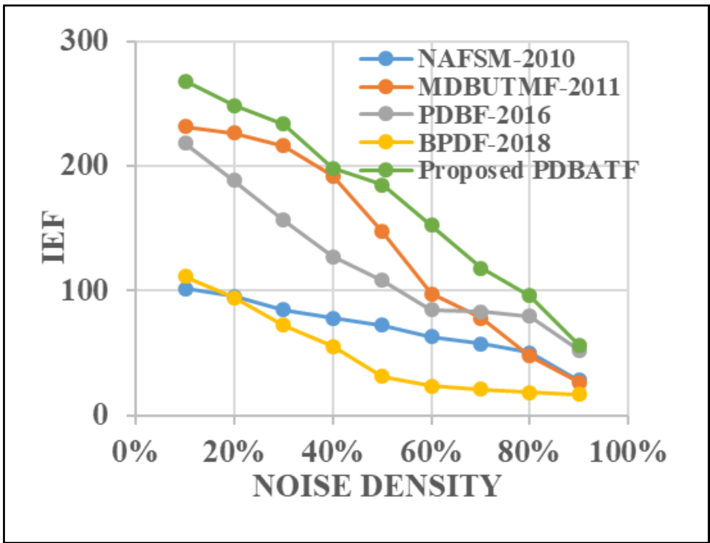


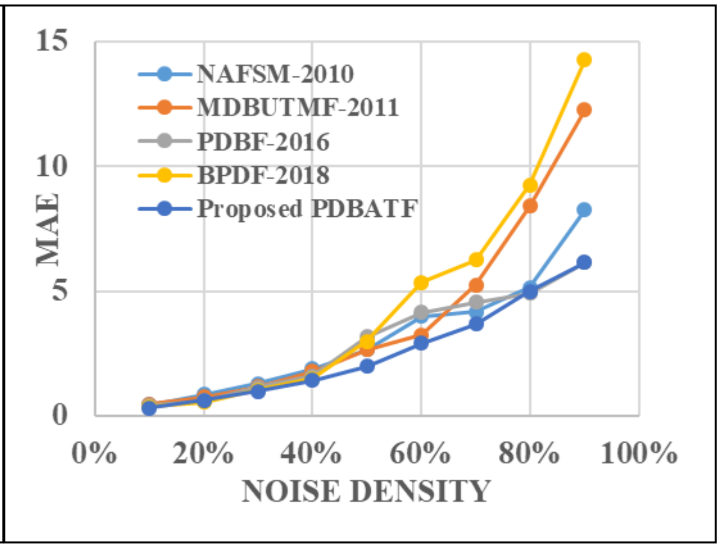
(a) Noisy Image *(b) NAFSM* *(c) MDBUTMF*

(d) PDBF *(e) BPDF* *(f) Proposed PDBATF*

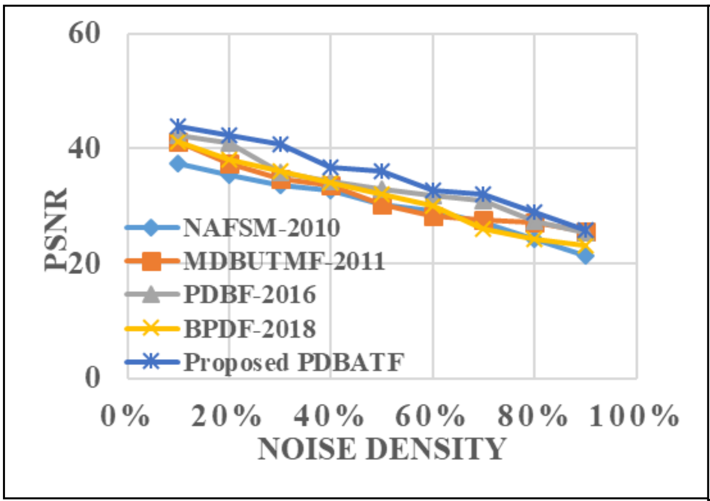
Figure 3 Visual comparison of the proposed PDBATF with considered algorithm using image House with ND 70%



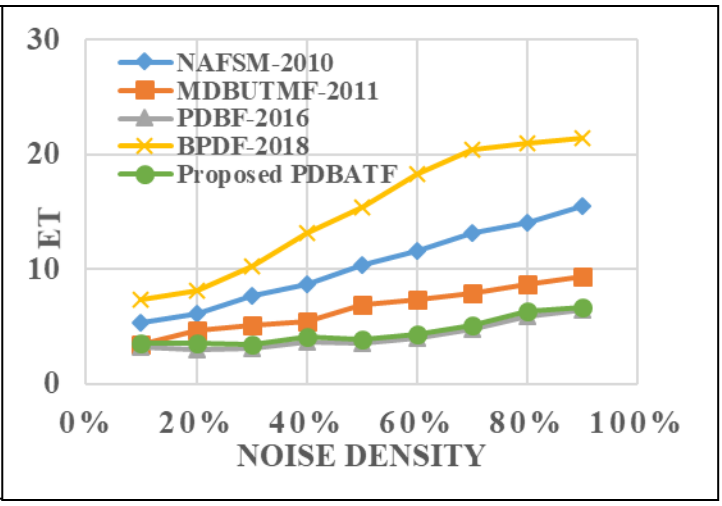
(a) Graphical representation of Lena in terms of IEF



(b) Graphical representation of Living room in terms of MAE



(c) Graphical representation of Chest in terms of PSNR



(d) Graphical representation of Malaria-blood-smear in terms of ET

Figure 4

IV. CONCLUSION

The proposed ATF developed for low noise density and the proposed PEATF developed for high noise density constitutes the proposed PDBATF. The relation among the NFP is calculated within the processing pixel using ATF for replacing noisy candidate. In case of high noise density, patch median is obtained in the proposed PEATF. Further it is verified for the non-existence of noisy element. If it exists then ATF is employed. The proposed algorithm outperforms several other state-of-the-art algorithms in de-noising an image contaminated with impulsive noise. It is efficient in retaining the edges of an image when compared with the recently developed algorithms. The proposed algorithm establishes itself as a very efficient algorithm for image pre-processing related to medical image for disease detection, agricultural image for crop health detection and in several images for image identification issues.

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