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M^2 FILTER FOR SPECKLE NOISE SUPPRESSION IN BREAST ULTRASOUND IMAGES

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Abstract

Breast cancer, commonly found in women is a serious life threatening disease due to its invasive nature. Ultrasound (US) imaging method plays an effective role in screening early detection and diagnosis of Breast cancer. Speckle noise generally affects medical ultrasound images and also causes a number of difficulties in identifying the Region of Interest. Suppressing speckle noise is a challenging task as it destroys fine edge details. No specific filter is designed yet to get a noise free BUS image that is contaminated by speckle noise. In this paper M^2 filter, a novel hybrid of linear and nonlinear filter is proposed and compared to other spatial filters with 3×3 kernel size. The performance of the proposed M^2 filter is measured by statistical quantity parameters like MSE, PSNR and SSI. The experimental analysis clearly shows that the proposed M^2 filter outperforms better than other spatial filters by 2% high PSNR values with regards to speckle suppression.

Keywords:

Ultrasound Imaging, Speckle Noise, Spatial Filters, M3 Filter, M^2 Filter

1. INTRODUCTION

Ultrasound imaging is one of the most valuable real time imaging and painless tools that uses high frequency sound waves to visualize the tendons, muscles, joints, vessels, lesions, cysts, and other internal organs in the body. It uses US waves of about 7.5 MHz to provide the details of superficial organs such as thyroid gland and breast. It is generally described as “safe test” since it avoids mutagenic ionizing radiation which may cause chromosome and cell damage [25]. Sound waves are emitted by the piezoelectric transducer and are bounced back by the tissues. These backscattered signals are digitized to 2D or 3D images. The frequency level of the backscattered signal determines the intensity value of pixel for an image in spatial resolution. A high-frequency sound wave produces superior resolution and image detail whereas the low-frequency sound wave produces less resolution image due to maximum absorption and penetration by the tissues. During the absorption, scattering, and mode conversion of US waves cause multiplicative speckle noise that affects the images captured by ultrasound imaging technique.

Among various US imaging modes such as A, B or 2D [10], M, and Doppler mode, B mode is the most widely used mode for diagnosis. It is commonly inherited by speckle noise which results in ambiguity for accurate diagnosis. Spatial, frequency and multi-scale filters have been recently developed as an eminent technique for de-noising [5], [20], [12], with minimum destruction of image features, especially edges. Since speckle inherit US image characterization, it is difficult to determine the intensity value of the pixel as edge or noisy component. Hence in this research work, a novel spatial filter, M^2 is developed to retain the edge information in images to extract further suspicious area without degrading image characterization.

1.1 OVERVIEW OF THE SPATIAL FILTERING METHOD

The Spatial filtering Method consists of three major steps – Step 1: Get the Original BUS Image and corrupt the image by simulated speckle noises to produce Noisy image. Step 2: the noisy image is subjected to filtering process to filter out or suppress the speckle noise and produce a noise free image. Step 3: Identifying the amount of speckle suppression in an image using performance metrics MSE, PSNR and SSI. Finally the Denoised image is derived for further analysis. The overview of the spatial filtering methodology is depicted in Fig.1.

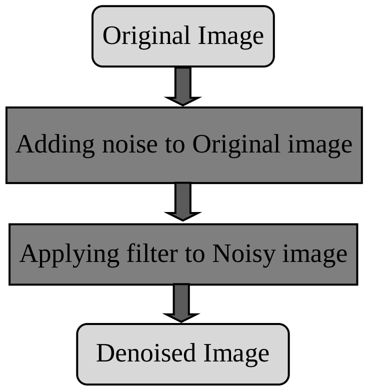


Fig.1. Spatial Filtering Method

The paper is organized as follows: section 2 explains speckle noise and its characterization, section 3 describes various spatial filters available for despeckling, and section 4 expounds the proposed M^2 filter with algorithm. The extensive experimental analysis of the proposed filter and comparative study are given in section 5. The proposed work is concluded in section 6 with further scope.

2. SPECKLE NOISE

Generally all the medical imaging systems suffer from the common phenomenon called ‘Noise’. Impulsive or random noise, Gaussian noise, frequency noise, multiplicative noise [19] and speckle noise are the various types of noise that affects medical imaging. Among various medical imaging modality, US imaging is highly degraded by inherited speckle noise which is multiplicative in nature and is directly proportional to the local grey level area of the two dimensional image. The speckle noise model is given as in Eq.(1),

$$I_{(m,n)} = O_{(m,n)} * U_{(m,n)} + V_{(m,n)} \tag{1}$$

where, $I_{(m,n)}$ is the noisy image, $O_{(m,n)}$ represents the noise free original image, $U_{(m,n)}$ and $V_{(m,n)}$ represent the multiplicative and additive noise respectively and *m*, *n* are spatial dimension (coordinates) of the image.

Speckle noise is of granular pattern that degrades the fine details and edge information, and limits the contrast resolution that causes a number of difficulties to detect small and low contrast lesions in the body. It is due to the blurring by the improper backscattered signals or waves from multiple objects inside the body. In many cases it always implies a sudden change in an image's intensity level and makes the image unsuitable for diagnosis. Filters used in spatial domain so far include Mean, Median, Wiener, Lee, and Gaussian filter, and other hybrid or modification of the statistical filters [17], [18], [21], [23], [24]. These filters perform better in speckle suppression with the cost of degrading the fine details. So the proposed filter emphasis on despeckling as well as preserving the edge components than these spatial filters to make image more suitable for diagnosis.

3. SPATIAL DOMAIN FILTERS FOR BUS IMAGES

In image processing, filters are mainly used for smoothing, enhancing and retaining the edges in the image to make it more suitable for further analysis. Filtering an image can be done either in the spatial or frequency domain. The spatial domain [19] deals with the image matrix of normal image *I*, in which a change of intensity value in any pixel position directly projects to a change in 2D or 3D space. Distances in *I* (in pixels) correspond to real distances (e.g. in meters) in space S. Spatial filters like Gaussian, Mean, Median, Local Region filter, Lee and Diffusion Filter, and Wiener filter are proposed so far for reducing various noises from the images. Mohamed Saleh Abuazoum [7] compared Gaussian filter with Wiener and Median filter and also showed that its performance is better than other filters in terms of PSNR with regards to despeckling noises from the medical images. Bhausaheb Shinde et al. [3] identified that the Median filter removed the sudden peak intensity values in US image by replacing the pixel values with the local statistical parameter that is considered. Speckle noise can be suppressed in US image to some extent by modifying and combining spatial filters [1], [2], [8], [9], [11]. The Table.1 summarizes some of the methods for despeckling Ultrasound images.

Table.1. Despeckling filters used for Ultrasound images

Filters	Author(s) and Year
Median, Adaptive, Average filter	Bhausaheb Shinde et al. 2012 [3]
Frost, Kaun, Lee, Gabour, Adaptive Shock filters	Eveline Pregitha et al. 2012 [4]
MNHP Filter, ANHP Filter, TNHP Filter, MMNHP Filter, AMNHP Filter and TMNHP Filter	Aroquiaraj et al. 2009 [1]
Median filter, Minimum and Maximum pixel within kernel	Bhateja et al. 2014 [2]
Median, Gaussian and Wiener filter	Mohamed Saleh Abuazoum, 2012 [7]
SMU (Srad Median Unsharp)	Njeh et al. 2011 [8]
Modified Wiener filter	Oke Alice et al. 2012 [9]
Lee, Hybrid Mean Median Filter	Shanthi et al. 2011 [11]

The various spatial filtering methods that are considered for this research work are explained clearly along with its computational steps to identify the design variation with proposed algorithm.

3.1 MEAN FILTER

Mean filtering is a simple method for smoothing images [3] by reducing the noise. It reduces the amount of intensity variation between one pixel and its neighborhood. The idea of mean filtering is to replace each pixel value in an image with the mean ('average') value of its neighbors, including its value. Mean filtering uses kernel (sub-region or mask) that slides over every pixel in the image. While sliding, the pixel values which are unrepresentative of its kernel surroundings are eliminated. Mostly 3 × 3 square kernel size is considered since it generally smoothes and preserves edge at maximum level. The computational step for mean filtering is given in Fig.2.

MEAN filtering Algorithm for speckle noise removal
Input: Noisy BUS Image as *I*
Output: Denoised BUS Image as *Q*

Step 1: Fix the kernel A of size $m \times n$.
Step 2: To handle image corners, zeros are padded to the required number of rows and columns according to the kernel size.
Step 3: A Pixel that is considered for filtering is the central pixel value I_C of its corresponding kernel.
Step 4: Replace I_C with the computed Mean value using Eq.(2)

$$M = \frac{\sum_{a=1}^{m}\sum_{b=1}^{n} A(a,b)}{m \times n} \tag{2}$$

of the corresponding kernel.
Step 5: Slide the kernel pixel by pixel over the whole image. Repeat steps 3, 4 and 5 until all the pixels of an image are replaced by the mean of its corresponding kernel.

Fig.2. Mean filtering Algorithm for Speckle noise removal from US Image

123	125	126	130	140
122	124	126	127	135
118	120	150	125	134
119	115	119	123	133
111	116	110	120	130

Neighborhood values: 115,119,120,123,124, 125,126,127,150
Mean value : 125

Fig.3. A Sub image for Mean filtering with 3 × 3 kernel size

A sample portion of an image with a highlighted 3 × 3 kernel is considered in Fig.3. The central pixel value of the kernel 150 is replaced by the mean value of the kernel i.e. 125.

3.2 GAUSSIAN FILTER

Gaussian Filter uses 2-D convolution smoothing operator [7], [19] to 'blur' images and smoothen the noise detail. It is similar to the mean filter, but it uses a different kernel that represents the shape of a Gaussian ('bell-shaped') hump. The 2D Gaussian distribution with mean zero and standard deviation σ = 1 is represented as in Eq.(3),

$$G(x,y)=\frac{1}{2\pi\sigma^2}e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (3)$$

where, σ is the standard deviation and x, y is the local coordinate of an image. The steps of Gaussian filtering are explained in Fig.4.

GAUSSIAN filtering Algorithm for speckle noise removal
Input: Noisy BUS Image as I
Output: Denoised BUS Image as Q

Step 1: Consider a window of size $m \times m$ and assume x, y as the coordinate system, centered to window.

Step 2: x and y takes the value from $-n$ to $+n$, where n is a real number. Then assume m to be odd by $m = 2n + 1$.

Step 3: Weight factors are calculated for a Gaussian bell by $w(x, y) = e^{-a}$ with $a = (x^2 + y^2)/(2\sigma^2)$, where radius σ is the standard deviation.

Fig.4. Gaussian filtering Algorithm for Speckle noise removal from US Image

3.3 LEE FILTER

Lee filter [6] is one of the effective filters in removing speckle noise especially in homogeneous or low variance areas. In high variance areas, the statistical parameters mean and standard deviation are adjusted to preserve edges. While preserving the edges, the speckle noise near and on the edges are retained. The variance over an area of low or constant value is evaluated for smoothing the image. If the variance is high, then smoothing will not be achieved at better level. Speckle noise in US images is generally assumed to be a multiplicative error model. Therefore the Lee filter is applied to the image after the multiplicative noise value is approximated. The algorithm for Lee filtering method is explained in Fig.5.

LEE filtering Algorithm for speckle noise removal
Input: Noisy BUS Image as I
Output: Denoised BUS Image as Q

Step 1: Fix the kernel (window) A of size $m \times n$.

Step 2: Estimate noise variation coefficient for each sub image as $C_u = SQRT(1/ENL)$ where ENL (Equivalent Number of looks) = $(\mu/\sigma)^2$, μ and σ is the mean and standard deviation.

Step 3: Calculate the image variation coefficient as $C_i = S/A$, where S the standard deviation and A is the mean value of pixel intensity of the kernel.

Step 4: Calculate the weighting function as $W = 1 - C_u^2/ C_i^2$.

Step 5: The center pixel of kernel I_C is calculated by $I_C = I_C * W + G * (1 - W)$

Step 6: Repeat steps 2 to 6 until all the pixels of the image is computed.

Fig.5. Lee filtering Algorithm for Speckle noise removal from US Image

3.4 MEDIAN FILTER

Median Filter slides over the image pixel by pixel for replacing each pixel with the median of its corresponding kernel. The kernel is called as "Window" and the concept is termed as "Sliding window" [7].

The computational step for the median filtering method is shown in Fig.6.

MEDIAN filtering Algorithm for speckle noise removal
Input: Noisy BUS Image as I
Output: Denoised BUS Image as Q

Step 1: Fix the window A of size $m \times n$, where m and n are odd number.

Step 2: To handle image corners, zeros are padded to the required number of rows and columns according to the kernel size.

Step 3: A Pixel that is considered for filtering will be the central pixel value I_C of its corresponding window. Sort all the pixel values from the surrounding neighborhood.

Step 4: Replace I_C with the computed Median value using Eq.(4) element of the corresponding window.

$$M = \frac{N}{2} + 1^{th} \quad (4)$$

Step 5: Move the window pixel by pixel over the image. Repeat steps 3 to 5 until all the pixels of the image is replaced by the median of its corresponding window.

Fig.6. Median filtering Algorithm for Speckle noise removal from US Image

123	125	126	130	140
122	124	126	127	135
118	120	150	125	134
119	115	119	123	133
111	116	110	120	130

3 × 3 kernel values:
115,119,120,123,124,
125,126,127,150
Median value : 124

Fig.7. 3×3 kernel of a sub image and computation of Median

For example, a sample portion of an image with a highlighted window of size 3 × 3 is considered for computing median. The central pixel value 150 of the window is replaced with the median of the window, 124 and the same is shown in Fig.7.

3.5 M3 FILTER

M3 Filter is a hybrid of linear and nonlinear filtering where the maximum of mean and median [15], [16] of each kernel is calculated to replace the intensity of the central pixel of kernel. The kernel slides over all the pixels in the image. This filter yields good result to a certain extent in enhancing the image and preserving the edges. Fig.8 shows the computational steps of M3 filter.

M3 filtering Algorithm for speckle removal
Input: Noisy BUS Image as *I*
Output: Denoised BUS Image as *Q*

Step 1: Fix the kernel *A* of size $m \times n$ to perform convolution.

Step 2: To handle image corners, zeros are padded to the required number of rows and columns according to the kernel size.

Step 3: A Pixel that is considered for filtering will be the central pixel value I_C of its corresponding kernel. Sort all the pixel values from the surrounding neighborhood.

Step 4: Compute Mean value as R1 using Eq.(2) and Median value as R2 using Eq.(4) for the kernel.

Step 5: Replace I_C with the maximum value of Mean and Median of the corresponding kernel *A*,

$$I_c = \max(R1, R2)$$

Step 6: Move the kernel pixel by pixel over the image. Repeat steps 3 to 6 until all the pixels of an image is replaced by the maximum value among mean and median of the corresponding kernel.

Fig.8. M3 filtering Algorithm for Speckle noise removal from US Image

123	125	126	130	140
122	124	126	127	135
118	120	150	125	134
119	115	119	123	133
111	116	110	120	130

Neighbourhood values:
115, 119, 120, 123,
124,125,126,127,150
Mean value *R*1 : 125
Median value *R*2: 124
Max Value : 125

Fig.9. M3 filtering for a 3 × 3 kernel of a sub image

An example for M3 filter is shown in Fig.9, where the sample portion of an image is considered with 3 × 3 kernel size. After sorting the kernel, the central pixel value 150 of the kernel is replaced with 125 which is the maximum of mean value *R*1 (125) and median value *R*2 (124).

4. PROPOSED FILTERING TECHNIQUE: M^2 FILTER

Filtering is the first and foremost step in designing computer aided diagnosis system. It plays a vital role in enhancing image and preserving edges to extract the Region of Interest in the image [13], [14], [15]. Spatial filters preserve edges in digital images, but sometimes they remove fine image details such as minute edges that cover suspicious portion. Enhancing or modifying spatial filters with linear and non-linear kernels or masks have the possibilities to suppress the noise and also preserve the image detail [6].

The proposed M^2 filter is the hybridization of mean and median filter, since mean filter will smoothen the image and median filter will preserve the edge. It preserves the edges and suppresses the speckle from US image better than other filters with 3 × 3 kernel size. It also helps in retaining the edges of suspicious portion with reasonable amount of speckle suppression that is more significant for further analysis. The computational step for the M^2 filtering is given in Fig.10.

M^2 filtering Algorithm for speckle removal
Input: Noisy BUS Image as *I*
Output: Denoised BUS Image as *Q*

Step 1: Fix the kernel *A* of size $m \times n$. Let *i* and *j* be the size of the image *I*.

Step 2: To handle image corners, zeros are padded to the required number of rows and columns according to the kernel size.

Step 3: Let I_C is the central pixel value of the kernel *A*.

Step 4: Sort the kernel A row wise and compute Median (R) of the middle column using Eq.(4).

Step 5: Sort the kernel A column wise and compute Median (S) of the middle row using Eq.(4).

Step 6: Compute mean of *R* and *S* and replace the central pixel value I_C with it.

Step 7: Move the kernel pixel by pixel over the image. Repeat steps 3 to 7 until all the pixels of the image is replaced by the mean of the medians of its corresponding kernel.

Step 8: Calculate PSNR, MSE, SSI for the input and output images to evaluate the noise suppression and image smoothening.

Fig.10. M^2 filtering Algorithm for Speckle noise removal from US Image

A sub image of kernel size 3 × 3 is considered as kernel in Fig.11. Sort the elements of each row and find the median (R = 6) of middle column. Then sort the pixel values of each column and find the median (S = 5) of middle row. Now replace the central pixel value IC with 5.5 which is the mean of *R* and *S*.

<table>
<tr><td rowspan="2">Kernel = $A_{3\times3}$
<table><tr><td>7</td><td>5</td><td>6</td></tr><tr><td>1</td><td>9</td><td>8</td></tr><tr><td>3</td><td>2</td><td>0</td></tr></table></td><td><table><tr><td>5</td><td>6</td><td>7</td></tr><tr><td>1</td><td>8</td><td>9</td></tr><tr><td>0</td><td>2</td><td>3</td></tr></table>Sort $A_{3\times3}$ row wise</td><td>For Middle Column:
R = median(2,6,8)
R = 6</td></tr>
<tr><td><table><tr><td>1</td><td>2</td><td>0</td></tr><tr><td>3</td><td>5</td><td>6</td></tr><tr><td>7</td><td>9</td><td>8</td></tr></table>Sort $A_{3\times3}$ column wise</td><td>For Middle Row:
S = median(3,5,6)
S = 5</td></tr>
</table>

Fig.11. A sub image of 3x3 kernel size for M^2 filter computation

5. EXPERIMENTAL RESULTS

Experimental setup is carried out using 20 BUS images collected from Samsung Medison and Ultrasoundcases.info database. Images belong to benign, malignant, normal and probably benign or probably malignant categories are considered. These original images are first subjected to contamination by the simulated speckle noise levels 0.01, 0.02, 0.03, 0.04 and 0.05 to obtain corrupted images i.e. $I(x, y) = O(x, y) + n(x, y)$ where, $O(x, y)$ is the original image, $n(x, y)$ denotes the speckle noise and $I(x, y)$, the corrupted image. The resultant corrupted BUS images are then subjected to Mean, Gaussian, Lee, Median, M3 and M^2 filters with 3 × 3 kernel size in MATLAB environment. During filtering process, each filter suppresses the noise to a better extent, and yields an understandable visual image. Finally, the output image of each filter is evaluated with the original image to identify the quality of image in preserving edge details and the amount of noise suppressed using standard metrics such as Mean Square Error (MSE), Peak Signal to Noise Ratio (PSNR), and Speckle Suppression Index (SSI) [11]. The MSE is an estimator to measure the average error rate of the square of difference between the noisy image and noise suppressed image. The PSNR is the ratio between the square of the maximum intensity value of image and the mean squared error of image. The SSI is the ratio of coefficient of variance of speckle suppressed image to that of corrupted image. The formula for MSE, PSNR and SSI performance metrics are tabulated in Table.2 as Eq.(5), Eq.(6) and Eq.(7).

Table.2. Performance Metrics

Standard Metrics	Formula
MSE	$\frac{1}{m \times n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[o(i,j)-G(i,j)]^2$ (5)
PSNR (in dB)	$10\log_{10}\left(\frac{MAXo^2}{MSE}\right)$ (6)
SSI	$\left(\frac{\sqrt{\mathrm{var}(O_{m\times n})}}{mean(O_{m\times n})}\right)\times\left(\frac{mean(G_{m\times n})}{\sqrt{\mathrm{var}(G_{m\times n})}}\right)$ (7)

O is a BUS image of size $m \times n$ and G is a reconstructed image in Table.2. MAXo is the maximum possible pixel value of the image. If the pixels are represented using 8 bits per sample, then MAXo will be 255.

A sample BUS image is corrupted by 5 different simulated speckle noises 0.01, 0.02, 0.03, 0.04 and 0.05 is shown in Fig.12(a)-(e).

SPECKLE NOISE LEVELS

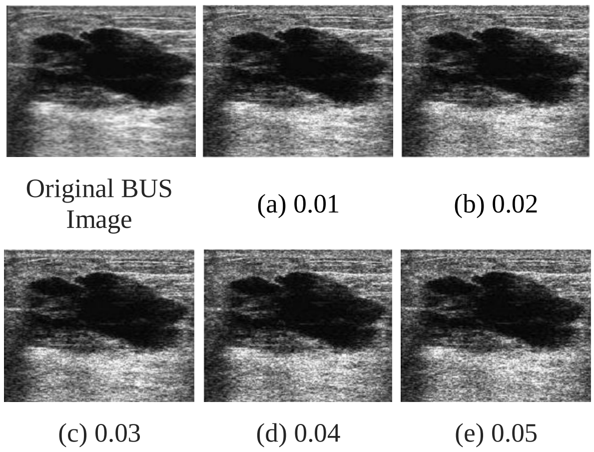
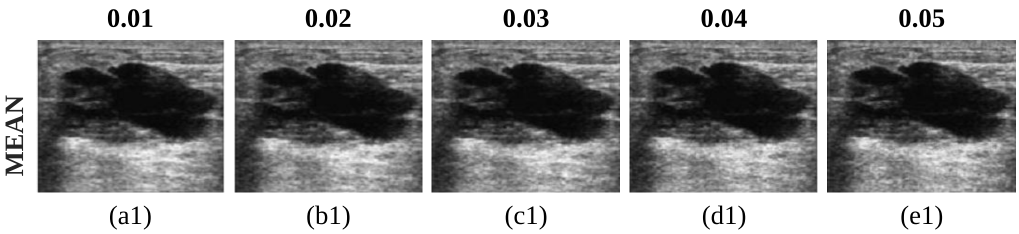


Fig.12(a)-(e). Original BUS image corrupted by speckle noise levels 0.01, 0.02, 0.03, 0.04 and 0.05

The corresponding output image (noise free image) by Mean, Gaussian, Lee, Median, M3 and M^2 filtering for various speckle noise levels 0.01, 0.02, 0.03, 0.04 and 0.05 are shown in Fig.13 a1-a6, b1-b6, c1-c6, d1-d6 and e1-e6 respectively.

SPECKLE NOISE LEVELS



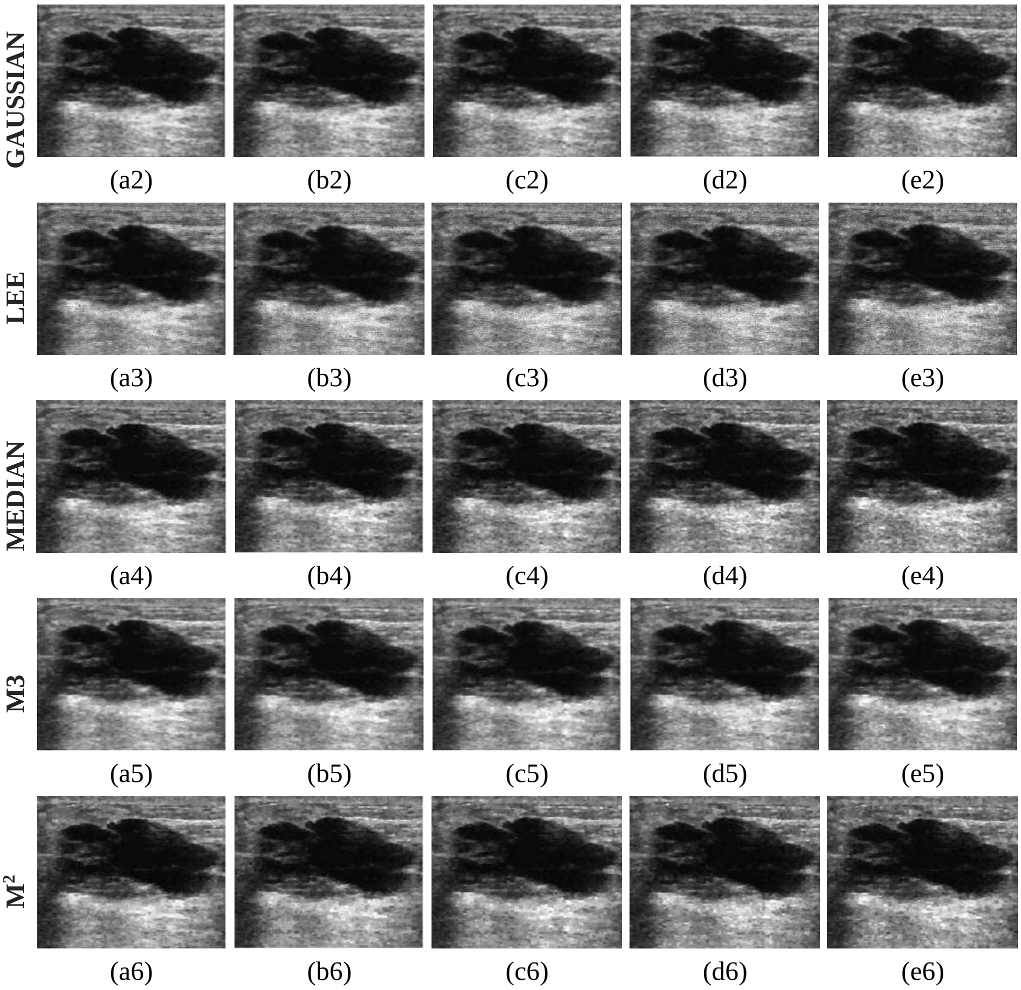


Fig.13. Despeckled image by Mean, Gaussian, Lee, Median, M3 and M^2 filter with 3 × 3 kernel for speckle noise levels – 0.01 (a1-a6), 0.02 (b1-b6), 0.03 (c1-c6), 0.04 (d1-d6) and 0.05 (e1-e6)

From Fig.13(a6)-Fig.13(e6), it is visually observed that the M^2 filter suppresses the speckle noise as well as enhances the image slightly better than other spatial filters for all defined speckle noise levels. Even though the output of Mean, Gaussian, Lee, Median, M3 and M^2 filters are visually figured out, it is very essential to analyze numerically by MSE, PSNR and SSI standard performance metrics. A filter is identified as a best fit model for speckle noise suppression only if it yields minimum MSE, SSI and maximum PSNR values. The average MSE, PSNR, SSI results of various filters for suppressing the speckle noises with levels (0.01, 0.02, 0.03, 0.04 and 0.05) in 20 corrupted BUS images are tabulated in Table.3, Table.4 and Table.5 respectively. The graphical representation of the corresponding average MSE, PSNR and SSI values are shown in Fig.14, Fig.15 and Fig.16 respectively.

Table.3. Average MSE values of spatial filters with various Speckle noise levels

FILTERS (Average value for 20 BUS images)	MSE↓				
	SPECKLE NOISE LEVELS				
	0.01	0.02	0.03	0.04	0.05
MEAN	0.0100	0.0112	0.0112	0.0137	0.0150
GAUSSIAN	0.0100	0.0112	0.0112	0.0137	0.0150
LEE	0.0221	0.0249	0.0248	0.0305	0.0333
MEDIAN	0.0133	0.0145	0.0145	0.0171	0.0185
M3	0.0019	0.0020	0.0020	0.0024	0.0025
M^2	0.0015	0.0017	0.0017	0.0021	0.0023

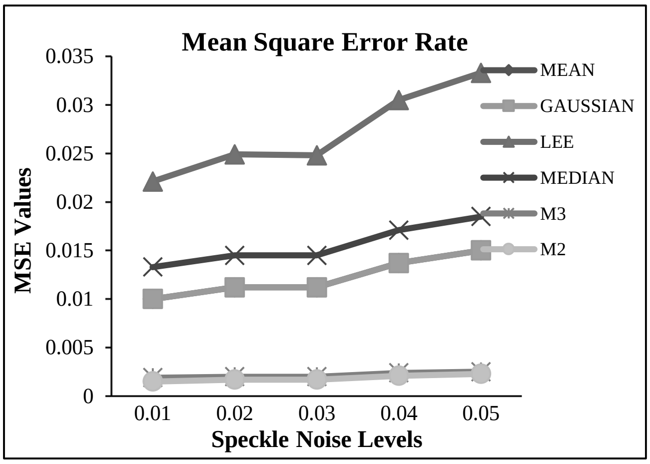


Fig.14. Average MSE of spatial filters for various speckle noise levels

From Table.3, it is revealed that the MSE values of M3 and M^2 filters for various speckle noise levels 0.01, 0.02, 0.03, 0.04 and 0.05 is very less than Mean, Gaussian, Lee and Median filters. It is also observed that the proposed M^2 filter produced MSE value 3% less than M3 filter and proved with low degradation in image information.

Table.4. Average PSNR values of spatial filters for 20 BUS images and different Speckle noise level

FILTERS (Average value for 20 BUS images)	PSNR↑				
	SPECKLE NOISE LEVELS				
	0.01	0.02	0.03	0.04	0.05
MEAN	67.80	66.95	66.56	66.21	66.04
GAUSSIAN	67.22	66.73	66.48	66.27	66.26
LEE	65.45	65.04	64.90	64.20	63.86
MEDIAN	67.41	66.92	66.68	66.37	66.09
M3	67.77	67.31	67.26	66.85	66.45
M^2	70.05	69.62	69.59	69.02	68.93

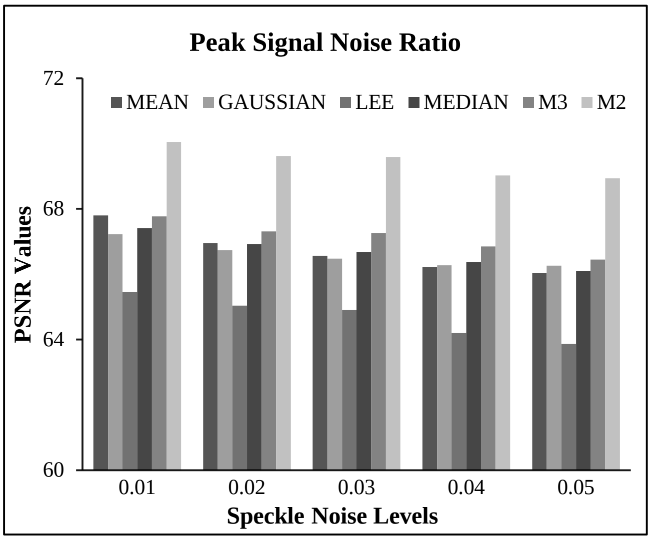


Fig.15. Average PSNR of 6 filters for 5 different speckle noise levels

From Table.4, it is observed that the PSNR values of M^2 filter for all the BUS images corrupted by different speckle noise levels are higher than the other spatial filters. The outcomes prove that the M^2 filter maintains its stableness in PSNR value for all speckle levels. M^2 filter produced higher PSNR value higher than other filters by 2% and retains the maximum edge detail. The pictorial representation proves it moves more preciously in Fig.15.

From Table.5, it is found out that M^3 and M^2 filters yield low SSI values than other filters. It is also revealed that the SSI values of M^2 filter for speckle noise level 0.01, 0.02, 0.03 and 0.04 are comparatively lower than M3 filter and proves its better speckle suppression in BUS images. The Fig.16 shows the SSI variation of M^2 filter more clearly. For 0.05 speckle noise level, SSI values for M^2 filter is slightly higher than the median and M3 filter.

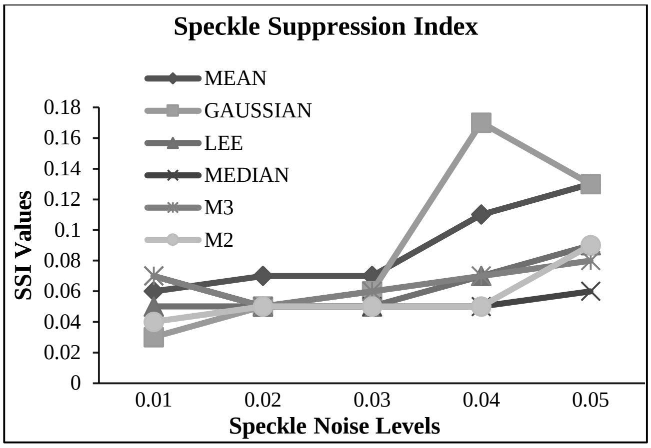


Fig.16. Average SSI of 6 filters with 3 × 3 for 5 different speckle noise levels

Table.5. Average SSI Performance of filters with 3 × 3 kernel, 20 BUS images and Speckle noise level 0.01-0.05

FILTERS (Average value for 20 BUS images)	SSI↓				
	SPECKLE NOISE LEVELS				
	0.01	0.02	0.03	0.04	0.05
MEAN	0.06	0.07	0.07	0.11	0.13
GAUSSIAN	0.03	0.05	0.06	0.17	0.13
LEE	0.05	0.05	0.05	0.07	0.09
MEDIAN	0.07	0.05	0.05	0.05	0.06
M3	0.07	0.05	0.06	0.07	0.08
M^2	0.04	0.05	0.05	0.05	0.09

From Table.3, Table.4 and Table.5, the average MSE values are 0.0015, 0.0017, 0.0017, 0.0021 and 0.0023, the average PSNR values are 70.05, 69.62, 69.59, 69.02 and 68.93 and the average SSI values are 0.04, 0.05, 0.05, 0.05 and 0.09 yielded by M^2 filter are comparatively better than other spatial filters for all speckle noise levels 0.01, 0.02, 0.03, 0.04 and 0.05 respectively. From these visual and numerical analyses, it is found that the M^2 filter with 3 × 3 kernel size is more suitable for suppressing speckle noise levels up to 0.04 yielding very low MSE, 2% higher PSNR and 2% lower SSI value. Hence the proposed method with 3 × 3 kernel size outperforms other spatial filters in speckle suppression and preserves edge details for BUS images.

6. CONCLUSION

Analysis of BUS images for effective diagnosis is possible only after filtering the speckle noise since it degrades the edges and fine details in the images. In this paper, a novel M^2 filter is introduced to suppress speckle noise and preserve the edges. The proposed filter is evaluated using parameters like MSE, PSNR and SSI and compared with other spatial filters. The experimental analysis clearly showed that M^2 filter outperforms well and it achieves an overall 2% PSNR value higher than other spatial filters with 3 × 3 kernel size for different speckle noise levels upto 0.04 noise levels. In future, the work can be extended to various medical image analysis and it can also hybridised with other single and multiscale domain filters for further improvement in speckle suppression in BUS images.

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