GAUSSIAN DE-NOSING TECHNIQUES IN SPATIAL DOMAIN FOR GRAY SCALE MEDICAL IMAGES

Nora Youssef, Abeer M.Mahmoud, El-Sayed M.El-Horbaty

***Abstract**: Image de-noising is the elimination of noise from digital images where noise is any undesired information that contaminates an image. De-nosing is achieved through various filtering techniques that not only enhance the image but also keeps all its important details. Filters are categorized into linear (Geometric mean and Harmonic mean filters) and non-linear (midpoint, alpha-trimmed and adaptive local noise reduction filter) techniques. This paper presents applying Gaussian de-noising techniques or algorithms in spatial domain for medical images. Actually, five de-noising techniques are developed on gray scale medical images corrupted by additive Gaussian noise with mean = 0, variance = 1000. In addition, the paper analyzes the de-nosing techniques in terms of MSE (Mean Square Error), PSNR (Peak Signal to Noise Ratio) for image quality assessment and time complexity for performance assessment. The results showed that the de-nosing technique named Harmonic filter was the best from PSNR prospective and the de-nosing technique named Geometric mean filter was the best form time prospective.*

***Keywords**: Gaussian noise elimination, Linear and non-linear filter*

Introduction

The field of digital image processing refers to processing of a digital image by means of digital computers [Rafael, Richard, 2008]. Today there is almost no area of technical endeavor that is not impacted in some way by digital image processing. Digital image enhancement is the process of making images more useful visually. There are many reasons for doing such operation e.g. highlighting interesting details, removing noise and\or making images more visually appealing for specific application. The word specific establishes the outset that enhancement techniques are problem oriented. Thus for example a method that is quite useful for enhancing X-ray images may not be the best approach for enhancing satellite images taken in the infrared band of the electromagnetic spectrum [Rafael, Richard, 2008]. Actually, enhancement stage is the basic process of medical image processing.

Noise is any undesired information that contaminates an image. Noise appears in image from various sources; the digital image acquisition process, which converts an optical image into a continuous electrical signal that is then sampled, is a primary process by which noise appears in digital image. There are several ways through which noise can be introduced into an image, depending on how the image is created [Salem et al, 2010]. In other words, 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. Image de-noising is a challenging process in digital image processing aiming at the removal or elimination of noise and is still a demanding problem for researchers [Ankita, Archana, 2013]. Image de-noising techniques may lose some dynamic image details these details may be very important specially when dealing with medial images, so when comparing image de-noising techniques we have to take in consideration the Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index (SSIM) [Zhou et al, 2004].

Filters are categorized into linear (Geometric mean and Harmonic mean filters) and non-linear (midpoint, alpha-trimmed and adaptive local noise reduction filter) techniques. This paper presents applying Gaussian de-noising techniques or algorithms in spatial domain for medical images. Actually, five de-noising techniques are developed on gray scale medical images corrupted by additive Gaussian noise with mean = 0, variance = 1000. In addition, the paper analyzes the de-nosing techniques in terms of MSE (Mean Square Error), PSNR (Peak Signal to Noise Ratio) for image quality assessment and time complexity for performance assessment. The rest of the paper is organized as follow, section II abstracts related literature work on image de-noising field. Noise signal, sources, types, degradation model definition, deeper details about the Gaussian noise then the inverse operation of image corruption, more precisely the noise removal and a classification of Gaussian elimination techniques are in Section III. Section IV shows experimental results and discussion. Section V ends with conclusion.

Related Work

Many studies have been held to improve the implementation of image de-noising throw many additions either by innovating a new techniques seeking for run time optimization or reach a better results in terms of image quality assessment factors; better PSNR and MSE, or by doing such a comparative study for the currently existing techniques. Below is a sample related work by recent first order.

[Monika, Sukhdev, 2014] presented a comparative study on images de-noising techniques for salt and pepper noise, they applied different spatial filters (Arithmetic, Geometric, Harmonic and Contra-Harmonic mean) for linear filtering and (Min & Max, Alpha trimmed, Midpoint and Median) for order statistics or nonlinear filtering. They compared these filters in terms of PSNR, SNR and MSE. Their showed that the Geometric mean was the best for PSNR and MSE such that it has the maximum PSNR and minimum MSE among all for window size variable range from 3X3 to 13X13.

[Nikola, Milan, 2012] gave an overview on image de-noising techniques by applying more than one type of noises in spatial and transform domain to find the best algorithm per noise type. For example, for spatial nonlinear filtering, the median filter is the most important one to remove random valued impulsive noise. Wiener filter yield most advantageous outcomes for Gaussian corruption model and accuracy criterion is mean square error in the wavelet domain in non-data adaptive transform subcategory under transform domain. [Reza et al, 2013] they found that the recently proposed methods haven’t yet attained a desirable level of applicability, So they presented a de-nosing algorithm based on fuzzy cellular automata, The algorithm can effectively eliminate the image noise and keeps edge information without blurring effect, It specially suits the wire bonding images which need high edge detection accuracy. It improves the visual quality of the image and presents higher PSNR compared with the traditional methods.

[Vikas et al, 2013] introduced a modified version of adaptive median filter in the spatial domain as a speckle noise removal technique for ultrasound images. Normal adaptive filter’s behavior changes based on statistical characteristics of the image inside the filter region; these adaptive filters are of a greater complexity and analyze how image characteristics vary from one point to another. The adaptive median filter preserves the details while smoothing impulse noise, but it has a problem that it does not work well for Gaussian and speckle noise. They applied a modification such that they made the use of Euclidian distance as a measure for smoothness of the working window, which is compared to a cut of value. On different test samples, their method achieved very good results.

Noising and De-noising

Noise

Noise is any undesired information that contaminates an image. Noise appears in image from various sources. The digital image acquisition process, which converts an optical image into a continuous electrical signal that is then sampled, is a primary process by which noise appears in digital image. There are several ways through which noise can be introduced into an image, depending on how the image is created [Salem et al, 2010]. Transmission of visual information in form of images is common and major method in image processing field, but during the transmission, images are harmed by a noise [Ravi, Urooz, 2013], Arises due to electronic circuit noise and sensor noise due to poor illumination and/or high temperature [Rafael, Richard, 2008]. There are various types of noise or noise models [Rafael, Richard, 2008] such as Gaussian, Impulsive, Speckle, Shot, White [Ravi, Urooz, 2013], Exponential, Rayleigh, Erlang (Gamme) noise [Rafael, Richard, 2008]. Impulsive noise can be either fixed valued like salt & pepper which is black and white spots on images or random valued which is the noise can have any random value between 0 and 255 hence its removal is very important and difficult [Nikola, Milan, 2012]. These types of noise are additive noise and can be described by a PDF (probability distribution function) [Rafael, Richard, 2008]. And this paper focuses on the Gaussian noise. There is another type of noise, which is called periodic noise it can corrupt the image from electrical or electromechanical interference during acquisition [Rafael, Richard, 2008].

Degradation Model

Degradation model for an image in spatial domain is given by Eq.1 [Rafael, Richard 2008]

$$g(x,y) = h(x,y) \star f(x,y) + \eta(x,y) \tag{1}$$

Such that $g(x,y)$ is the noisy image, $h(x,y)$ is the degradation function, $f(x,y)$ is the original image and $\eta(x,y)$ is the noise. The symbol means a convolution process in spatial domain. In addition, Eq. 2 [Rafael, Richard 2008] gives the corresponding equation in transform/frequency domain with the same meaning as the Eq.1 above [Rafael, Richard 2008].

$$G(u,v) = H(u,v)F(u,v) + N(u,v) \tag{2}$$

Gaussian Noise

Gaussian noise is additive in nature it is independent at each pixel and independent from signal strength. It also called “Normal” noise, and is mathematically tractable in spatial and frequency domain. It arises due to electronic circuit noise and sensor noise due to poor illumination and/or high temperature. It is given by probability destiny function (PDF) Eq.3. [Rafael, Richard, 2008]

$$p(z) = \frac{1}{\sqrt{2\pi}\,\delta} e^{-(z-z`)/2\delta^2} \quad (3)$$

Such that z represents intensity, z` is the mean (average) value of z and δ is its standard deviation, the standard deviation squared is called variance of z, and the Fig.1 is a plot for Eq.3 mathematical representation. When z is described by the equation above approximately 70% of its values will be in range $[(z` - \delta), (z` + \delta)]$ and about 95% of its values will be in range $[(z` - 2\delta), (z` + 2\delta)]$ [Rafael, Richard, 2008]. Figure 2 below shows an example for a Gaussian noisy image and its corresponding histogram representation [R & R Online Lib].

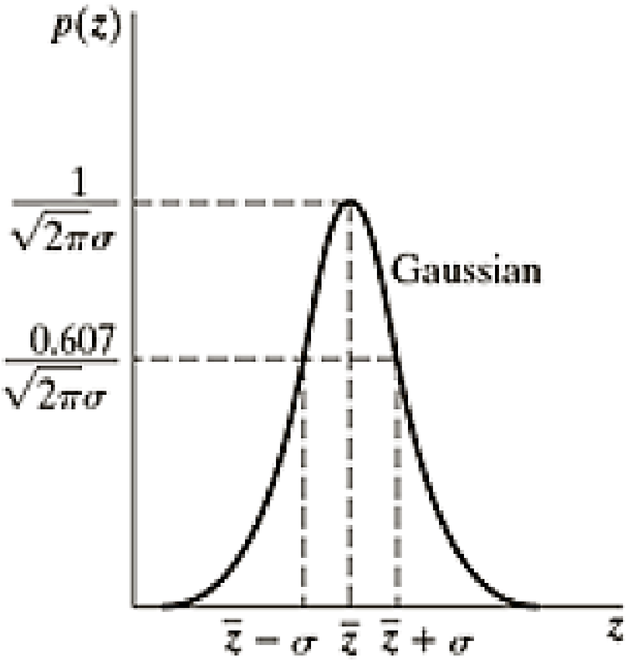


Figure 1. Gaussian Plot

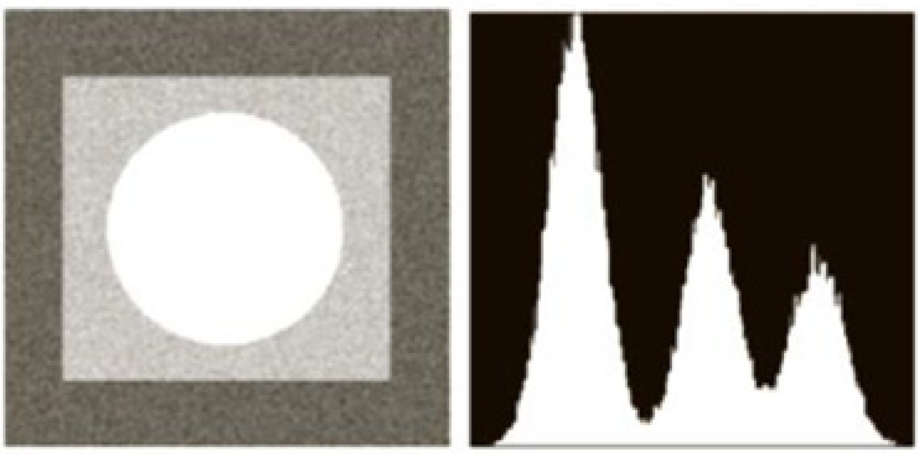


Figure 2. Gaussian Histogram Representation

De-noising

Image de-noising is a challenging process in digital image processing aiming at the removal/elimination of noise and is still a demanding problem for researchers [Ankita, Archana, 2013]. Image de-noising techniques may lose some dynamic image details these details may be very important specially when dealing with medial images, so when comparing image de-noising techniques we have to take into consideration the Peak Signal to Noise Ratio (PSNR) and Structural Similarity Index (SSIM) [Zhou et al, 2004]. Spatial filters suits the additive noise but frequency domain filters suits the periodic noise. In noise elimination, we assume that the degradation function is equal to 1 such that the image was degraded only by noise with no external factors as well as the noise is independent of spatial coordinate and uncorrelated to the image itself [Rafael, Richard, 2008]. The de-noising of the image can be done in two ways: linear filtering and nonlinear filtering. Figure 3 shows the selected Gaussian elimination techniques. There are common mathematical notations used for expressing the filters such as $f`(x, y)$ is the restored image at point x, y, mXn is the size of the neighborhood or subimage window, $g(x, y)$ the noisy image at the same point x, y, $S_{x,y}$ is the set of image point in the subimage window.

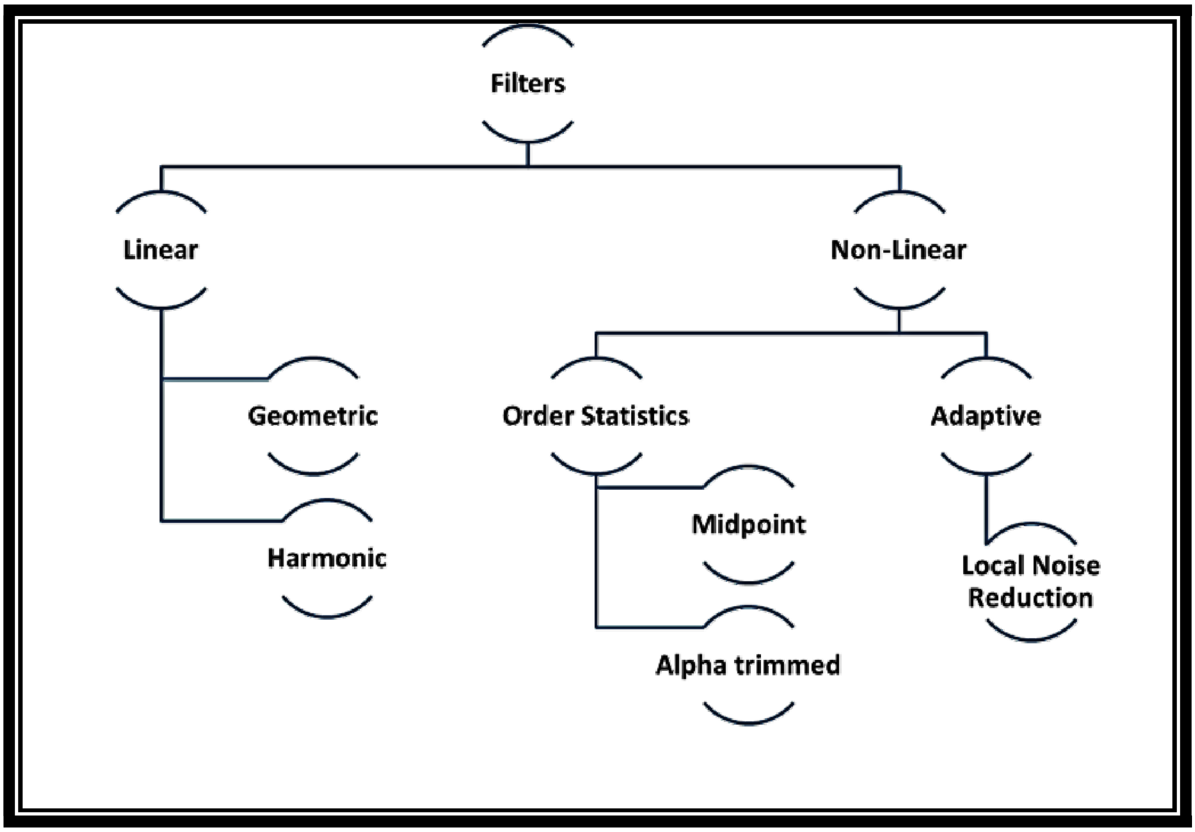


Figure 3. Selected Gaussian Elimination Techniques

Linear filtering

The noise reduction algorithm is applied for all pixels of the image linearly without knowing about noisy pixel and non-noisy pixel. e.g. Geometric and Harmonic filters. Geometric filter is given by Eq. 4 [Rafael, Richard, 2008] and it works as each restored pixel is given by the product of the pixels in the subimage window, raised to the power $1/_{mn}$ it gives a smoothing effect and tends to lose very little details of the image [Rafael, Richard, 2008]. Eq. 5 [Rafael, Richard, 2008] represents Harmonic filter. It represents the concept of sliding window is used in which a window is considered around pixel to be noised and neighborhood pixel is considered for computation of harmonic mean. The mathematical harmonic mean is calculated based on gray values of neighborhood pixels within the window region [Monika, Sukhdev, 2014].

$$f`(x,y) = [\prod_{(s,t\,\epsilon\, S_{x,y})} g(s,t)]^{\frac{1}{mn}} \tag{4}$$

$$f`(x,y) = \frac{mn}{\sum_{(s,t)\epsilon\, S_{xy}} \frac{1}{g(s,t)}} \tag{5}$$

Nonlinear filtering

Employ a low pass filtering on groups of pixels with an assumption that noise occupies the higher frequency region of the spectrum. Generally, spatial filters eliminate noise to a considerable extent but at the cost of blurring images, which in turn makes the edges in pictures invisible [Vikas et al, 2013]. Order statics filters are spatial filters whose response is based on ordering (ranking) the values of the pixels contained in the image area encompassed by the filter e.g. Midpoint. Adaptive filters whose behavior changes based on statistical characteristics of the image inside the filter region e.g. local noise reduction filter. Midpoint filter is given by Eq. 6 [Rafael, Richard, 2008], which gives each restored pixel the average value between the pixel with maximum value and the pixel with minimum value. Alpha-trimmed mean filter is given by Eq. 7 [Rafael, Richard, 2008], such that d takes a value in range from 0 to mn-1 when d = 0 it won't work as a best for Gaussian such that the filter will be reduced to arithmetic mean filter [Rafael, Richard, 2008]. Local noise reduction filter is given by Eq. 8 [Rafael, Richard, 2008], such that δ_L^2 is the local variance and η_L is the local mean of subimage window $S_{x,y}$, δ_η^2 is the noise variance. There is an assumption that the ratio $\frac{\delta_\eta^2}{\delta_L^2} = 1$ because the local variance is a subset of the whole image variance and we seldom know the variance of the noise [Rafael, Richard, 2008]

$$f`(x,y) = \frac{1}{2}[max_{(s,t)\epsilon\, S_{xy}}\{g(s,t)\} + min_{(s,t)\epsilon\, S_{xy}}\{g(s,t)\}] \tag{6}$$

$$f`(x,y) = \frac{1}{mn-d} \sum_{(s,t)\epsilon\, S_{xy}} g(s,t) \tag{7}$$

$$f`(x,y) = g(x,y) - \frac{\delta_\eta^2}{\delta_L^2}[g(x,y) - \eta_L] \tag{8}$$

Quality Assessments Metrics

Objective methods for assessing perceptual image quality traditionally attempted to quantify the visibility of errors (differences) between a distorted image and a reference image (Ground Truth) using a variety of properties. Quality metrics contain four main measurements these measurements are 1) ***MSE*** – (Mean Squared Error) computed by averaging the squared intensity differences of distorted and reference image pixels [Zhou et al, 2004] and is computed by Eq.9 [Salem et al, 2010]. 2) ***SNR*** – (Signal to Noise Ratio) defined as ratio of average signal power to average noise power for an image of size MxN [Monika, Sukhdev, 2014] *3)* ***PSNR*** – (Peak Signal to Noise Ratio) defined as the ratio of peak signal power to average noise power. PSNR looks at how many pixels in the text image differ from the ground truth image values and find quantity of the pixels. Higher the value of PSNR indicates better result [Monika, Sukhdev, 2014] and is computed by Eq. 10 [Salem et al, 2010]. 4) ***SSIM*** – (Structural Similarity) that compares local patterns of pixel intensities that have been normalized for luminance and contrast [Zhou et al, 2004].

$$\mathrm{MSE} = \frac{1}{MN}\sum_{i}^{M}\sum_{j}^{N}[g(i,j)-f(i,j)]^2 \quad (9)$$

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

Results and Discussions

Experiment was done on four sample medical images corrupted by additive Gaussian noise. De-nosing trials are done in spatial domain filters with subimage/window size range from 3X3 to 9X9

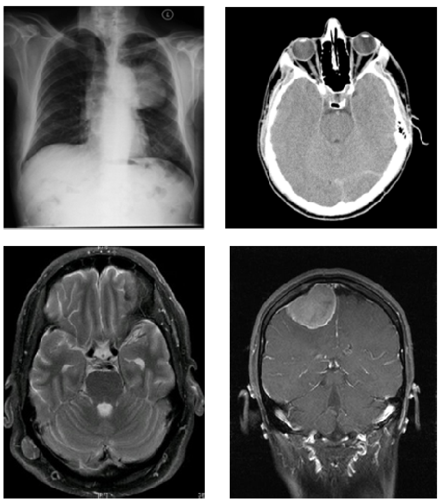


Figure 4. Input Ground Truth Images

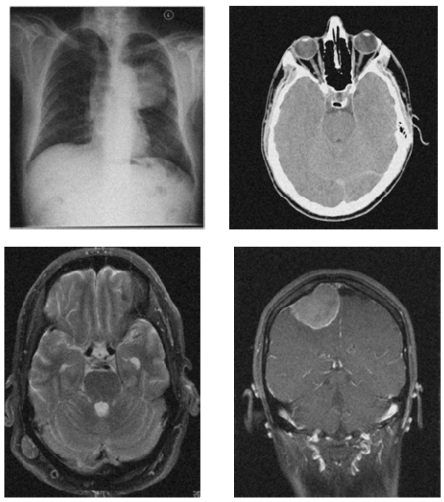
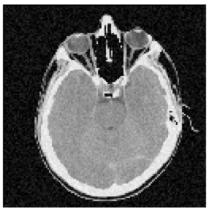
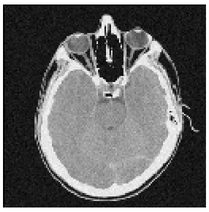
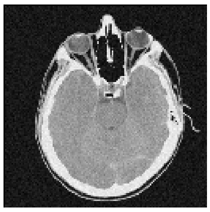
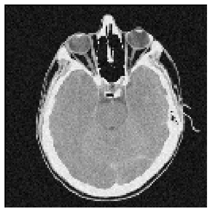
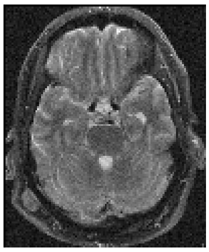
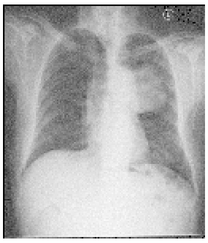
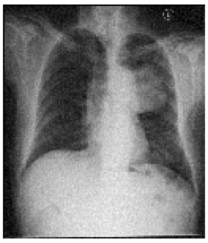
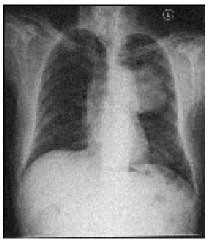
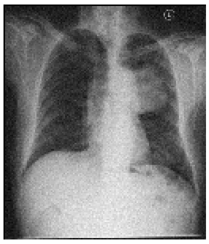
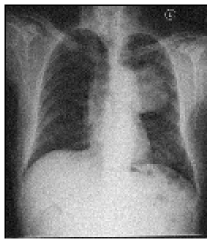
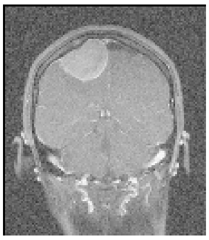
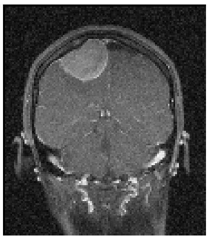
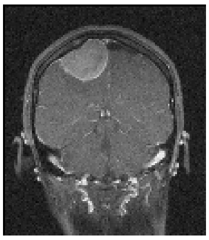
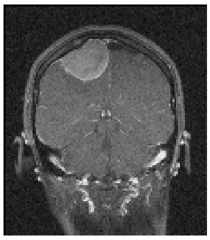
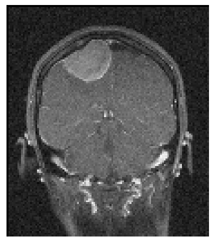


Figure 5. Gaussian Noisy Images

Experimental Settings

Figure 4 shown selected sample of ground truth medical images downloaded from [R & R Online Lib; Open I]. Figure 5 shown the same sample after being corrupted with Gaussian noise with mean = 0 and variance = 1000. In addition to applying post processing technique for contrast starching from 0 – 255.

Table 1. Gaussian Elimination Techniques Output - 3X3 Window Size

Geometric Mean Filter	Harmonic Mean Filter	Mid-Point Filter	Alpha Trimmed Filter	Local Adaptive Noise Reduction
				
				
				
				

Results

The five de-nosing techniques were implemented in visual C#. Table 1 shows the results of the data sample after applying the five de-nosing techniques, where a window filter size 3X3 is used in this illustration. Figures 6, 7, 8, 9 show a graphical representation for the results for different window/filter size 3X3, 5X5, 7X7 and 9X9 consequently. From the figures, it is obvious that harmonic filter de-nosing technique is the best from PSNR prospective and the de-nosing technique Geometric mean filter was the best form time prospective.

De-nosing filters gave the best PSNR when the filter size was 3X3 while they gave the worst results when filter size was 9X9; Geometric filter had the largest time complexity regardless the window or filter size. Midpoint filter is the best filter (gave the largest PSNR) among nonlinear filtering selected techniques while the Harmonic gave the least time complexity regardless the filter size.

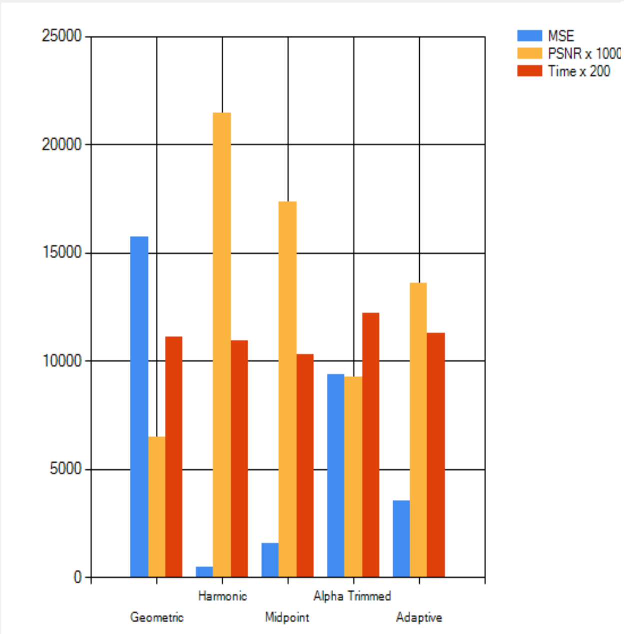


Figure 6. Avg. 3X3 Results

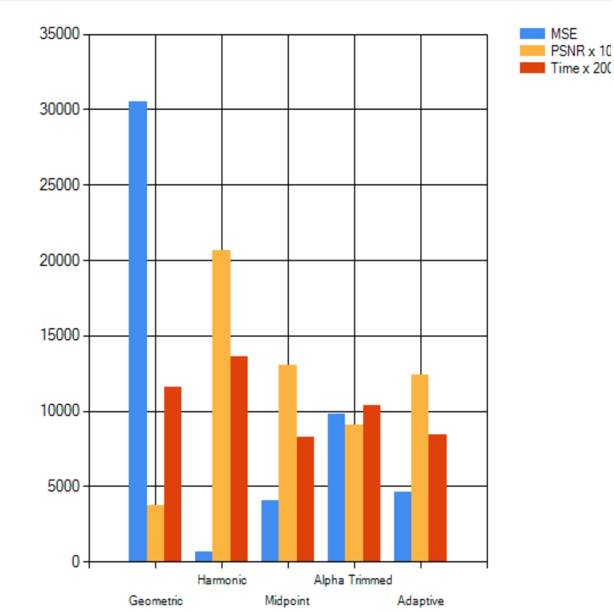


Figure 7. Avg. 5X5 Results

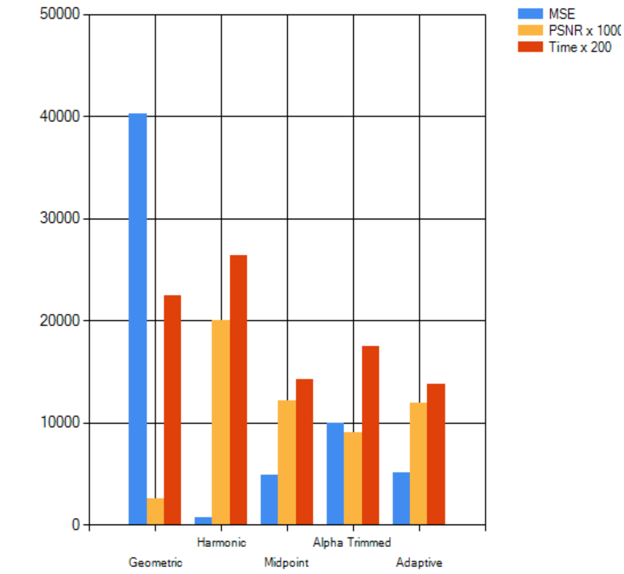


Figure 8. Avg. 7X7 Results

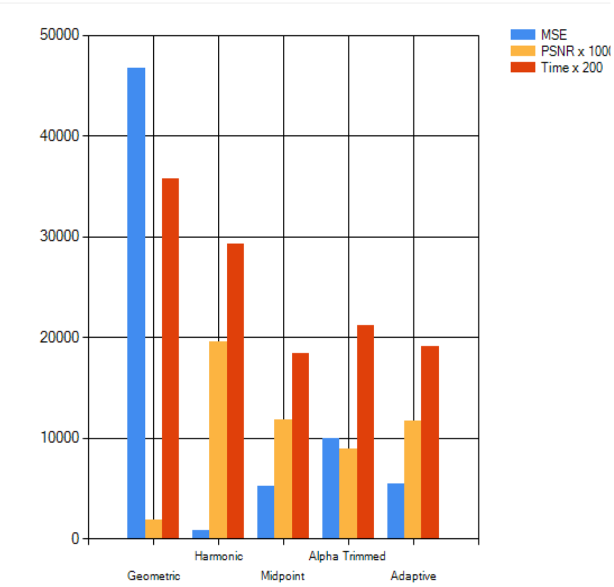


Figure 9. Avg. 9X9 Results

Conclusion

Image de-noising is the elimination of noise from digital images where noise is any undesired information that contaminates an image. De-nosing is achieved through various filtering techniques that not only enhance the image but also keeps all its important details. Filters are categorized into linear (Geometric mean and Harmonic mean filters) and non-linear (midpoint, alpha-trimmed and adaptive local noise reduction filter) techniques. This paper presented applying Gaussian de-noising techniques or algorithms in spatial domain for medical images. Actually, five de-noising techniques are developed on gray scale medical images corrupted by additive Gaussian noise with mean = 0, variance = 1000 in visual C# environment. In addition, the paper analyzed the de-nosing techniques in terms of MSE (Mean Square Error), PSNR (Peak Signal to Noise Ratio) for image quality assessment and time complexity for performance assessment. The results showed that the Harmonic filter was the best from PSNR prospective and Geometric mean filter was the best form time prospective.

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