High Density Impulse Noise Removal Using Robust Estimation Based Filter

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Abstract— **In this paper a novel method for removing fixed value impulse noise using robust estimation based filter is proposed. The function of the proposed filter is to detect the outlier pixels and restore the original value using robust estimation. Comparison shows the proposed filter effectively removes the impulse noise with significant image quality compared with the standard median filter, center weighted median filter, weighted median filter, progressive switching median filter, adaptive median filter and recently proposed methods. The visual and quantitative results show that the performance of the proposed filter in the preservation of edges and details is better even at noise level as high as 98%.**

Index Terms— **High density Impulse noise, Robust estimation.**

I. Introduction

Generally impulse noise contaminates images during data acquisition by camera sensors and transmission in the communication channel. In the case of images corrupted by fixed value impulse noise, the noisy pixels can take only the maximum and the minimum values in the dynamic range [1]. In images, edge contains essential information. Filtering techniques should preserve the edge information also. In general, linear filtering techniques available for image denoising tend to blur the edges. An important non linear filter that will preserve the edges and remove impulse noise is standard median filter [2]. But if the noise density increases the median filter does not work well. Specialized median filters [3]-[11] such as center weighted median filter [3] weighted median filter [4], progressive switching median filter [8], and adaptive median filter [9] remove low to medium density fixed value impulse noise but fail to preserve edges if noise density increases.

In [10] Chan and Nikolova proposed a two-phase algorithm. In the first phase of this algorithm, an adaptive median filter (AMF) is used to classify corrupted and uncorrupted pixels; in the second phase, specialized regularization method is applied to the noisy pixels to preserve the edges and noise suppression. The main drawback of this method is that the processing time is very high because it uses a very large window size of 39X39 in both phases to obtain the optimum output; in addition, more complex circuitry is needed for their implementation. In [11] Srinivasan and Ebenezer proposed a sorting based algorithm in which the corrupted pixels are replaced by either the median pixel or neighborhood pixel in contrast to AMF and other existing algorithms that use only median values for replacement of corrupted pixels. At higher noise densities this algorithm does not preserve edge and fine details satisfactorily. In this paper a novel robust estimation based filter is proposed to remove fixed value impulse noise effectively. The proposed filter removes low to high density fixed value impulse noise with edge and detail preservation upto a noise density of 90%.

The outline of this paper is as follows: Section II discusses the background work. Section III discusses the proposed algorithm to remove fixed value impulse noise. Section IV compares the results of our method with other methods and conclusion is presented in section V.

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II. Background

Recently, nonlinear estimation techniques have been gaining popularity for the problem of image denoising. The well-known Wiener filter for minimum mean-square error (MMSE) estimation is designed under the assumption of wide-sense stationary signal and noise (a random process is said to be stationary when its statistical characteristics are spatially invariant) [12]. For most of the natural images, the stationary condition is not satisfied. In the past, many of the noise removing filters were designed with the stationarity assumption. These filters remove noise but tend to blur edges and fine details. In [7] Eng and Ma proposed a median based nonlinear adaptive algorithms under non-stationary assumption to remove impulse noise in images. This algorithm fails to remove impulse noise in high frequency regions such as edges in the image.

To overcome the above mentioned difficulties a nonlinear estimation technique for the problem of image denoising has been developed based on robust statistics. Robust statistics addresses the problem of estimation when the idealized assumptions about a system are occasionally violated. The contaminating noise in an image is considered as a violation of the assumption of spatial coherence of the image intensities and is treated as an outlier random variable [12]. In [14] Kashyap and Eom developed a robust parameter estimation algorithm for the image model that contains a mixture of Gaussian and impulsive noise.

Recently in [15] Hamza and Krim , [16] Sardy et al. and [17] Ponomaryov et al. have proposed some new filters for removing mixed and heavy tailed noise based on robust

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statistics. In [12] a robust estimation based filter is proposed to remove low to medium density Gaussian noise with detail preservation. In this paper a robust estimation based filter is proposed to remove low to high density impulse noise present in images.

Robustness is measured using two parameters; influence curve and breakdown point. The influence curve tells us how an infinitesimal proportion of contamination affects the estimate in large samples. Breakdown point is the largest possible fraction of observations for which there is a bound on the change of the estimate when that fraction of the sample is altered without restrictions.

To increase robustness, an estimator must be more forgiving about outlying measurements. In this paper, the redescending estimators are considered for which the influence of outliers tends to zero with increasing distance [13]. Lorentzian estimator has an Influence function which tends to zero for increasing estimation distance and maximum breakdown value; therefore it can be used to estimate the original image from noise corrupted image.

The Lorentzian estimator and its influence function are shown in equations (1) and (2)

$$\rho(\mathrm{x}) = \log(1 + \frac{\mathrm{x}^2}{2\sigma^2}) \qquad (1)$$

$$\psi_{\mathrm{lorentz}}(\mathrm{x}) = \frac{2\mathrm{x}}{2\sigma^2 + \mathrm{x}^2} \qquad (2)$$

Robust estimation is applied to estimate image intensity values in image denoising. Image model is assumed non stationary and, thus, the image pixels are taken from fixed windows and robust estimation algorithm is applied to each window.

III. Proposed Algorithm

In this proposed approach impulses are first detected based on the minimum, median and maximum value in the selected window. If the median pixel and the current pixel lie inside the dynamic range [0,255] then it is considered as noise free pixel. Otherwise it is considered as a noisy pixel and replaced by an estimated value.

Let Y denote the noise corrupted image. For each pixel $Y_{i,j}$, a 2-D sliding window Sij of size 3X3 is selected in such a way that the current pixel Yij lies at the center of the sliding window. Assume S_{min} , S_{med}, and S_{max} are the minimum, median and maximum gray level values in the sliding window.

STEP 1: Initialize WSIZE = 3.

STEP 2: Compute S_{min}, S_{med} and S_{max}, in $S_{i,j.}$

STEP 3: If $S_{min} < S_{med} < S_{max}$, then go to step 5. Otherwise, set WSIZE=WSIZE+2 until the maximum allowed size is reached.

STEP 4: If WSIZE ≤ $WSIZE_{max}$, go to step 2. Otherwise, choose pixels in the window such that $S_{min} < S_{i,j} < S_{max}$ and go to Step 6.

STEP 5: If $S_{min} < Y_{i,j} < S_{max}$, then $Y_{i,j}$ is not a noise candidate, else choose pixels in the window such that $S_{min} < S_{i,j} < S_{max}$ and go to Step 6.

STEP 6: Difference of each pixel inside the window with respect to median value of the window (x) is calculated and the influence function.

$$\psi(x) = 2x/(2\sigma^2 + x^2) \qquad (3)$$

is evaluated, where σ is outlier rejection point is given by,

$$\sigma = \frac{\tau s}{\sqrt{2}} \qquad (4)$$

where τs is the maximum expected outlier, σ_N is the local estimate of the image standard deviation

$$\tau s = \zeta \sigma_N \qquad (5)$$

Here ζ is a smoothening factor and it is chosen as 0.3 for low to medium smoothening.

STEP 7: Pixel is estimated using equations (6) and (7)

$$S1 = \sum_{l \in L} \frac{pixel(l) * \psi(x)}{x} \qquad (6)$$

$$S2 = \sum_{l \in L} \frac{\psi(x)}{x} \qquad (7)$$

where L is number of pixels in the window, Ratio of S1 and S2 gives the estimated pixel value. Table I shows the maximum window size used for different noise densities.

Table I Noise Density (p) vs Maximum window size

Noise Density	Maximum size ($WSIZE_{max}$)
10%≤p≤ 20%	3x3
20%<p≤45%	5x5
45%<p≤75%	7x7
75%<p≤80%	9x9
80%<p≤85%	11x11
85%<p≤90%	15x15
90%<p≤98%	17x17

IV. Results

The proposed filter is tested using the Lena, bridge, pepper and Elaine of 512x512 8 bits /pixel images. These images corrupted by fixed value impulse noise at various noise densities and performance is measured using the following parameters; Peak signal-to-noise ratio (PSNR), Mean absolute error (MAE), Mean square error (MSE)., Structural Similarity Index (SSIM) and correlation. These are defined by the following formulas,

$$\mathrm{PSNR} = 10 \log_{10}\left(\frac{255^2}{\mathrm{MSE}}\right) \qquad (8)$$

$$\mathrm{MAE} = \frac{1}{MN} \sum_{i,j} \left| y_{ij} - x_{ij} \right| \quad (9)$$

$$\mathrm{MSE} = \frac{1}{MN} \sum_{ij} (y_{ij} - x_{ij})^2 \quad (10)$$

$$\mathrm{SSIM}(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)} \quad (11)$$

$$COR = \frac{\sum_{ij}^{MN} (y_{ij} - \mu_y)(x_{ij} - \mu_x)}{\sqrt{\sum_{ij}^{MN} (y_{ij} - \mu_y)^2 \sum_{ij}^{MN} (x_{ij} - \mu_x)^2}} \quad (12)$$

Where $y_{i,j}$ and $x_{i,j}$ denote the pixel values of the restored image and the original image, respectively. MxN is the size of the image. μ_x and μ_y represent the mean of the original and restored images. σ_x and σ_y represent the standard deviation of the original and restored images. σ_{xy} represent the co-standard deviation of the original and restored image. C_1 and C_2 represent small constant are added to avoid instability [18].

In order to check the visual quality, Lena and bridge images are corrupted by 70% impulse noise and applied to various filters such as standard median filter (SMF), Center weighted median filter (CWMF), weighted median filter (WMF), progressive switching median filter (PSMF), adaptive median filter (AMF), Srini-Ebenezer method, Raymond chan method and proposed algorithm.

Restoration results are shown in figure 1 and figure 2 for Lena and bridge image respectively. The visual quality clearly shows that the proposed filter out perform than the other methods in terms of noise removal and edge preservation. Table II, III, and IV shows the comparison of PSNR, MAE and MSE of various filters for the Lena image corrupted by different noise density. Figure 3, 4 and 5 shows the comparison graph of PSNR, MAE and MSE of various filters for the lena image for different noise densities.

Figure 6 and figure 7 shows the restoration results of applying recently proposed filters and the proposed algorithm to the lena image and bridge image corrupted by 90% fixed value impulse noise respectively.

The visual quality results show that the proposed filter remove impulse noise completely with out any blurring and sticking effect (shown in the srini-ebenezer method) as compared with other filters. From the comparison tables and graphs, the proposed filter produce high peak signal to noise ration (PSNR), low mean square error (MSE) and low mean absolute error (MAE) than the other existing methods.

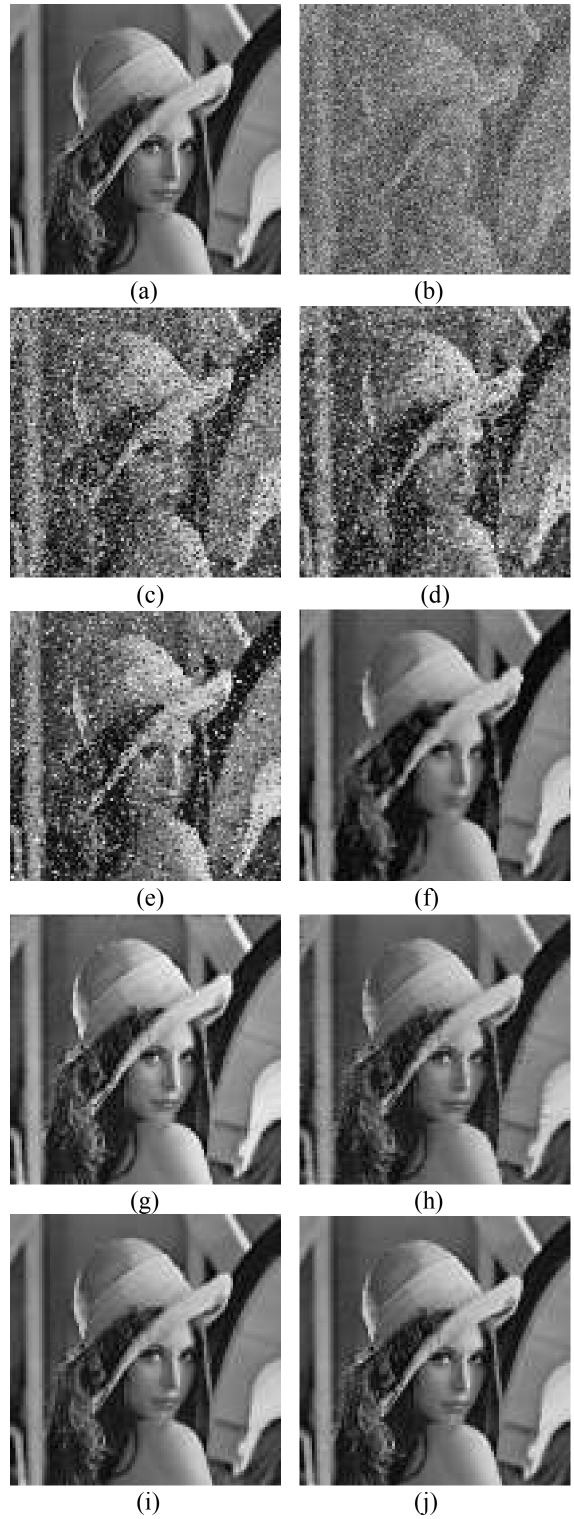


Figure.1 (a) Original Lena Image (b) Corrupted Lena Image with Noise density 70%. Restoration Results of (c) SMF (d) CWMF (e) WMF (f) PSMF (g) AMF (h) Srini-Ebenezer Method (i) Raymond Chan Method (j) Proposed Method.

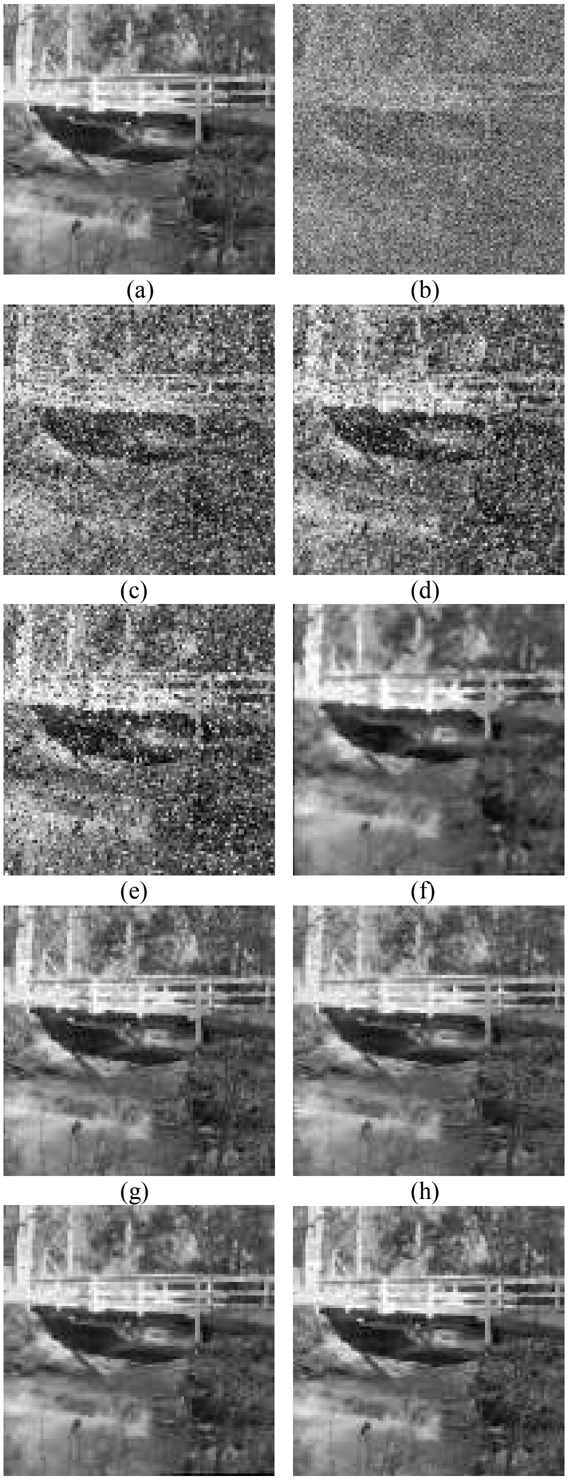


Figure.2 (a) Original Bridge Image (b) Corrupted Bridge Image with Noise density 70%. Restoration Results of (c) SMF (d) CWMF (e) WMF (f) PSMF (g) AMF (h) Srini-Ebenezer Method (i) Raymond Chan Method (j) Proposed Method.

Table –II
Comparison table of **PSNR** of different filters for lena.jpg image

Noise Density	SMF	CWMF	WMF	PSMF	AMF	Srini-Ebenezer	Proposed Method
10	33.72	33.67	34.22	36.35	28.39	34.62	42.53
20	29.62	25.81	27.08	32.74	27.55	30.25	39.03
30	24.03	20.04	21.66	30.39	27.09	29.76	36.66
40	19.03	16.19	17.57	28.81	26.71	29.02	34.58
50	15.45	13.12	14.22	27.6	25.9	27.58	32.87
60	12.44	10.59	11.64	24.13	25.73	25.98	31.37
70	10.09	9.12	9.49	22.87	24.69	24.11	30.01
80	8.19	7.64	7.9	18.34	23.22	21.73	28.05
90	6.69	6.46	6.58	15.28	20.55	18.31	24.58

Table –III
Comparison table of **MAE** of different filters for lena.jpg image

Noise Density	SMF	CWMF	WMF	PSMF	AMF	Srini-Ebenezer	Proposed Method
10	2.74	1.72	2.12	0.73	4.99	2.18	0.37
20	3.4	3.08	3.17	1.5	5.53	3.05	0.77
30	5.06	6.67	5.7	2.42	5.85	3.72	1.23
40	9.1	13.21	10.75	3.92	6.1	4.4	1.79
50	16.39	24.05	19.87	5.17	6.49	5.19	2.32
60	28.92	38.18	33.45	7.11	6.71	6.2	2.99
70	46.68	56.78	52.44	9.55	7.37	7.78	3.76
80	70.01	78.18	73.9	13.63	8.59	11.01	4.88
90	96.98	101.66	99.01	23.67	11.5	27.89	6.74

Table –IV
Comparison table of **MSE** of different filters for lena.jpg image

Noise Density	SMF	CWMF	WMF	PSMF	AMF	Srini-Ebenezer	Proposed Method
10	31.17	27.73	26.20	21.34	93.89	22.37	3.55
20	89.45	162.37	116.748	47.79	113.20	38.56	8.12
30	277.72	634.85	449.80	83.55	126.78	56.10	14.02
40	832.31	1585.28	1210.81	159.44	138.53	81.36	22.60
50	1968.56	3103.94	2509.47	220.05	149.08	113.20	33.55
60	3800.46	5339.14	4517.86	339.76	173.18	163.84	47.39
70	6569.87	7971.85	7201.72	500.8	221.71	251.85	64.85
80	9977.24	11201.9	10537.6	875.41	309.05	435.97	101.8
90	14185.4	14878.7	14413.6	1923.8	571.68	957.28	178.16

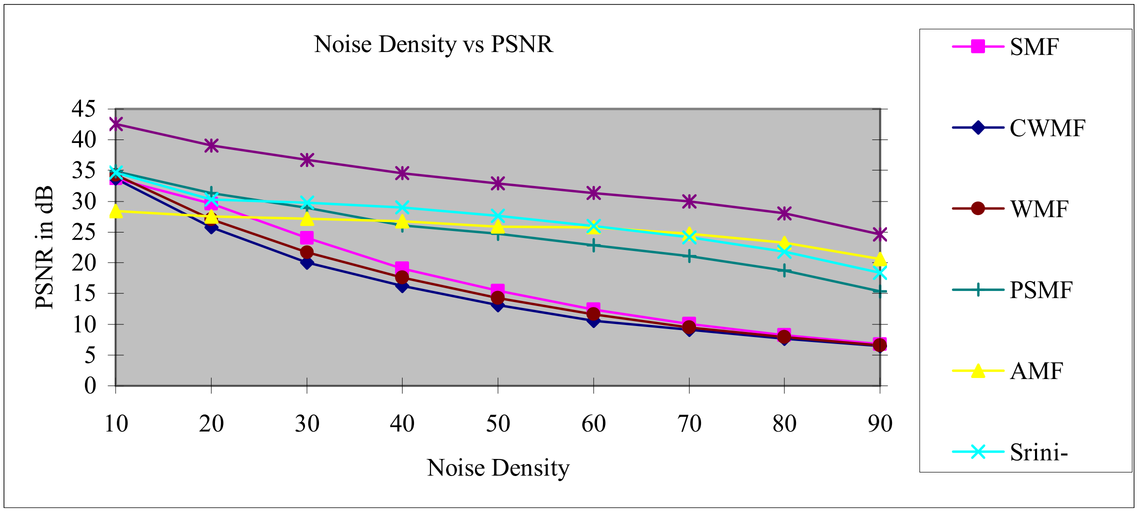


Figure.3 Comparison graph of **PSNR** of different filters for lena.jpg image

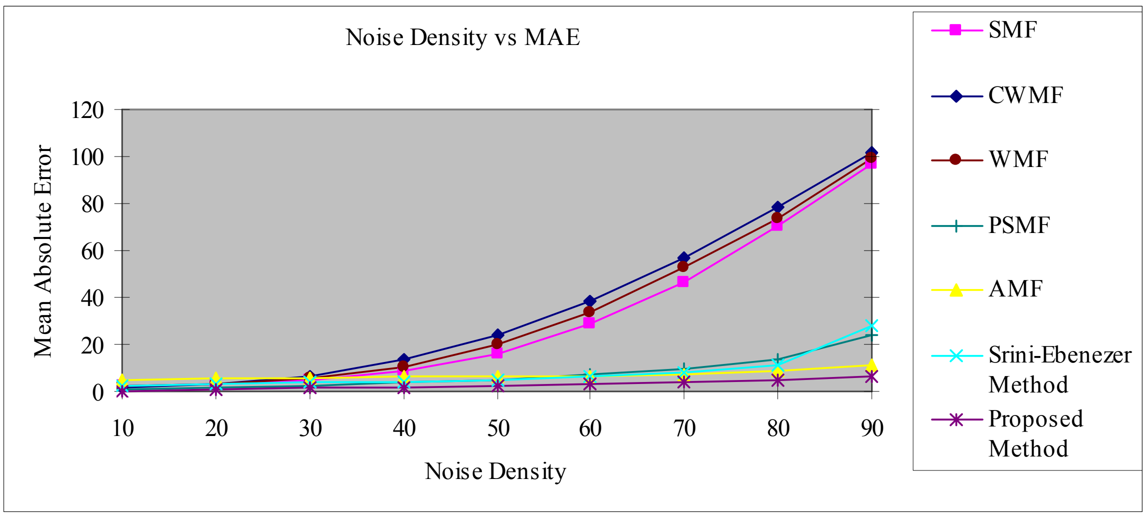


Figure.4 Comparison graph of **MAE** of different filters for lena.jpg image

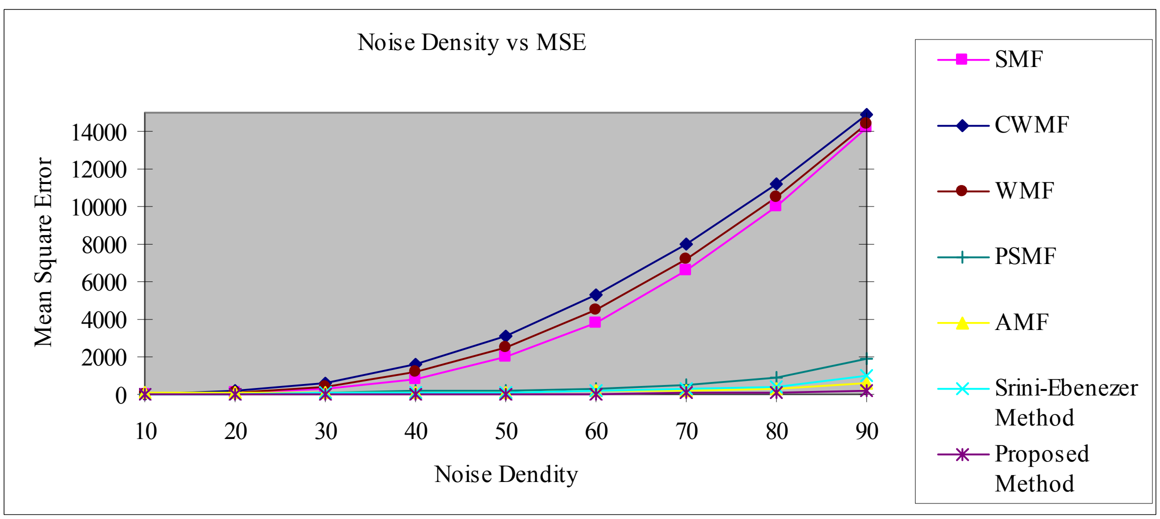


Figure.5 Comparison graph of **MSE** of different filters for lena.jpg image

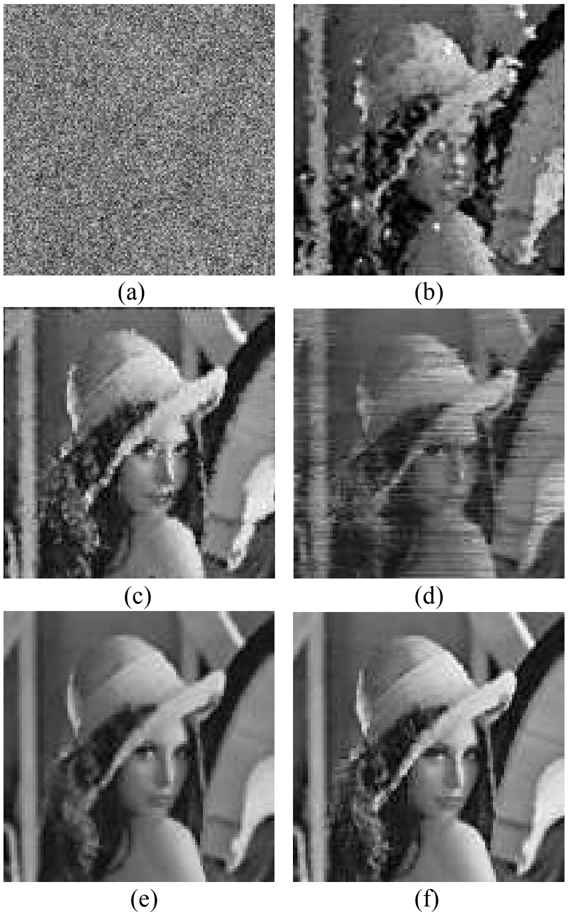
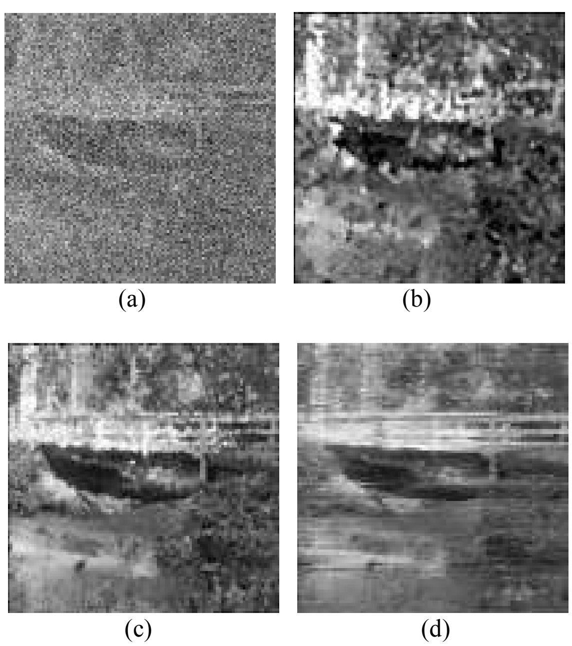


Figure.6 (a) Lena image Corrupted by 90% Noise density. Restoration Results of (b) PSMF (c) AMF (d) Srini-Ebenezer Method (e) Raymond Chan Method (f) Proposed Method



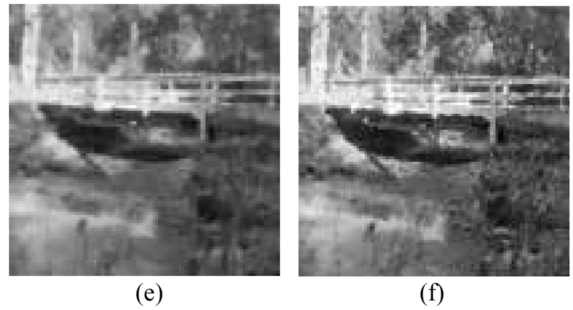


Figure.7 (a) Bridge image Corrupted by 90% Noise density. Restoration results of (b) PSMF (c) AMF (d) Srini-Ebenezer Method (e) Raymond Chan Method (f) Proposed Method

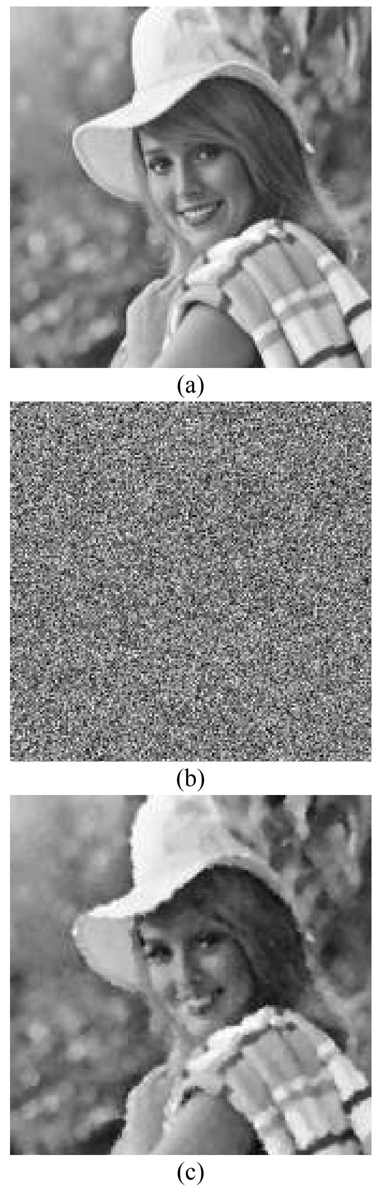
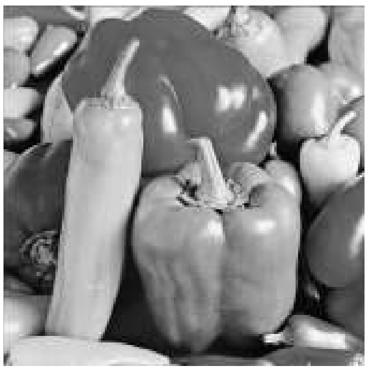


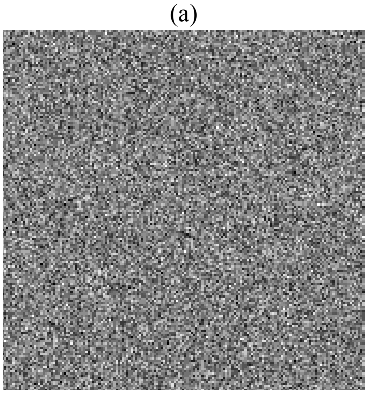
Figure.8 (a) Original Elaine Image (b) Elaine image corrupted by 95 % Noise Density (PSNR=5.6986). (c) Restored image using the proposed Method (PSNR=25.1264).

Table V
Performance comparison of our method with recently proposed Raymond Chan and Srini-Ebenezer Method for lena image

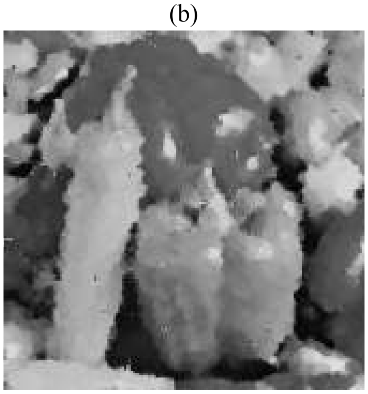
Quantitative Metrics	PSNR		MAE		COR		MSSI		Time in Seconds	
Noise Density	70%	90%	70%	90%	70%	90%	70%	90%	70%	90%
Raymond-Chan Method [10]	29.26	25.39	4.41	7.49	0.98	0.96	0.85	0.75	972.14	1928.88
Srini- Ebenezer Method [11]	23.25	17.23	8.295	20.87	0.94	0.76	0.69	0.34	21.25	22.68
Proposed Method	28.81	24.57	4.12	7.46	0.98	0.96	0.87	0.74	108.96	211.594



(a)



(b)



(c)

Figure.9 (a) Original Pepper Image (b) Pepper image corrupted by 98 % Noise Density (PSNR= 5.3857). (c) restored image using Proposed Method (PSNR=20.0491).

Table V shows the performance comparison of our proposed method with very recently proposed Raymond Chan method and Srini-Ebenezer method in terms of PSNR, MAE, Correlation, Structural similarity index and CPU time in seconds for the Lena image corrupted by 70% and 90% noise density respectively. MATLAB 7.1 on a PC equipped with 2.4 GHz CPU and 256 MB of RAM memory for the evaluation of computation time of all algorithms. To show high performance of the proposed algorithm, Elaine image is corrupted by 95% of impulse noise and pepper image is corrupted by 98% of impulse noise and applied to the proposed filter. The restoration results are shown in the figure 8 and figure 9 respectively. These results show again that the proposed method works effectively under very high probability of impulse noise.

V. CONCLUSION

In this paper a new algorithm to remove very high density impulse noise is proposed using robust estimation. Computation time of the proposed algorithm is much less compared to recently proposed Raymond chan method [10] and no sticking effect as in the case of recently proposed Srini-Ebenezer method [11]. Extensive experimental results clearly show that the proposed method performs much better than the standard non linear median-based filters and some recently proposed methods. The proposed algorithm gives better result for low to high density impulse noise levels and preserves fine details such as edges satisfactorily. It can be further improved for the application of the images corrupted with random valued impulse noise and other signal dependent noises.

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