Performance analysis of frequency domain filters for noise reduction

Amit Shukla[1], Dr R.K. Singh[2]

1. Computer Science & Engineering Department, Kamla Nehru Institute of Technology, Sulatnpur
2. Electronics Engineering Department, Kamla Nehru Institute of Technology, Sulatnpur

Abstract

Image denoising is an important pre-processing task before further processing of image like segmentation, feature xtraction, texture analysis etc. The purpose of denoising is to remove the noise while retaining the edges and other detailed features as much as possible. This noise gets introduced during acquisition, transmission & reception and storage & retrieval processes. As a result, there is degradation in visual quality of an image. In this study two sets of experiments are conducted. The objective of first set of study is to compare the performance of the frequency domain filters for noise reduction of the facial and distant images. The objective of the second set of study of is to compare the performance of the frequency domain filters for the different values of the n (order of the filter) and threshold.

Keywords: Filters, Noises, Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE) and Execution Time (ET).

Introduction

Digital image processing techniques are gaining importance because the major transmission of information took place via electronic medium. The information (data, image or video) gets corrupted during data acquisition, transmission, reception, and retrieval stages. Noise is any unwanted signal that contaminates an image that result in pixel values not reflecting the true nature of the scene. Noise can be caused in images by random fluctuations in the image signal. The prime objective of the image processing is to extract clear information from the images corrupted by noise. Such technique for noise removal is called filtering or denoising [1, 3]. This study considers four different types of noises (salt & pepper, speckle, poisson and gaussian) among the noise categories: substitutive/impulsive noise, additive noise and multiplicative noise. This research is focused on the two dimensional image filtering in the frequency domain. The frequency domain is generally faster to perform two 2D Fourier transforms and filters multiply than to perform a convolution in the image (spatial) domain [4]. This study considers the Low-pass, high-pass and high-boost filters for examining the performance analysis of the filets for betters noise reduction. MSE, PSNR and ET objective metrics are used to measuring image quality.

Review of Literature

R. Graham (1962) explained that it is possible to separate "picture" from "noise" in a television image. He considered smoothing filters are for the maximum suppression of noise without picture blurring [18].

Harry C. Andrews (1974) research is based on tow main areas: image coding and image restoration-enhancement. His research paper presents both a survey of the field as well as specific examples of projects currently in progress [20].
Raymond H. Chan, Chung-Wa Ho, and Mila Nikolova (2005) propose a two-phase scheme for removing salt-and-pepper impulse noise. An adaptive median filter is used to identify pixels which are likely to be contaminated by noise in the first phase and the image is restored using a specialized regularization method that applies only to those selected noise candidates in the second phase. The results were good in comparison to non-linear filters [9].
Celia A. Zorzo Barcelos and Marcos Aure´lio Batista (2007) explored the inpainting and denoising in his research. He presented a new approach for denoising by the smoothing equation working inside and outside of the inpainting domain. Besides smoothing, the approach here permits the transportation of available information from the outside towards the inside of the inpainting domain. The experimental results show the effective performance of the combination of these two procedures in restoring [10].
A.Z.R. Langi, K. Soemintapura and T.L. Mengko (1997) propose that image quality measures are based on multifractality preservation. Mean square error (MSE) and peak signal to noise ratio (PSNR) are traditional quality or distortion measures used to calculate the difference between the original and distorted image. He proposed the multifractal measures for image singularities [12].
Zhou Wang and Hamid R. Sheikh (2004) developed a Structural Similarity Index and demonstrate its promise through a set of intuitive examples, as well as compared to both subjective ratings and state-of-the-art objective methods on a database of images [14].
Chi Chang-yan, Zhang Ji-xian, Liu Zheng-jun (2008) explained that noise is an important factor that influences image quality. MSR and PSNR are calculated to evaluate the processed image and results suggest that the methods used in this paper are suitable in processing the noises [15].

Methodology

Here software 'Matlab 7.8' is used for the processing and analyzing the images. Following steps are followed to achieve the objectives.
1. Two grayscale images as shown in fig. 1.1(a) & 1.1(b), 'Lena.jpg' and 'Cameraman.jpg' of 128*128 pixels are considered for the analysis.


Figure 1.1 (a):
Lena Grayscale


Figure 1.2 (b):
Cameraman Gray

2. Salt & pepper, speckle, poisson and gaussian noises are introduced in both the 'Lena.jpg' and 'Cameraman.jpg'. The noisy 'Lena.jpg' and 'Cameraman.jpg' images are shown blow.


Salt &Pepper Speckle Noisy


Poisson Noisy Gaussian Noisy


Salt &Pepper Speckle Noisy


Poisson Noisy Gaussian Noisy

3. Set the initial value n=1 & threshold=10.

4. Lena salt and pepper noisy image is filtered through low-pass gaussian filter, low-pass butterworth filter, high-pass gaussian filter, high-pass butterworth, high-boost gaussian filter and high-boost butterworth filter serially.
5. The output image (filtered image) is then compared to its original images of and various parameters like MSE, PSNR and ET are calculated to determine the filter performance individually [4, 5, 6, 7].
6. Step 4 and step 5 are repeated for the speckle noisy, poisson noisy and gaussian noisy of 'Lena.jpg'.
7. Again step 4 and step 5 are repeated for salt & pepper, speckle, poisson and gaussian noisy image of 'Cameraman.jpg'.
8. Now set n=2 (order of the filter) and threshold=20 (cut-off radius in frequency domain filters).
9. Step 4 and step 5 are repeated for the salt & pepper, speckle, poisson and gaussian noisy image of 'Lena.jpg' and 'cameraman.jpg'.

All the image quality parameters values are tabulated and then all the filters performance is analyzed individually and comparatively.

Results

Table 4.1: MSE, PSNR and ET Values of Salt & Pepper Noisy Filtered Lena Image for n=1 and Threshold=10

Noise	**Filters**		**Lena.jpg**		
			MSE	**PSNR (dB)**	**ET (sec)**
Salt & Pepper Noise	Low Pass	Gaussian	955.27	18.33	0.062263
		Butterworth	1003.80	18.11	0.061902
	High Pass	Gaussian	12336.00	7.22	0.062662
		Butterworth	11838.00	7.40	0.136718
	High Boost	Gaussian	1377.10	16.74	0.062634
		Butterworth	1243.10	17.19	0.099532

Table 4.2: MSE, PSNR and ET Values of Speckle Noisy Filtered Lena Image for n=1 and Threshold=10

Noise	**Filters**		**Lena.jpg**		
			MSE	**PSNR (dB)**	**ET (sec)**
Speckle Noise	Low Pass	Gaussian	944.40	18.38	0.152167
		Butterworth	989.55	18.18	0.059749
	High Pass	Gaussian	11899.00	7.38	0.067494
		Butterworth	11530.00	7.51	0.177975
	High Boost	Gaussian	2132.40	14.84	0.098342
		Butterworth	1980.00	15.16	0.077279

Table 4.3: MSE, PSNR and ET Values of Poisson Noisy Filtered Lena Image for n=1 and Threshold=10

Noise	**Filters**		**Lena.jpg**		
			MSE	**PSNR (dB)**	**ET (sec)**
Poisson Noise	Low Pass	Gaussian	941.99	18.39	0.061466
		Butterworth	987.74	18.18	0.060103
	High Pass	Gaussian	12241.00	7.25	0.059685
		Butterworth	11796.00	7.41	0.060337
	High Boost	Gaussian	1366.50	16.77	0.200510
		Butterworth	1233.70	17.22	0.094611

Table 4.4: MSE, PSNR and ET Values of Gaussian Noisy Filtered Lena Image for n=1 and Threshold=10

Noise	Filters		Lena.jpg		
			MSE	PSNR (dB)	ET (sec)
Gaussian Noise	Low Pass	Gaussian	919.66	18.49	0.068442
		Butterworth	941.84	18.39	0.101656
	High Pass	Gaussian	11599.00	7.49	0.070811
		Butterworth	11215.00	7.63	0.067784
	High Boost	Gaussian	2599.20	13.98	0.059995
		Butterworth	2461.50	14.22	0.059242

Table 4.5: MSE, PSNR and ET Values of Salt & Pepper Noisy Filtered Cameraman Image for n=1 and Threshold=10

Noise	Filters		Cameraman.jpg		
			MSE	PSNR (dB)	ET (sec)
Salt & Pepper Noise	Low Pass	Gaussian	2665.20	13.87	0.089598
		Butterworth	2708.30	13.80	0.074347
	High Pass	Gaussian	18572.00	5.44	0.087997
		Butterworth	17676.00	5.66	0.067187
	High Boost	Gaussian	1473.30	16.45	0.081988
		Butterworth	1294.30	17.01	0.062413

Table 4.6: MSE, PSNR and ET Values of Speckle Noisy Filtered Cameraman Image for n=1 and Threshold=10

Noise	Filters		Cameraman.jpg		
			MSE	PSNR (dB)	ET (sec)
Speckle Noise	Low Pass	Gaussian	2665.20	13.87	0.066772
		Butterworth	2706.10	13.81	0.065883
	High Pass	Gaussian	17833.00	5.62	0.062024
		Butterworth	17214.00	5.77	0.059099
	High Boost	Gaussian	2431.10	14.27	0.070028
		Butterworth	2189.20	14.73	0.060890

Table 4.7: MSE, PSNR and ET Values of Poisson Noisy Filtered Cameraman Image for n=1 and Threshold=10

Noise	Filters		Cameraman.jpg		
			MSE	PSNR (dB)	ET (sec)
Poisson Noise	Low Pass	Gaussian	2644.30	13.91	0.062183
		Butterworth	2677.40	13.85	0.072826
	High Pass	Gaussian	18331.00	5.50	0.063492
		Butterworth	17541.00	5.69	0.059678
	High Boost	Gaussian	1490.90	16.40	0.058715
		Butterworth	1295.20	17.01	0.060668

Table 4.8: MSE, PSNR and ET Values of Gaussian Noisy Filtered Cameraman Image for n=1 and Threshold=10

Noise	Filters		Cameraman.jpg		
			MSE	PSNR (dB)	ET (sec)
Gaussian Noise	Low Pass	Gaussian	2649.40	13.90	0.225244
		Butterworth	2672.40	13.86	0.081504
	High Pass	Gaussian	17998.00	5.58	0.089145
		Butterworth	17279.00	5.76	0.175362
	High Boost	Gaussian	2266.60	14.58	0.084556
		Butterworth	2040.60	15.03	0.059934

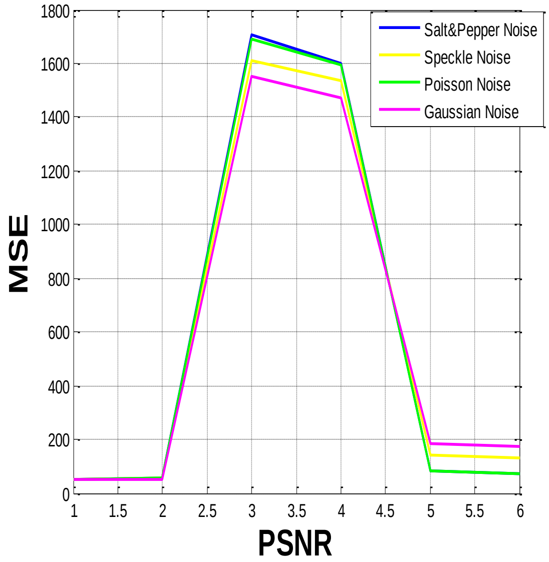

Figure 4.1: Ratio of MSE and PSNR of Lena Noisy Images at n=1 and Threshold=10

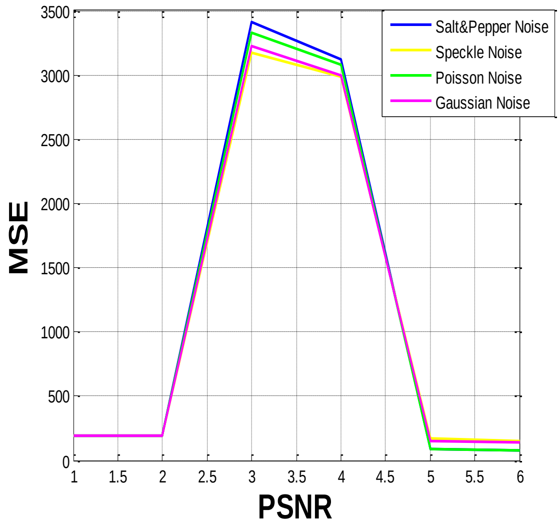

Figure 4.2: Ratio of MSE and PSNR of Cameraman Noisy Images at n=1 and threshold=10

Table 4.9: MSE, PSNR and ET Values of Salt & Pepper Noise Filtered Lena Image for n=2 & Threshold=20

Noise	**Filters**		**Lena.jpg**		
			MSE	**PSNR (dB)**	**ET (sec)**
Salt & Pepper Noise	Low Pass	Gaussian	485.321	21.2705	0.097093
		Butterworth	560.502	20.6450	0.089534
	High Pass	Gaussian	13758.000	6.7453	0.095737
		Butterworth	13738.000	6.7514	0.120793
	High Boost	Gaussian	1431.800	16.5721	0.093647
		Butterworth	1523.200	16.3033	0.130375

Table 4.10: MSE, PSNR and ET Values of Speckle Noisy Filtered Lena Image for n=2 & Threshold=20

Noise	Filters		Lena.jpg		
			MSE	PSNR (dB)	ET (sec)
Speckle Noise	Low Pass	Gaussian	480.826	21.311	0.085499
		Butterworth	557.640	20.667	0.086812
	High Pass	Gaussian	13072.000	6.967	0.075809
		Butterworth	13050.000	6.975	0.105739
	High Boost	Gaussian	2249.200	14.611	0.080467
		Butterworth	2332.100	14.453	0.090051

Table 4.11: MSE, PSNR and ET Values of Poisson Noisy Filtered Lena Image for n=2 & Threshold=20

Noise	Filters		Lena.jpg		
			MSE	PSNR (dB)	ET (sec)
Poisson Noise	Low Pass	Gaussian	472.551	21.386	0.079501
		Butterworth	550.671	20.722	0.090563
	High Pass	Gaussian	13664.000	6.775	0.081560
		Butterworth	13631.000	6.786	0.090998
	High Boost	Gaussian	1437.800	16.554	0.079560
		Butterworth	1526.000	16.295	0.092890

Table 4.13: MSE, PSNR and ET Values of Salt & Pepper Noisy Filtered Cameraman Image for n=2 & Threshold=20

Noise	Filters		Cameraman.jpg		
			MSE	PSNR (dB)	ET (sec)
Salt & Pepper Noise	Low Pass	Gaussian	1114.400	17.660	0.070853
		Butterworth	1273.700	17.080	0.082279
	High Pass	Gaussian	21316.000	4.844	0.096793
		Butterworth	21267.000	4.854	0.080702
	High Boost	Gaussian	1842.300	15.477	0.069996
		Butterworth	1954.700	15.220	0.084722

Table 4.14: MSE, PSNR and ET Values of Speckle Noisy Filtered Cameraman Image for n=2 & Threshold=20

Noise	Filters		Cameraman.jpg		
			MSE	PSNR (dB)	ET (sec)
Speckle Noise	Low Pass	Gaussian	1121.400	17.633	0.231738
		Butterworth	1278.900	17.062	0.081669
	High Pass	Gaussian	20103.000	5.098	0.058377
		Butterworth	20089.000	5.101	0.100010
	High Boost	Gaussian	2919.900	13.477	0.067378
		Butterworth	3028.000	13.319	0.073604

Table 4.15: MSE, PSNR and ET Values of Poisson Noisy Filtered Cameraman Image for n=2 & Threshold=20

Noise	Filters		Cameraman.jpg		
			MSE	PSNR (dB)	ET (sec)
Poisson Noise	Low Pass	Gaussian	1082.200	17.788	0.070810
		Butterworth	1247.400	17.171	0.091618
	High Pass	Gaussian	20996.000	4.910	0.065358
		Butterworth	20948.000	4.919	0.085601
	High Boost	Gaussian	1794.900	15.591	0.074407
		Butterworth	1912.600	15.315	0.078117

Table 4.16: MSE, PSNR and ET Values of Gaussian Noisy Filtered Cameraman Image for n=2 & Threshold=2

Noise	Filters		Cameraman.jpg		
			MSE	PSNR (dB)	ET (sec)
Gaussian Noise	Low Pass	Gaussian	1127.900	17.608	0.062968
		Butterworth	1290.600	17.023	0.073752
	High Pass	Gaussian	20334.000	5.049	0.072253
		Butterworth	20324.000	5.051	0.088694
	High Boost	Gaussian	2736.300	13.759	0.073276
		Butterworth	2847.200	13.587	0.081789

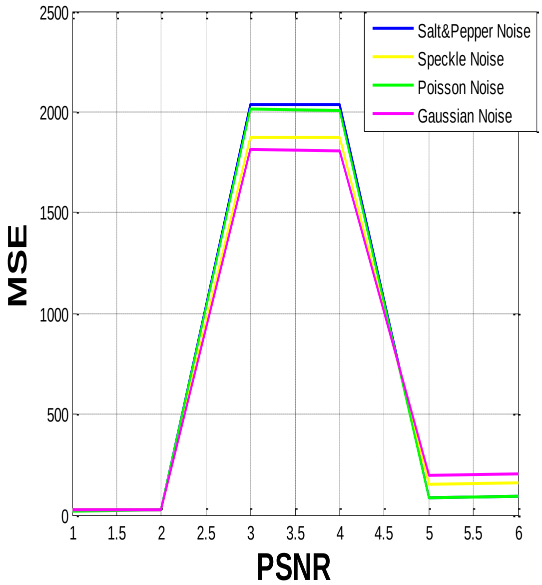

Figure 4.3: Ratio of MSE and PSNR of Lena Noisy Images at n=2 and Threshold=20

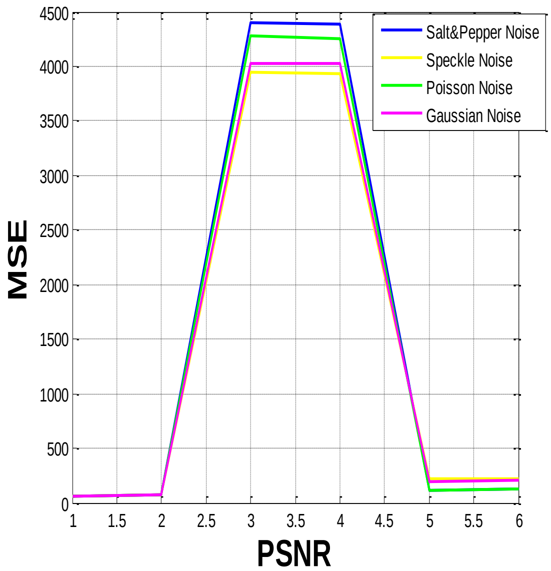

Figure 4.4: Ratio of MSE and PSNR of Cameraman Noisy Images at n=2 and Threshold=20

Conclusion

Here two sets of experiments are conducted in this study. The objective of first set of study is to compare the performance of the frequency domain filters for the facial (Lena.jpg) and distant (Cameraman.jpg) images.
The objective of the second set of study of is to compare the performance of the frequency domain filters for the different values of the n (order of the filter) and threshold (cut-off frequency).
The experimental and mathematical results shown above in this study that the combination of the lower value of MSE and higher value of the PSNR is given *gaussian low pass filter* for the facial (captured form near to object) images for the first and second order of the filter having threshold equal to 10 and 20 respectively.

In case of distant images *butterworth highboost filter* provides the best result at n=1 & threshold=10. As we increase the order of filter and cut-off frequency (n=2 and threshold=20), the experimental results shows that the again *gaussian low pass filter* provides the best combination of the lower MSE and higher PSNR.
So, it have been concluded that amongst all frequency domain filters considered in this study, *Gaussian Lowpass filter* is best filter for filtering the facial images for first order filter (threshold=10) and for second order filter (threshold=20) also.
In case of distant noisy images *butterworth highboost filter* is the best filter for first order filter (threshold=10) and *gaussian Lowpass filter* provides best filtering results for second order filter (threshold=20).

Scope for Future Work

There should be a large number of images taken to bolster the results statistically. A future work can be extended for color images also. The filters behaviors' and results can be analyzed for the different combination of n and threshold. Further combination of the filters can be taken to obtain better results and more than one noise can be added to a single image and then filter parameters can be determined. Other filters can be applied to the same process. Also, other images like CT, Ultrasound, X-ray images etc. can also be taken and effects of various parameters can be studied on them.

References

[1] Rafael C. Gonzalez, Richard E. Woods, Digital Image Processing. Second edition upper saddle River, NJ: Prentice Hall, 2006.
[2] Rafael C. Gonzalez & Richard E. Woods, Digital Image Processing using Matlab. Third edition: Pearson education, 2005.
[3] William K. Pratt, Digital Image Processing Third edition, A Wiley-Interscience Publication 2001.
[4] Huiyu Zhou,Jiahua Wu and Jianguo Zhang, Digital Image Processing. Part II, 2010.
[5] Jain, Anil K. Fundamentals of Digital Image Processing. Prentice Hall of India, 2002.
[6] S.Sridhar, Digital Image Processing. Oxford University Press, 2011.
[7] Bernd Jähne, Digital Image Processing Sixth edition, Springer 2005.
[8] Huiyu Zhou,Jiahua Wu and Jianguo Zhang, Digital Image Processing. Part I, 2010.
[9] Raymond H. Chan, Chung-Wa Ho, and Mila Nikolova, "Salt-and-pepper noise removal by median-type noise detectors and detail-preserving regularization," IEEE Transactions on Image Processing, vol. 14, no. 10, October 2005.
[10] Celia A. Zorzo Barcelos and Marcos Aure´lio Batista, "Image restoration using digital inpainting and noise removal," Image and Vision Computing 25, page 61–69, 2007.
[11] Ce Liu, Richard Szeliski, Sing Bing Kang, C. Lawrence Zitnick and William T.Freeman, "Automatic estimation and removal of noise from a single image," IEEE Trans. on Pattern Analysis and Machine Intelligence, vol. 30, no. 2, February 2008.

[12] A.Z.R. Langi, K. Soemintapura and T.L. Mengko, "**Multifractal measures of image quality**," **Information, Communications and Signal Processing,** 1997.

[13] Zhou Wang, Alan C. Bovik, Hamid R. Sheikh and Eero P. Simoncelli, " Image quality assessment: from error visibility to structural similarity," IEEE Trans. on Image Processing, vol. 13, no. 4, April 2004.

[14] Sonja Grgi, Mislav Grgi and Marta Mrak, " Reliability of objective picture quality measures," Journal of Electrical Engineering, vol. 55, no. 1-2, pp. 3-10, 2004.

[15] Chi Chang-yan, Zhang Ji-xian, Liu Zheng-jun, "Study on methods of noise reduction in a stripped image," The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XXXVII. Part B6b. Beijing 2008.

[16] Frank Y. Shih, Image Processing and Mathematical Morphology Fundamentals andApplications. CRC Press, 2009.

[17] Madasu Hanmandlu Member IEEE and Devendra Jha "An Optimal Fuzzy System for Color Image Enhancement," IEEE Trans on Image Process., 2006.

[18] R. Graham, "**Snow removal-A noise-stripping process for picture signals**," **Information Theory, IRE Transactions on** , vol. 8 , **issue 2** , 1962.

[19] T.S. **Huang, W. Schreiber** and O.J. Teritak, "Image processing," **Proceedings of the IEEE** , vol.59, **issue 11**, 1971.

[20] Harry C. Andrews, "Digital image processing," IEEE Computer, vol.7, issue 5, 1974.

[21] Tomáš Kratochvíl, Pavel Šimíček, "Utilization of matlab for picture quality evaluation," Institute of Radio Electronics, Brno University of Technology.

[22] "Matlab 6.5 Image Processing Toolbox," Tutorialhttp://www.cs.otago.ac.nz-/cosc451/Resources/matlab_ipt_tutorial.pdf.

[23] Marta Mark,Sonja Gargic and Mislav Gargic, "Picture quality measures in image compression system," IEEE Eurocon, 2003.

[24] Eduardo Abreu, Michel Lightstone, Sanjit K. Mitra and Kaoru Arakawa, "A new efficient approach for the removal of impulse noise from highly corrupted images," IEEE Transactions on Image Processing, vol. 5, no. 6, June 1996.

[25] "ImageProcessingToolbox,"http://www.mathworks.in/products/image/.

[26] "Originalimage:Lena,"http://www.cosy.sbg.ac.at/~pmeerw/Watermarking/lena.html.

[27] "Help," http://www.mathworks.in/help/matlab/ref/help.html.