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Investigation of Different Spatial Filters Performance toward Mammogram De-noising

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Abstract: De-noising is one of the important aspects of image preprocessing, mainly for medical images, in order to filter out the undesired elements without affecting any fine details. In this study, spatial filters namely Mean, Median, Wiener and Gaussian filters were employed and the processed images were evaluated for Mean Squared Error (MSE), Peak Signal to Noise Ratio (PSNR) and Correlation Coefficient (CC). The numerical analysis of the accomplished results reveals that Gaussian filter delivered the best outcome for matrix size of 7x7. Although Gaussian filter provided optimal result in this work, visual difference among retrieved images by other filters at particular matrix size where the best outcome occurred, were extremely small. Therefore, improvement in future work may be implemented using transform domain filters.

Keywords: Mammogram, De-noising, Spatial Filter

1. Introduction

Preprocessing is the very first step to analyze any kind of image as was illustrated in [1], particularly for medical images and it is done to remove noise, enhance the quality of the image, smoothen and also blur or un-blur it depending on the requirement. In this paper only digital images are considered and the noise removal, in other word de-noising, is emphasized.

A digital image is represented as a matrix of two dimensional (2D) array, $x(i, j)$, where x is the light intensity measurement represented by pixel value at coordinates (i, j). It can be a color, gray level or binary image which differs in terms of bits per pixel and array for colors. For the sake of simplicity in notation and display of experiments, 2D grey-level images were used for this experiment.

Digital images suffer two issues namely blur and noise where the former solely depends on image acquisition system as per the Shannon–Nyquist sampling rules [2]. The digital noise $n(i, j)$ at location (i, j) can be described as the residual part of the image after segregating the desired signal or image and hence, the output image can be mathematically expressed as:

$$I(i, j) = x(i, j) + n(i, j) \tag{1}$$

The noise is generated either during image acquisition, for example via amplifiers and sensors, or during quantization and processing, or during transmission [3] and thus, can be classified in several types namely additive, multiplicative, impulse, shot, uniform and periodic noise.

Additive Noise – Gaussian noise is additive in nature [3], in which the output image is the addition of the original image along with the noise, as is expressed in Equation (1) and follows Gaussian distribution on image pixels.

Multiplicative Noise – Speckle noise is an example of this type [4], wherein the corrupted image is produced by the multiplication of the noise with the original image expressed as:

$$I(i, j) = x(i, j) \times n(i, j) \tag{2}$$

Impulse Noise – Impulsive sharp variation in the image signal [4] is the concept behind this noise where the noise pixel values are selected alternatively to maximum and minimum levels. Salt & Pepper noise is an example of this type where pepper represents 0 and salt 255 in gray scale image exhibiting fixed values. However, if it varies randomly, then it is hard to remove the noise.

Shot Noise – The lack of furnishing of statistical information by the image sensor during acquisition due to less photon count generates this noise, such as Poisson noise.

Uniform Noise – It is produced during the quantization of the image pixel to a number of distinct levels like quantization noise.

Periodic Noise – The electromechanical or electrical interference during acquisition of image is the reason behind this noise which is easy to be found in frequency domain.

Several filters found their application as de-noising technique, which can be segregated in two main sections, namely spatial domain filters and transform domain filters [5]. Spatial domain filters are divided into linear and non-linear types. In this study, only spatial filters were tested to achieve the best filtered effect on the medical images. The edges and fine lines in an image may be blurred as an effect of Linear filtering [5] and hence, edge detection is not preferred by it. This can be overcome by the use of Non-linear filtering. In this paper

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only Mean, Median, Wiener and Gaussian filters are considered on the selected mammogram.

Mean Filter – This is a linear type spatial filter where a specified matrix is used as kernel or window to mask each image pixel. Based on the average of the kernel matrix and the neighboring pixel values, the resultant pixel is derived for which the filtered image has a smooth effect [6] and it works well against grain noise [7], which is also known as film grain. With the increasing kernel size, the strength of averaging will be amplified and as a result the image will be blurred. Due to its linear characteristic, it is not able to preserve the edge. Moreover, the Peak Signal to Noise Ratio (PSNR) is lower than that obtained by non-liner filters [6].

Median Filter - It is spatial nonlinear filter. Within the specified image window, it finds out the median pixel value from the neighboring pixels and replaces the central pixel with this median magnitude. Due to its working principle, it is slow and has complex computation [7]. It is most commonly used in removing Salt & Pepper noise and detecting edges.

Wiener Filter – The main advantage of using this linear filter is to achieve the optimal Mean Squared Error (MSE) [6]. It works on statistical approach assuming that the image signal and noise both are stationary in nature with an identified spectral condition [7] and this data must be known in advance. Thus, it is not suitable for the retrieval of the signal when the original image and noise are of non-stationary nature and the noise structure is not recognized for which it becomes a non-adaptive filter.

Gaussian Filter – It is a linear low pass filter that works on the central pixel of the image window putting more weight for correction considering it as the peak or the impulse and also corrects the neighboring pixels with lesser weight based on convolution method and hence, provides smoothing effect to the filtered image. The filter window matrix can be calculated as per the rule (6σ - 1), where σ is the standard deviation of the Gaussian distribution and it is rotationally symmetric with respect to its mean. Minimum σ value must be 0.5. The smoothness of the filtered image is proportionate with σ, i.e., the higher the σ, the bigger will be the matrix size and the greater is the smoothness, which in turn will produce a blurred image.

The de-noising can be performed in two ways. In first method, initially the original image will be contaminated with noise and then the restoration will be executed on the noisy image. The second technique assumes that the original image is already adulterated with noise and thus, the retrieval is directly done on the original image. This work followed the former procedure.

Ultimately, the assessment of the reconstructed image quality is essential for which not only the mathematical calculations are there, but also Human Visual System (HVS) can be considered for perceptual measurement [3]. Since this work added noise on the original image, therefore the restored image was compared with the original one to measure the extent of their resemblance by using MSE, PSNR and CC.

Mean Squared Error (MSE) – It is a parameter less metric to measure the normalized statistical variance between the original and the filtered image expressed as

$$MSE = \frac{1}{s \times t} \sum_{i=1}^{s} \sum_{j=1}^{t} (I_{ij} - J_{ij})^2 \tag{3}$$

where the image size is represented by the matrix $s \times t$ and the filtered image as J. Therefore, mathematically lowest MSE must provide the best reconstructed image.

Peak Signal to Noise Ratio (PSNR) – It approximates the human perception while restoring the image and is the ratio between the maximum possible power or pixel value of the original image and the power of its noise. PSNR is expressed in decibel (dB) and is illustrated in Equation (4) stating its dependence on MSE:

$$PSNR = 20 \times \log_{10}\left(\frac{Max_I}{\sqrt{MSE}}\right) \tag{4}$$

where Max_I is the highest pixel value of the image, i.e, for gray scale image it may be 255. This equation implies that higher PSNR should yield better reconstructed image.

Correlation Coefficient (CC) – It is used as a metric to measure the disparity in between two images. It can also compare the image registration and object recognition [8]. Correlation coefficient is expressed as r and stated below:

$$r = \frac{\sum_{i=1}^{s}\sum_{j=1}^{t} (x_{ij} - x_m) \sum_{i=1}^{s}\sum_{j=1}^{t} (y_{ij} - y_m)}{\sqrt{\sum_{i=1}^{s}\sum_{j=1}^{t} (x_{ij} - x_m)^2 \sum_{i=1}^{s}\sum_{j=1}^{t} (y_{ij} - y_m)^2}} \tag{5}$$

where x_{ij} and y_{ij} are two images at location (i, j) and x_m and y_m are the mean intensity of respective images. Thus, if r=0, it means that the images are not at all related and it reflects the nonlinearity. While r=1 means that the images are completely similar.

2. Method

In this study, a digital mammogram of cranio-caudal view [9] with benign mass was considered as original image which is shown in Fig. 1a and investigation was conducted using MATLAB. It is assumed that the original image was noise free and thus, in the beginning noise was applied on it. Several types of noises were elaborated in the introduction of this paper. However, for this work the random Gaussian distributed noise matrix was generated and it was then multiplied with 15 to increase its intensity so that the noisy effect can be visible. Any number bigger than 15 will increase the visual noisy effect. Finally this noise was added with the mammogram. The Mean, Median, Wiener and Gaussian filters were then applied on the noisy image to investigate which filter can provide the best result using matrix size of 2x2, 3x3, 4x4, 5x5, 6x6, 7x7, 8x8, 9x9, 10x10, 13x13 and 17x17. The matrix size of Gaussian filter depends on σ. Thus to maintain the matrix sizes, accordingly σ values were calculated. Theoretically, the Gaussian distribution is non-zero everywhere and in that case the convolution kernel must be infinitely large. But in reality, it is effectively zero when $\sigma > 3$ from the mean. Therefore, this work considers maximum σ value of 3. For Mean filter, the ones matrix was used.

The following steps were executed to obtain the various outcomes. The results of Mean filter with matrix size 3x3, Median and Weiner filters for matrix size 5 x 5, and Gaussian filter with matrix size 7x7 are exhibited in 1c to 1f:

Step 1: The mammogram was cropped to remove the black area without information.

Step 2: The image was resized to 512x512 and converted to gray scale.

Step 3: The image data type was changed to double and then saved.

Step 4: The noise matrix was created with Gaussian distributed random values and multiplied by 15. Then the noise matrix was added with the original image.

Step 5: The threshold was administered on the noisy image to maintain the pixel range within 0 to 255 and then saved it as noisy image as can be seen in Fig. 1b.

Step 6: The algorithm for the above mentioned filters were applied on the noisy image one at a time with specified matrix size to reconstruct it.

Step 7: The MSE, PSNR and CC values were collected for all the filters by comparing the original and the filtered image.

Step 8: Matrix sizes were changed and repeated from Step 6 for all the selected filters.

Step 9: The MSE, PSNR and CC values were logarithmically plotted as shown in Figs. 2, 3 and 4 as per Tables 1, 2 and 3, respectively, for all the filters against different matrix sizes.

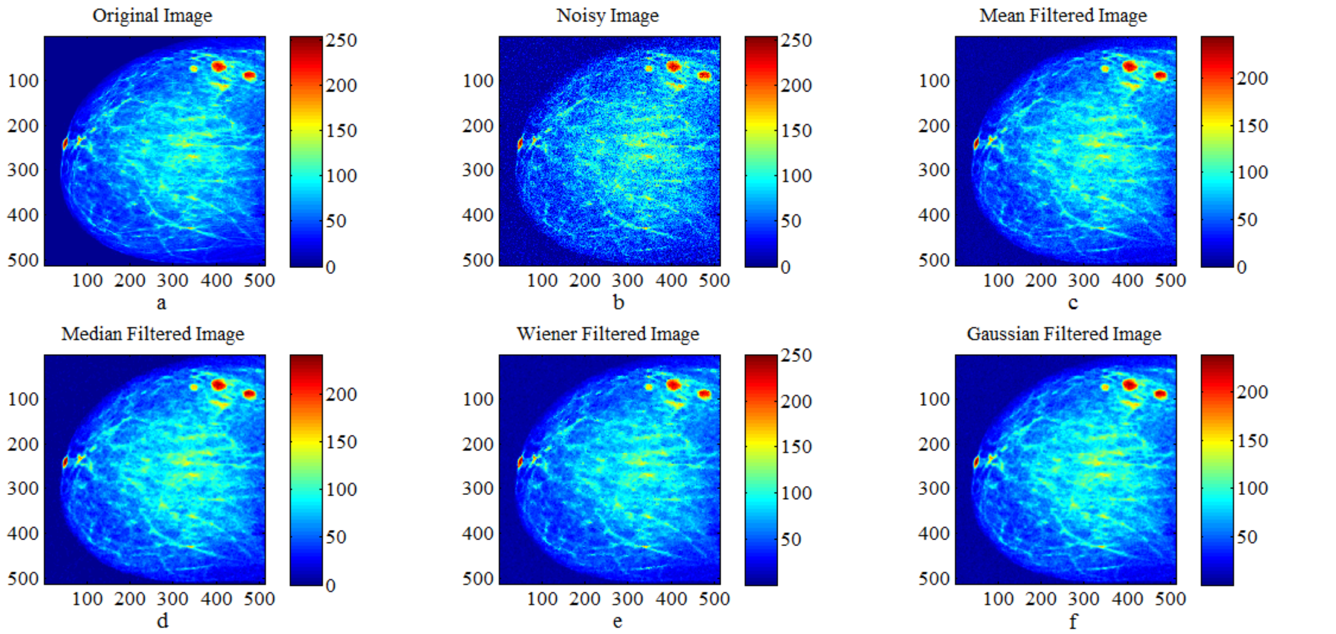

Fig. 1 **a.** Original cranio-caudal (CC) view of mammogram from a patient with benign mass referred from [9] **b.** Image obtained after adding Gaussian noise with the original image **c.** Mean filtered effect with matrix size 3x3 **d.** Median filtered image with matrix size 5x5 **e.** Wiener filtered image obtained with matrix size 5x5 **f.** Gaussian filter output image with σ =1.33 and matrix size 7x7. The color-bar represents the intensity of signal.

3. Results and Discussion

The obtained MSE, PSNR and CC values of the original and the noisy image were calculated as 2594.911, 13.99 dB and 0.924 respectively. The same for the entire filtered and original image are tabulated in Tables 1, 2 and 3 and accordingly they were plotted against various matrix sizes as depicted in Figs. 2, 3 and 4.

If the achieved results are numerically analyzed, then it can be interpreted that the Gaussian filter performed best among others in terms of all metrics because it gave the smallest MSE and highest PSNR and CC for matrix size 7 x 7. At the same time, the analysis of other filters performances reveal that the best result obtained by Mean filter was with matrix sixe 3x3 and the same via Median and Wiener filters were with matrix size 5x5. These optimum level values of Mean, Median and Wiener filters were very near to the best outcome of Gaussian filter and thus, in human eyes it is tough to discriminate all the acquired images by different filters at their optimum levels as can be seen in Figs. 1c to 1e. As it was elaborated in the introduction, it was also observed that with increasing matrix sizes, the filtered image was blurred and the fine details were lost.

4. Conclusion

This paper studied the effect of Mean, Median, Wiener and Gaussian filters with different matrix sizes on randomly Gaussian distributed noise added to the mammogram. The obtained result was analyzed with two approaches namely quantitative and visual. It can be interpreted that the Gaussian filter is the best as per the quantitative analysis. Nonetheless no remarkable change is observed visually among all the restored images by Mean, Median, Wiener and Gaussian filters with the corresponding matrix sizes which provided optimal results for them as illustrated in Fig. 1. On the other hand, the MSE is good as an error sensitive metric, but not practical in identifying structural changes [3] that Human Visual System can identify easily. At the same time, the CC value closer to 1, represents much similarity between two images. But its interpretation is complex; this parameter is over-sensitive to pixel noise and sometimes behaves undesirably when images contain more or less fine structures [8]. Therefore, in future study transform domain filters will be attempted in order to select the best de-noising system along with the consideration of Human Visual system.

Table 1 The obtained MSE values against various matrix sizes for the employed filters.

Matrix	Filter			
	Mean	Median	Wiener	Gaussian
2x2	68.963	75.57	87.746	68.963
3x3	36.302	41.311	49.787	47.809
4x4	39.832	39.791	41.529	45.203
5x5	36.523	32.642	36.57	31.415
6x6	45.051	40.947	38.059	37.401
7x7	46.66	39.088	38.696	30.603
8x8	56.124	49.454	42.036	37.801
9x9	60.051	50.11	44.181	34.11
10x10	69.548	60.949	48.032	41.254
13x13	88.35	76.447	57.229	45.31
17x17	113.846	103.145	69.628	58.53

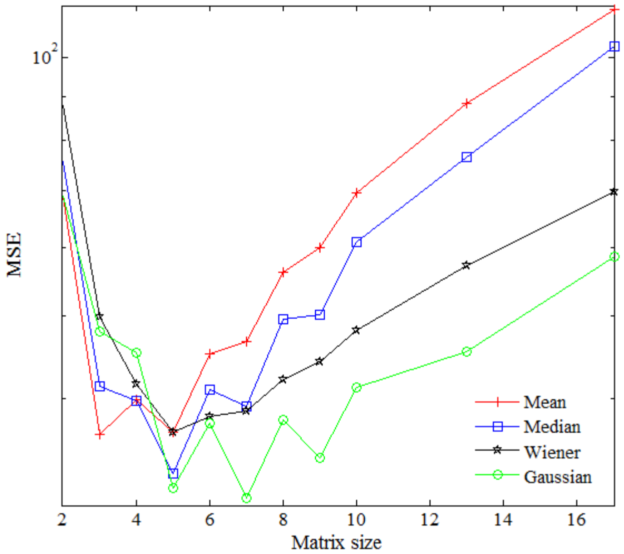

Fig. 2 The log plot of the obtained MSE values against different matrix sizes for the employed filters.

Table 2 The calculated PSNR values against different matrix sizes for the applied filters.

Matrix	Filter			
	Mean	Median	Wiener	Gaussian
2x2	29.745	29.347	28.699	29.745
3x3	32.531	31.97	31.16	31.336
4x4	32.128	32.133	31.947	31.579
5x5	32.505	32.993	32.5	33.159
6x6	31.594	32.009	32.326	32.402
7x7	31.441	32.21	32.254	33.273
8x8	30.639	31.189	31.895	32.356
9x9	30.346	31.132	31.678	32.802
10x10	29.708	30.281	31.315	31.976
13x13	28.669	29.297	30.555	31.569
17x17	27.568	27.996	29.703	30.457

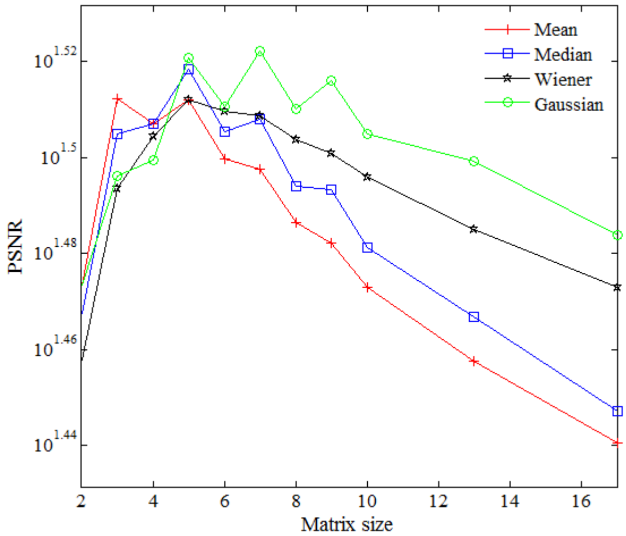

Fig. 3 The logarithmic graphical representation of the calculated PSNR values in dB for all the filters used in this study against different matrix sizes.

Table 3 The computed Correlation Coefficients against different matrix sizes for the considered filters.

Matrix	Filter			
	Mean	Median	Wiener	Gaussian
2x2	0.973	0.97	0.965	0.973
3x3	0.987	0.983	0.981	0.982
4x4	0.986	0.984	0.985	0.983
5x5	0.987	0.987	0.987	0.989
6x6	0.984	0.984	0.987	0.987
7x7	0.984	0.984	0.986	0.99
8x8	0.98	0.98	0.985	0.987
9x9	0.978	0.98	0.984	0.989
10x10	0.975	0.976	0.983	0.986
13x13	0.967	0.969	0.979	0.985
17x17	0.956	0.959	0.974	0.979

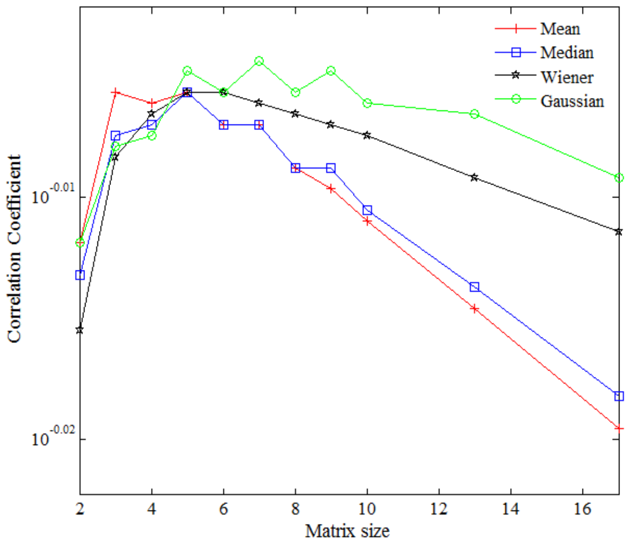

Fig. 4 The log graph of the collected correlation coefficients for different employed filters versus various matrix sizes.

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