2015 Seventh International Conference on Computational Intelligence, Modelling and Simulation

Removal of High Density Impulsive Noise in Image Using Non Linear Filters

Hassan M. ElKamchouchi, Ahmed E. Khalil
Faculty of Engineering,
Alexandria University
Alexandria, Egypt
ahmed_yody@hotmail.com

Samy H. Darwish
Faculty of Engineering,
Pharos University in Alexandria, PUA
Alexandria, Egypt
salord1960@gmail.com

***Abstract* — Images will pick up noise from a variety of sources that include flecks of dust inside the camera and faulty sensor. One goal in image restoration is to remove the noise from the image where the "original" image is discernible. This paper presents an overview of effective algorithms in image restoration as untrimmed decision based median filter (UDBMF) and decision based median filter (DBMF). These filters are used and compared with number of existing non linear filters with different levels of noise based on the calculations of mean square error, peak signal to noise ratio, image enhancement factor, mean absolute error, and correlation ratio. The results show that (UDBMF) and (DBMF) can perform better than the other nonlinear filters for noise level up to ninety percent. Also the necessary details in image were preserved.**

Keywords — image restoration, untrimmed decision based median filter, nonlinear filters.

I. INTRODUCTION

Image is defined as an array, or a matrix arranged in rows and columns. Image processing is a form of signal processing for which the input is an image, such as a photograph or video frame; the output may be either an image or a set of characteristics or parameters related to the image. The field of digital image processing refers by means of a digital computer. It includes many techniques as: image segmentation, image recognition, image differencing, color corrections, digital composition, and image restoration, etc [1].

Digital images are often corrupted by impulse noise, due to faulty camera sensors, transmission of images over faulty channels. Impulse noise is of two types: salt and pepper noise and random valued impulse noise [2].

Image denoising plays a vital role in digital image processing. There are many schemes for removing noise from images. The good denoising scheme must able to retrieve as much of image details even though the image is highly affected by noise [3]. There are two types of image denoising model, linear model and nonlinear model. Generally linear model are being considered for imaged noising, the main benefits of using linear noise removing models is the speed ,while the limitation of the linear models is: the models are not able to preserve edges of the images. In an efficient manner; Non-linear models can preserve edges in a much better way than linear models but it is very slow [4].

This paper has been organized in the following manner, section II describes restoration process, section III contains image noise models, section IV discuss the means of filters, while filtering techniques are given in section V, section VI briefly illustrates the proposed methodology, simulation and the discussions of results are presented in section VII, conclusions were presented in section VIII, section IX give a scope of the future work. Finally, the references that used for completion of this work were incorporated.

II. RESTORATION PROCESS

Image restoration is the operation of taking a corrupted/noisy image and estimating the clean original image. The techniques that used for image restoration are oriented towards modeling the degradations (usually blur and noise) and applying various filters to obtain an approximation of the original scene [5]. Today, image restoration is one of the key fields in digital image processing due to its wide area of applications. There are a variety of reasons that could cause degradation of an image. Commonly occurring degradations include blurring, motion blurring and noise [6].

The possible approach for noise removal is using filters such as low-pass filters or median filters. More sophisticated methods assume a model of how the local image structures look like, a model which distinguishes them from the noise; that's by first analyzing the image data in terms of the local image structures, such as lines or edges, and then controlling the filtering based on local information from the analysis step [7].

Restoring an original image, when given the degraded image with or without knowledge of the degradation function degree and type of noise present is an ill posed problem [5].Figure1.shows block diagram for the degradation/restoration process. The objective of restoration is to find the estimated $F(x,y)$ that closely approximates the original input image $f(x,y)$ [5][8].

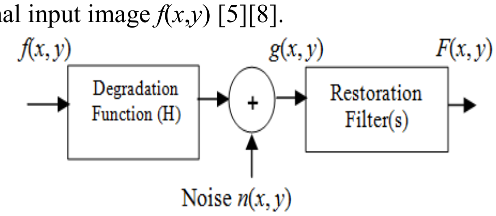


Figure 1. Model of the image degradation/restoration process.

2166-8523/15 $31.00 © 2015 IEEE
DOI 10.1109/CIMSim.2015.20

In figure 1, if H is a linear, position-invariant process, then the degraded image [8] is given in the spatial domain by:

$$g(x,y) = h(x,y) * f(x,y) + n(x,y) \qquad (1)$$

Where,

$g(x,y)$ is degraded image,
H is degradation function,
$h(x,y)$is the spatial representation of H**,**
The symbol (*) indicates convolution,
$f(x,y)$ is given input image,
$F(x,y)$ is restored image and
$n(x,y)$ is additive noise.

III. IMAGE NOISE MODELS

Where the Noise is a disturbance that affects a signal; it may distort the information carried by the signal. Presence of noise is manifested by undesirable information, which is not at all related to the image under study, but in turn disturbs the information present in the image. The noise is translated into values, which are getting added or subtracted to the values on the levels of image pixels. Image noise can be originated due to camera quality, acquisition condition illumination level, calibration. Image noise can also be originated due to the electronic noise in the sensors in the digital cameras, and it can be a function of the scene environment [9].

Image denoising is a process by which an image suffering some forms of degradation can be recovered to its original form. From this point of view, it is very necessary to study noise models. There are two basic types of noise models, noise in the spatial domain and noise in the frequency domain, these noises are mainly classified and modeled as follows:

A. Additive Noise

This kind of noise is also called as additive white Gaussian noise (AWGN), it is a basic noise model used in information theory to mimic the effect of many random processes that occur in nature. The modifiers denote specific characteristics: 'Additive' because it is added to any noise that might be intrinsic to the information system. 'White' refers to idea that it has uniform power across the frequency band for the information system. It is an analogy to the color white which has uniform emission at all frequencies in the visible spectrum. 'Gaussian' because it has a normal distribution in the time domain with an average time domain value of zero. AWGN is commonly used to simulate background noise of the system under study.

Wideband noise comes from many natural sources; the summation of many random processes will tend to have distribution called Gaussian or Normal. Thermal noise is an example for random fluctuations that present and affect the electronic systems as image sensor [9].

The mathematical model given for this type of noise is:

$$f(i,j) = y(i,j) + w(i,j) \qquad (2)$$

Where,

$1 \leq i \leq M$, $1 \leq j \leq N$
$f(i,j)$ is the corrupted image,
$y(i,j)$ is the original image,
$w(i,j)$ denotes the noise introduced into the image,
(i,j) is a position of pixel in image,
M and N are number of pixels in horizontal and vertical directions in the image.

B. Multiplicative Noise

This kind of noise is also called as the speckled noise. This noise gives a 'magnified' view of the original image. For example, when this noise is applied to high pixel intensities or bright area in an image, a higher random variation will be observed. On the other hand, when this noise is applied to a darker region in the image, the random variation observed is not that much as compared to that observed in the brighter areas. Thus, this type of noise is signal dependent and distorts the image in a big way [9]. The mathematical model for this type of noise is can be described by:

$$f(i,j) = y(i,j)w(i,j) \qquad (3)$$

Where,

$f(i,j)$, $y(i,j)$, and $w(i,j)$ as in (2)

C. Impulsive Noise

Impulse noise has two types, salt and pepper noise and random valued impulse noise. The intensity of salt and pepper noise always takes relatively high or low gray level [2].

In salt and pepper noise model, there are only two possible values a and b .The probability of getting each of them is less than 0.1 (else, the noise would greatly dominate the image). For 8 bit/pixel image, the intensity value for pepper noise typically found nearer to 0 and for salt noise it is near to 255. Salt and pepper noise is a generalized form of noise typically seen in images. In image criteria the noise itself represents as randomly occurring white and black pixels [4]. Figure2 represents different simulated noisy images.

(a) *(b)* *(c)* *(d)*

Figure 2. Simulation for different noises: (a) Original image, (b) Gaussian (c) Speckle, and (d) Salt and pepper.

IV. THE MEANING OF FILTERS

Elimination of noise is one of the major works to be done in image processing, as noise leads to the error in the image [1].A good noise filter is required to satisfy two criteria namely, to reducing the noise and suppressing the useful information in the signal. The main purpose of image denoising is to reform corrupted pixels estimate as in the original image from the noisy image [10].

A digital filter [11] is used to remove noise from the degraded image. Thus the image, which gets contaminated by the noise, is the degraded image and using different filters can filter this noise. Thus filters are used for image enhancement, as it removes undesirable signal components from the signal of interest. Filters can be represented in different types (linear or nonlinear filters) [12].

In early times, as the signals handled, the analog, filters were used .Gradually digital filters were took place because of their flexibility, low cost, programmability, reliability, etc. The design-of digital filters involves three basic steps: (1) the specification of the desired properties of the system, (2) the approximation of these specifications using a causal discrete time system, and (3) the realization of the system using finite precision arithmetic [1].

V. FILTERING TECHNIQUES

Filtering is a technique for enhancing the image. Linear filtering is the filtering in which the value of an output pixel is a linear combination of neighborhood values, which can produce blurring in the image. Thus a variety of smoothing techniques have been developed, that are non linear filters [1].

A. Method Used

The standard median filter (SMF) has good denoising power and computational efficiency. But the main drawback of this filter is that it is effective only for low noise densities. At high noise densities, SMF often exhibit blurring for large window size and insufficient noise suppression for small window size [13]. When the noise level is over 50% the edge details of the original frame will not be preserved by SMF. However, most of the median filters operate uniformly and it modifies both noise and noise-free pixels, and causes information loss. Ideally, the filtering should be applied only to corrupted pixels not to uncorrupted ones [14].

The weighted median filter (WMF) is an extension of the median filter, which gives more weight to some values within the window. This WM filter allows a degree of control of the smoothing behavior through the weights that can be set, and therefore, it is a promising image enhancement technique [13].

The adaptive wiener filter (AWF) is a real time optimal filter renovated from the Wiener filter technology, which became available in 1940. Wiener filter is a linear adaptive filter, tailoring itself to the local image variance. Where the variance is large, Wiener filter performs little smoothing, where the variance is small, it performs more smoothing. This approach often produces better results than other linear filters. It is more selective than a comparable linear filter, preserving edges and other high-frequency parts of an image. However, Wiener filter requires more computation time compared to other linear filters. The Wiener filtering is optimal in terms of the mean square error, i.e. it minimizes the overall mean square error and noise smoothing. Wiener filtering is a linear estimation of the original image. However, Wiener filtering is usually used to remove additive noise and not the impulsive noise. With Wiener filter alone, we cannot remove the salt-and-pepper noise efficiently [15].

In (DBMF), the noisy and noise-free pixels in the image are detected by checking the pixel values against the maximum and minimum values which will be in the dynamic range (0, 255).If the pixel is being currently processed has a value within the minimum and maximum values in the currently processed window, then it is a noise-free pixel and no modification is made to that pixel. If the value doesn't lie within the range, then it is a noisy pixel and will be replaced by either the median pixel value or by the mean of the neighboring processed pixels [16].

In (UDBMF), the selected 3 x 3 window elements are arranged in either increased or decreased order This filter is called trimmed median filter because the pixel values 0's and 255's are removed from the selected window, then the median value of the remaining pixels is taken in consideration. This median value is used to replace the noisy pixel. The processing pixel is checked whether it is noisy or noisy free. That is, if the processing pixel lies between maximum and minimum gray level values then it is noise free pixel, it is left unchanged. If the processing pixel takes the maximum or minimum gray level then it is noisy pixel which is processed by untrimmed decision based median filter [17][18].

B. Mathematical Analysis

To assess the performance of the proposed filters for removals of impulse noise and to evaluate their comparative performance, different standard performance indices have been used[2],[9],[13]– [19] .These are defined as follows:

*1) Mean Squared Error (MSE):*It is computed pixel-by-pixel by adding up the squared difference between the uncorrupted (original) image $s(i\ ,\ j)$ and the restored image $r(i, j)$ and dividing by the total pixel count., it is defined as:

$$MSE = \frac{1}{m \times n} \sum_{i=1}^{m} \sum_{j=1}^{n} \left(s(i, j) - r(i, j)\right)^2 \qquad (4)$$

Where $m\times\ n$ is image size, the minimum value of *MSE* reflects the better visual.

2) Peak Signal to Noise Ratio (PSNR): is the ratio between the maximum pixel value of an image and the mean square error. It is measured in decibel (dB) and for gray scale image it is defined as:

$$PSNR(dB) = 10\log_{10}\left[\frac{(255)^2}{MSE}\right] \quad (5)$$

The higher value of the *PSNR* in the restored image, the better is its quality.

3) Image Enhancement Factor (IEF): is a measure of Image quality, and is defined as:

$$IEF = \frac{\sum_i \sum_j [\psi(i,j) - s(i,j)]^2}{\sum_i \sum_j [r(i,j) - s(i,j)]^2} \quad (6)$$

Where $\psi(i,j)$ is the pixel value of corrupted image. The higher value of *IEF* reflects the better visual, and restoration performance.

4) Mean Absolute Error (MAE): is a quantity used to measure how close as restored image are to the original, and it is defined as:

$$MAE = \frac{1}{m \times n}\sum_{i=1}^{m}\sum_{j=1}^{n}\left|r(i,j) - s(i,j)\right| \quad (7)$$

Where $r(i,j)$ and $s(i,j)$ are the pixel values of restored and original images respectively at the location (i,j).The minimum value of *MAE* reflects the better visual.

5) Correlation ratio (CORR): measures the degree to which two images vary together or oppositely and taking values from 0.0 to 1 .0 and it is defined as:

$$CORR = \frac{\sum_i (x_i - x_m)(y_i - y_m)}{\sqrt{\sum_i (x_i - x_m)^2 (y_i - y_m)^2}} \quad (8)$$

Where x_i is the intensity of the i^{th} pixel in original image, y_i is the intensity of the i^{th} pixel in the restored image, x_m is the mean intensity of the original image, and y_m is the mean intensity of the restored image. The value of *CORR* which gets close to 1.0 reflects the better visual impression.

VI. PROPOSED METHODOLOGY

The proposed algorithm can be described in the following: read input image then salt and pepper as an impulse noise were added with different levels of noise densities beginning with 10% up to 90%, after having noisy image different non linear filters were applied as SMF, AWF, WMF, DBMF and UDBMF then a quantitative & qualitative parameters as MSE, PSNR, IEF, MAE, and CORR are calculated for each filter for comparison. Figure.3. illustrates the flow chart of the computerized program that used to satisfy the suggested methodology.

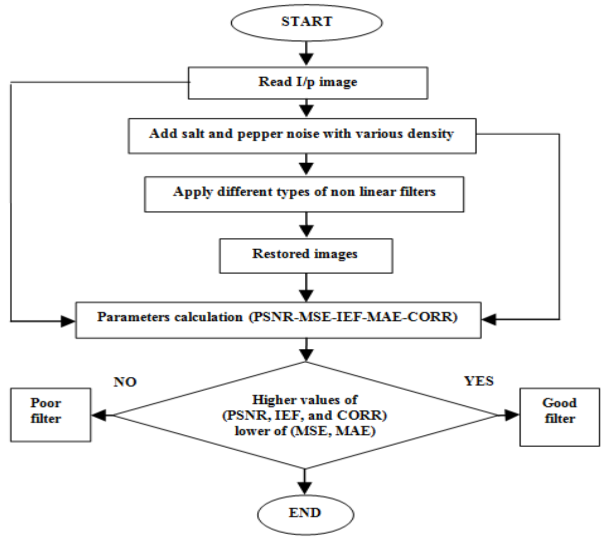


Figure 3. Flowchart of suggested methodology.

VII. SIMULATION RESULTS & DISCUSSIONS

To validate the proposed suggested methodology, a Barbara 512×512 PNG image is used in the simulation at different levels of noise densities. The proposed algorithm has been implemented using five programs that designed under MATLAB 7.10.0.499 (R2010a); as a language of technical computing. The performance of the proposed algorithm is evaluated with comparable study for various standard filters as: SMF, WMF, AWF, DBMF, and UDBMF. Figures (4-8) give the used noisy images and the restored images. The comparison was done in terms of MSE (4), PSNR (5), IEF (6), MAE (7), and CORR (8); where the results are illustrated in Figure 9.

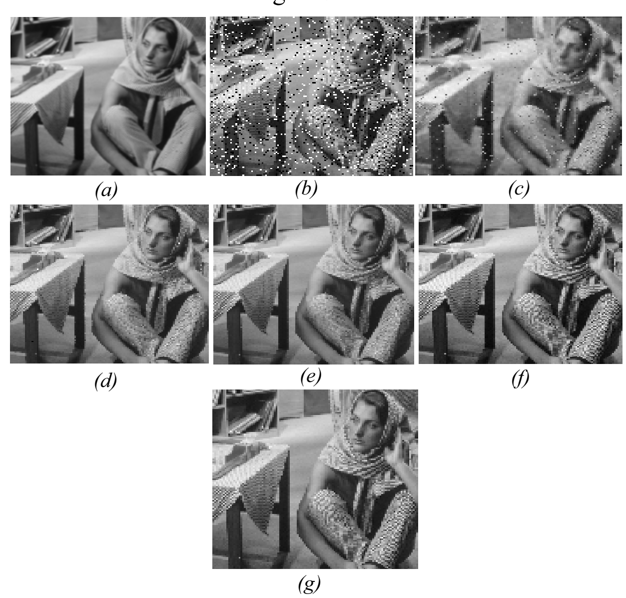


Figure 4. Results for 10% noise corrupted Barbara image: (a) Original image, (b) Noisy image, (c) AWF, (d) WMF, (e) SMF, (f) DBMF, and (g) UDBMF.

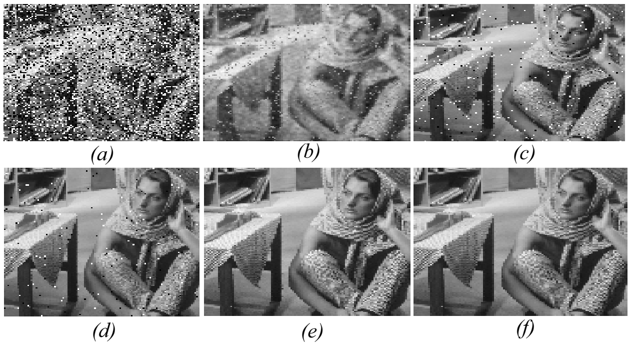


Figure 5. Results for 30% noise corrupted Barbara image:(a)Noisy image, (b) AWF, (c) WMF, (d) SMF, (e) DBMF, and (f) UDBMF.

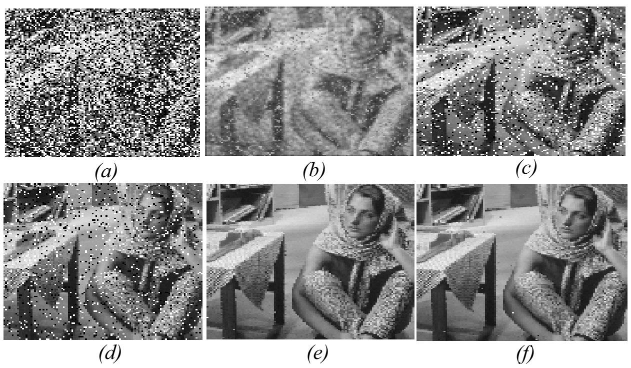


Figure 6. Results for 50% noise corrupted Barbara image:(a)Noisy image, (b) AWF, (c) WMF, (d) SMF, (e) DBMF, and (f) UDBMF.

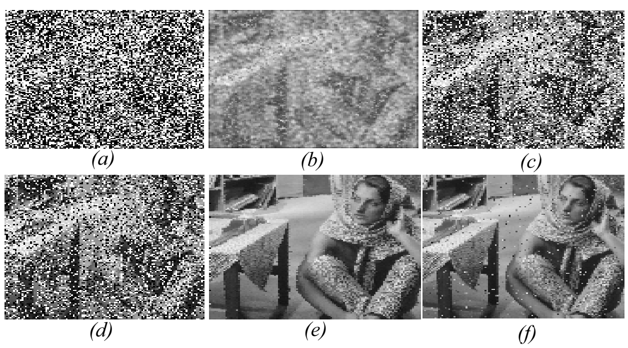


Figure 7. Results for 70% noise corrupted Barbara image:(a)Noisy image, (b) AWF, (c) WMF, (d) SMF, (e) DBMF, and (f) UDBMF.

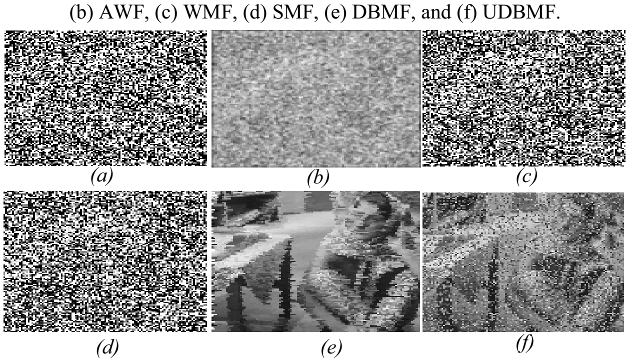
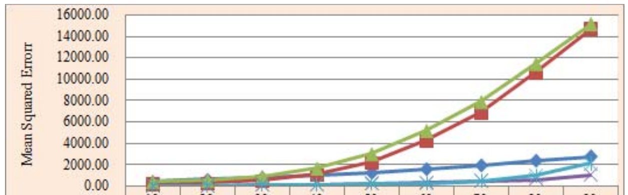
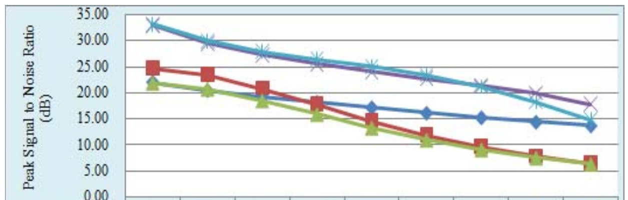


Figure 8. Results for 90% noise corrupted Barbara image:(a)Noisy image, (b) AWF , (c) WMF, (d) SMF, (e) DBMF, and (f) UDBMF.



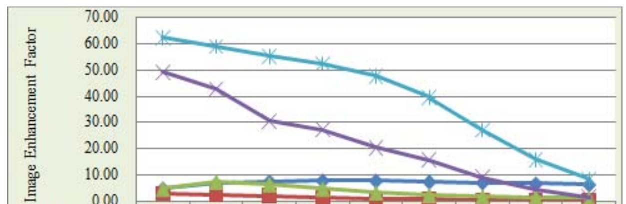
Noise Density(%)	10	20	30	40	50	60	70	80	90
AWF	412.89	597.75	784.22	995.28	1259.9	1598.6	1943.6	2370.2	2773.9
SMF	218.84	292.88	530.77	1091.8	2235.2	4257.5	6936.5	10619.	14651.
WMF	418.32	541.22	913.54	1669.1	3023.8	5208.0	7896.1	11408.	15109.
DBMF	32.99	72.55	123.34	182.71	256.41	343.34	470.33	658.25	1079.1
UDBMF	31.08	65.96	105.15	147.18	203.14	294.51	498.21	987.00	2129.0

(a)



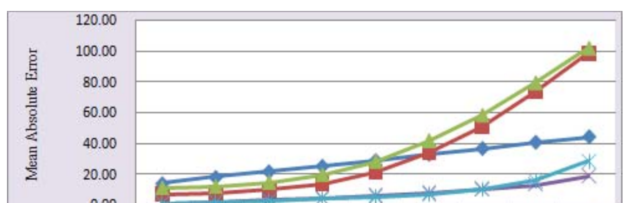
Noise Density(%)	10	20	30	40	50	60	70	80	90
AWF	21.97	20.37	19.19	18.15	17.13	16.09	15.24	14.38	13.70
SMF	24.73	23.46	20.88	17.75	14.64	11.84	9.72	7.87	6.47
WMF	21.92	20.80	18.52	15.91	13.33	10.96	9.16	7.56	6.34
DBMF	32.95	29.52	27.22	25.51	24.04	22.77	21.41	19.95	17.80
UDBMF	33.21	29.94	27.91	26.45	25.05	23.44	21.16	18.19	14.85

(b)



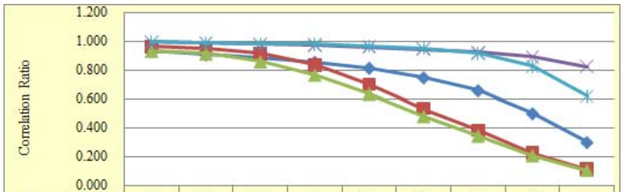
Noise Density(%)	10	20	30	40	50	60	70	80	90
AWF	4.69	6.50	7.40	7.75	7.65	7.28	6.97	6.55	6.26
SMF	3.06	2.69	1.99	1.22	0.74	0.41	0.25	0.14	0.11
WMF	4.63	7.18	6.35	4.62	3.19	2.23	1.71	1.36	1.15
DBMF	49.29	42.92	30.54	27.23	20.41	15.73	9.09	4.44	1.45
UDBMF	62.26	58.87	55.19	52.38	47.46	39.50	27.18	15.72	8.16

(c)



Noise Density(%)	10	20	30	40	50	60	70	80	90
AWF	14.11	18.07	21.73	25.20	28.83	32.86	36.54	40.56	44.05
SMF	7.12	8.06	10.08	14.06	21.61	34.36	51.14	73.82	98.91
WMF	11.32	12.28	14.88	19.91	28.53	42.00	58.55	79.69	102.2
DBMF	1.03	2.11	3.37	4.76	6.34	8.12	10.30	13.22	18.70
UDBMF	0.95	1.91	2.97	4.11	5.36	7.05	9.89	15.76	28.31

(d)



Noise Density(%)	10	20	30	40	50	60	70	80	90
AWF	0.932	0.906	0.882	0.855	0.814	0.748	0.659	0.499	0.300
SMF	0.963	0.950	0.912	0.832	0.703	0.533	0.381	0.227	0.112
WMF	0.930	0.910	0.856	0.763	0.635	0.479	0.343	0.205	0.103
DBMF	0.994	0.988	0.979	0.969	0.957	0.942	0.921	0.891	0.822
UDBMF	0.995	0.989	0.982	0.975	0.966	0.950	0.915	0.830	0.620

(e)

Figure 9. Comparison graphs and results for: (a) MSE, (b) PSNR, (c) IEF, (d) MAE, and (e) Correlation ratio for Barbara image at different noise densities.

From Figure 9, it can be illustrated that (SMF, WMF, and AWF) filters didn't give better results when they are compared with (DBMF-UDBMF) filters at different noise densities from (10% to 90%).The results of DBMF and UDBMF give lower (MSE, MAE), and higher (PSNR, IEF, CORR) and it can be observed that the performance of the UDBM filter is superior to the other filters at these percentages of noise density MSE(10% - 60%),MAE (10% - 70%),IEF(10%- 90%),PSNR (10% - 60%) and CORR (10% - 60%), but the DBM filter is the best at MSE values (70% - 90%),MAE (80% - 90%), PSNR (70% - 90%) and CORR (70% - 90%).

VIII. CONCLUSION

In this work, filters have been used as a tool for removing low and high density salt and pepper noise with edge preservation in digital images.

As a visual inspection; for low noise density up to 30%, all the filters perform well in removing the salt and pepper noise, For noise densities above 40%, bad impressions are given by the existing filters such as SMF, WMF, and AWF. The other filters as DBMF and UDBMF can remove noise at high densities but they produce streaking effect for noise densities (above 70%).

Related to the calculated parameters; at noise10% UDBMF give higher values for PSNR, IEF, and CORR (up to 33.21, 62.26, and 0.995 respectively). The lower values for MSE and MAE satisfied when using UDBMF, where it gives (31.08 and 0.95) as minimum values respectively.

Both visual and quantitative results are demonstrated that the DBM, UDBM filters are effective for salt and pepper noise removal in images at high noise densities.

IX. FUTURE SCOPE

In the future, various techniques can be considered and applied in further transformed domain to incorporate with the proposed algorithm to improve the performance and preserve more details in corrupted images. The comparative study can be further extended by including the 100-year-oldphoto blog to validate the filtering performance.

REFERENCES

[1] Charu Khare, Kapil Kumar Nagwanshi, "Image Restoration Technique with Non Linear Filters,"International Journal of Engineering Trends and Technology- May to June Issue 2011.

[2] Sushant S. Haware, Diwakar S. Singh, Tushar R. Tandel, Abhijeet Valande & N. S., "A Decision Based Algorithm for the Removal of High Density Salt and Pepper Noise," International Journal on Advanced Computer Theory and Engineering (IJACTE), 2319–2526, Volume-2, Issue-3, 2013.

[3] Astola, J., Kuosmanen, P.,Fundamentals of Non-linear Digital Filtering, CRC Press, New York, Boca Raton, 1997.

[4] Govindaraj.V, Sengottaiyan.G, "Survey of Image Denoising using Different Filters," International Journal of Science, Engineering and Technology Research (IJSETR) Volume 2, Issue 2, February 2013.

[5] Satyadhyan Chickerur, Aswatha Kumar, "A Biologically Inspired Filter for Image Restoration," International Journal of Recent Trends in Engineering, Vol 2, No. 2, Nov 2009.

[6] H. C. Andrews & B. R. Hunt, Digital Image restoration, Englewood cliffs, NJ, Prentice Hall, 1977.

[7] Shenbagarajan Anantharajan1, A. Siva Ganesh, V. Rajesh Kumar and C. Balasubramanian, "Image Restoration: Design of Nom-linear Filter (LR)," ICTACT Journal on Image and Video Processing, November 2012, Issue: 02.

[8] Rafael C. Gonzalez and Richard E. Woods, Digital image processing, 2nd edition, Addison- Wesely, 2004.

[9] Mohammed Ghouse, Dr. M. SIDDAPPA," Adaptive Techniques Based High Impulsive Noise Detection of a Digital Image,",Journal of Theoretical and Applied Information Technology, ©2005 – 2011.

[10] Archita Singh Parihar and Megha Jain,"A Review: Various Image Denoising Techniques,"International Journal of Computer Applications (0975 – 8887) Volume 95– No.6, June 2014.

[11] A.K.Jain, Fundamentals of Digital Image Processing, Englewood Cliff, N. J.: Print ice Hall, 2006.

[12] H.Taub,D.L. Schilling, Principles of Communication Systems, Second Edition,TMH, 1991.

[13] Anisha Bhatia & Ramesh K Kulkarni,"Removal of High Density Salt-And-Pepper Noise through Improved Adaptive Median Filter," International Conference on Computer Science and Information Technology (CSIT 2012), May 19th, 2012, Bangalore.

[14] Nieminen, A., P. Heinonen, and Y. Neuvo (1987), "A new class of detail-preserving filters for image processing," IEEE Trans. Pattern Anal. Mach. Intell., 9, 74-90.

[15] Nisha and Ravind erkhanna,"A Review of Image Restoration Techniques for Salt-and-Pepper with Resaults,"International Journal of Advanced Research in Electronics andCommunication Engineering (IJARECE) Volume 4, Issue 2, February 2015.

[16] Madhu S. Nair, K. Revathy, and Rao Tatavarti,"Removal of Salt-and Pepper noise in images: A New Decision-Based Algorithm," (Proceedings of the International Multi-Conference of Engineers and Computer Scientists 2008 Vol-I, IMECS 2008, 19-21 March, 2008, Hong Kong).

[17] S. Balasubramanian, S. Kalishwaran, R. Muthuraj, D. Ebenezer, V. Jayaraj, "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 -2009, 4th-6th June 2009.

[18] S. Esakkirajan, T. Veerakumar, Adabala N. Subramanyam, and C. H. PremChand, "Removal of High Density Salt and Pepper Noise Through Modified Decision Based Unsymmetric Trimmed Median Filter," IEEE Signal Processing Letters, VOL. 18, NO. 5, MAY 2011.

[19] A. Miranda Neto, A. Correa Victorino, I. Fantoni, D. E. Zampieri, J. V. Ferreira and D. A. Lima ," Image Processing Using Pearson's Correlation Coefficient: Applications on Autonomous Robotics,"13th International Conference on Mobile Robots and Competitions (Robotica), Lisbon: Portugal (2013).