High Density Salt and Pepper Noise Removal in Images using Improved Adaptive Statistics Estimation Filter

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Summary
In this paper a Non-linear Adaptive Statistics Estimation Filter to remove high density Salt and Pepper noise is presented. The algorithm detects the pixel corrupted by salt and pepper noise and replaces them with a value estimated using proposed algorithm. The algorithm detects the corrupted pixel at the initial stage itself. The performance of proposed algorithm is compared with various filters and has better image quality than the existing filters. The proposed method removes noise effectively even at noise level and preserves the fine details and edges effectively with reduced streaking at higher noise densities. The proposed filter has better image quality then existing Non-linear filters of this type.

Key words:
Salt and Pepper noise, Median filter, Estimation filter, Lorentzian Estimator.

1. Introduction

During the transmission of images and videos over channels, images and videos are often corrupted by noise and degradations due to faulty communication or noisy channels. Such noises may be introduced due to faulty camera or the like [1], [2]. In early development of signal and image processing linear filters were the primary tools. But linear filters have poor performance in the presence of noise that is additive in nature. They do not perform well in the presence of signal dependent noise. In image processing linear filters tend to blur the edges and do not remove impulse noise effectively. Non-linear filters are developed to overcome these limitations. A standard median filter is a basic non-linear filter that will preserve the edges and remove impulse noise. Median filter replaces every pixel by its median value neighborhood. But this removes some desirable details in the image [3], [4]. Different remedies of the median filter have been proposed, e.g. the Standard Median Filter (SMF), Weighted Median Filter (WMF) [5],[6],[7] and Adaptive Median Filter [8]. These filters first identify possible noisy pixels and then replace them by using the median filter or its variants, while leaving all other pixels unchanged. In these filters more weight is given to some pixels in the processing window. The main drawback of these filters is that the noisy pixels are replaced by some median value in their vicinity without taking into account local features such as the possible presence of edges. Hence details and edges are not recovered satisfactorily, especially when the noise level is high. Decision Based Median Filtering Algorithm(DBA) [9], Robust Estimation Algorithm(REA) [10] was proposed to remove high density impulse noise. Decision Based Algorithm removes high density salt and pepper noise. The corrupted pixels are replaced by median or the immediate neighborhood pixel. At higher noise densities the median may also be a noisy pixel and this produces streaking at higher noise densities. The major disadvantage of this method is, the quality of the restored image degrades as the noise level increases above 50 percentage..

2. Robust Statistics Estimation

Robust estimation is based on the principle that in robustness safety is more important than efficiency [11]. Consider Median as an estimator. Let x1, x2, x3…xn denote a random sample from a distribution having Pdf f(x). Let Y1 be the smallest of Xi, Y2 the next Xi in order of magnitude, and Yn the largest of Xi. That is Y1 < Y2 < …. < Yn. (X1, X2…Xn, are arranged in ascending order pf magnitude). Yi, I = 1, 2…n is called the ith order statistic of the random sample X1, X2,.. .Xn. The median is based on L1 norm or it is an ML estimate for Laplacian Distribution. The asymptotic efficiency is greater than one for long tailed distributions. For median the influence function is constant. This property makes median a good and robust estimator. The robust property is shown in Figure 1[12].An M-estimator which is fairly good for a distribution having outliers (extreme data value in the scatter) is called Robust estimator. Median is a robust estimator. Robust estimators are compared in terms of

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influence function. The influence function for median estimators is given in equation 1.

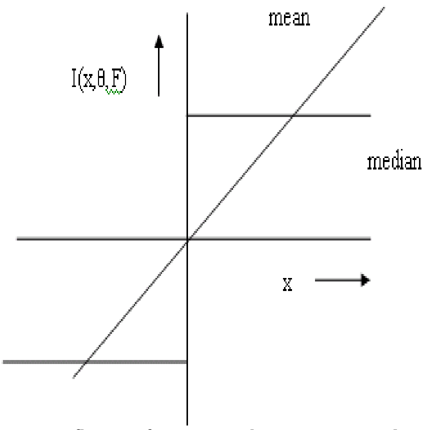


Fig. 1 Influence function with respect to outlier.

$$\varphi(x)=\begin{cases} 1 & x>0 \\ -1 & x<0 \end{cases} \qquad (1)$$

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 (2) and (3).

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

$$\psi_{lorentzian} = \frac{2x}{2\sigma^2 + x^2} \qquad (3)$$

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.

3. Robust Statistics Estimation Algorithm

In this approach impulses are first detected based on the minimum (0) and maximum (255) value. If the current pixel lies 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 a value determined by the following algorithm using lorentzian estimator. Let X denote the noise corrupted image and for each pixel X (i, j), the following algorithm is applied.

3.1. Pseudo code for the Proposed Algorithm

```
Let X (i, j) = corrupted image
Let output (i, j) = restored image
Wmax = 7 X 7
Window size , W=3;
for i = 1 X no of Rows in a image
   for j = 1 X no of Columns in a image
         if X (i,j) == 0 or X (i,j) == 255 then
            S= pixel elements in the window;
                  Smed = Median(S);

                  if Smed == 0 or Smed == 255
then
                        if W < W max    then
                           W = W + 2;
Corrupted pixel = processed neighbhourhood pixel value;
                        else
                           process the next
window;
                        end
                  else
                     p (i,j) = Smed –   X(i,j);
                        if   p == 0 then
          Corrupted pixel = neighbhourhood pixel
value;
                        e lse
            //calculate the   robust influence function
      Ψ (p) = 2p / (2 σ  2 + p2)                    (4)
      σ  =  τ s/√ 2;     // outlier rejection point
       τ s = ζ  *  σ  N      ; (5) // maximum expected
outlier
      σ  N     = image standard deviation
      ζ  = 0.3; // a smoothening factor

 calculate   the estimate values from (6) and (7)
```

$$S1 = \sum_{i \in L} \frac{pixel(I) * \psi(p)}{P} \qquad (6)$$

$$S2 = \sum_{i \in L} \frac{\psi(p)}{P} \qquad (7)$$

```
Estimated pixel value = s1 / s2;
                  end
            end
    end
 end
```

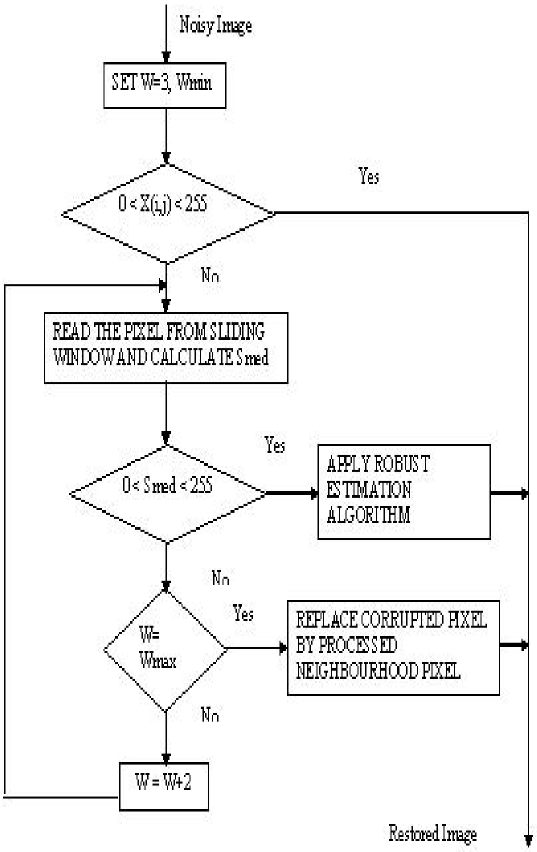


Fig. 2. Flow chart for the Proposed Algorithm

4. Results and Discussions

The proposed algorithm is tested using images such as Lena and baboon (gray and colour) and shown in Figure (3) – Figure (8). The performance of filters is tested at different levels of noise densities, and the results are shown in Tables 1 - 4. The performance of the proposed algorithm is tested for various levels of noise density and compared with standard filters namely Standard Median Filter (SMF), Weighted Median Filter (WMF), Adaptive Median Filter (AMF), Decision Based Algorithm (DBA), Robust Estimation Filter(REF) are compared in terms of Peak Signal-To-Noise Ratio (PSNR)(8), Mean Absolute Error (MAE)(9) , Mean Square Error (MSE)(10) , Image Enhancement Factor(IEF) (11) and the results are plotted in Figure 4.

Fig 3. (a) Original Lena image (b) Noisy image of noise density 70%. Restoration results of (c)Standard median filter (d) Weighted median filter (e) Adaptive median filter (f) Decision based algorithm (g) Robust Estimation algorithm (h) proposed method

Table 1: Comparative results of various filters in terms of PSNR for Lena. jpg image

Noise Density	PSNR					
	SMF	WMF	AMF	DBA	REA	PA
10%	32.95	34.15	30.53	38.23	39.02	42.1359
20%	28.81	30.72	29.73	36.45	36.82	38.0724
30%	27.38	25.39	28.48	29.76	33.96	35.6471
40%	23.28	21.65	27.43	29.02	32.1	33.2816
50%	19.82	18.63	25.75	27.58	30.25	31.7198
60%	16.89	16.15	24.1	25.98	28.42	29.5542
70%	14.62	14.1	24.43	24.11	24.85	27.3863
80%	12.73	12.48	20.8	23.28	23.84	25.0247
90%	11.64	11.11	18.01	20.01	20.73	21.2553

Table 2: Comparative results of various filters in terms of MAE for Lena. jpg image

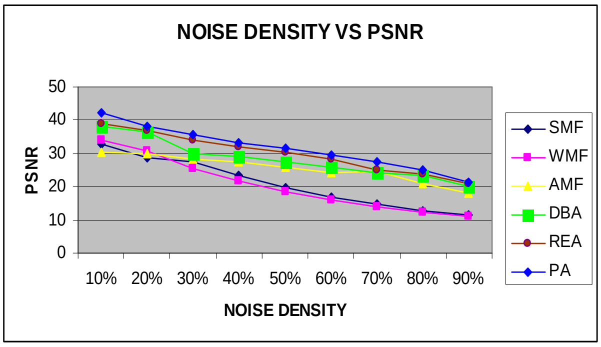
Noise Density	MAE					
	SMF	WMF	AMF	DBA	REA	PA
10%	1.44	1.12	2.19	2.18	0.88	0.3729
20%	1.71	1.49	2.34	3.05	1.42	0.7902
30%	2.31	2.43	2.49	3.72	2.53	1.2592
40%	3.63	4.22	2.87	4.41	2.96	1.827
50%	6.5	7.15	2.98	5.19	3.63	2.457
60%	10.18	11.56	3.13	6.25	4.81	3.3181
70%	15.86	17.42	3.41	7.78	6.73	4.4894
80%	22.42	25.48	3.89	10.32	9.51	6.3685
90%	32.09	32.9	4.93	19.36	17.32	11.0442

Table 3: Comparative results of various filters in terms of MSE for Lena. jpg image

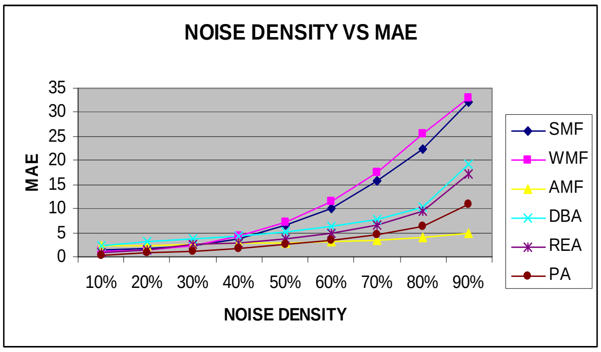
Noise Density	MSE					
	SMF	WMF	AMF	DBA	REA	PA
10%	25.9	20.341	35.76	20.64	5.25	3.9764
20%	46.1	56.25	36.6	38.56	12.2	10.1354
30%	117.5	179.56	83.53	56.1	26.11	17.716
40%	305.2	444.366	125.66	81.36	40.29	30.5434
50%	677.05	895.804	147.37	113.2	61.35	43.7624
60%	1330.06	1586.43	254.72	163.84	88.96	72.0549
70%	2241.23	2524.05	466.56	251.85	200.73	118.6995
80%	3464.5	3672.36	517.56	305.39	290.39	204.4621
90%	4883.21	5031.06	1041.99	730.72	563.21	437.25

Table 4: Comparative results of various filters in terms of IEF for Lena. jpg image

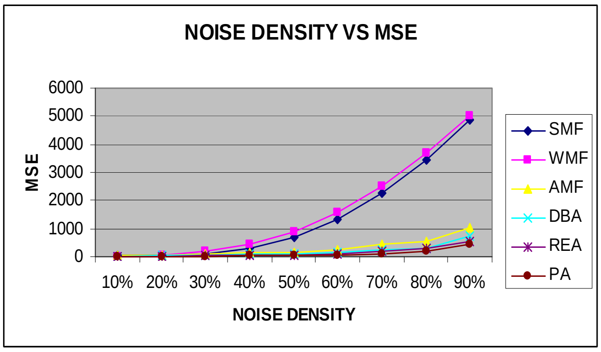
Noise Density	IEF					
	SMF	WMF	AMF	DBMF	REA	PA
10%	40.6	42.36	43.32	200.7	216.73	487.406
20%	30.33	35.36	41.24	180.36	193.84	377.1596
30%	19.74	25.12	36.69	146.69	168.2	323.1798
40%	16.61	20.01	25.44	129.51	145.95	253.5016
50%	14.44	17.92	21.9	107.35	131.52	220.1948
60%	6.75	8.36	8.14	99.31	105.43	160.5526
70%	3.551	4.36	5.32	95.93	99.82	113.9032
80%	2.039	3.52	3.289	66.16	70.36	75.6299
90%	1.36	1.57	1.622	25.13	27.51	35.7671



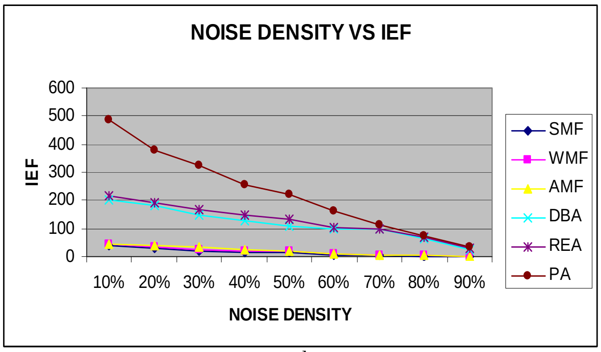
a



b



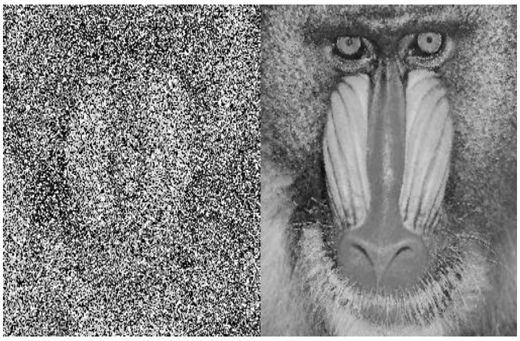
c



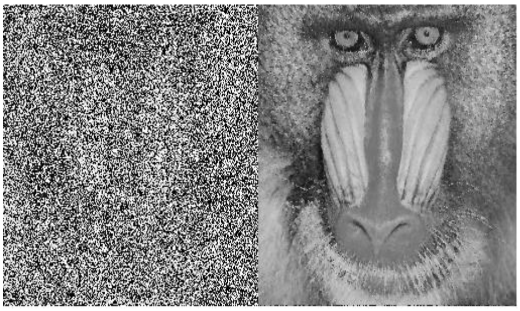
d

Fig.4. Comparison graph for PSNR, MAE, MSE and IEF for different noise densities of Lena.jpg image

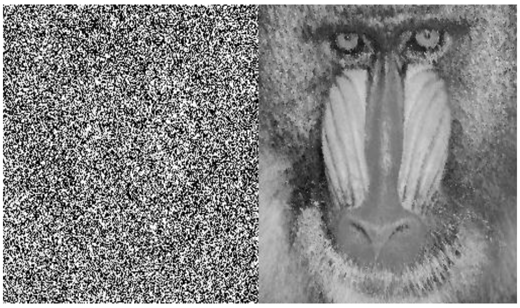
Corrupted image Denoised image



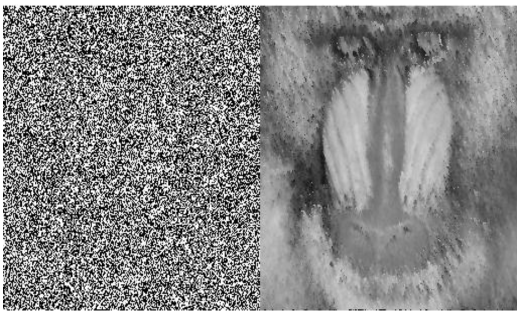
a. 60 % Noise Density



b. 70 % Noise Density



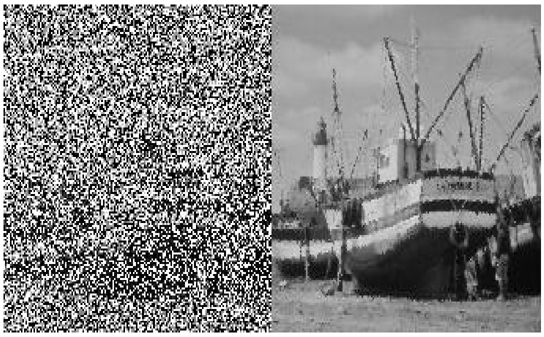
c. 80 % Noise Density



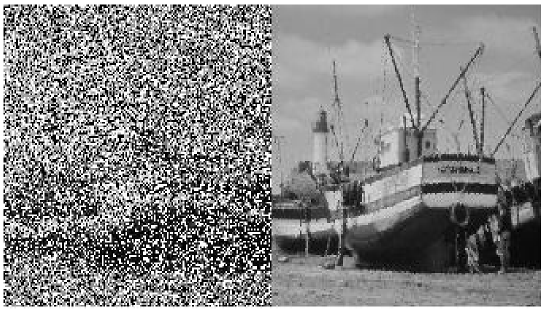
d. 90 % Noise Density

Fig 5. Corrupted and Denoised images of Baboon.jpg at different noise densities

Corrupted image Denoised image

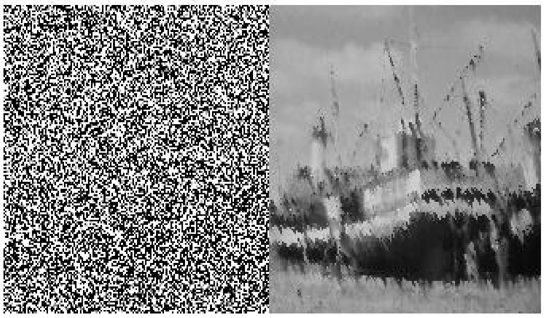


a. 60 % Noise Density



b. 70 % Noise Density

c. 80 % Noise Density



d. 90 % Noise Density

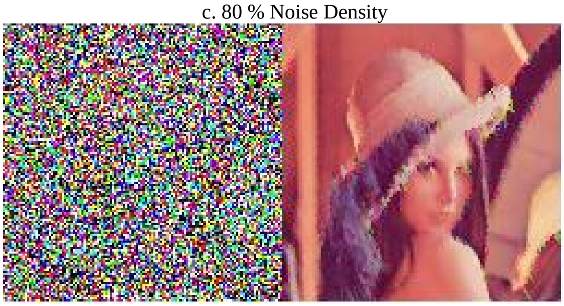
Fig. 6. Corrupted and Denoised images of Boat.jpg at different noise densities

Corrupted image Denoised image

a. 60 % Noise Density

b. 70 % Noise Density

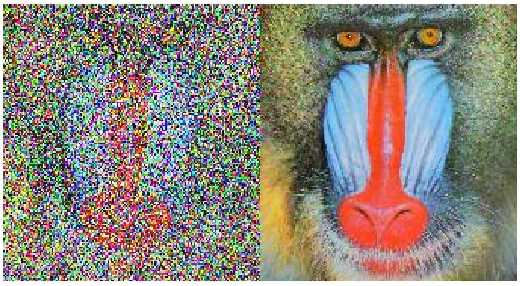
c. 80 % Noise Density



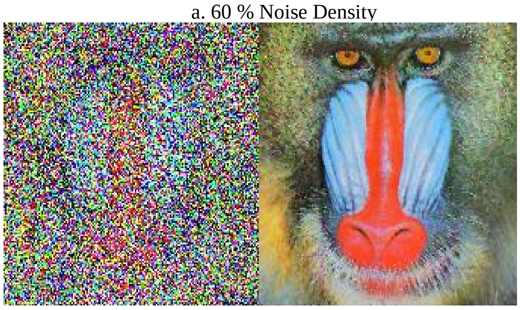
d. 90 % Noise Density

Fig. 7. Corrupted and Denoised images of Lenacolour.jpg at different noise densities

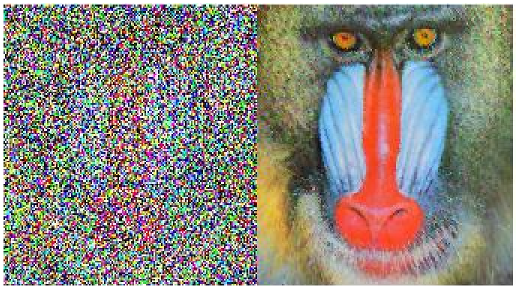
Corrupted image Denoised image



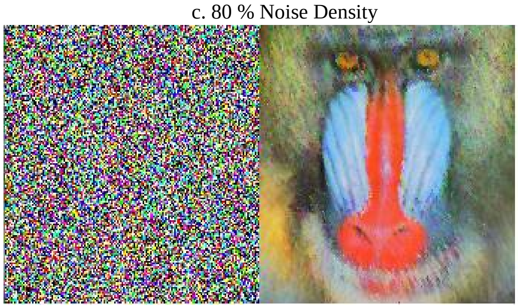
a. 60 % Noise Density



b. 70 % Noise Density



c. 80 % Noise Density



d. 90 % Noise Density

Fig. 8. Corrupted and Denoised images of Baboonlour.jpg at different noise densities

$$PSNR = 10\log_{10}\left(\frac{255^2}{\frac{1}{MN}\sum_i\sum_j (r_{ij}-x_{ij})^2}\right) \quad (8)$$

$$MAE = \frac{1}{MN}\sum_i\sum_j |r_{ij}-x_{ij}| \quad (9)$$

$$MSE = \frac{1}{MN}\sum_i\sum_j (r_{ij}-x_{ij})^2 \quad (10)$$

$$IEF = \frac{\left[\sum_{i,j=1}^{M} r_{ij} - s_{ij}\right]^2}{\left[\sum_{i,j=1}^{M} r_{ij} - x_{ij}\right]^2} \quad (11)$$

Where r_{ij} is the original image, x_{ij} is the restored image, n_{ij} is the corrupted image.

4. Conclusion

An Adaptive Robust Statistics Estimation Based Filter to remove low to high-density salt and pepper noise with edge preservation in digital images is proposed in this paper. The proposed filter performs well for both gray scale and color images. For lower noise density up to 30% almost all the algorithms perform equally well in removing the salt and pepper noise completely with edge preservation. For noise densities above 50%, the standard algorithms such as SMF, WMF, AMF fail to remove the salt and pepper noise completely. In case of high density noise, the performance of these methods is very poor in terms of noise cleaning and edge detail preservation. The recently proposed algorithm DBA and REA remove noise at high densities but they produce streaking effect and not suitable for noise densities above 60%. Experimental results show that the proposed method restores the original image much better than standard non-linear median-based filters. The proposed filter requires less computation time when compared to other adaptive methods.

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