COMPARATIVE ANALYSIS OF IMAGE DENOISING TECHNIQUES

Monika Pathak

Assistant Professor

Multani Mal Modi College, Patiala

monika_mca@yahoo.co.in

Sukhdev Singh

Assistant Professor

Multani Mal Modi College, Patiala

tomrdev@gmail.com

ABSTRACT

These days the concept of denoising is not restricted to the field of photography or publication where image needs to be improved for printing purpose. It is quite useful tool in number of digital image processing application such as space exploration where noise can be introduced due to artifacts generated by mechanical or optical system of a telescope. Image denoising finds application in field of medical science where high quality images are required in the form of x-ray images, ultrasound and city scan images. A good quality medical image can be useful to diagnose diseases. In the field of forensic science, where evidence sometimes is available in extremely bad quality, in such case, denoising tools are used to produce quality images. Moreover core digital image processing applications like text extraction from images, number plate detection, OCR etc. use denoising as a pre-processing tool. Removing noising from digital images is still a challenging task. There are various methods available in literature but not a single method is suitable for all type of image noises. In this paper, we have discussed various algorithms with assumptions, advantages and disadvantages. The comparative analysis of these noising techniques is carried out to find the most suitable and reliable method for image denoising.

Keywords: Spatial filter, Arithmetic mean Filter, Geometric mean filter, Harmonic mean filter, Median filter, Salt and pepper noise.

INTRODUCTION

The digital image contains vital information in the form of object and text that can be used for various purposes like object recognition, face recognition and text recognition. In most of the applications, under pre-processing phase image denoising techniques are involved to manipulate image such that its visual quality can be improved. After the denoising, the improved quality image can be used for further processing. The aim of denoising technique is to remove unwanted signals from the image while saving important information. The noise in image is a disturbance that distorts the information and degrades the quality of the image. The noise is introduced in the image due to various reasons such as electronic and photometric disorder, transmission media error due to noisy channel, error in measurement and quantization of digital information. On the basis of source of error, different noise models have been proposed in literature. These models are also discussed in the paper in detail. The denoising techniques tend to be problem specific. It means a technique that is used to denoise the medical images may not be suitable for denoise the document scanned images. Every technique has its own merits and demerits with reference to different types of noises. The objective of present study is to analyse different techniques to find suitable method to remove the noise from digital image. We have included elementary introduction to some of frequently used filters. Experimental results and comparison of these filters the comparative analysis is carried out with the help of analysis parameters such as mean square error, signal to noise ratio and peak signal to noise ratio.

TYPES OF IMAGE NOISE

Noise is basically a disturbance that distorts the information present in the image. It is usually an unwanted signal that can create a variation in image intensity levels of pixels which cause degradation of image quality. The noise is introduced in image automatically due to following reasons:

Digital Image Acquisition Process: In acquisition process, the optical image is converted into a series of electronic signals. During this process, unwanted signals may be added into original series of electronic signals. There may be certain other unavoidable situations such as mechanical problem, out of focus blur, motion, in appropriate illumination.

Image Transmission Process: The most of time noise is added during transmission process[1] such as scanning of image using scanner, converting one image format into another format, wireless network transmission of image etc. During transmission process, noisy channel and error due to measurement process may introduce unwanted signals into data stream which results in noised image.

Sensitivity of Image Sensors: The image sensors are sensitive[2] to motion and cause noising during capturing process due to malfunctioning of pixel elements in the camera sensors, faulty memory locations, or timing errors in the digitization process.

There are different types of noise occur in digital images.

Gaussian Noise: Gaussian noise [3] is evenly distributed over the image. This means that each and every pixel in the image have values which is considered as sum of true values plus noise value from gaussian distribution . The Gaussian noise is given as

$$P(z) = \frac{1}{\sqrt{2\pi\sigma}} e^{-(z-\bar{z})/2\sigma^2}$$

Where, z represents gray levels. Σ represents standard deviation.

Uniform Noise: This noise [4] can be used to generate different types of noises for experimental purpose. In uniform noise, the gray level values of the noise are evenly distributed across a specific range in an image. The following equation can be used to express uniform noise:

$$P(z) = \begin{cases} \frac{1}{b-a} & if\ a \le z \le b \\ 0 & otherwise \end{cases}$$

Where mean $\mu = (a+b)/2$ and variance $\sigma^2 = (b-a)^2/12$

Impulse Noise/Salt and Pepper Noise: It is generally caused due to errors in transmission. It is based on the concept[] that a noise pixel has only two possible values, one has high value and another has low value. In this way, each pixel has probability less than 0.1. The noised pixels give Salt and Pepper appearance to the image. It appears as sprinkle of both light and dark spot in image. The following equation defines impulse noise in an image.

$$P(z) = \begin{cases} Pa & for\ z = a \\ Pb & for\ z = b \\ 0 & otherwisw \end{cases}$$

Where a, b represent different gray levels [0,255] in image, if b>a, intensity b will appear as light dot in image and intensity a will appear as dark dot in image.

The variables Pa, Pb are noise probability levels, if Pa or Pb is zero then impulse noise is called unipolar noise otherwise probability is zero.

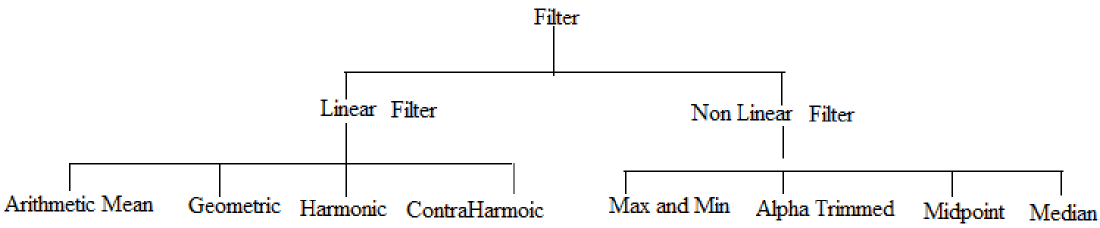
Multiplicative Noise/Speckle Noise: Multiplicative noise [5] is a single dependent form of noise whose magnitude is related to the value of the original pixel. It is generally found in medical images such as Ultrasound images. The following equation defines multiplicative noise:

$w(x, y) = s(x, y) \times n(x, y)$

Where s(x,y) is the original signal, n(x,y) denotes the noise introduced into the signal to produce the corrupted image (x,y), and (x,y) represents the pixel location.

DENOISING TECHNIQUES

The goal of denoising is to remove the noise while retaining as much as possible original information of the image. The denoising of the image can be done in two ways: linear filtering and nonlinear filtering. In the case of linear filtering, the noise reduction algorithm is applied for all pixels of the image linearly without knowing about noisy pixel and non-noisy pixel. Whereas, nonlinear filters are applied on pixels surrounded by noisy pixels. The following diagram shows the categorization of linear and nonlinear filters.



Mean Filter: The mean filter is a spatial domain filter and has high speed processing as compared to transform domain filtering. It is a traditional way to remove noise from digital image to employ statistical formulas like: arithmetic mean, geometric mean, harmonic mean and contra-harmonic mean. The computation of mean filter is performed on sub image sometime called mask/window which is a rectangular region consider around pixel to be noised.

Arithmetic Mean Filter: It is an averaging filter[6] that has used neighbourhood pixel values around pixel to be denoised. The arithmetic mean computes the average value of a neighbourhood and places the average value at the centre. The following mathematical equation can be used to represent arithmetic mean filter:

$f(x, y) = 1/mn \ \Sigma \ g(s, t)$ where $(s, t) \epsilon \ S_{xy}$

The arithmetic filter smooths the image but blurring is increased.

Geometric Mean Filter: In this filter[6], a window is considered around pixel to be noised and neighbourhood pixel is considered for computation of geometric mean. The centre pixel of window is replaced by the product of pixels with raised to power 1/(mXn) the neighbourhood of the window. The following mathematical equation can be used to represent geometric mean filter:

$f(x, y) = [\cap \ \Sigma \ g(s, t)]^{1/mn}$ where $(s, t) \epsilon \ S_{xy}$

It is better than arithmetic mean filter but it lose some important image information during filtering.

Harmonic Mean Filter: In the harmonic mean filter[6], the concept of sliding window is used in which a window is considered around pixel to be noised and neighbourhood pixel is considered for computation of harmonic mean. The mathematical harmonic mean is calculated on the basis of gray values of neighbourhood pixels within the window region. Let us consider S_{xy} represents pixels values within rectangular window of size mXn. The following mathematical equation is used to represent harmonic mean filter:

$f(x, y) = mXn / \Sigma \ 1/g(s, t)$ where $(s, t) \epsilon \ S_{xy}$

The harmonic filter works well for gaussian noise as well as salt noise.

ContraHarmonic Mean Filter: Let us consider S_{xy} represents pixels values within rectangular window of size mXn. The rectangular window is considered around a pixel to be noised and its neighbourhood pixels are consider for contra-harmonic computation. The following mathematical equation[6] is used to represent contra-harmonic mean filter:

$$f(x, y) = \Sigma g(s, t)^{q+1} / \Sigma g(s, t)^{q} \quad \text{where } (s, t) \epsilon S_{xy}$$

Where q is called order of filter. It place significant role in filtration as with positive value of q. The filter performs well on pepper noise. When the value of q is negative, it works well for salt noise. But both cannot eliminate simultaneously. It acts as arithmetic mean filter when q=0.

Order Statistics Filter: The order static filter [7] is based on ordering of gray scale values of neighbourhood pixels of window consider around pixel to be noised. It will replace the value of the centre pixel by performing ranking of pixels in neighbourhood. The methods to find out ranking of gray values of neighbourhood pixels are median, max/min, mid-point and alpha-trimmed mean.

Median Filter: In median filter[8], a sliding window concept is used in which a square window called mask is used to surround the pixel to be denoised. Generally, mask size of 3X3 is used. Let us consider (x, y) is a location of pixel to be noised. The pixel value is changed to median of all pixels in the window of locations {(x+1, y), (x-1, y), (x, y-1), (x,y+1), (x+1, y+1), (x-1, y-1), (x-1, y+1), (x+1, y-1)}. It is hardly affected by small number of discrepant values among pixels in neighbourhood.

$$f(x, y) = \text{median } \{g(s, t)\} \text{ where } (s, t) \epsilon S_{xy}$$

During the process, the median is calculated by first sorting all pixel values of neighbourhood into numeric order and replace pixel being consider with middle value. It has been observed that median filter is good for smoothing purpose and it also preserve small and sharp detail. But it does not preserve small size component as compared to neighbourhood pixel values.

Max and Min Filter: In this filter[8], sliding window of size mXn is used to find out max and min values of neighbourhood pixels to be denoised pixel under consideration. The max and min value is calculated by comparing values in the neighbourhood and resultant value is replaced with pixel under consideration. The following mathematical equation represents max and min filter

$$f(x, y) = \max \{g(s, t)\} \text{ where } (s, t) \epsilon S_{xy} \text{ and}$$

$$f(x, y) = \min \{g(s, t)\} \text{ where } (s, t) \epsilon S_{xy}$$

Where max filter is used for paper noise and it will find the brightest pixel in the sub image. In case of min filter, it will find darkest pixel in the sub image and is useful for salt noise.

Mid-Point Filter: The midpoint filter[] computes the mid-point intensity value between the maximum and minimum intensity values in the sub images area S_{xy} of the corrupted image g (x, y). The following mathematical equation represents the mid-point filter:

$$f(x, y) = 1/2[\max \{g(s, t)\} + \min \{g(s, t)\}] \text{ where } (s, t) \epsilon S_{xy}$$

Mid-point filter is good for gaussian white noise or uniform noise.

Alpha-Trimmed Mean Filter: Alpha-trimmed mean filter[] is an averaging filter which finds out averaging within window neighbourhood by deleting the d/2 lowest and d/2 highest gray value intensity levels. Let us consider S_{xy} is the window neighbourhood and gr(s, t) represents remaining (mn-d) pixels. The following mathematical equation represents the Alpha-trimmed filter:

$$f(x, y) = 1/mn\text{-}d \ \Sigma \ gr(s, t) \text{ where } (s, t) \epsilon S_{xy}$$

Where, the parameter d can range from 0 to mn-1. When d=0, then alpha-trimmed mean filter work as arithmetic mean filter and it acts as median filter when d= (mn-d)/2.

COMPARATIVE ANLAYSIS: In the present study we have implemented following denoising techniques like Arithmetic Mean Filter, Geometric Mean Filter, Harmonic Mean Filter, Contra-Harmonic Mean Filter[9].

Denoising Technique	Input Noised Image	Output Denoised Image	Denoising Technique	Input Noised Image	Output Denoised Image
Arithmetic Mean Filter			Median Filter		
Geometric Mean Filter			Max and Min Filter		
Harmonic Mean Filter			Mid-Point Filter		
Contra-Harmonic Mean Filter			Alpha Trimmed Filter		
Median Filter			Median Filter		

The following parameters have been used to compare the results of different denoising techniques.

MSE: (Mean Square Error)[10] Mean square error is defined as

MSE=1/MN Σ mjΣkn(xj,k-x’i,j)2

SNR: (Signal to Noise Ratio) it is defined as ratio of average signal power to average noise power for an image pf size MxN. It may be calculated as

SNR= 10 log10 Σ iΣjx(i,j)/ Σ iΣj(x(i,j)-y(I,j)2

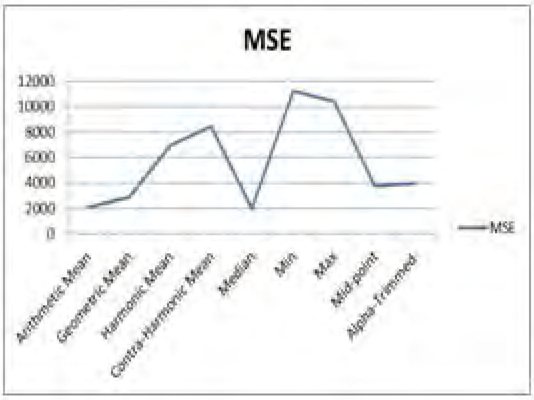
PSNR: (Peak Signal to Noise Ratio) it is defined as the raio of peak signal power to average noise power. PSNR looks at how many pixels in the text image differ from Ground truth image values and find quantity of the pixels. Higher the value of PSNR indicates better result .It can be calculated as

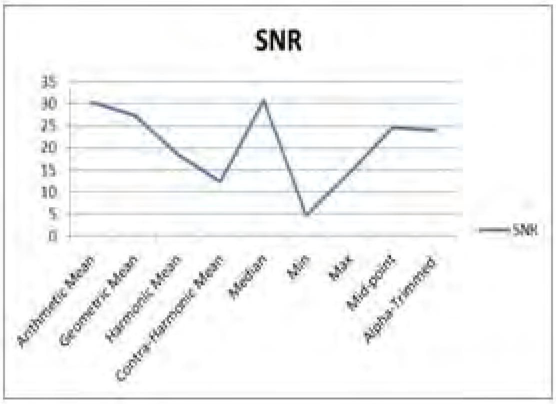
PSNR= 10 log10 2552*MN/ Σi Σj(x(i,j)-y(i,j)2

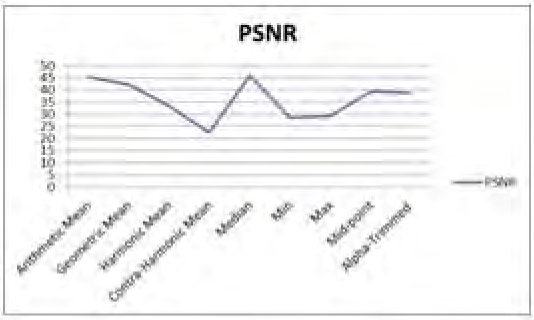
The following table shows values of MSE,SNR and PSNR.

Denoising Technique	MSE	SNR	PSNR
Arithmetic Mean Filter	2110.1567	30.2690	45.2662
Geometric Mean Filter	2834.8955	27.3166	42.3137
Harmonic Mean Filter	6939.3262	18.36461	33.3617
Contra-Harmonic Mean	8427.872	12.291	22.28901
Median Filter	1999.1612	30.8093	45.8065
Min Filter	11254.1811	4.8423	28.52644
Max Filter	10427.872	14.291	29.28901
Mid-point Filter	3743.1015	24.537	39.53469
Alpha-Trimmed Filter	3969.7386	23.9496	38.94683

The graph has been plotted between values of MSE,PSNR for all the methods.

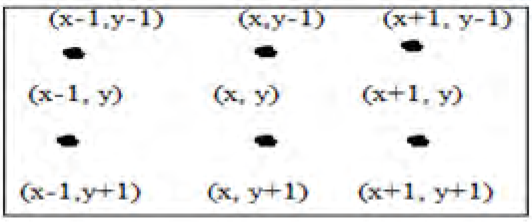






These graphs show the levale of noise with different methods. The value of MSE is maximum with Min and Max Filter and is Minimum with Arithmatic Filter. The value of SNR is maxium with Median Filter and Arithmatic Filter. Simillary in case of PSNR values.

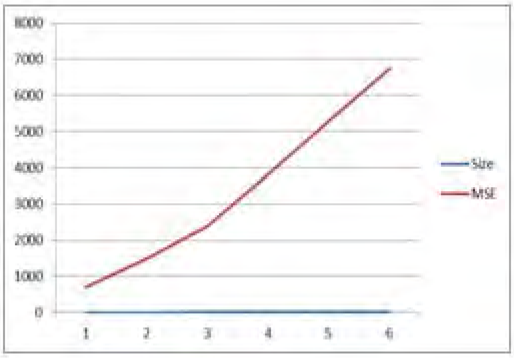
Impact of window size on performance of denoising filter: In the present study we have implemented one of the median filters with variable window size to analyse the impact of window size on output denoised image. The sliding window is considered around pixel (x, y) and a neighbourhood of mxn is observed. The following diagram shows the neighbourhood around pixel (x, y).

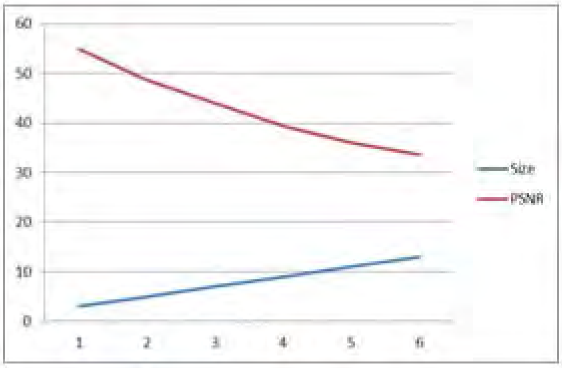


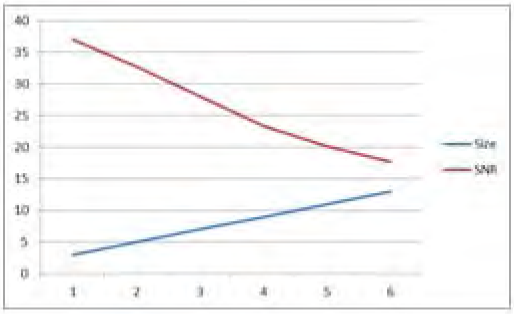
We have experimented variable window size of 3x3, 5x5, 7x7, 9x9, 11x11and 13x13. To analyse the output images, we have considered well known noise analysis factors such as MSE, SNR, PSNR

Size of Window	Denoised Image	MSE	SNR	PSNR
3 x 3		700.662	37.000	54.931
5x5		1500.978	32.741	48.672
7x7		2390.439	28.088	44.0190
9x9		3823.651	23.390	39.321
11x11		5298.221	20.129	36.060
13x13		6752.752	17.703	33.634

Above data is represented into graphical form which demonstrates impact of window size on MSE, SNR, PSNR as shown below:







As we can see graphs show, there is inclide curve of MSE with increase of size of window and decline cureve has been observed in case of PSNR. Similar observation has be noticed in case of SNR courves with window size.

These graphs show that the size of window improved the performace of the denoising process.

CONCLUSION

In the present research, linear and non-linear spatial filters have been implemented in visual C++ and outputs are analysed using parameters MSE, SNR, PSNR. The input images have been taken from ICDAR 2011. After analysing graphs based on MSE, SNR, PSNR, important observations are such as mean filter is useful for removing grain noise but remove outlines, median filter performs well as compared to mean filter. Median filter also preserves edge information as compared to mean filter. The computational time for median filter is more as compared to mean filter as median filter consume time in sorting purpose. The size of sliding window plays an important role in denoising the digital image. If the number of neighbourhood pixels is very large due to large window size then it will increase computational overhead. On the other part, if number of neighbourhood pixels is very small in size then it will not represent sub image and result is loss of information. Through the experiments, we have come to the conclusion that ideal size of sliding windows is 3X3 or 5X5.

REFERENCES

[1] Jaspreet Kaur, Manpreet Kaur, Poonamdeep Kaur, Manpreet Kaur, " Comparative Analysis of Image Denoising Techniques", International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, Voi. 2, 2012.

[2] M. Antonini, M. Barlaud, P. Mathieu, and I. Daubechies, Image coding using wavelet transform, IEEE Trans. Image Processing, Vol. 1, pp.205-220, 1992.

[3] J. Romberg, H. Choi and R. G. Baraniuk, Bayesian wavelet domain image modeling using hidden Markov models," IEEE Transactions on Image Processing, Vol. 10, pp. 1056-1068, 2001.

[4] Subhojit Sarker, Shalini Chowdhury, Samanwita Laha and Debika Dey "Use of Non-Local Means Filter to Denoise Image Corrupted By Salt and Pepper Noise", Signal & Image Processing: An International Journal (SIPIJ), Vol.3, No.2, 2012.

[5] W. Luo, "A new efficient impulse detection algorithm for the removal of impulse noise", IEICE Trans. Fundam., Vol. E88-A, pp. 2579–2586, 2005

[6] Yiqiu Dong, Raymond H. Chan, and Shufang Xu,"A detection statistic for random valued impulse noise IEEE transaction on image processing", Vol. 16, No. 4, April 2007.

[7] Kailath, T., Equations of Wiener-Hopf type in filtering theory and related applications, in Norbert Wiener: Collected Works vol. III, P.Masani, Ed. Cambridge, MA: MIT Press, pp. 63–94, 1976.

[8] E. P. Simoncelli and E. Adelson, "Noise removal via Bayesian wavelet coring", the in proceeding of IEEE International Conference on Image Processing, pp. 279–382, 1996.

[9] S. Grace Chang, Bin Yu and Martin Vetterli, "Adaptive Wavelet Thresholding for Image Denoising and Compression," IEEE Trans. Image Processing, Vol 9, No. 9, Sept 2000, pp 1532-1546.

[10] S. J. Ko, Y. H. Lee, "Center Weighted Median Filters and their Applications to Image Enhancement," Transactions on Circuits and Systems, pp.984-99,1991