A comprehensive analysis of adaptive image restoration techniques in the presence of different noise models

Adnan Khan[1], Imtiaz Alam[2], Muhammad Fawad Khan[3], Ibtihaj Ahmed[4], Zain Ul Islam[5], Muhammad Azam[6], Awais Akhtar[7]

[1]Department of Electrical and Computer Engineering, Pak-Austria Fachhochschule: Institute of Applied Sciences and Technology, Mang, Khanpur Road, Haripur, Khyber Pakhtunkhwa, Pakistan.

[2]Mavenir Testing Services, Tokyo, Japan

[3]Department of Electrical Engineering, Military College of Signals (MCS), National University of Sciences & Technology (NUST), Islamabad, Pakistan

[4]Department of Computer Science and Engineering, Northwestern Politechnical University (NPU), China.

[5]Department of Electronic Engineering and Information Science, University of Science and Technology of China (USTC)

[6]School of Energy and Power Engineering, Jiangsu University, China.

[7]School of Electrical Engineering and Computer Science, National University of Sciences & Technology (NUST), Islamabad, Pakistan

[1]adnan.khan@fecid.paf-iast.edu.pk, Imtiazalam99@outlook.com, [3]fawadkhan896@gmail.com, [4]ibtihajahmad@nwpu.edu.cn, [5]zainulislam@mail.ustc.edu.cn, [6]azamlyh@gmail.com

***Abstract*— Any deprivation caused by the image signal can be thought of as a noise. When an image signal is routed through a wireless or wired medium, it experiences deterioration because of channel characteristics. By knowing the type of noise that interfered in the signal, we can use the pertinent filtering techniques to remove the image's noise. Restoration of the image signal corrupted by noise is essential for better communication. This paper provides digital image handling techniques in MATLAB to restore the corrupted image. In this paper, different filtering methods have been discussed in the presence of two separate noise models that distort images. Four different filtering techniques, Mean/Average filtering, Median filtering, Adaptive median filtering, and Image Averaging, have been chosen against selected noise models. At the end of the paper we will compare which filtering technique works best for removing a particular noise.**

***Index Terms*—adaptive filtering, noise model, wiener filter, image averaging.**

I. INTRODUCTION

Image restoration and the quality enhancement is of great importance in image processing analysis these days. Much research is dedicated to improving image quality and noise models that effect image. First, a detailed study of a noise model should be carried out to understand the image degradation factor to rectify any image. i.e. how different noises distort an image and their visual and graphical effects on an image described in [1]. In today's world, all communication has turned into digital communication, which involves converting signals from analogue to digital and vice versa. Signals are transmitted over very long ranges using a wired or wireless medium. In the process of transferring images electronically, it is expected that the image will be degraded. This electrical noise's behaviour will distort the image, and it depends on the noise model that is causing the disturbance. Characteristics of different types of noises are studied in this paper. This classification has made the study of noise very easy.

The noise models discussed in this paper are the *"salt & pepper*" noise model and the *"Gaussian'* noise model presented in [2] and [3]. While noise models are being discussed, different filtering techniques used to filter them are also discussed in the paper. These different techniques are termed "image filters ". Every filter uses a different approach or technique to recover the image from the noise added to it. Out of all filtering techniques, some techniques have better results than others, depending on the type of noise, as stated in [4]. A filter giving good results on a particular noise model does not need to give same result for another noise model. It depends on the nature of noise, as illustrated in [4] and [5], which will be discussed further in the paper: section II, II. A and II.B discusses the noise models while section III, III.A, III.B, III.C and III.D discusses the filtering techniques used and section IV, IV. A and IV.B presents the results of our analysis. Section V concludes our paper.

II. NOISE MODELS

Usually, noise is considered as any undesirable change in the original signal. Similarly, in digital images, any distortion or undesired change in image is considered noise [6] and [7]. Noise in an image can be viewed as black white dots on an image, blurred image, blurred or dull edges, unclear image, and dark backgrounds.

This noise can be removed or filtered using different techniques. The goal is always to get the best result in minimum time and processing. To remove the noise from any image, we first have to study its characteristics, source, and the best way of cancelling or avoiding situations causing noise addition.

Different noise models affect the image in such ways that are different from one another, but one thing is common that they all intend to distort the image described in [8]. We have chosen two widespread types of noise models, i.e. 'Salt and Pepper noise' and' Gaussian noise' for our paper, discussed in section II.A and II.B.

II.A Salt & Pepper Noise Model

Also known as impulse valued or shot noise, Salt & pepper noise changes pixel's values to a maximum or minimum possible value between 255 and 0, respectively. Salt & Pepper noise does not contaminate the whole picture or each pixel; it only changes some pixel's value. Its effect on an image is in black and white dots scattered all over the picture, as shown in figure 1 taken from [9]. Some common sources of this noise are the failure of memory cells, the malfunctioning of the camera's sensor cells, and transmission in digitizing the image.

The probability density function (PDF) of (Bipolar) impulse noise is given by equation 1 from [9].

$$p(z) = \begin{cases} p_a & for \quad z=a \\ p_b & for \quad z=b \\ 0 & otherwise \end{cases} \qquad \textbf{1}$$

A bright dot in the image appears when grey-level 'b' is greater than grey-level 'a'. Otherwise, grey-level 'a' appears like a shady dot. Impulse noise is also called unipolar when either $\mathbf{p_a}$ or $\mathbf{p_b}$ is zero. The impulse noise values bear a resemblance to salt and pepper granules that are arbitrarily distributed over the image when in any case, the probability is zero or approximately equal. That is the reason why impulse noise is also called Salt and Pepper noise.

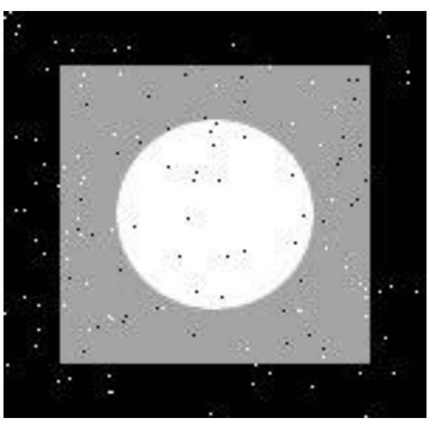


Figure 1**:** Salt and Pepper noise

II.B Gaussian Noise Model

Gaussian noise is also known as electrical noise, as it arises due to electronic components. This noise is additive because it disturbs all the pixel value of an image, unlike Salt & pepper noise, which changes only a few pixel values, as shown in [10] and [11]. This noise is additive, i.e. the corrupt pixel is the sum of the pixel's true or actual value and a random Gaussian noise distribution in an image.

Gaussian noise follows a normal distribution, also known as Gaussian distribution, as shown in equation 2 from [9], so its PDF also follows these distributions. This noise usually disturbs grey values; that is why its elimination involves the analysis of grey value histogram.

$$p(z) = \frac{1}{\sqrt{2\pi\sigma}} e^{-(z-\mu)^2/2\sigma^2} \qquad \textbf{2}$$

Where z = grey value, σ= standard deviation and μ= mean. Gaussian noise model gives the best approximate values for real-life scenarios. Approximately 70% of the grey level values will be in the range (μ-σ) and (μ+σ), and about 95% will be in the range (μ-2σ)and (μ+2σ). The PDF of Gaussian noise is shown in fig 2 taken from [9].

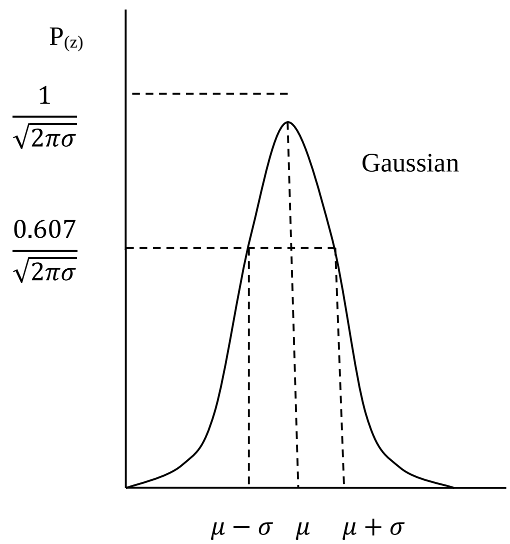


Figure 2: PDF of Gaussian noise

Some common sources of Gaussian noise are during acquisition because of sensor noise caused by poor illumination and/or high temperature during transmission, i.e. from electronic components. Usually, this noise is evenly distributed over the frequency domain. Normally, images contain low-frequency information, so they can be removed using low pass filters.

III. Noise Filtering

Removal of the noises mentioned above is an important task. Noise cannot be eliminated, but it can be removed to a maximum level using different techniques. Here in this paper, we have used different techniques, i.e. (Mean filter, Median filter, Adaptive Median/Weiner filter, Image Averaging filter) on above mentioned two types of noises and evaluated which filter works best for the particular type of noise based on MSE (Mean Square Error). Mean filter is discussed in section III.A, Median filter in section III.B, Adaptive median/Weiner filter in section III.C and Image Averaging filter in section III.D.

III.A MEAN FILTER / MEAN AVERAGING TECHNIQUE

Mean filter is also known as an averaging filter or mean average filter. It is a low pass linear filter. A mean average filter is a window that slides over the noisy image, and one by one, computes a new value for the middle pixel, which is the average of all the pixels in the window. Generally, a 3x3 size of the window is taken, but we can also take larger windows like 5x5 or 7x7.

A drawback of this filter is that while reducing the noise, it also decreases the image quality, as stated in [12], i.e. image details are lost. As we increase the window size, much noise is removed, but image quality also diminishes, as discussed in [13]. Since it is a low pass filter, and low pass filters are poor at preserving edges.

The results obtained by using a large window can also be obtained by increasing the filter of smaller window size computations. A 3x3 size window is taken in table 1 from [4], and the result of the mean averaging filter is computed.

Average= round(1+4+0+2+2+4+1+0+1)/9 = 2

Input

1	4	0	1	3	1
2	2	4	2	2	3
1	0	1	0	1	0
1	2	1	0	2	2
2	5	3	1	2	5
1	1	4	2	3	0

Output

1	4	0	1	3	1
2	2	2	2	1	3
1	2	1	1	1	0
1	2	1	1	1	2
2	2	2	2	2	5
1	1	4	2	3	0

Table 1*:* Mean Averaging Filter

III.B MEDIAN FILTER

Median filters are low pass non-linear filters that are a bit complex compared to mean filters but are better in preserving edges. They also work in a manner somewhat similar to mean filters; median filters also have a window that slides over the image matrix. Median filters sort the window in ascending order and replace the current pixel value with the ordered window's median value. Like in mean filters, the window size can also be varied in median filters, e.g. 3x3, 5x5, 7x7etc.

Median filters perform better for *Salt & pepper* noise, as discussed in [14] and [15]. By increasing the window's size, the noise level is reduced, but high-frequency information is lost. A median filter cannot remove the noise efficiently if it is greater than 40%. Nevertheless, if we increase the number of computations of a filter, we can restore an image even if it has a noise of 70%-90%. The working principle of a 3x3 size window of the median filter is shown in Figure 2, taken from [9]. In this figure, the image's median pixel value is too large, and the neighbouring values are quite small. So, the median filter takes the window of 3x3 and averages the pixel values to compute the middle pixel's result.

Original Intensities

3	3	4
4	87	4
4	5	5

Sorted Pixel Values: 3,3,4,4,4,4,5,5,87
Median filtered value: 4

Table 2: Median Filter

III. C ADAPTIVE MEDIAN FILTER

Adaptive median filter or *wiener2* filter is a linear filter whose results are based on a statistical approach. This filter uses mean and variance in noise removal. This filter smoothes the image. Smoothing is less when the variance is large, whereas the filter performs better for a small variance value. This filter is better at preserving edges and retaining high-frequency elements in an image. Its mathematical model is related to the spectral property of noise as in the equation. *3* stated in [9]:

$$G(u,v) = \frac{H^*(u,v)}{|H(u,v)|^2 P_s(u,v) + P_g(u,v)} \quad \mathbf{3}$$

The Fourier domain of the Wiener filter is where:
H(u, v) = Complex conjugate of degradation function*
$P_g(u,v)$ *= Power Spectral Density of Noise*
$P_s(u,v)$ *= Power Spectral Density of non-degraded image*
H (u, v) = Degradation function

III.D Image Averaging Filter

Image averaging is a technique used for noise removal that uses the approach of generating multiple copies of same image and taking the average of all the images. Greater the number of copies, the better is the result. Taking the average of the multiple copies of the same image, produce results very close to the original, thus greatly reducing the MSE. In many cases, we have seen that some filters giving reasonable value of MSE but do not produce very pleasing visual results; however, image averaging technique is not one of them.

IV. Results

We have applied above mentioned four filters on two different types of noises i.e. salt and pepper noise and Gaussian noise. To obtain results, a standard image of Lenna from [9] has been chosen against different noise factors for all the filters. Original Lenna image is shown in *figure 3*.

Figure 3*:* Original Image of Lenna

Visual effects can be seen in the figures plotted against each filter, and a table of MSE and Peak signal-to-noise ratio (PSNR) is also provided. First, Salt and pepper noise results are discussed in the next section, i.e. section IV. A and then the results for Gaussian noise are discussed in section IV.B.

IV.A Salt and pepper noise

Mean filter, median filter, adaptive median filter, and image averaging techniques have been applied in figure 3 for salt and pepper noise with 10% to 70% of noise factor against the step size of 10. A table of M.S.E and PSNR is also obtained and presented in *Table 3* against each filter. The visual result of noisy image is presented in *Table 5 f*or only 10%, 40% and 70 % of noise factor. The results suggest that the mean filter does not perform effectively on Salt & Pepper noise, visual effect of which is shown in *Table 5*. As we can see in *Table 3* that the mean square error of mean filter is very high and signal to noise ratio is very low. The visual effect of the median filter is shown in Table 5, suggesting the filter's better performance but still does not provide the desired good results as can be verified from *Table 3*. The visual result of the wiener filter is shown in *Table 5*. It has far better results than the previously applied two filters when the noise factor is greater than 50%. *Table 3* suggest that it has very low M.S.E and very high PSNR for the high noise factor. The last technique is the averaging image technique, which is shown in *Table 5*. This technique has taken an average of 32 images (we can take an average of more images depending upon the required results). It can be seen in *Table 3* that this technique has very good results as compared to other techniques applied before. It has the highest PSNR and very low M.S.E, which depicts greater efficiency of recovery of the image. From the above discussion the averaging image technique has the best response to the image restoration.

Table 3: Different Filter Response for Salt and Pepper noise

% noise	Mean		Median		Weiner filter		Averaging	
	MSE	**PSNR**	**MSE**	**PSNR**	**MSE**	**PSNR**	**MSE**	**PSNR**
10	630.5235	20.1338	1.10E+03	17.264	877.2712	18.6995	0.0103	19.872
20	1.03E+03	18.0114	2.05E+03	15.0158	1.32E+03	16.9088	0.0399	13.9935
30	1.33E+03	16.8802	2.90E+03	13.5103	1.60E+03	16.1021	0.0869	10.6106
40	1.53E+03	16.2921	3.61E+03	12.558	1.81E+03	15.5594	0.1463	8.3470
50	1.72E+03	15.7781	4.24E+03	11.8618	1.95E+03	15.2232	0.2139	6.6974
60	1.84E+03	15.4736	4.83E+03	11.2891	2.09E+03	14.9246	0.2858	5.4390
70	1.99E+03	15.1525	5.93E+03	10.8112	2.21E+03	14.6908	0.352	4.5344

IV.B Gaussian Noise

The results for 10%-70% of noise factor for Gaussian noise are obtained in this particular section. Since Gaussian noise is multiplicative and spreads all over the image equally, so it has a very bad effect on the image. First, we have applied a mean filter to the image. The result in *Table 4* shows that the mean filter has an adequate response to Gaussian noise, which can also be verified from Table 6 where the visual effect is presented. Table 4 presents that the mean filter has high PSNR and low M.S.E and does a good job removing Gaussian noise. Next, we have applied a median filter of window 3x3 on *figure 5,* and the visual result is shown in *Table 6*. The result suggests that it does not have a very good effect in recovering the image. In the Salt & Pepper noise, this filter had considerable effect, but it does not perform as desired in Gaussian noise, which can also be verified from *Table 4*. Weiner filter has intermediate filtering results; its M.S.E is greater than the mean filter and less than the median filter, and PSNR is less than the mean filter and greater than a median filter. So, we can say that the median and Wiener filters are not the best choice for recovering an image when Gaussian noise is present in the image. As discussed in section V, the image averaging technique performs best; *Table 4* suggests that the same is when Gaussian noise is added to the signal. The visual result of the image averaging technique on Gaussian noise is shown in *Table 6*. *Table 4* shows that the averaging image technique has very low M.S.E and very high PSNR. It also has a very good visual effect on the image and the results can be improved by taking the average of more images.

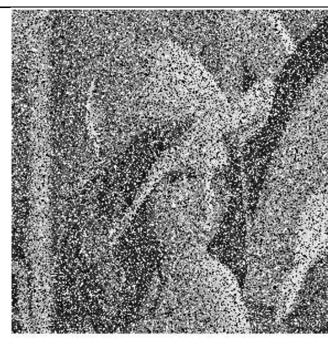
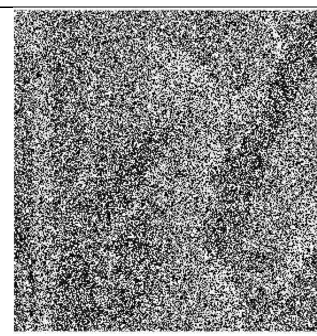
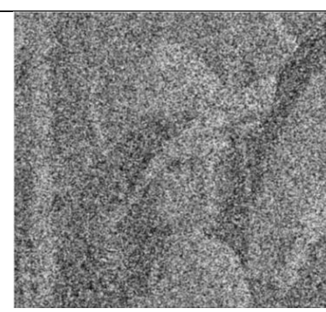
Table 4: Different Filter Response for Gaussian noise

% noise	Mean		Median		Weiner filter		Averaging	
	MSE	**PSNR**	**MSE**	**PSNR**	**MSE**	**PSNR**	**MSE**	**PSNR**
10	2.73E+02	23.763	30.45	33.294	363.77	22.522	0.0014	28.36
20	541.5097	20.7947	83.24	28.92	529.798	20.889	0.0039	24.05
30	866.098	18.7551	292.05	23.476	719.59	19.559	0.0074	21.29
40	1.20E+03	17.3249	827.873	18.9512	925.549	18.466	0.012	19.21
50	1.59E+03	16.1177	1.93E+03	15.2691	1.57E+03	17.496	0.0175	17.56
60	2.02E+03	15.0798	3.76E+03	12.3740	1.44E+03	16.563	0.024	16.19
70	2.57E+03	14.2068	6.55E+03	9.9715	1.77E+03	15.651	0.031	14.99

IV. Conclusion

The effect of four selected filtering techniques has been studied on a standard image with salt and pepper noise and Gaussian noise models in this Paper. The results suggest that averaging image filter outperforms the other selected techniques quite considerably. The results can be further improved by averaging more and more images. Other filters show better results for certain types of noises as the case with median filter performs better for salt and pepper noise but reduces its efficiency when Gaussian noise is added in the image, and the noise factor is high. We suggest that the averaging image technique is the best choice for the above mentioned two types of noise model.

Table 5: Results of Salt & Pepper Noise

Filter/Percentage of noise	10%	40%	70%
Noisy Image(Salt and Pepper)			
Mean			

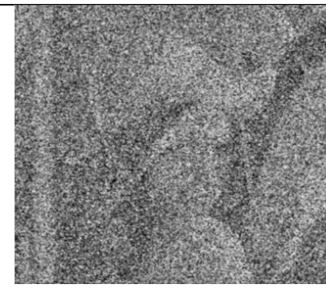
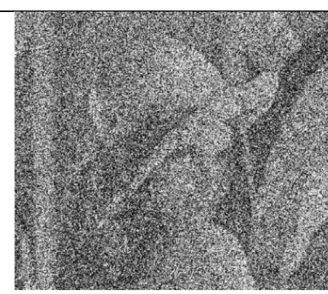
Median			
Wiener			
Image averaging			

Table 6: Results of Gaussian Noise

Filter/Percentage of noise	10%	40%	70%
Noisy Image(Gaussian)			
Mean			

Median			
Wiener			
Image averaging			

References

[1] Hossein Hosseini and Farokh Marvasti, "Fast restoration of natural images corrupted by high-density impulse noise", EURASIP Journal on Image and Video Processing, December 2013.

[2] R.H.Chan, Chung-Wa Ho and M.Nikolova, "Salt and Pepper Noise Removal by Median-Type Noise Detectors and Detail-Preserving Regula-rization IEEE Trans. Image Process, Vol. 14, No. 10, September 2005.

[3] Joshi2, A. K. , "A review paper: noise models in digital image processing". Signal & Image Processing: An International Journal (SIPIJ) Vol.6, No.2, April 2015.

[4] Rowaida, S. T., "A Comparative Study of Various Image Filtering Techniques for Removing Various Noisy Pixels in Aerial Image", International Journal of Signal Processing, Image Processing and Pattern Recognition, Vol.9, No.3, 2016.

[5] A. Achim, E.E. Kuruoglu and J. Zerubia, "SAR image filtering based on the heavy – tailed Rayleigh model", IEEE Trans. Image Process., Vol. 1, No. 9, pp. 2686-2693, Sept. 2006

[6] Alan C. Bovik," Handbook of Image and Video Processing", 2nd edition, (2005).

[7] Tzu-Chao Lin and Pao-Ta Yu, "Salt-Pepper Impulse Noise Detection and Removal Using Multiple Thresholds for Image Restoration",January 2006.

[8] Joshi, A., Boyat, A. and Joshi, B. K. "Impact of Wavelet Transform and Median Filtering on removal of Salt and Pepper noise in Digital Images," IEEE International Conference on Issues and Challenges in Intelligant Computing Teachniques, Gaziabad.April 2014.

[9] Rafael C. Gonzalez Richard E. Woods, "Digital Image Processing", Third Edition, August 2017.

[10] Makitalo, M. and Foi, A. "Optimal inversion of the genralized Anscombe transformation for Poisson-Gaussian noise," IEEE Trans. Image Process., vol. 22, no. 1, pp. 91-103, 2013.

[11] Luisier, F., Blu, T. and Unser, M. 'Image denoising in mixed Poisson-Gaussian noise', IEEE Trans. Image Process., Vol. 20, No. 3, pp. 696–708. (2011)

[12] Mukesh C. Motwani, Mukesh C. Gadiya, Rakhi C. Motwani "survey of image denoising techniques", Proceedings of GSPx 2004, Santa Clara Convention Center, Santa Clara, CA. P.27-30, 2004

[13] Tzu-Chao Lin and Pao-Ta Yu," Salt-Pepper Impulse Noise Detection and Removal Using Multiple Thresholds for Image Restoration", Vol. 22, pp. 189-198, No. 1, January 2006

[14] Raymond H. Chan, Chung-Wa Ho, and Mila Nikolova, "Salt-and-Pepper Noise Removal by Median-type Noise Detectors and Detail-preserving Regularization", Image Processing, IEEE Transactions. Volume 14, pp: 1479 – 1485, Issue 10, Oct. 2005

[15] James C. Church, Yixin Chen, and Stephen V. Rice, "A Spatial Median Filter for Noise Removal in Digital Images", IEEE Conference in Southeastcon, pp: 618- 623, 2008.