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A Novel Method for the Removal of High Density Salt and Pepper Noise in Grayscale and Color Images

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Abstract: Mean of unsymmetrical trimmed variants is used as a detector for the detection of fixed valued impulse noise is proposed. A fixed 3×3 window is kept constant for the increasing noise densities. The processed pixel is considered as noisy if the absolute difference between processed pixels and mean of unsymmetrical trimmed variants is greater than fixed threshold. Under high noise densities if the processed pixel is noisy and computed median is also noisy then replace the processed pixel with mean of unsymmetrical trimmed variants else if the processed pixel is noisy and computed median is not noisy then the corrupted pixel is replaced by computed median else the pixel is termed uncorrupted and it is left unaltered. If the entire pixels of the current processing window are noisy then global mean of the image is replaced as output. The Proposed Algorithm (PA) is tested on different varying detail images. The proposed algorithm is compared with the standard algorithms and found to give good results both qualitative and quantitatively for increasing noise densities.

Key words: Image processing, image denoising, image enhancement, image reconstruction, image restoration

INTRODUCTION

During the transmissions of images over channels, images are often corrupted by impulse noise due to faulty communication channels. The impulse noise is classified into salt and pepper noise and random valued impulse noise. If a salt and pepper noise is corrupted in a Gray scale image, pixels corrupted by positive impulses appear as white dots and those corrupted by negative impulses appear as black dots. Filtering is an essential part of any signal processing system which involves estimation of a signal degraded in this case by salt and pepper noise. Two types of filters are used for noise reduction 1. Linear filters accomplish noise reduction with blurring 2. Non-Linear filters have a good edge and image detail preservation properties that are highly desirable for image filtering. Median filters are especially suitable for reducing salt and pepper noise (Astola and Kusmanen, 1997). Median filter is a spatial filtering operation which uses a 2D mask that is applied to each pixel in the input image. Median filtering preserves sharp edges whereas linear low-pass filtering blurs such edges. Median filters are very efficient for smoothing of spiky noise. Median filter will preserve the edges and remove the low density impulse noise (Huang *et al*., 1979). Several special filters such as center weighted median filter, weighted median filter, progressive switching median filter and adaptive filter to remove low density fixed value impulse noise but fails to preserve edges if the noise density is high. These filters were proposed to improve the performance of the median filter by giving more weight to some selected pixel in the filtering window (Ko and Lee, 1991; Brownrigg, 1984; Abreau and Mitra, 1996; Chen and Ma, 1999; Eng and Ma, 2001; Wang and Zhang, 1999; Hwang and Haddad, 1995). Eng and Ma (2001) proposed a median based non linear adaptive algorithms under non stationary assumption to remove impulse noise in a images. This algorithm fails to overcome impulse noise in high frequency region such as edges in the images. Wang and Zhang (1999) gave a new class of median filters called progressive switching median filter. This filter uses switching scheme for detection of impulses thus only proportion of all filters is being filtered. The progressive methods employed detects the impulses and noise filtering is applied progressively. Chan *et al*. (2005) proposed a two phase algorithm where first phase uses adaptive filter to classify whether the pixels are noise free or not. The second phase is regulation methods which are applied to corrupted pixel and the outcome is that it preserves edges and suppresses noise (Chan *et al*., 2005). Srinivasan and Ebenezer (2007) proposed a decision based sorting algorithm where the corrupted pixels are replaced either by median or preprocessed pixel when other algorithms used only used median value for

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replacement. Hamza and Krim (2001) have proposed new filter for the removal of mixed and heavy tailed noise based on robust estimation statistics. Vijayakumar *et al.* (2008) proposed a robust estimation filter which works on two phases. The drawback of this approach is that it used the window of size 17×17 under high density impulse noise which is less complex comparing to Chan algorithm but still the operation needs large time for complexity and hardware. But the algorithm is capable of retrieving the image which is very highly corrupted (95% of noise) (Vijayakumar *et al*., 2008). Manikandan and Ebenezer (2008) came out with multilevel algorithms for different artifacts but uses only 5×5 matrix window size is maximum but the method is adaptive.

Roomi *et al.* (2007) proposed an iterative, selective based edge preserving filter that differentiate pixels as noisy and noise free pixel and specialized decision for finding noisy edges and noise free edges which uses Blur metric for iteration. Florencio and Schafer (1994) roposed switching schemes where it employed no filtering to preserve true pixels and a simple median filter to remove impulse noise. Roomi *et al.* (2006) proposed a method which gave normalized, truncated, trimmed and scaled Gaussian weighed function as weights using statistical estimation based on the non noisy neighborhood pixel and the filter is applied recursively on noisy pixels and it uses adaptive filtering approach. Wang *et al.* (2005) used a novel impulse detection techniques which detects the noisy pixels by sorting the window and values less than the minimum of the window and the value greater than the maximum of the window is considered to be noisy.

Xu *et al.* (2004) proposed a new two pass median filter, the first pass is a mere median filter and the output of the first pass is to clean the noisy image and estimate the amplitude of impulse noise. In second pass an adaptive process is carried out to selectively replace some pixels by original pixel values. Modified Decision Based Unsymmetrical Trimmed Median Filter (MDBUTMF) (Esakkirajan *et al.*, 2011) is proposed to eliminate the flaw of streaking and edge preservation in other methods. This algorithm replaced the corrupted pixel with median of the trimmed output. At very high noise densities the filter smudges the edge. Hence, a suitable impulse detection algorithm followed by a correction methodology is a need for any good filter for better result.

Noise Model: The Noise Model for salt and pepper noise is given as follows. If (0; 255) denote the dynamic range of y', i.e., $0 \le y'ij \le 255$ for all (i, j) then they are denoted by salt and pepper noise: the gray level of y at pixel location (i, j) is shown in the equation:

$$yij = \begin{cases} 0 \text{ with probability } p \\ y'ij \text{ with probability } 1-p-q; \\ 255 \text{ with probability } q \end{cases}$$

where, s = p + q denotes the salt and pepper noise level (Bovik, 2000).

Proposed algorithm

Unsymmetrical Trimmed filters: The crux behind the above filter is to eliminate the outliers inside the current window and preserve edges at high noise densities. All the pixels of an image lie between the dynamic ranges [0, 255] (8 bit image). Hence, rank order the pixels of the current window and trim (eliminate) on either side for 0 or 255. The elements that are not outliers survive the elimination process. The arithmetic mean or median or midpoint of the untrimmed pixels from the above operation is the idea behind un-symmetrical trimmed filters. Here, the trimming of values is done un-symmetrically based on the local pixel information.

Unsymmetrical Trimmed Midpoint Filters (UTMPF): Consider a 3×3 window from the corrupted image. Order the pixels of the current window in increasing order. Now perform trimming on either side of the ordered array for outliers. The elements that are not eliminated are considered as non noisy candidates of the processed window. The midpoint of the untrimmed pixels from the above operation is the anatomy of un-symmetrical trimmed midpoint filters.

Unsymmetrical Trimmed Median Filters (UTMF): Consider a 3×3 window from the corrupted image. Arrange the pixels of the processing window in ascending order. Now perform trimming on either side of the ordered array for outliers. The elements that are not eliminated are considered as non noisy candidates of the processed window. The median of the untrimmed pixels from the above operation is the basic idea behind of un-symmetrical trimmed median filters (Esakkirajan *et al.*, 2011).

Unsymmetrical Trimmed mean filters (UTmeanf): Consider a 3×3 window from the corrupted image. Arrange the pixels of the processing window in ascending order. Now perform trimming on either side of the ordered array for outliers. The elements that are not eliminated are considered as non noisy candidates of the processed window. The mean of the untrimmed pixels from the above operation is the basic idea behind of Un-Symmetrical Trimmed Mean filters. The above are termed as unsymmetrical trimmed variants.

Proposed algorithm: The brief illustration of the proposed algorithm is as follows:

Step 1: Choose 2D window of size 3×3. The processed pixel in current window is assumed as pxy.

Step 2: Sort the 2D window data in ascending order which is given by S. Now convert sorted 2D array into 1D array. Smed is the median of the sorted array.

Step 3: Mean of unsymmetrical trimmed variants.

Initialize two counters, forward counter (F) and reverse counter (L) with 1 and 9, respectively. When a 0 or 255 are encountered inside the sorted array (S), F is incremented by 1 or L is decremented by 1, respectively. The resulting array will be holding non noisy pixels of the current window. Find the midpoint, median and the mean of the non noisy pixels in the current which is coined as Unsymmetrical Trimmed Variants (MUTV). At very high noise densities the current processing window has no non noisy pixels in the current processing window then the global mean of the image.

Step 4: Salt and pepper noise detection using mean of Unsymmetrical Trimmed Variants (MUTV).

Case 1: If the absolute difference between the processed pixel and Mean of Unsymmetrical Trimmed Variants (MUTV) which is stored in DEL is greater than the fixed Threshold (T) then pixel is considered as noisy. As illustrated in Eq. 1:

$$\text{If } |P(x, y) - MUTV| > T \quad (1)$$

Case 2: If the case 1 is true find the absolute difference between the median and Mean of Unsymmetrical Trimmed Variants (MUTV). Check the difference is greater than the fixed Threshold (T1) then median is considered as noisy as shown in Eq. 2. Case 2 is done for high noise densities where the computed median is also noisy:

$$\text{If } |Smed - MUTV| > T1 \quad (2)$$

Step 4 (Salt and pepper noise correction logic): If the case 1 |P (x, y)−MUTV|>T is true then check for the second case 2 |Smed−MUTV|>T1. If both the condition are true then processed pixel and computed median is noisy.

Hence, replace the corrupted pixel with median of Unsymmetrical trimmed midpoint. If condition 1 is true and condition 2 is false then corrupted pixel is replaced with the median of the sorted array.If both Case 1 and 2 fails then the pixel is termed as non noisy. The pixel is left unaltered.

Step 5: If there are no non noisy pixels in the current processing window then the global mean of the image is used as detector in the place of MUTV and the process is repeated as above.

Step 6: The above process is repeated for the entire image.

MATERIALS AND METHODS

The bigger matrix refers to image and values enclosed inside a rectangle is considered to be the current processing window. The element encircled refers to processed pixel.

0	0	255	0	255
94	177	205	155	255
0	0	255	25	123
0	0	187	124	255
0	255	255	255	255

Corrupted image segment

0	0	255	0	255
94	177	205	155	255
0	0	136	25	123
0	0	187	124	255
0	255	255	255	255

Restored image segment

Case a: Initialize forward counter F = 1 and reverse counter L = 9. Convert the 2D array into 1D array and sort the converted array. F and L counter moves in forward and reverse directions, respectively. When a 0 is detected F is incremented by 1 and when a 255 is detected L is decremented by 1.

- Unsorted array: 177 0 0 205 255 187 155 25 124
- Sorted array Sxy: 0 0 25 124 155 177 187 205 255

Here for the given example Unsymmetrical Trimmed mean filter (UTmeanf) is 145, UTMPF is 106, UTMF is 166 and the mean of all the above is termed as Unsymmetrical Trimmed mean (UTVmeanf) which is 136. The median Smed value is 155. Now check for the presence of 0 or 255 in the sorted array. Every time a 0 is detected F is incremented by 1 and if 255 is detected L is decremented by 1. In the above example there is two 0 and one 255. Hence, F is incremented by two times and L is decremented by one time. Now finally F is holding 3 and L is holding 8. Now the variable DET is assigned with the UTVmean which is 136. Now perform first step detection |255-136|>40. This condition is true. The Second condition is checked |155-136|>20 and the second condition is also true. Hence, the pixel is considered as noisy and median is also noisy. The corrupted pixel is replaced by UTVmean, i.e., output = 136.

0	0	255	0	255
94	177	0	0	125
0	0	185	0	255
0	0	102	255	255
0	255	255	204	255

Corrupted image segment

0	0	255	0	255
94	177	0	0	125
0	0	185	125	255
0	0	102	255	255
0	255	255	204	255

Restored image segment

Case b: Initialize forward counter F = 1 and reverse counter L = 9. Convert the 2D array into 1D array and sort the converted array. When a 0 is detected F is incremented by 1 and when a 255 is detected L is decremented by 1.

- Unsorted array: 0 185 102 0 0 255 125 255 255
- Sorted array Sxy: 0 0 0 102 125 185 255 255

Here for the given example Unsymmetrical Trimmed mean filter (UTmeanf) is 137, UTMPF is 143, UTMF is 125 and the mean of all the above is termed as Mean of Unsymmetrical Variants (MUTV) which is 135. The median Smed value is 125. Now check for the presence of 0 or 255 in the sorted array. Every time a 0 is detected F is incremented by 1 and if 255 are detected L is decremented by 1. In the above example there is three 0 and three 255.

Hence, F is incremented by three times and L is decremented by three times. Now finally F is holding 4 and L is holding 6. Now the variable DET is assigned with the median of the rank ordered unsymmetrical trimmed output. Now perform first step detection |0-135|>40. This condition is true. The second condition is checked |125-135|>20 and the second condition is false. Hence, the processed pixel is noisy and the computed median is considered as non noisy. Hence, the corrupted pixel is replaced median ie 125 output = 125.

0	0	255	0	255
104	119	255	255	255
0	103	255	255	123
0	122	255	124	255
0	255	255	255	255

Corrupted image segment

0	0	255	0	255
104	119	255	255	255
0	103	255	255	123
0	122	255	124	255
0	255	255	255	255

Restored image segment

Case c: Initialize F = 1 and L = 9. Find all the unsymmetrical trimmed variants for the current processing window. After sorting the current window in ascending order, the counters propagate in the 1D array resulting in holding count = 6, F = 4 and L = 6. Here for the given example Unsymmetrical Trimmed mean filter (UTmeanf) is 163, UTMPF is 111, UTMF is 104 and the mean of all the above is termed as Mean of Unsymmetrical Trimmed mean (MUTV) which is 126. The median Smed value is 104. Now perform impulse detection |119-104|>40. This condition is false and hence processed pixel is considered as non noisy hence, left unaltered.

255	255	255	0	255
255	255	255	165	255
255	255	255	255	147
0	122	255	124	255
0	255	255	255	255

Corrupted image segment

255	255	255	0	255
255	139	255	255	255
255	255	255	255	123
0	122	255	124	255
0	255	255	255	255

Restored image segment

Case d: Initially calculate the global mean by finding the non noisy pixel in the given image (as shown in the example we have illustrated with the corrupted image segment). Find the arithmetic mean of non noisy pixel in the given image. If the current processing window consists of all the pixel elements to be 0 or 255 then this case is obtained. From the above example the number of non noisy pixels in the window is 165, 147, 122, 124 and the mean of these pixels is computed as 139. If the current processing window holds all nine pixel elements as 0 or 255 then the forward counter points to 10 or the reverse counter points to 0, respectively. Under this circumstance the global mean is taken as detector. |255-139|>40, this condition is true hence the processed pixel is noisy. The computed median Smed is also 255. Hence, |255-139|>20 gives the result that the computed median is also noisy. Hence, the global mean 139 is replaced in the output.

RESULTS AND DISCUSSION

The quantitative performance of the proposed algorithm is evaluated based on Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE) and Image Enhancement Factor (IEF) which is given in Eq. 3-5, respectively:

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

$$MSE = \frac{\sum_i \sum_j (r_{ij} - x_{ij})^2}{M \times N} \quad (4)$$

$$IEF = \frac{\left(\sum_i \sum_j n_{ij} - r_{ij}\right)^2}{\left(\sum_i \sum_j x_{ij} - r_{ij}\right)^2} \quad (5)$$

Where:

r = Original image

n = Corrupted image

x = Restored image

M×N = The size of processed image

The Linear filters used for the comparison are Mean filter, Midpoint filter, Detail Preserving filter, Alpha Trimmed Mean filter, Mean as Detector, Unsymmetrical Trimmed Mean filter. The Non-Linear filters used for the comparison are SMF 3×3, SMF 5×5, Adaptive Mean Filter (AMF), Center Weighted median Filter (CWF), Threshold Decomposition Filter (TDF), Progressive Switched Median Filter (PSMF), Decision Based Filter (DBF), Modified Decision Based Unsymmetrical Trimmed Mean Filter (MDBUTMF). The qualitative performance of the proposed algorithm is tested on various images (images are chosen as per the details of the image).

Quantitative analysis is made by varying noise densities in steps of ten from 10-90% on low detail, medium detail and high detail images and comparisons are made in terms of PSNR and IEF. Results and graphs are given in Table 1-4 and Fig. 1-5, respectively.

Table 1: Performance (PSNR and IEF) of various linear filters for fixed valued impulse noise removal on Lena image

	PSNR							IEF						
ND (%)	Mean FILT	MIDPT FILT	DPF	αTMF α = 4	Mean DET	UTMF	PA	Mean FILT	MIDPT FILT	DPF	αTMF α = 4	Mean DET	UTMF	PA
10	24.0	14.3	33.8	31.3	37.30	32.6	39.3	7.30	0.78	69.1	39.90	157.0	52.1	242.9
20	20.9	13.3	27.5	28.9	30.70	32.3	36.3	7.10	1.23	32.4	44.60	68.0	98.2	247.1
30	18.9	13.3	23.1	25.8	24.20	31.9	34.4	6.73	1.86	17.8	33.10	22.9	132.0	239.0
40	17.4	13.6	19.7	22.7	19.20	31.3	33.0	6.29	2.65	10.7	21.30	9.6	156.0	230.8
50	16.1	13.9	16.8	19.5	15.50	30.6	31.7	5.91	3.54	6.8	12.90	5.0	166.0	214.8
60	15.1	14.1	14.5	17.1	12.40	29.5	30.5	5.56	4.46	4.8	8.90	3.0	155.0	194.9
70	14.1	14.2	12.5	14.7	10.00	28.5	29.2	5.22	5.37	3.5	5.97	2.0	141.0	167.4
80	13.4	14.3	10.7	12.7	8.21	26.3	27.4	5.02	6.25	2.7	4.29	1.5	99.2	125.5
90	12.6	14.3	9.2	11.1	6.73	23.3	24.9	4.73	7.05	2.1	3.34	1.2	59.1	80.0

Table 2: Performance (PSNR) of various non linear filters for fixed valued impulse noise removal on Lena image

ND (%)	SMF (3×3)	SMF (5×5)	AMF	PSMF	CWF	TDF	DBA	MD (BUTMF)	PA
10	34.9	32.4	39.30	38.8	35.20	32.7	39.0	43.1	39.3
20	30.3	31.0	36.90	33.4	28.10	27.8	36.8	41.2	36.3
30	23.9	29.2	34.60	29.4	22.20	23.3	35.8	37.9	34.4
40	19.0	27.3	32.20	25.4	17.80	19.0	33.2	36.4	33.0
50	15.9	24.1	27.30	23.3	14.30	15.3	31.4	34.3	31.7
60	12.3	18.8	21.60	20.2	11.70	12.4	29.6	32.1	30.5
70	10.0	14.2	16.60	9.9	9.62	10.0	27.8	29.6	29.2
80	8.1	10.5	12.70	8.1	7.97	8.1	25.5	26.8	27.4
90	6.6	7.5	9.86	6.6	6.56	6.6	21.8	22.4	24.9

Table 3: Performance (IEF) of various non linear filters for fixed valued impulse noise removal on Lena image

ND (%)	SMF (3×3)	SMF (5×5)	AMF	PSMF	CWF	TDF	DBA	MD (BUTMF)	PA
10	89.0	50.9	246.8	219.8	95.9	38.2	230.3	630.8	242.9
20	61.0	73.7	281.3	124.9	37.2	25.0	276.3	762.7	247.1
30	21.4	72.9	254.4	74.5	14.4	19.6	331.1	665.5	239.0
40	9.1	61.8	192.9	40.1	6.9	9.2	242.3	521.0	230.8
50	4.9	36.5	78.3	39.6	3.9	4.8	199.9	384.8	214.8
60	2.9	13.2	25.0	19.1	2.5	2.9	157.8	282.1	194.9
70	2.0	5.3	9.1	1.9	1.8	2.0	123.0	183.4	167.4
80	1.4	2.6	4.3	1.4	1.4	1.4	81.5	110.5	125.5
90	1.1	1.4	2.5	1.1	1.1	1.1	39.1	45.5	80.0

Table 4: Performance (MSE) of various non linear filters for fixed valued impulse noise removal on Lena image

ND (%)	SMF (3×3)	SMF (5×5)	AMF	PSMF	CWF	TDF	DBA	MD (BUTMF)	PA
10	20.9	36.5	7.4	8.4	20.3	26.5	8.1	2.0	7.6
20	60.6	50.4	13.1	29.6	102.7	105.5	13.4	4.9	15.1
30	259.3	76.9	22.1	74.5	409.9	286.6	16.9	8.2	23.2
40	814.2	119.9	38.5	185.2	1082.3	800.9	30.6	14.2	32.4
50	1877.0	252.9	118.0	187.5	2367.0	1909.9	46.4	23.9	43.4
60	3776.0	844.0	443.0	484.2	4295.0	3732.0	70.7	39.6	57.2
70	6637.0	2440.0	1421.0	600.0	7109.0	6450.7	105.9	69.1	77.7
80	9945.0	5700.0	3413.0	1000.0	10624.0	9843.5	182.6	134.6	118.2
90	14179.0	11400.0	6708.0	1396.0	14513.0	13922.0	427.1	369.2	209.1

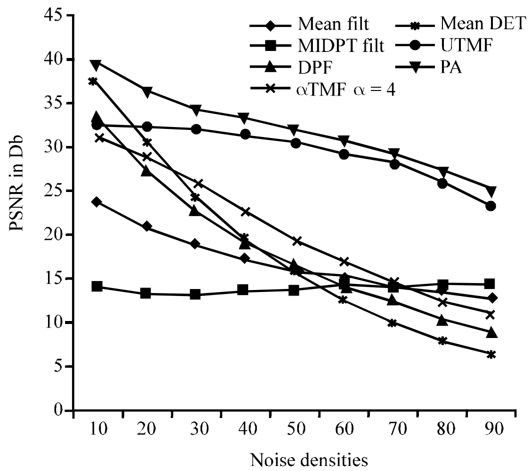

Fig. 1: Performance of various Linear filter on Lena image for PSNR

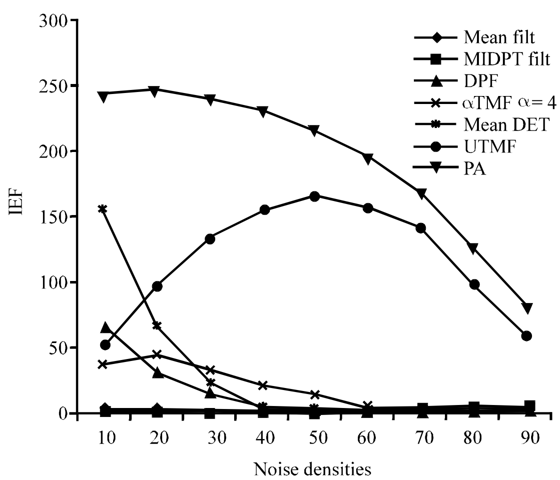

Fig. 2: Performance of various Linear filter on Lena image for IEF

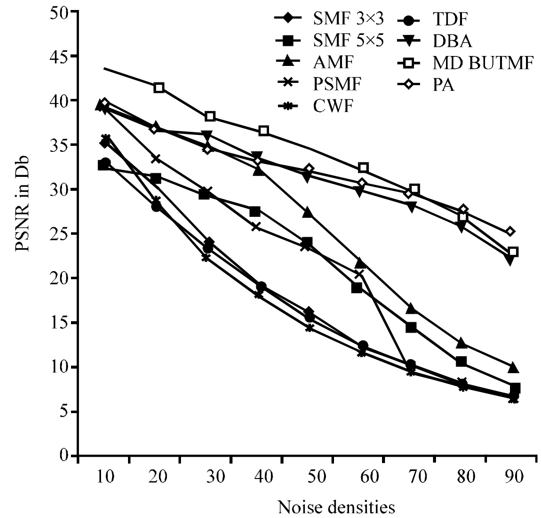

Fig. 3: Performance of various non-linear filter on Lena image for PSNRc

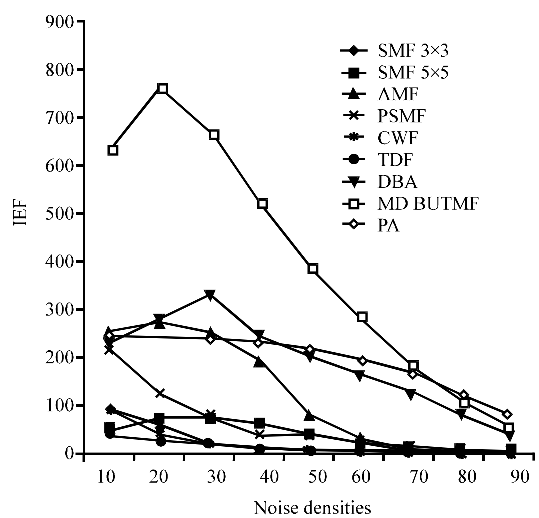

Fig. 4: Performance of various non-linear filter on Lena image for IEF

Figure 6 and 7 gives the qualitative performance of the proposed algorithm in terms of salt and pepper noise elimination in both Grayscale and color images. All the simulation is done in dual CPU E2140@1.6 Ghz with 1GB RAM capacity. Better results were obtained when the pre-defined threshold T was between 20 and 40. And the second threshold T1 was between 15 and 30. The reason for keeping window size constant for increasing noise densities is that even at high noise densities there are occurrences of certain pixel information within the fixed 3×3 window which are useful in restoring the corrupted pixels back.

From the Table 1, researchers infer that for the proposed algorithm has a very good PSNR and IEF value is very high indicating how good is the proposed algorithm in eliminating salt and pepper noise effectively even at high noise densities when compared to standard linear filter. Table 2-4 give the comparison of various non linear filters over the proposed algorithm on PSNR, IEF and MSE. It was found that the proposed algorithm fairs better in comparison with other Non-Linear filters. The proposed algorithm performs on par for low density salt and pepper noise when compared to recently proposed filters such as DBA and MDBUTMF but for high noise densities the proposed algorithm fairs better than DBA and MDBUTMF for all the three quantitative performance measure. At very high noise densities both the Linear and Non-Linear filter fails to eliminate the noise or induce streaking (as in the case of DBA) or fading effect (as in the case of MDBUTMF). The proposed algorithm does not induce any of these effects at very high noise densities. Table 5 gives the comparison of various cascaded algorithm over the proposed algorithm. It was found that the proposed algorithm faired less on comparison to the various cascaded Algorithm but the entire cascaded algorithms proposed so far has two stages for the elimination of salt and pepper noise. First stage is a non linear filter and the second stage is either linear or non-linear filter. All the cascaded filters were effective only after using two stages of filters. The proposed algorithm is a single level algorithm that eliminates salt and pepper noise even at high noise densities. It was found graphically from Fig. 1 and 2 that the proposed algorithm outclasses all the traditional linear filters at low, medium and high detailed image. Figure 3-5 give the performance of various non linear filters graphically in terms of PSNR, IEF and MSE, respectively. It was found that the proposed algorithm performs better in eliminating high density salt and pepper noise at higher noise densities. The proposed algorithm is outclassed by MDBUTMF at low and medium noise densities but for very high noise densities the proposed algorithm is better than other algorithms. Figure 6 indicate the qualitative aspect of the proposed algorithm for Lena image corrupted by 70% salt and pepper noise for gray scale images. It was found that the proposed algorithm is on par with recently proposed filters and better than the traditional filters. Figure 7 gives the qualitative performance of various filters corrupted by salt and pepper noise on baboon color image. It is vivid from the

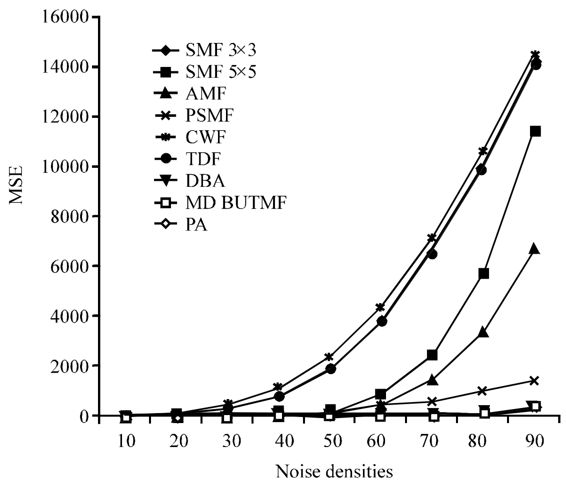

Fig. 5: Performance of various Non-Linear filter on Lena image for MSE

Table 5: Performance (PSNR) of various cascaded filters for fixed valued impulse noise removal on Lena image

ND (%)	CDBM (UTMF)	CUD (BMPF)	CUTMF	PA
10	32.4	32.30	34.40	39.3
20	32.1	32.10	34.30	36.3
30	31.8	31.83	33.90	34.4
40	31.4	31.48	33.30	33.0
50	31.0	31.11	32.60	31.7
60	30.5	30.38	31.80	30.5
70	29.7	30.21	30.90	29.2
80	28.5	29.35	29.40	27.4
90	26.0	27.40	26.26	24.9

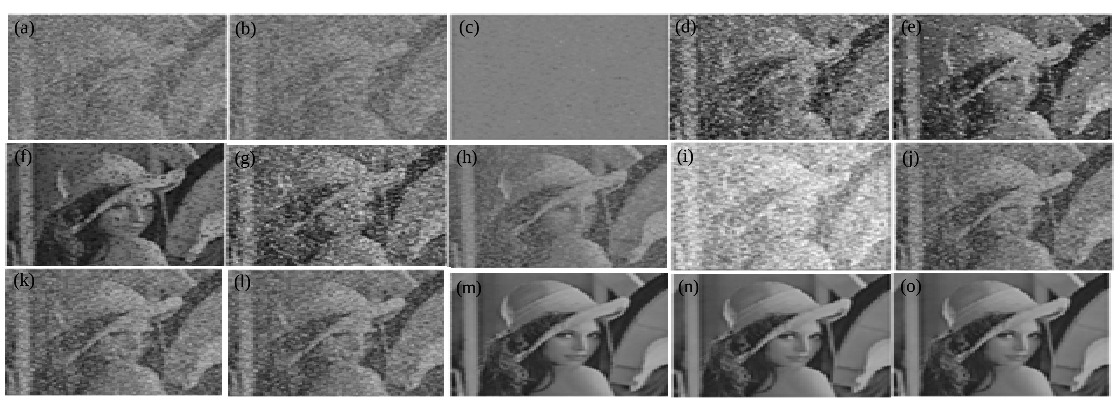

Fig. 6: Performance of various filter on Lena image corupted 70% fixed value impulse noise; a) 70% noise corrupted Lena image; b) Arithmetic Mean filter; c) Mid Point filter; d) SMF 3×3; e) SMF (5×5); f) Adaptive Median Filter (AMF); g) Center Weighted Median filter (CWF); h) Threshold Decomposition Filter (TDF); i) Alpha Trimmed Mean Filter (αTMF); j) Detail Preserving Filter (DPF); k) Mean as Detector (Mean DET); l) Median as Detector (MED DET); m) Decision Based Filter (DBF); n) Modified Decision Based Unsymmetrical Trimmed Mean Filter (MDBUTMF) and o) Proposed algorithm

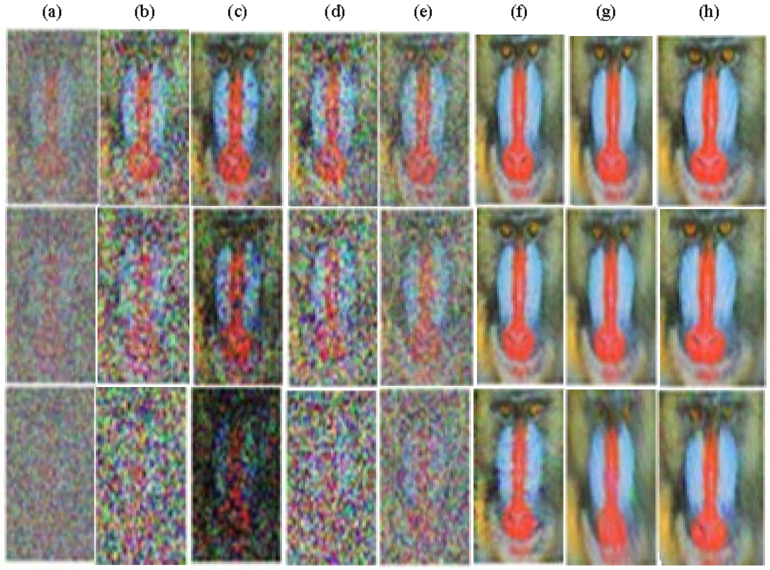

Fig. 7: Performance of various filter on baboon color image for 70-90% for fixed value impulse noise from row 1-3, respectively column a-h give the performance of various filters; a) noise corrupted baboon image; b) SMF 3×3; c) Adaptive Median Filter (AMF); d) Progressive Switched Median Filter (PSMF); e) Detail Preserving Filter (DPF); f) Decision Based Filter (DBF); g) Modified Decision Based Unsymmetrical Trimmed Mean Filter (MDBUTMF) and h) Proposed algorithm

images that the traditional filters fails to eliminate the salt and pepper noise at very high noise densities. The decision based filter in column 6 of Fig. 7 exhibit streaking at high noise densities. The qualitative result of MDBUTM filter is given in column 7 of Fig. 7 which exhibits fading. Column 8 of Fig. 7 gives the qualitative performance of proposed algorithm. The proposed algorithm is very good in eliminating salt and pepper noise even at very high noise densities.

CONCLUSION

A 3×3 fixed window is proposed with thresholds based detector is proposed which gives excellent noise suppression capabilities in both gray scale and color images. The computed mean of unsymmetrical trimmed mean, midpoint and median is very close to median and hence the proposed algorithm is good in preserving edges of the images. The proposed algorithm outclasses many Linear filters, Detector Based filters, Standard filters and Existing Non-Linear filters both in quantitative and qualitative aspects. The proposed algorithm would also require less number of hardware for implementation.

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