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A NEW TRIMMED MEDIAN-MEAN BASED FILTER FOR THE REMOVAL OF HIGH DENSITY FIXED VALUE NOISE IN MEDICAL IMAGES AND VIDEOS

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ABSTRACT

A new trimmed median-mean based filter for the removal of high density fixed value impulse noise is proposed. A fixed 3x3 window is kept constant for the increasing noise densities. The pixel is termed as noisy, if the processed pixel is between the outliers. The corrupted pixel is replaced by unsymmetrical trimmed mean or median or midpoint or mean of the current processing window based on the content of the current processing window. The proposed algorithm (PA) is employed on different varying detail images. The proposed algorithm is compared with the standard and existing algorithms and found to exhibit good noise suppression capability. The algorithm also shows a good qualitative and quantitative result for increasing noise densities. The proposed algorithm removes salt and pepper noise at high noise densities by preserving fine details of an image.

Keywords: unsymmetrical trimmed variants filter, salt and pepper noise, edge preservation, noise removal.

1. INTRODUCTION

Images are often corrupted by Salt and Pepper noise due to error in transmission. The Key behind all noise removal is to eliminate high density salt and pepper noise without inducing any arte facts such as blurring, streaking, fading etc., When eliminating non Gaussian noise, the linear filters were not effective. Hence nonlinear filters were introduced. Median is an on linear operation that eliminated the outliers effectively. The median operation was applied to images corrupted by salt and pepper noise. The median operation eliminated salt and pepper noise by preserving the fine details of an image. At high noise densities the Standard median filter does not work to remove the noise properly. Also the operation is done on entire image irrespective the pixels are noisy or not [1].Adaptive median filter (AMF) employs increasing window for the suppression of salt and pepper noise. Increasing window size cause blurring of images at high noise densities [2].Over the years many decision based median filters were proposed to detect and correct only the corrupted pixel [3]-[4]. The main flaw of the decision based median filters is that it detects and corrects the salt and pepper noise subsequently, but did not take local feature such as edges into account. For the removal of high density impulse noise Decision based (DBA) filters were proposed [5].At high noise densities the DBA algorithm induces streaks in images. The reason behind is the repeated replacement of neighborhood pixel. To suppress streaking at heavy noise conditions a cascaded approach [6] was introduced. These cascaded algorithms works in two stages. The first stage of the filter performs impulse detection by comparing the processed pixel with the outlier values of the given gray scale image. If the current processing pixel is corrupted then median is replaced else left unaltered. The second stage of the cascaded algorithm is just replacement of unsymmetrical trimmed midpoint filter. This process can destroy the information of an image. Hence at high noise densities, the two stage algorithm destroys the fine details at monolithic regions. Modified decision based median filter (MDBMF) [7] replaced the noisy pixel by finding trim median of non noisy pixels. At very high noise densities MDBMF fails to retain the information of an image and shows fading effect at high noise densities. If the entire window is noisy the algorithm fails at this case. Modified decision based unsymmetrical trimmed median filter (MDBUTMF) [8] is proposed as an improved version of the MDBMF algorithm. This algorithm replaced the corrupted pixel with median of the trimmed output. At very high noise densities the filters mudges the information of the image.

Fast and efficient median filter (FEMF) uses prior information to get natural pixels for restoration. Without any iteration it detects impulse noises intuitively leaving the others unaltered. So it has fast execution speed [9].The Noise adaptive fuzzy switching median filter (NAFSM) utilizes the histogram of the corrupted image to identify noise pixels and employs fuzzy reasoning to handle uncertainty present in the extracted local information as introduced by noise [10].

In the new filter proposed in [11], the corrupted pixels are replaced by using a median filter or estimated by their neighbors' values. In this work, we propose a new trimmed median-mean based filter (NTMMBF) to remove salt and pepper noise for high level noise. This paper aims to propose a filter that removes salt and pepper noise at high noise densities without inducing streaking, fading and smudging and preserving the edges. This paper is organized as follows. Section II deals with new trimmed median-mean based filter algorithm. Section III briefs the illustration of the proposed algorithm in detail. Section IV

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gives the qualitative and quantitative comparison of proposed filter with existing filters. Section V gives the concluding remarks for this letter.

2. PROPOSEDALGORITHM

The proposed new trimmed median-mean based filter (NTMMBF) algorithm processes the corrupted images by first detecting the impulse noise. The processing pixel is checked whether it is noisy or noise free. That is, if the processing pixel lies between maximum and minimum gray level values than it is noise free pixel, it is left unchanged. If the processing pixel takes the maximum or minimum gray level it is noisy pixel which of processed by NTMMBF.

The proposed algorithm on images and videos is explained in the following steps. In case of videos separate videos into frames. Now every frame will act as an image.

Step-1: Choose 2-D window of size 3×3. Let P_{ij} is pixel being processed in the noisy image.

Step-2: Convert sorted 2-D array into 1D array. Arrange the 1D data in increasing order using Modified Shear Sorting algorithm for improving computational efficiency.

Step-3: Check the processed pixel P_{ij} for 0 or 255.

Step-4: If P_{ij}= 0 or P_{ij}= 255 then P_{ij} is a corrupted pixel.

Step-5: Check the four neighbors of the processed pixel for 0 or 255.

Case (i): If some of the neighbors are found to be noisy (i.e., holding 0 or 255) (But all are not noisy) and number of noisy pixels is greater than 3 in the current processing window then the noisy pixel is replaced by the mean of current processing window.

Case (ii): If all the neighbors are found to be noisy (i.e., holding 0 or 255) and number of noisy pixels is greater than 3 in the current processing window then the noisy pixel is replaced by the mean of the four neighbors.

Case (iii): If some of the four neighbors are noisy (i.e., holding 0 or 255) and number of noisy pixels is less than or equal to 3 in the current processing window then the noisy pixel is replaced by the unsymmetrical trimmed median.

Case (iv): If some of the four neighbors are noisy (i.e., holding 0 or 255) and number of noisy pixels greater than 3 in the current processing window then the noisy pixel is replaced by the unsymmetrical trimmed midpoint.

Case (v): if the processed pixel is termed as noisy and the number of noisy pixels in the current processing window is equal to one then the corrupted pixel is replaced with Unsymmetrical trimmed mean.

Step-5: If 0 <P_{ij}< 255 then $P_{ij}$is an uncorrupted pixel and its value is left unchanged. This is illustrated in case (vi) of section III

Step-6: Move the window to the next pixel. The above steps from 1 to 5 are repeated for the entire image. In case of videos, apply the above algorithm for all the frames. Join frames together to play the restored video.

3. ILLUSTRATION OF NTMMBF ALGORITHM

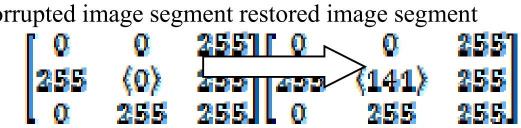
Each and every pixel of the image is checked for the presence of salt and pepper noise. Different cases are illustrated in this Section.

Case (i): Pixel is noisy, some of the four neighbors are noisy (But all are not noisy), Noise count is greater than 3, and all the elements inside the window are noisy.

This case deals with the condition that the processed pixel is noisy (which is 255), now check for the 4 neighbors of the processed pixel, here all the neighbors of the processed pixel are noisy. Count the number of noisy pixels inside the current processing window (which is 9 for this case).We cannot apply unsymmetrical trimmed midpoint because there is no data uncorrupted to find the trimmed midpoint. Hence we find local mean of the current processing window. The corrupted pixel is replaced by the local mean, which is given as

(0+0+255+255+0+255+0+255+255)/9=141.
Unsorted array : 0,255,0,0,0,255,255,255,255
Sorted array : 0, 0, 0, 0,255,255,255,255,255
Neighbors array : 0,255,255,255

Corrupted image segment restored image segment

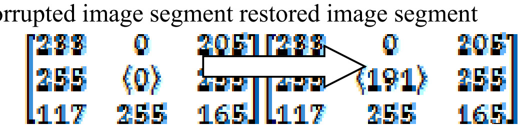


Where "0" is processing pixel, i.e., $\langle P_{ij} \rangle$

Case (ii): Pixel is noisy; all the four neighbors are noisy
In this case the processed pixel is noisy which is(0), now check for the 4 neighbors of the processed pixel (which are 0255 255 255). It was found that all the 4 neighbors are noisy. Hence find the mean of the 4 neighbors which is illustrated as follows (255+255+255+0)/4 = 191. The processed pixel is noisy, the 4 neighbors of the processed pixel is also noisy and hence replace the noisy pixel with mean of the 4 neighbors (which is 191).

Unsorted array : 233, 255, 117, 0, 0,255,205,255,165
Sorted array : 0, 0, 117, 165,205, 233,255,255,255
Trimmed array : 117,165,205,233
Neighbors array : 0,255,255,255

Corrupted image segment restored image segment



Case (iii): Pixel is noisy, some of the four neighbors are noisy, and count is less than or equal to 3.
The processed pixel is 0 which is considered to be noisy. Now check the 4 neighbors of the processed pixel which is

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given as 0, 145, 103, and 243. Some of the four neighbors are also noisy. Hence count the number of noisy pixels inside the current processing window. Arrange the data inside the current processing window in increasing order. In this case the number of noisy pixels inside the current processing window is 2.

Unsorted array : 233,145, 117, 0, 0,103,205,243,165
Sorted array : 0, 0,103,117,145,165,205,233,243
Trimmed array : 103,117,145,165,205,233,243
Neighbors array : 0,145,103,243

The number of noisy candidate is less than three inside the current processing window. The processed pixel is termed as noisy and the noisy pixel is replaced by unsymmetrical trimmed median, which is evaluated as follows. Find the median of uncorrupted pixel (which is Median (103 117 145165 205 233 243) resulting in 165 which replaces the corrupted pixel.

Corrupted image segment restored image segment

$$\begin{bmatrix} 233 & 0 & 205 \\ 145 & \langle 0 \rangle & 243 \\ 117 & 103 & 165 \end{bmatrix} \Rightarrow \begin{bmatrix} 233 & 0 & 205 \\ 145 & \langle 165 \rangle & 243 \\ 117 & 103 & 165 \end{bmatrix}$$

Case (iv): Pixel is noisy, some of the four neighbors are noisy, and Noise count is greater than 3.

In this case the processed pixel is 255 which are considered to be noisy. Now check the 4 neighbors of the processed pixel which is given as 0, 164, 103, and 255. Some of the four neighbors are also noisy. Hence count the number of noisy pixels inside the current processing window. Arrange the data inside the current processing window in increasing order. In this case the number of noisy pixels inside the current processing window is 7.

Unsorted array : 0, 164, 0, 0,255,103,255,255,255
Sorted array : 0, 0, 0,103,164,255,255,255,255
Trimmed array : 103,164
Neighbors array : 0, 164, 0,255

The number of noisy candidate is greater than three inside the current processing window. The processed pixel is termed as noisy and the noisy pixel is replaced by un symmetrical trimmed midpoint, which is calculated by adding (103+ 164)/2which is equal to 133.

Corrupted image segment restored image segment

$$\begin{bmatrix} 0 & 0 & 205 \\ 164 & \langle 255 \rangle & 255 \\ 0 & 103 & 255 \end{bmatrix} \Rightarrow \begin{bmatrix} 0 & 0 & 205 \\ 164 & \langle 133 \rangle & 255 \\ 0 & 103 & 255 \end{bmatrix}$$

Case (v): Pixel is noisy, Noise count is equal to one, and all the elements inside the window are noisy.

This case deals with the condition that the processed pixel is noisy (which is 0), Count the number of noisy pixels inside the current processing window. In this case the number of noisy pixel is one. Apply unsymmetrical trimmed mean. Hence we find mean of the current processing window without outliers. The corrupted pixel is replaced by the unsymmetrical trimmed mean, which is given as (122+124+127+155+163+165+205+215)/8=159.

Unsorted array : 127, 163, 122, 205, 0,155,215,165,124
Sorted array : 0,122,124,127,155,163,165,205,215
Trimmed array : 122,124,127,155,163,165,205,215
Neighbors array : 205,163,155,165

Corrupted image segment restored image segment

$$\begin{bmatrix} 127 & 205 & 215 \\ 163 & \langle 0 \rangle & 165 \\ 122 & 155 & 124 \end{bmatrix} \Rightarrow \begin{bmatrix} 127 & 205 & 215 \\ 163 & \langle 159 \rangle & 165 \\ 122 & 155 & 124 \end{bmatrix}$$

Case (vi): Processed pixel is not noisy

The processed pixel is 119 which are between 0 and 255. The processed pixel is termed as non noisy and processed pixel is unaltered

Corrupted image segment restored image segment

$$\begin{bmatrix} 0 & 0 & 255 \\ 104 & \langle 119 \rangle & 255 \\ 0 & 103 & 255 \end{bmatrix} \Rightarrow \begin{bmatrix} 0 & 0 & 255 \\ 104 & \langle 119 \rangle & 255 \\ 0 & 103 & 255 \end{bmatrix}$$

4. RESULTS AND DISCUSSIONS

The Quantitative performance of the proposed algorithm is evaluated based on Peak signal to noise ratio (PSNR) and structural similarity index metric (SSIM). The equation (1), (2), (3) gives the PSNR, MSE and SSIM, respectively.

$$PSNR = 10\log_{10}\left(\frac{255^2}{MSE}\right) \quad (1)$$

$$MSE = \frac{\sum_i \sum_j (r_{ij} - x_{ij})^2}{M \times N} \quad (2)$$

Where r_{ij} refers to original image, x_{ij} denotes restored image, M×N is the size of processed image.

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \quad (3)$$

Whereμ_x is the average of x, μ_y is the average of y, σ_x Standard deviation of x,σ_y is the Standard deviation of y. C_l= $(K_1L)^2$, C_2= $(K_2L)^2$ two variables to stabilize the division with weak denominator; L is the dynamic range of the pixel-values (for an 8 bit image it takes from 0 to 255), K_1=0.01 and K_2=0.03 by default.
The Figure of merit (FOM) of Pratt, which calculates the alikeness between two edge images, is given equation (4).

$$Pratt's\ FOM = \frac{1}{Max(K_I, K_B)} \sum_1^{K_D} \frac{1}{(1 + \alpha d_i^2)} \quad (4)$$

Where K_I and K_B are the different points of edges in there stored image and original image, respectively, d_i is the distance between a edge pixel and the nearest edge pixel of the original and α is a constant and was used α = 1/9, optimal value established by Pratt. The existing algorithms used for the comparison are DBA, New [7], MDBUTMF,

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FEMF, NAFSMF and New Algorithms [11]. In this work the new trimmed median-mean based filter (NTMMBF) is referred as PA.

Table-1. PSNR of various algorithms on lung CT scan image corrupted by salt and peper noise.

NOISE DENSITY	DBA	NEW [7]	MDB UT MF	FE MF	NA FS MF	NEW ALGORITHMS [11]	PA
10	27.68	38.85	39.02	39.06	42.10	43.12	44.83
20	24.64	33.41	36.84	37.34	40.84	41.22	41.31
30	21.03	29.41	35.84	35.38	38.22	37.92	38.77
40	17.99	25.45	33.26	33.93	35.8	36.41	37.11
50	15.73	23.39	31.45	32.88	33.52	34.32	35.47
60	13.82	20.27	29.63	31.8	31.01	32.15	33.86
70	12.37	19.94	27.88	30.17	28.59	29.61	32.31
80	11.12	18.12	25.51	28.33	25.99	26.83	30.46
90	10.12	16.16	21.82	24.08	21.94	22.45	27.73

Table-2. SSIM of various algorithms on lung CT scan image corrupted by salt and pepper noise.

Noise Density	DBA	New [7]	MDB UT MF	FE MF	NA FS MF	New Algorithms [11]	PA
10	0.869	0.980	0.970	0.970	0.992	0.992	0.992
20	0.627	0.940	0.962	0.963	0.983	0.982	0.983
30	0.369	0.882	0.950	0.951	0.971	0.971	0.972
40	0.206	0.764	0.930	0.934	0.955	0.957	0.961
50	0.124	0.554	0.903	0.915	0.931	0.938	0.945
60	0.078	0.093	0.866	0.894	0.897	0.910	0.926
70	0.050	0.044	0.814	0.864	0.846	0.870	0.901
80	0.033	0.021	0.735	0.816	0.764	0.800	0.867
90	0.021	0.010	0.592	0.690	0.690	0.676	0.808

Table-3. FOM of various algorithms on lung CT scan image corrupted by salt and pepper noise.

Noise Density	DBA	New [7]	MDB UT MF	FE MF	NA FS MF	New Algorithms [11]	PA
10	0.875	0.885	0.892	0.942	0.733	0.940	0.941
20	0.861	0.871	0.856	0.896	0.688	0.890	0.893
30	0.813	0.823	0.831	0.861	0.670	0.852	0.849
40	0.777	0.787	0.797	0.813	0.647	0.807	0.825
50	0.733	0.743	0.758	0.763	0.641	0.735	0.7669
60	0.689	0.699	0.727	0.651	0.621	0.664	0.735
70	0.572	0.582	0.670	0.528	0.558	0.587	0.6675
80	0.457	0.467	0.580	0.441	0.477	0.468	0.598
90	0.322	0.332	0.425	0.306	0.392	0.326	0.480

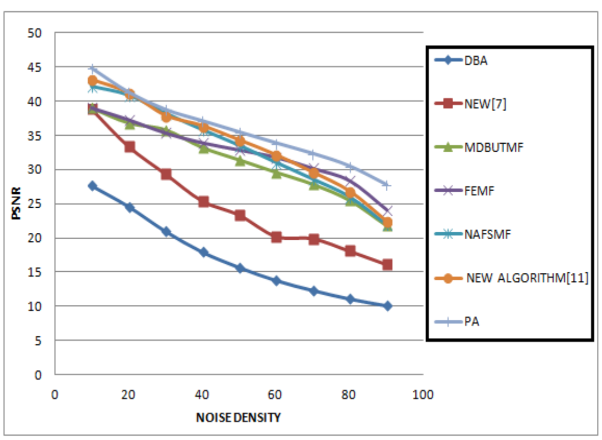

Figure-1. PSNR performance of various algorithms over lung CT scan image corrupted by salt and pepper noise.

Quantitative analysis is made by varying noise densities insteps of ten from 10% to 90% given in Table-1, 2 3 and Figure-1, 2, 3 respectively. All the filters are simulated in MATLAB in PC equipped with 2.66GHZ operating speed, 2GB RAM. From the tables and graphs it is clear that the proposed algorithm liminates noise at high noise densities. Hence the proposed new trimmed median-mean based filter (NTMMBF) has high PSNR and SSIM when compared to other algorithms. High Values of PSNR and SSIM indicate the noise suppression and high structure preservation capability of the proposed algorithm. Table-III illustrates the Pratt's FOM of the various algorithms. Pratt's FOM is a quantitative measure for edge preservation. From Table-3 those high values of Pratt's FOM in the last column indicate the edge preservation capability of the proposed algorithm. The qualitative aspect of the NTMMBF against various algorithms for noise densities (10% to 90%) for Lung CT scan image, 1st frame of the 3D modelling of CT images of the Abdomen Video Sequence with 30% noise, MRI Scan Brain Image with 80% noise, CT Scan Brain Image with 80% noise and edge preservation of synthetic image at 90% is shown in Figure-4, 5, 6 and 7, respectively.

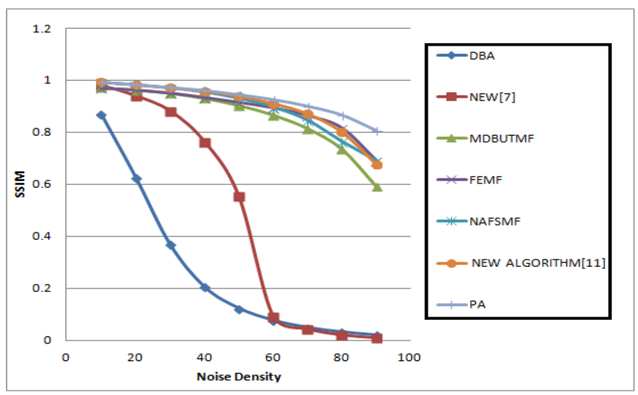

Figure-2. SSIM performance of various algorithms over lung CT scan imagecorrupted by salt and pepper noise.

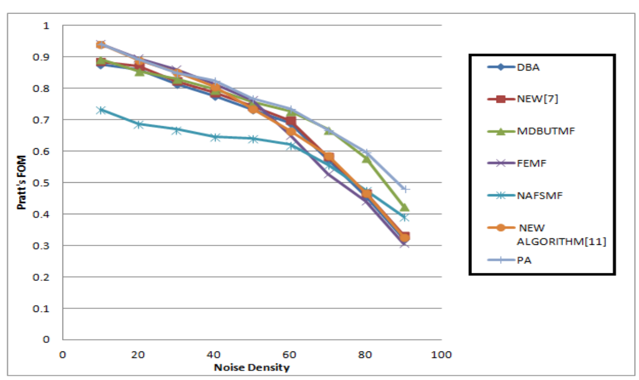

Figure-3. Pratt's FOM performance of various algorithms over lung CT scan image corrupted by salt and pepper noise.

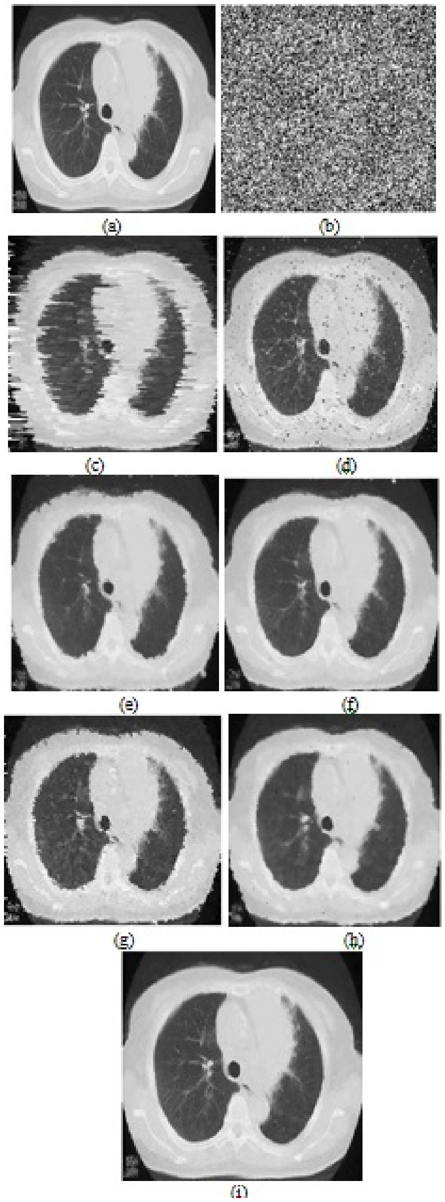

Figure-4. Simulation results for lung CT scan image corrupted with 90% salt and pepper noise.
(a) Original (b) Noisy (c) DBA(d) New [7] (e) MDBUTMF(f) FEMF(g) NAFSMF (h) New algorithms [11] (i) PA.

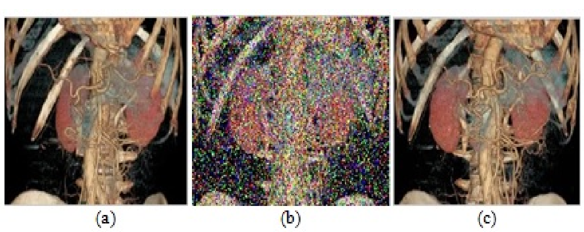

Figure-5. (a) Original 1st frame (b) Noisy frame corrupted by 30% of salt-and-pepper noise (c) Proposed algorithm.

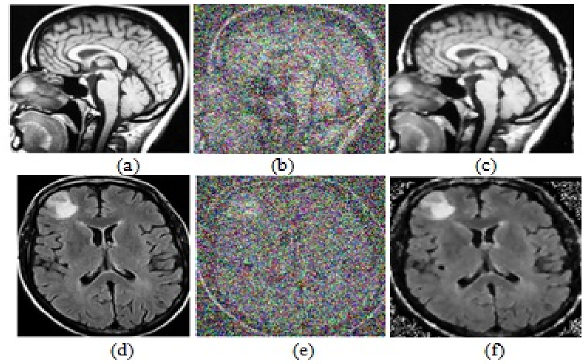

Figure-6. (a) Original MRI scan brain image (b) 80% noise image (c) Proposed filtered image.(d) Original CT scan brain image (e) 80% Noise image (f) Proposed filtered image.

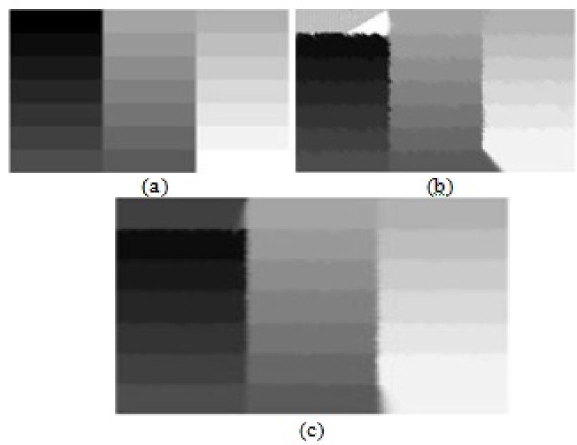

Figure-7. (a) Original(b) MDBUTMF (c) Proposed algorithm. Qualitative analysis of the various algorithm corrupted by 90% salt and pepper noise on synthetic image.

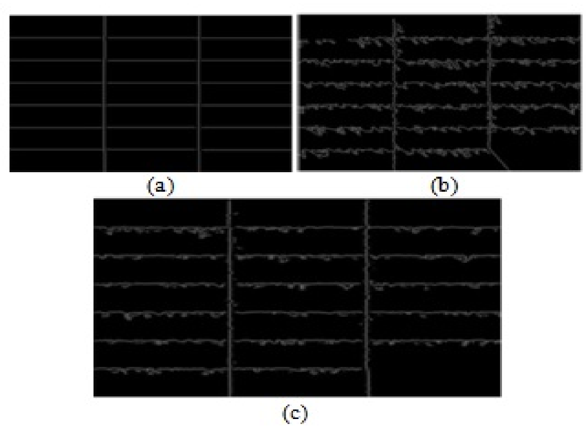

Figure-8. (a) Original(b) MDBUTMF (c) Proposed algorithm edge map of the MDBUTMF and proposed algorithm for synthetic image.

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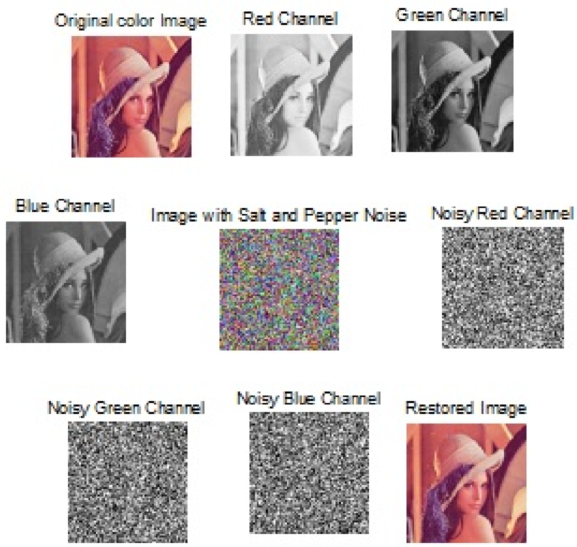

Figure-9. Qualitative performance of the proposedalgorithm corrupted by 90% salt and pepper noise Lena color image.

Figure-10. Performance of the proposed algorithm on rhino.avi video corrupted by 70% salt and pepper noise.

It was found that NTMMBF retains the global and local edges where other filter fails. At high noise densities that the DBA fails to preserve local edge and causes fading, the New [7] algorithm induces streaking. Hence the fine details are not preserved. Figure-4 (e)-(f) shows the blurring of images due to MDBUTMF and FEMF algorithm at high noise densities. Figure-5 show for the Original 1st frame of the 3D modelling of CT images of the Abdomen Video Sequence, the noisy frame and the result of obtained by Propose algorithm. From Figures 5(c) it can be seen that the proposed method performs well both in noise suppression and detail preservation and yields the best visual effect. Figure-6 show the reconstructed results of MRI scan brain and CT Scan Brain Image corrupted with 80% of noise of proposed algorithm. From the restored results the proposed filter produce excellent quality image for high noise density. The fine detail preservation of the NTMMBF algorithm is tested on a synthetic image. The synthetic image is constructed using 21visually differentiable gray scale image for human eyes. It is clear from the Figure-7 that the MDBUTMF filter fails at very high noise densities. The edge performance of the propped algorithm is assessed based on various regions in the synthetic image. The performance of the MDBUTMF on the constant regions such as first row, first rectangle (Black Color) is completely attenuated as shown in Figure-8(b).The region between white and lesser white is considered as a line edge also gets attenuated. The edge jittering also takes place in the edges of the various rectangles causing blurring of edges. The proposed algorithm attenuates the step edge by converting Black rectangle into a gray rectangle. The ramp edges are preserved by the proposed algorithm (values in all 21 gray levels and the information is preserved). The line edges are attenuated by the proposed algorithm. Hence the proposed algorithm has a good edge preservation property even after removing high density salt and pepper noise. The proposed algorithm works well even on color image in removing salt and pepper noise as shown in Figure-9. The proposed algorithm also works well in videos at higher noise densities as shown in Figure-10.

5. CONCLUSIONS

The performance of the proposed algorithm is found good in terms of PSNR and SSIM indicating good noise removal capability. The high Pratt's FOM indicates the good edge preservation capability even after removing high density salt and pepper noise. Hence an algorithm for the removal of high density fixed value impulse noise from medical images and videos is excellent compared to existing methods.

REFERENCES

[1] J. Astola and P. Kuosmaneen. 1997. Fundamentals of non linear Digital Filtering. Boca Raton, FL: CRC.

[2] H. Hwang and R. A. added. 1995. "Adaptive median filter: New algorithms and results," IEEE transaction on image processing, Vol. 4, No. 4, pp. 499-502, April.

[3] P. E. Ng and K. K. Ma. 2006. “A switching median filter with boundary discriminative noise detection for extremely corrupted images,” IEEE Transactions on image processing, vol.15, no.6, pp. 1506-1516, June.

[4] S. Zhang and M.A. Karim. 2002. “A new impulse detector for switching median filters,” IEEE Signal processing letters, Vol. 9, No. 11, pp. 360-363, November.

ARPN Journal of Engineering and Applied Sciences

[5] K.S. Srinivasan and D. Ebenezer. 2007. “A new fast and efficient decision based algorithm for the removal of high density impulse noise," IEEE Signal processing letters, Vol. l4, No.3, pp.189-192, March.

[6] S. Balasubramanian, S. Kalishwaran, R. Muthuraj, D. Ebenezer and V. Jayaraj. 2009. “An efficient Non linear cascade filtering algorithm for removal of high density salt and pepper noise in image and video sequence", International Conference on control, Automation, communication and Energy Conservation.

[7] K. Aiswarya, V. Jayaraj, and D. Ebenezer. 2010. “A new and efficient algorithm for the removal of high density salt and pepper noise in images and videos,” insecond international conference on computer modeling and simulation, pp. 409-413.

[8] S. Esakkirajan, T. Veerakumar, Adabala N. Subramanyam and C.H. Prem Chand. 2011. “Removal of high density Salt and pepper noise through modified decision based Unsymmetrical trimmed median filter." IEEE Signal processing letters, Vol. 18, No.5, pp.287-290, May.

[9] M.H. Hsieh, F.C. Cheng, M. C. Shie, and S. J. Ruan. 2013. “Fast and efficient median filter for removing 1-99% levels of salt-and-pepper noise in images,” Eng. Applicat. Artif.Intell.,vol.26, pp.1333–1338.

[10] K. K. V. Toh and N. A.M. Isa. 2010. “Noise adaptive fuzzy switching median filter for salt-and-pepper noise reduction,” IEEE Signal Process. Lett., Vol. 17, No. 3, pp. 281–284.

[11] A. Jourabloo, A. H. Feghahati and M. Jamzad. 2012. “New algorithms for recovering highly corrupted images with impulse noise,” Sci. Iranica, Vol.19, No.6, pp.1738–1745, 2012.