NONLINEAR FILTER PERFORMANCE FOR REMOVING SALT AND PEPPER NOISE FROM GRAY SCALE IMAGES: AN EXPERIMENTAL ANALYSIS

[1]Sangita Choudhury,[2]Prithvi Narayan Sinha,
[1]Assistant Professor,[2]Assistant Professor
[1]Electrical Engineering,
[1]NGirijananda Chowdhury Institute of Management and Technology, Guwahati,India

Abstract : Noise elimination from image is one of the most challenging and important task in digital image processing. Now-a-days, nonlinear filters are most extensively applied for removing salt and pepper noise from gray scale images. In this paper salt and pepper noise removal using different nonlinear filters are analyzed based on the restoration performance of the filters by undergoing various simulations in MATLAB environment on a set of standard images. Also the performance of the filters are compared in terms of some well known image quality metrics such as Mean square error (MSE), Peak signal to noise ratio (PSNR) and mean structural similarity index (MSSIM).

IndexTerms - **Noise, pixel, window, noise removal, nonlinear filtering, gray scale image, salt and pepper noise.**

I. INTRODUCTION

Noise is an unwanted signal or disturbance which may distort the information carried by the signals from different sources and thus interfering the normal operation of a device or system.It is a known fact that the digital images are noise prone. Image enhancement and restoration in noisy environment is a challenging task and one of the active areas of research in digital image processing. Depending upon the different sources of the images, there are several types of noises that can be added to the digital images.Impulse noise is one of the most important noise occurred in digital images due to noisy sensor at the time of acquisition or due to channel errors or faulty storage. Impulse noise can be categorised as salt and pepper noise and random valued impulse noise.

The image which has salt-and-pepper noise present in image will show dark pixels in the bright regions and bright pixels in the dark regions. [1]. There is drastic change in the image data which are affected by salt and pepper noise as the corrupted pixels are having either relatively very high or very low intensity levels keeping the other pixels values intact. On the other hand, the random valued impulse noise is more realistic as it has varying amplitudes and produces impulses having gray level values within a predetermined range.Thus the corrupted pixels values of the image do not reflect the actual intensities which degrades the quality of the image. To restore the original image and to preserve the image details, the noise has to be removed from the images by adopting various noise filtering techniques. To remove the impulse noise, different linear and non-linear filtering techniques have been proposed and still research is going on. In linear filtering, the high frequency including the sharp details of the image are lost leading to serious blurring affect. As in linear filters, the noise reduction techniques do not take into account whether the pixels are noisy or noise free which lead to damaging of the noise free pixels. Due to these reasons, linear filter losing its usability and to overcome the shortcomings of linear filter, non-linear filters are adopted and most widely used now days. In subsequent sections of this paper, different nonlinear filters performance for removal of salt and pepper noise are analyzed and compared.

II. NOISE MODEL

The name salt and pepper noise is due to the “salt and pepper” like appearance of the noise affected image as it develops white and/or black spots in gray scale images. The 8-bit gray scale image is corrupted by two fixed values, 0 and 255 with the same probability. If the pixel location in an image is *(i, j)*and the intensity value of that pixel is *s(i, j)*, then the probability density function of the salt and pepper noise affected pixel *x(i, j)*having noise density ‘*p’* can be modelled as follows-

$$f(x) = \begin{cases} p/2 & \text{for } x = 0 \\ 1-p & \text{for } x = s(i,j) \\ p/2 & \text{for } x = 255 \end{cases}$$

The probability density function for this type of noise is shown in figure-1 below-

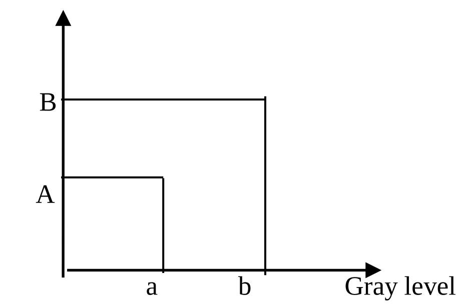

Fig. 1 Probability density function for salt-and-pepper noise

$$PDF_{(\text{salt-and-pepper})} = \begin{cases} A & \text{for } g=a \text{ (pepper)} \\ B & \text{for } g=b \text{ (salt)} \end{cases}$$

This means that for an 8 bit gray image a and b are the two extreme values a=0 (black/pepper) and b=255 (white/salt) where unaffected image pixels remains unchanged.The degradation image cause by salt and pepper is shown in figure-2.

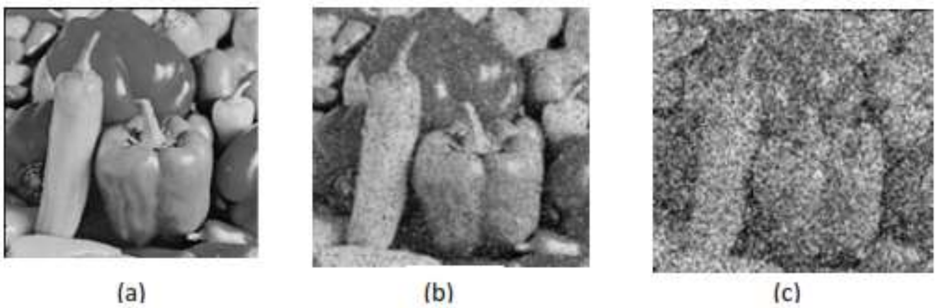

Fig. 2 (a) Original image (b) Image with 20% and (c) Image with 50% salt and pepper noise

Let an original input image be $f(i,j)$ which after affected by salt and pepper noise with noise term $\eta(i, j)$ becomes $x(i,j)$, which is a noisy image. Then we have to use denoising filter which operates on the noisy image $x(i,j)$, to obtain an estimate of the original image and this restoration model in spatial domain as shown in figure-3 is given by-

$$x(i,j)= f(i,j)+\eta\ (i, j)$$

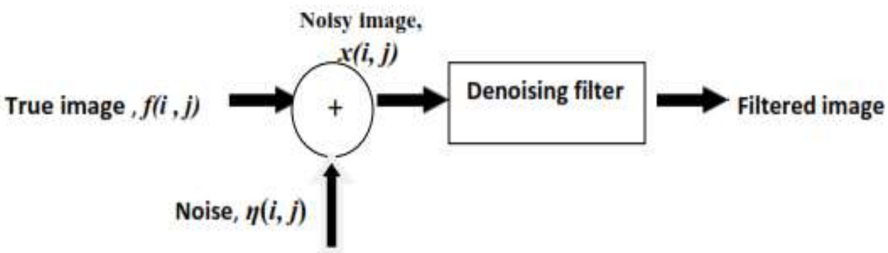

Fig. 3 Model of noise removal process

III. Non Linear Filer Variants For Removal Of Salt And Pepper Noise

There are different application oriented non-linear techniques for removal of salt and pepper noise from angray scale digital image, some having better performance than the others in various noisy conditions.

3.1Signal Dependent Rank Ordered Mean Filter (SD-ROM)

In this technique, to determine the noisy pixel all the elements in the window excluding the current pixel are rank ordered and then comparison of the threshold value with the difference between current pixel and ordered pixel are done and if the pixel is found to be noisy, it is replaced by the rank ordered mean value.

The output of SD-ROM filter is [2]–

$$Y_{ij} = \begin{cases} m(n) & \text{if } d_i(n) > T_i \text{ i.e. noisy} \\ X_{ij} & \text{otherwise} \end{cases}$$

for i= 1 to 4

$$d_i(n) = \begin{cases} r_i(n) - X_{ij}(n) & \text{if } X_{ij}(n) \le m(n) \\ X_{ij}(n) - r_{9-i}(n) & \text{if } X_{ij}(n) > m(n) \end{cases}$$

and $T = [T_1, T_2, T_3, T_4] = [8, 20, 40, 50]$

3.2 Adaptive Center Weighted Median Filter (ACWM)

This filter is an improved centre weighted median (CWM) filter which mainly works on varying the weight of the central pixel and then taking the difference of the current pixel and the output of the CWM filter (d_k) which finally decides whether to stick on the current pixel value or to switch to median value of the window. Now subtracting all pixel values in the neighborhood with the median value MAD (Absolute Deviations from the Median) is obtained.

The ACWM filter output is expressed as follows [3]-

$$\hat{X}_{ij} = \begin{cases} Y_{ij}^{1}, \text{ if } \exists k, d_k > T_k \text{ (noisy condition)} \\ X_{ij}, \text{ otherwise} \end{cases}$$

Where T_k is the value of the threshold calculated as: $T_k = s.\text{MAD} + \delta_k$

The determination of the thresholds is simplified to the adjustment of parameter 's'.

3.3 Directional Weighted Median Filter (DWM)

To assign weight to the pixel, this technique uses the four directions of the window on which neighbouring pixels of the window are aligned and then the difference between the current pixels and the neighbouring pixels are taken to find the noisy pixel which is finally replaced by the output of the median filter.

In a 5x5 window centered at *(i,j)* , for each direction, the sum of absolute difference of the gray-level values is given by direction index $d_{ij}^{(k)}$ which is defined as [4]-

$$d_{ij}^{(k)} = \sum_{(s,t)\in S_k^0} w_{s,t} \left| Y_{i+s,j+t} - Y_{i,j} \right|, \quad 1 \le k \le 4$$

where

$$w_{s,t} = \begin{cases} 2, & (s,t) \in \Omega^3 \\ 1, & \text{otherwise} \end{cases}$$

$$\Omega^3 = \{ (s,t): -1 \le s,t \le 4 \}$$

The impulse detector is defined as -

if $r_{i,j} > T$, current pixel is noisy pixel

if $r_{i,j} \le T$, current pixel is noise free pixel

Now, the standard deviation for gray-level values with $(s,t) \in S_k^0$ is given by –

$$l_{i,j} = \operatorname{argmin} \{ \sigma_{ij}^{(k)} : k = 1 \text{ to } 4 \}$$

Argmin is to find the minimize of a function, thus $l_{i,j}$ shows minimum standard deviation directions.

Now, $$m_{i,j} = \text{median} \{ \tilde{w}_{s,t} \lozenge Y_{i+s,j+t} : (s,t) \in \Omega^3 \}$$

where

$$\tilde{w}_{s,t} = \begin{cases} \tilde{w}_m = 2, & (s,t) \in S^0_{l_{i,j}} \\ 1, & \text{otherwise} \end{cases}$$

The output of DWM filter is

$$\hat{X}_{ij} = \alpha_{i,j} Y_{i,j} + (1 - \alpha_{i,j}) m_{i,j}$$

where $$\alpha_{i,j} = \begin{cases} 0, & \text{if } r_{i,j} > T \\ 1, & \text{if } r_{i,j} \le T \end{cases}$$

$T_0 = 510$, *is the initial threshold and*

T_n *is the threshold in the* n^{th} *step*

$$T_{n+1} = T_n \,.\, 0.8 \quad (n \geq 0)$$

The selection of the value of n depends on the filtering performance and S_k denotes a set of co-ordinates aligning with the k^{th} direction centred at (0, 0) and $S_k^0 = S_k \setminus (0, 0)$ for all k from *1 to 4.*

3.4 Switching median filter with boundary discriminative noise detection (BDND)

In this filtering method, all the windowing pixels are classified in to three intensity levels i.e. lower and higher intensity levels along with uncorrupted pixel group having intensities in between the two extreme levels out of which filtering operation is performed only on the corrupted extreme levels pixels. Only the pixels which are found to be noisy in the detection part are filtered using switching median filtering method.

The maximum window size,

$$W_D = \begin{cases} 3 \times 3 & \text{for noise density } p, \quad 0\% < p \leq 20\% \\ 5 \times 5 & \text{for noise density } p, \quad 20\% < p \leq 40\% \\ 7 \times 7 & \text{for noise density } p, \quad p > 40\% \end{cases}$$

Starting window size , $W_F = 3$, $S_{in} = \frac{1}{2}(W_F \times W_F)$

Starting with 3x3 filtering window, if number of uncorrupted pixel (Nc) in the window is less than half of the total number of pixel in the window, then the window size (W_F) will be keep on increasing by 2 [5].

$$\textit{i.e.} \quad \{(Nc < S_{in} \text{ and } W_F \leq W_D) \text{ or } Nc = 0\}$$

With window size $W_F \times W_F$, standard median filter (SM) is applied to a noisy pixel excluding the concerned pixel (as it is already marked as noisy), the output of the filter ($Y_{i,j}$), is given by –

$$(Y_{i,j}) = median \{ X_{i-s,\, j-t} : (s,t) \in W,\ (s,t) \neq (0,0) \}$$

$$where \quad W = \{ (s,t): -(W_F - 1)/2 \leq s,t \leq (W_F - 1)/2 \}$$

IV. RESULTS AND DISCUSSION

Having defined the noise removal non linear filters, now we test these filtering methods on MATLAB environment on various gray scale images such as Lena, House and Boat in PNG format to compare their restoration performances at different noise densities based on the following image quality metrics.

An Image quality (IQ) metric is an objective mathematical way to calculate quality without human observers [6].

4.1 Mean Squared Error (MSE)

Lower the value of MSE, better is the reconstruction performance and zero MSE indicates perfect reconstruction.

4.2 Peak Signal to Noise Ratio (PSNR)

It is a quantitative measure in logarithmic scale for image performance. Higher values indicate better restored image quality.

4.3 Mean Structural Similarity Index (MSSIM)

The SSIM index considers a number of structural parameters like structures, luminance and contrast to measure the visible difference between two images and to check the similarity. As the index value moves from 0 to 1, it indicates better quality performance of the filter. A detailed description can be found in [7].

Table 1 and 2 summarize the performance of different images in terms of MSE, PSNR and MSSIM of restored images by different non linear filtering techniques at different noise densities.

In figure 4, the results of the restored images are shown for the comparisons of performance of different filters.

Table 1 Restoration Results in MSE and PSNR for Images at Corrupted with Salt and Pepper Noise

Noise (in %)	Methods	MSE			PSNR		
		Test images			Test images		
		Lena	Boat	House	Lena	Boat	House
20	SD-ROM	117.0197	125.8195	130.4780	27.4482	27.1333	26.9754
	ACWM	17.5068	47.5322	25.5281	35.6987	31.3609	34.0606
	DWM	19.4505	53.7455	19.1906	35.2415	30.8274	35.2999
	BDND	25.2907	43.9102	47.8507	34.1012	31.7052	31.3319
40	SD-ROM	986.1551	997.9717	1079.8	18.1914	18.1396	17.7976

	ACWM	115.6653	201.7893	165.9559	27.4988	25.0818	25.9309
	DWM	70.2969	145.4939	64.2108	29.6614	26.5024	30.0547
	BDND	290.2893	285.0478	342.7999	23.5025	23.5816	22.7804
70	SD-ROM	7050.9	7047.5	7193.4	9.6483	9.6505	9.5615
	ACWM	3550.9	4170.9	3973.3	12.6275	11.9285	12.1393
	DWM	3258.5	3904.4	3206.6	13.0007	12.2152	13.0704
	BDND	2567.8	2537.2	2411.2	14.0352	14.0873	14.3084
90	SD-ROM	14678	14399	14822	6.4642	6.5475	6.4218
	ACWM	11909	12587	12719	7.3722	7.1316	7.0864
	DWM	14898	14734	14488	6.4995	6.4475	6.5207
	BDND	13333	12469	11823	6.8814	7.1726	7.4034

Table 2 Restoration Results in MSE and PSNR for Images at Corrupted with Salt and Pepper Noise

MSSIM				
Noise (in %)	**Methods**	**Test Images**		
		Lena	**Boat**	**House**
20	SD-ROM	0.8516	0.8640	0.8994
	ACWM	0.9681	0.9357	0.9628
	DWM	0.9558	0.9115	0.9632
	BDND	0.9649	0.9492	0.9649
40	SD-ROM	0.3951	0.4396	0.4102
	ACWM	0.8612	0.8079	0.8556
	DWM	0.8977	0.8325	0.9063
	BDND	0.7609	0.7637	0.7591
70	SD-ROM	0.0462	0.0563	0.0490
	ACWM	0.1463	0.1507	0.1377
	DWM	0.2936	0.2466	0.3000
	BDND	0.2209	0.2204	0.2380
90	SD-ROM	0.0113	0.0129	0.0101
	ACWM	0.0352	0.0350	0.0405
	DWM	0.0472	0.0469	0.0519
	BDND	0.0732	0.0671	0.0755

From the analysis of the data, we can have an idea that none of the non linear filtering proposed in the literature can perform well in all the noise density levels. Generally the ACWM filtering technique performance is better compared to the other techniques when noise density is comparatively low (up to 30%) and then again performance is noticeable at noise density near about 80%. When noise density is about 40%-70% i.e. medium noise density the restored image quality obtained using DWM filtering method is good and image details and edges integrity are also preserved.

BDND filter [5][8] performs much better in comparison with the other non linear filters in especially when the noise level is as high as 80% but performance decreases with higher noise levels.

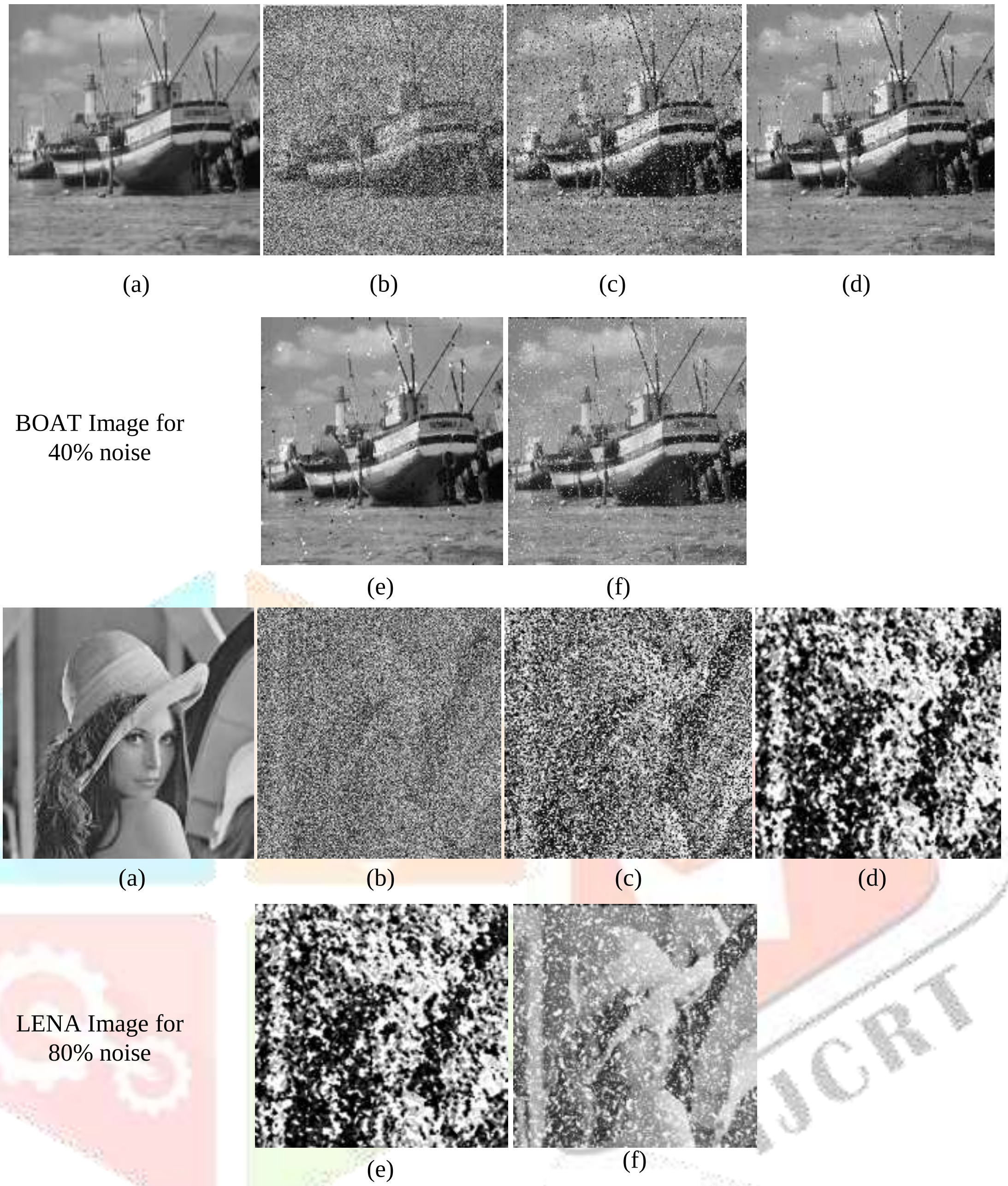

Fig.4 Restoration results of 40% BOAT, 80% LENA images (a) Original image (b) Noisy image (c) SD-ROM filter (d) ACWM filter (e) DWM filter (f) BDND filter

IV. Conclusion

This paper presents an experimental analysis to evaluate the performance of non linear filtering techniques for removal of salt and pepper noise for the standard gray scale images. The experimental results reveal that among the compared methods, DWM and BDND filters exhibit visually appealing results for medium and higher noise densities. The other non linear filters like SD-ROM, ACWM filers are not effective in preserving the edges details while retaining some noise components but they are applicable for removal of lower noise density. But when noise density is too high, BDND yields better filtering performance in terms of MSE, PSNR and MSSIM. But it is clear that the detection of noise process between corrupted pixels and the uncorrupted pixels prior to applying the non-linear filtering is highly desirable to protect the signal details of non-noise pixels [9]. However for future work, we propose a new idea for better performance of non linear filter in noise suppression while preserving line, edge and texture well.

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