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Performance Analysis of Best Speckle Filter for Noise Reduction in Ultrasound Medical Images

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Abstract

In the past few years, one of the most attracted and search topic within medical imaging is the speckle phenomenon that and highly affects the ultrasound images and generates a negative impact on diverse image interpretation tasks. Recently, huge and remarkable efforts have been performed in order to develop an effective denoising method. Although, some noticeable and obvious results have been achieved toward speckle reduction and noise enhancement effectiveness. However, many of the proposed and developed methods still suffer from low computational efficiency, image features damaging and characterized also by low speckle reduction. Thus, this paper mainly presents a new method of speckle reduction in medical ultrasound imaging utilizing an effective and optimized acquisition/post-processing combination technique. Within this manuscript, the developed approach consists of three main stages, in which the first stage applied to select the datasets (speckle ultrasound images) and proceed to the next stage. At Stage 2, the optimized post-processing combination approach is applied as an improved reducing technique, where several filters can be applied to real dataset including median filter, Wiener filter, h-median, frost-diffusion, and more toward reducing the speckle noise from the medical images. Stage 3 is significant to show the result and histogram of the developed technique. Finally, the performance of the proposed method will be contacted using qualitative and quantitative measures, which demonstrate strong denoising capability and image details preserving than many previously proposed methods of speckle reduction.

Keywords: Medical imaging, speckle reduction, ultrasound images, optimized post-processing.

I. INTRODUCTION

One of the most powerful and significant techniques which have been utilized for imaging soft tissues, the human body, internal parts and organs in numerous therapeutic procedures and clinical diagnosis over the past decades is an ultrasonography imaging. The utilization of ultrasound imaging, in biomedical diagnosis, pioneered in the 1950s, and today it is particularly widespread [1]. The researches, scientists, developers, and specialises in medical imaging field have investigated for long-term various imaging modalities toward producing a significant prominent diagnostic technology, which can be used for most daily scenario and wide clinical purposes [2]. Through this introduction section, we started by briefly recalling the ultrasound medical imaging as the main key to clinical diagnosis and its progression which lead to several multiplicative types of noise models. Where among medical image modality and technologies in the medical sector, ultrasound has the advantageous over various existent imaging techniques including Computed Tomography CT, PET, X-ray, and the Magnetic Resonance Imaging MRI. Ultrasound-imaging technology is a prominent diagnostic, which characterize with better performance, free of radiation risk, real-time acquisition, economical and effective in cost, reliability, portability, easy to use, acceptability, noninvasive, versatile, capabilities, safety, and secure, these pros made ultrasound imaging more suitable for diagnosis of diseases in contrast to previous imaging methods [3], [4].

Ultrasound imaging is steadily growing in the medical field. This is particularly due to three main reasons including the used for detection and generation of the ultrasound technologies. The second reason is linked to the advancement brought by development in digital technologies, especially the improvement in image and signal processing methods. The last reason is the huge variety of applications in the medical field, where the applications are as varied as the diverse parts of the human body including echocardiogram, bone-sonometric, fetal ultrasound, abdominal ultrasound. While, among past decades and with the huge advancement of signal processing and digital technologies, the ultrasonic diagnostic device's resolution has been constantly improving [5], [6].

On the other hand, ultrasound imaging utilization has increased the demand for significant signal resolution techniques. However, the quality of images is lower than other devices of medical diagnostic. The major cause and reason of this problem and significant issue is the noise of the granular pattern through the acquiring process of the ultrasound image which defined as the speckle noises, this ultrasound imaging characteristic is known as random deterministic involvement pattern generated with coherent radiation of a medium which degrades contents, fine details and edges of an image, that certainly noises level growing with the average gray level of a specific local area. This significant phenomenon is the unavoidable and rough attribute which complicates the search and detection of specific and fine details, while it upsets the diagnosis the capabilities of ultrasonic images in the medical area [7], [8].

In general, speckle noises are generated because of the travelling path difference of the particular coherent acoustic waves that presents the interference. Speckle noises are quite different from other classical noises sorts such as impulse and Gaussian noises. It has a shape like the granular spot in the whole image space. The specific denoising techniques applied to remove impulse noise or Gaussian noises are not sufficient for de-speckling unless these methods are adjusted based on the characteristic of speckle noise. It is quite difficult for recognizing and extracting features of ultrasound imaging since this sort of noise is particularly being affecting directly the diagnostic value of the imaging form. Where the elimination of these noises is a primary target while analyzing and observing the ultrasound images for significant disease characterization. Thus, the development and implementation of methods and preprocessing stages that are capable of speckle reduction is a critical step toward making the ultrasound image remarkable and favourable source [9].

From the perspective of the medical aspect such as clinical applications, speckle noises are significantly degrading the quality of ultrasound imaging and this influenced the accurate diagnosis, particularly for doctors with less experience. The main target of the existing studies is focused on eliminating speckle noises on the ultrasound images. The speckle reduction and elimination techniques are categories in two classes. The first category is image averaging, while the second is image filtering. The image averaging method is commonly achieved by averaging a series of uncorrelated or non-correspond ultrasound images from diverse viewpoints. But, these techniques have some problems including the loss of spatial resolution [10]. In contrast, image filtering techniques which can be categories as single scale filtering including the linear and nonlinear filtering techniques [11]. The multiscale filtering techniques such as diffusion-based [12]. Many additional multiscale techniques are applied especially in diverse transform domain including wavelet method, pyramid [13], curvelet, based techniques, and ridgelet method [14]. The de-speckling becomes a core stage before the analysis, observation, and processing of ultrasound images. Many researchers, developers, and scientists are inspired to dedicate their efforts to this problem toward a more accurate diagnosis.

This paper contents and outlines are organized and structured as follows. In Section I, an introduction of ultrasound-imaging and speckle noises elimination are presented with more details. Section II summarizes some of the previous research works and studies of ultrasound-imaging, speckle noise reduction, filters techniques, and algorithms development on ultrasound images. In Section III multiple speckle noise elimination filters are described and discussed. In Section IV, the structure of the applied algorithm is contacted and presented. In Section V the quantitative evaluations are described and discussed. In Section VI, the obtained results are discussed and evaluated. Section VII presents the conclusions of this study.

II. RELATED STUDIES

Through our ordinary life, people were suffering from long-term and dangerous diseases such as kidney failure, blood processing, cancer, heart blockage, asthma, and other more diseases. The earlier detection of such these diseases at an initial stage is a quite significant term, especially as real time. The ultrasound imaging as image processing plays a key role in this part, where currently it has become a high target than before. While, the removal of speckle noises from ultrasound imaging still a quite challenging task. The speckle noise generally affects the ultrasound image quality and it also minimizes several important information and data from these images including shape, the image edges, the intensity values, etc. Thus, numerous researches, concepts, and studies of speckle noise reduction have been investigated and contacted worldwide. Where various methods based on these studies have been developed and implemented for eliminating speckle noises while preserving and maintaining the critical features in ultrasound images. One main challenge is how to specify the measure, which can efficiently differentiate features of the image from the speckle noise since both of them, are come with high frequencies in many cases.

The speckle noise appears in the specific forms of multiplicative noises. This particularly refers that, the variance of speckle noise is comparable to the variance of the feature. The speckle noise in ultrasound images can be eliminated by two individual methodologies which are the post-processing methodology and compounding methodology or usually both methods are applied. The post-processing technique significantly involved the following main categories :(1) The spatial domain which is used directly with the original image and (2) The transform domain which is generally transformed to the frequency domain by fast Fourier transformation method, and then followed with denoising in the frequency domain. While, the compounding technique reduces noises when the images are acquired utilizing various transducers. Same regions of the images gained by each transducer are combined or integrated in order to form the final image with enhancing and maximizing quality [15].

The resolution smoothness compression technique had addressed the problems of resolution and visibility of the ultrasound image. Where the frequency and spatial compounding methods were proved to highly improve the signal to noise ratio. In addition, as the measuring frequency range of the ultrasonic waves is improved, the resolution is increased for the ultrasound image. Adaptive speckle elimination was inherently well-known as signal processing algorithm. Whereas it was used to identify and remove the dominated speckle of the ultrasound image. With applying the processing of complementary or integral hulling method, the geometric filter is used to decrease the speckle noises [16].

As previously mentioned, the speckle is primary a factor term that restricts the contrast resolution of images, this way obstructing the detection of low and small contrast lesions as well as converting the images interpretation toward a real challenging task. Speckle noises are also limiting the application efficiency of investigated algorithms and image processing for the region, segmentation, edge detection and classification purposes. Thus, the speckle noises have been presented in images since early time, and specifically have been documented since the 1970s. Authors and researchers such as Burckhardt, Goodman, and Wagner have described the statistical and fundamentals properties of speckle [17]. The de-speckling has always been a significant trade-off between loss of information and noise suppression. This considers as a critical problem particularly with the involvement of medical diagnosis. Whereas a multiplicative noise, Wagner et al, has outlined the statistical and fundamentals properties of the speckle problems as cited by [18].

III. PROBLEMS AND CHALLENGES

In a more close analysis, The reduction of speckle noise can be performed by spatial filtering or multi-look processing as mentioned in the previous discussion. The multi-looking operation is usually achieved among the data acquisition stage, while the spatial filtering for speckle reduction by is done on an image after the acquiring process. Regardless of which technique is applied to minimize the affection of speckle noise, the most ideal speckle reduction technique can significantly preserve information, important details, edges, features and more. In this manuscript, we addressed the speckle noise problems on ultrasound medical images which are used to gain core information imaging of soft tissues, internal pars of the human body, and organs in clinical diagnosis and therapeutic procedures for treatment of the diseases. These noises make computer-assisted detection methods and human interpretation inconsistent and difficult. It degrades the quality ultrasound medical images (US images) and therefore minimizes the ability for observers and specialist to distinguish the fine details of diagnostic check and examination. Besides, many applications and systems efficiency of investigated algorithms, image processing, and computer vision get restricted in their region, segmentation, edge detection and classification purposes due to the Speckle noises. Thus, this approach is providing data manipulation (filtering technique) of the ultrasound images toward high-quality results in image denoising.

IV. SPECKLE NOISE AND FILTERING TECHNIQUES

There are diverse types of noises appeared on images. These noises are occurred and generated due to various factors including the image capturing, acquisition of images, compressing images, transforming, and more. Therefore, it is necessary and essential to provide diverse techniques based on sort of noise. As implicitly presented previously, speckle noises are containing high-frequency components due to several factors including temporal movement (e.g. heart, brain, etc.). Thus, among the past few years, a lot of effort has been dedicated in order to overcome the speckle noise problems and challenge. Multiple filtering techniques have been proposed and developed for speckle noises reduction toward a significant resolution of ultrasound image [19].

Through the years and until now numerous distinguished filters are applied for speckle noises minimization. A large number of these filters are a convenience in visual interpretation, while as major are effective in noise reduction and smoothing capabilities. Some of these filters are utilizing window method to eliminate speckle noise, known as the kernel. This window size can be particularly organized from (3 *x* 3) window to (33 *x* 33). While to achieve an accurate result, small window sizes are recommended, since these window sizes are able to remove tiny and thin objects in the contents of images [20]. A fundamental representation is the directional smoothing filters have a speckle reduction term which implements filtering in a square-moving window known as kernel relying on the statistical relationship between the central pixel and its own surrounding pixels as shown in Figure 1.

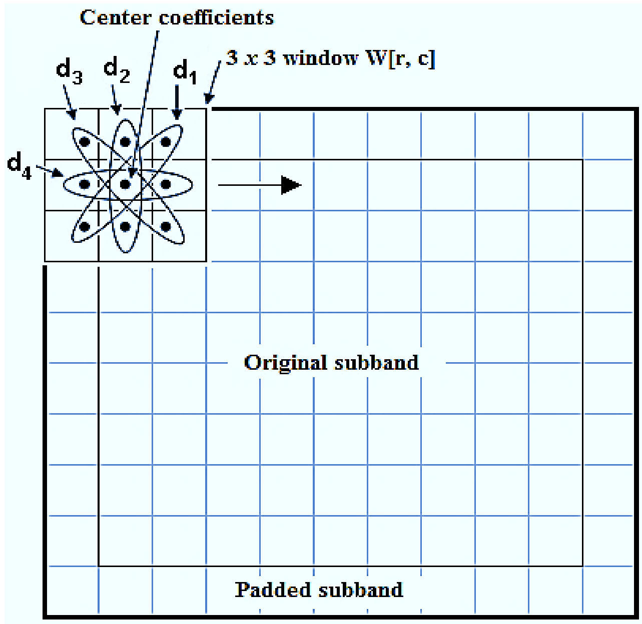

Figure 1: A 3 *x* 3 filter window on a particular sub-band

The investigations in this area focused and included numerous highlighted methods as follows:

1. Mathematical Model of Speckle-Noise

Speckle noise is a significant pattern of random intensity generated by mutual interference of a group of waves that exists incoherent imaging including ultrasonic imaging, laser imaging, SAR, radar, and more. Specifically, speckle noise behaviour is similar to Brownian motion [21]. The speckle noise's amplitude has a Gaussian distribution and can be presented as shown in Equation (1).

$$A = A_R + j A_I \quad (1)$$

where the A_R indicate to the phase component, and the A_I represents the e quadrature component for the amplitude of the speckle. The two components are considered statistically independent random parameters with Gaussian distribution, identical variance, and zero mean. The speckle noise intensity [22] is presented as shown in Equation (2).

$$u = A_R^2 + A_I^2 \quad (2)$$

The intensity of the speckle noise has a negative exponential distribution [22] is given as illustrated in Equation (3).

$$p(u) = \frac{1}{\bar{u}} e^{-\frac{u}{\bar{u}}} \quad (3)$$

the term $\bar{u}$ refers to the mean intensity of the speckle

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While, because of the multiplicative behaviour of the speckle noise, the image obtained by the coherent imager can be modelled as a multiplicative model with significant exponential distribution. Thus, the general model of speckle noise can be given as shown in Equation, [23], [24].

$$I(x, y) = R(x, y)\, u(x, y) \quad (4)$$

The (x, y) variables are indicating the image spatial coordinates, I is the obtained image. The R refers to the observed scene, while u is the multiplicative noise of speckle which statistically independent of with unit variance and mean. From the above discussion and model, it significantly clear that the speckle noise has effects on the parts of an image with high intensity more than parts of an image with low intensity. Besides, the speckle noise has multiple characteristics including speckle noises are considered multiplicative noises that are in direct proportion in any area to the local gray level, the noise and signal are statistically independent, the variance and sample mean of the single pixel are equal to the variance and mean of the local area.

2. Filtering Techniques

Broadly and through the medical field, the diagnosis has become more intricate because of the presence of speckle noise. Thus, several reliable types of filtering techniques are designed and implemented which plays a major role in smoothing the images. These techniques have different characteristics and structures toward removing undesired components and elements, which they can be either processes or devices. Generally, filters are utilized to smooth and improve the quality of images prior to its phases, which often depend on the type of noise [25].

In this paper, several speckle filters were evaluated based on local statistics, noise reduction and enhancement including Adaptive Filters (e.g. Kuan Filter, Lee filter, Frost filter, enhanced Lee and enhanced Frost filters, Sigma filter Coherence Diffusion, Anisotropic Diffusion, Wavelet Filtering, Weiner Filter). However, these techniques are far from becoming an optimal tool. Later, these filtering techniques are enhanced by first categorizing the whole pixels into three clusters and using particular processing on each cluster. While, the results from these filtering methods are usually sensitive to the empirical parameter including the shape and size of the window. Besides, scalar filters are depending on the ratio of local statistics, that advance and increase the smoothness inhomogeneous regions for the images where speckle is completely advanced and decreased appreciably in the other regions of the image toward preserving the important details of an image. A fundamental

Sort of scalar filters is the median filter and its advanced filters such as adaptive weighted median filter [7], adaptive median filter, and directional median filter [8].

In the de-speckling of ultrasound images, the spatial domain filters can be classified into significant categories, the scalar filters and adaptive filters. Scalar filters are relying on local statistic ratio that advances the smoothing in homogenous regions of an image. While, many adaptation filtering methods are developed to achieve more quality results, perceived image features and details by varying window sizes.

The and fundamental sorts and general mathematical models of scalar filters are presented as follows:

a) Mean Filter

A linear filtering technique that is also known as an averaging filter, which replaces each value of the pixel in an image by the average the gray levels of the neighbourhood. The technique does not eliminate speckle noise at a whole, but it decreases to some extent. The filter has an effect on blurring and smoothing the image. While, since the speckle noise is commonly multiplicative, the basic mean technique is not an effective and less satisfactory method. The mean filter performs as a low-pass filter, where the mathematical model representation defined as shown in equation (5).

$$h[i, j] = \frac{1}{M} \sum_{(k,l)\in N} f[k, l] \quad (5)$$

where M variable indicates the number of pixels in the surrounding N. The h [i, j] and f [k, l] represent both old and new image pixels. While, the size of the neighbourhood N handles the degree of filtering. Huge neighbourhood sizes will give a greater degree of filtering.

b) Median Filter

The median filtering technique is an operation that is crucial in order to achieve high filtering performance, particularly at high noise density, a median is also known as non-linear and order statistics filtering technique. The filter standard model is simply applied as a preprocessing method. This filter is widely utilized in image processing area in order to eliminate noises from the corrupted images, and it also applied to preserve edges and maintain the useful details and feature in an image. The basic main idea of the median filter is to go among the image completely, where the pixel value of the image is change with the median value. While, the median value is obtained by first organizing all the pixel values in descending or ascending order, then change the pixel being obtained with the middle pixel value. However, if the considered neighbouring pixel of an image does not contain pixels, then it often replaces a pixel with the average of two middle pixel values. This filter gives the features of removing the effect of input noise values, it also provides significant results when the percentage of impulse noise is less than 0.1. [26], [27]. The median filter mathematical model is shown in equation (6).

$$f^{\wedge}(x, y) = median\{g(s, t), where\ s, t \in S_{xy}\} \quad (6)$$

where S_{xy} indicates to set of coordinates in particular rectangular sub-image window, that center at (x, y). The $f^{\wedge}(x, y)$ refers to the restored image. While the median filter measures the median of the corrupted image which indicated as g (x, y) for the area S_{xy}. In addition, toward reducing impulse noise and the speckle noises from the ultrasound images, many advance and effective techniques for corrupted images are proposed. These techniques include adaptive weighted median filter [7], adaptive median filter, and directional median filter [8] for image highly corrupted with particularly speckle noise and random valued impulse noise.

The filters techniques with adaptive nature are having a mathematical model defined as follows:

i. Frost Filter

This approach is a method that also applied to maintain a suitable balance between the preservation of edges and segmentation. The balance is achieved by applying an exponentially damped kernel that adapts based on diverse regions by commonly exploiting the local statistics such as the variance and mean of the neighbouring window generated at each pixel [28], [29].

$$DN = \sum_{n\,x\,n} K\alpha e^{-\alpha|t|} \quad (7)$$

The α can be formulated as follows

$$\alpha = \left(\frac{4}{n\sigma^2}\right)\left(\frac{\sigma^2}{\bar{I}^2}\right) \quad (8)$$

where the k is representing the normalized constant, $\bar{I}$ indicates to local mean. the σ is the local variance, and $\bar{\sigma}$ is the image coefficient of variation value. The variable |t| = |X-X_0|+|Y-Y_0|, while n is the moving kernel size.

ii. Lee Filter

This technique is upon the reduction of the mean-square error (MSE) by deliberate on the weighted average of the sub-regions generated at every pixel locations. While, the relationship between enhancing done by the Lee filter and the variance of a region is generally inversely proportional to each other. This certainly means enhancing process is not achieved when the variance of a region is completely high, particularly close to edges. In contrast, an effective enhancing process is achieved by Lee filter to minimize the speckle noise from the low variance regions including the flat regions or homogenous regions [30], [31]. The significant model for Lee filter is presented as follows:

$$Img(i,j) = Im + W^*(Cp - Im)$$

Where the Img indicates to the pixel value after filtering, the Im refers to mean intensity of filter window. Cp is the Center pixel, W is the window filter, where W presented as $W = \sigma^2(\sigma^2 + \rho^2)$. The σ^2 is the variance of the pixel, which presented as $\sigma^2 = \left[\frac{1}{N}\sum_{j=0}^{N-1}(X_j)^2\right]$. The N is the size of filter window, $X_j the$ is the pixel value at j. The $\rho = \left[\frac{1}{M}\sum_{j=0}^{N-1}(Y_j)^2\right]$, where ρ is the additive noise variance, for M image's size and Y_j. However, this filter has the limitation of non-effectively remove the speckle noise near edges.

iii. Kuan Filter

Kuan filtering method considered as a significant approach that utilizes to reduce the speckle noises on ultrasound image and preserving edges. The filter is mainly upon the conversion of multiplicative noise into the signal dependent additive noise model. Where the mathematical function used in the Kaun filter has the same structure as Lee filter, but with a diverse weighting function. However, the core disadvantage of these conventional speckle minimization (SR) filters are, they diffused the edges and eliminate the weak which make the ultrasound images unusual and harder to interpret particularly for physicians and doctors. Thus, it is quite difficult to give an appropriate diagnosis to a patient suffering from a critical disease [32]–[34]. For Kuan filter, the weighted function W is given as:

$$W = \frac{\left(1 - \frac{Cu}{Ci}\right)}{(1 + Cu)} \quad (9)$$

where the Cu refers to the estimated noise variation coefficient, and the Ci indicates the variation coefficient of an image.

V. Diffusion Filter

A diffusion filter is one of the nonlinear filtering techniques. In this filtering method, the coefficient of variation is applied in order to enhance the contrast of the images and minimizing the speckle. This method (anisotropic diffusion) is generated by combining the frost's adaptive filter and Lee's adaptive filter into the algorithm of anisotropic diffusion. The Bayes shrink method implements soft thresholding with sub-band dependent threshold and the data-driven. Correspondingly, each performance has its process to eliminate the speckle noise and smooth the medical ultrasound image [35], [36].

VI. Wiener Filter

Wiener Filtering technique is a sort of linear filter that is used to target image adaptively and based on the local image variance, the filter adjusts itself [37]. Among the image-processing, more enhancement is fundamental since it adjusts its variance to a significantly large value. While, through less enhancement is fundamental its variance is adjusted to a particularly small value. The Wiener filtering method requires more computation time for execution. The general mathematical formula of this filter is presented as follows

$$f(u,v) = \left[\frac{H(u,v)^*}{H(u,v)^2 + \left[\frac{Sn(u,v)}{Sf(u,v)}\right]}\right] G(u,v) \quad (10)$$

The term $H(u,v)$ refers to the degradation function and the $H(u,v)^*$ is the conjugate complex. The $G(u,v)$ indicates to degraded the image. While, the $Sn(u,v)$ represents the power spectra of noise, and the $Sf(u,v)$ is the power spectra of original image.

iv. Modified Frost filter and the modified Lee

Both methods of modified Frost filter and the modified Lee filter are often assumed that the windows centred at features are certainly had bigger variation degree more than other of speckle noise. Thus, the variation degree within the filter window is assessed, then the low-pass filtering method was used to enhance the regions with a low coefficient of variation for eliminating speckle noise, in contract identity filtering was particularly within regions which have a high variation coefficient for maintaining features. However, these techniques are far from becoming an optimal tool. Later, these filtering techniques are enhanced by first categorizing the whole pixels into three clusters and using particular processing on each cluster. While, the results from these filtering methods are usually sensitive to the empirical parameter including the shape and size of the window.

Table 1: Several speckle noises removal with their features and limitations

NO	Filter	Features	Limitations	References
I.	Median Filter	Highly and effective noise removal, Preserves image edges and corners.	Generate horizontal lines and additional signal point that not necessary for the applications.	[38], [6]
II.	Wiener filter	Destroy the speckle noises efficiently Materials in the layout are restored.	Run out of corners. Mismatching between noise power spectrum and the real thing lead to the presence of speckle noises.	[39], [40]
III.	Mean filter	Eliminate speckle noise at the whole The filter has an effect on blurring and smoothing the image.	The speckle noise is commonly multiplicative, the basic mean filtering is not effective and less satisfactory.	[41], [42]
IV.	Hybrid median	High effective noise removal Preserves image edges	Required a bit more computational processing.	[43]
V.	Kalman Filter	Less complex filter design as well as the signal the variance quality.	Filter deduces linear models for observation and system models. While, it is not applicable in real applications.	[44]
VI.	Anisotropic Diffusion	This filter does not require to recognize the patterns of noise and power spectrum. Remove speckle noises efficiently.	Highly computation and more consuming time.	[45], [46]
VII.	Lee filter	Capable of minimizing the speckle noise from the low variance regions,	Non-effectively remove the speckle noise near edges.	[47]
VIII.	Frost Filter	Preserve a suitable balance between keeping edges and segmentation. Apply weighting components which able to reduce the variance.	In this filter based on the variance esteem, variables are balanced, which affect the enhancement at the edges.	[32]
IX.	Wavelet Filter	Provide suitable accuracy even with the presence of noises in applications.	This filter does not raise the SNR ratio as high as possible.	[44]
X.	Local Statistics Filter	In this filter, the fine details are left without smoothing.	Non- entirely remove the speckle noise near lines and edges.	[48]
XI.	Homomorphic Filter	Illumination and reflectance components have filtered separately, thus final images have good sharpness.	For noise diminish, the filtering of the stage spectrum can't be connected.	[49]

VII. APPLIED ALGORITHM

In this paper, the enhancement medical ultrasound image is the priority target and the main object. Thus, this section is addressing the speckle noises reduction by fully described our implemented technique with more details. The fundamental structures of the applied algorithm for speckle noises reduction on medical ultrasound image are presented and discussed. A significant and complete illustration of overall framework method algorithms is formulated. In Figure1, the structure of our applied approach of speckle noises reduction is shown.

While, the fundamental and outlines aspects of this approach will be further explained as follows:

The overall frameworks of the developed speckle noises reduction on medical ultrasound image are formulated into three main stages: Through Stage (1), as an initial process, the speckle ultrasound images are chosen. Whereas, several real datasets of speckle medical ultrasound images are executed and conserve to be further processed. The contents of these images are involved with speckle noise which need to be eliminated and smoothed. Stage (2) involved the main developed algorithm as GUI post-processing algorithm. Where the selected speckle ultrasound image as an output of Stage (1) is further processed to Stage (2). In Stage (2), the GUI post-processing algorithm is formulated, where multiple filters of speckle reduction are proposed and applied to remove the speckle noises on medical ultrasound images.

Each applied filter has a specific structure and characteristics, with different output results.

In Stage (3), the major contributions of each applied filter are analyzing and discussed based on speckle reduction outputs. Each filter with its pros and cons. Several evaluation equations are involved to validate the obtained results by all filters such as peak signal to noise ratio (PSNR), mean square error (MSE), structural similarity index matrix and more toward selecting the most ideal technique which improves the quality of medical ultrasound images.

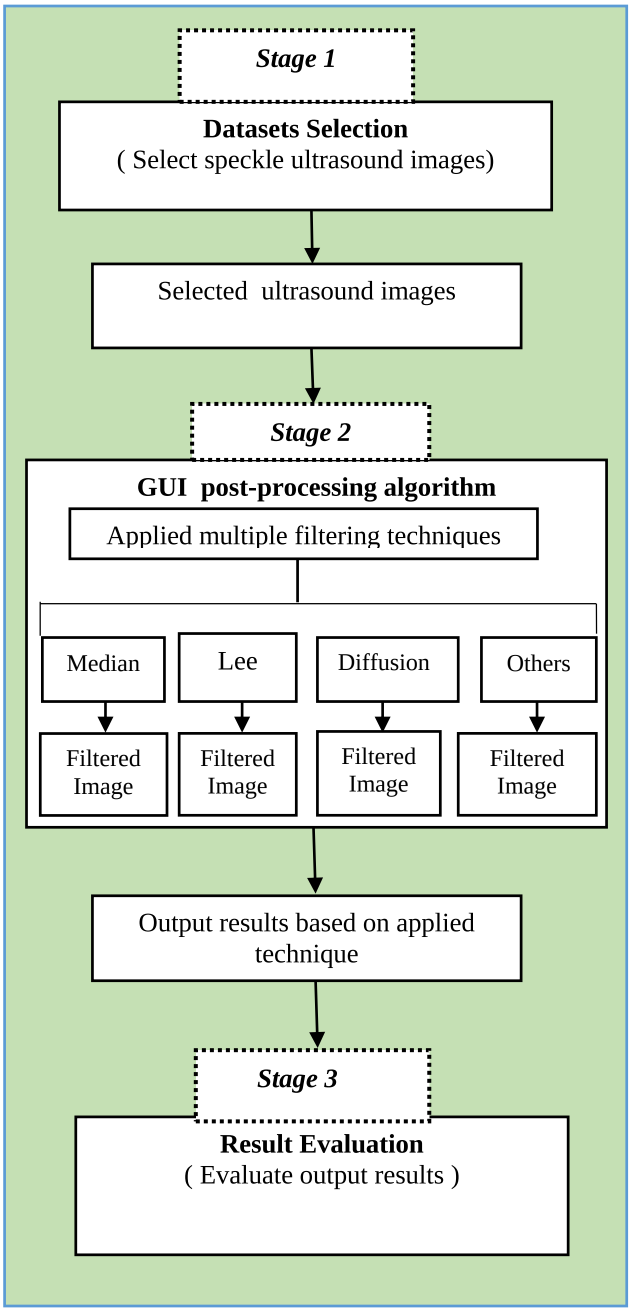


Figure 1: Structure and block diagram of developed speckle noises reduction on an ultrasound image

VIII. EVALUATION APPROACH

In this section, the objective validation part has been achieved by applying multiple evaluation functions to validate the performance of all obtained acquired output results. Whereas, the initial evaluation function applied to evaluate our output results known as the estimation of root mean square error (RMSE). The root mean square error is based on the Mean Squared Error (MSE) that used to find the average of squared errors between original and filtered images [20]. The mathematical model is given by equation (11)

$$MSE = \frac{1}{MN}\sum_{y-1}^{M}\sum_{x-1}^{N}\left[\left(I_{filt}(x,y)\right)-\left(I_{ref}(x,y)\right)^2\right] \quad (11)$$

Both M and N variables are indicating to the rows and columns of the original of $I1$ and filtered images $I2$ respectively. Where the minimum value of the MSE refers that, the cumulative or progressive squared error is lower. Thus, the RMSE is presented as shown in equation (12).

$$RMSE = \sqrt{MSE} \quad (12)$$

The second evaluation function is the Peak Signal to Noise Ratio (PSNR). This function is connected to the RMSE function by including the function as part of its framework. Where for 256 gray levels PSNR is given as shown in equation (13).

$$PSNR = 20\log_{10}\left(\frac{255}{RMSE}\right) \quad (13)$$

For PSNR's function, the increase or maximum values indicate the better quality results. While, the third evaluation function is known as the Structural Similarity Index Metric (SSIM) to calculate the similarity between two images. While, this function has better consistency with the qualitative appearance of the image [50].

$$SSIM = \frac{1}{M}\sum\frac{(2\mu_1\mu_2+C_1)(2\mu_{1,2}+C_2)}{(\mu_1^2+\mu_2^2+C_1)(\sigma_1^2+\sigma_2^2+C_2)} \quad (14)$$

Where the $\mu_1$and μ_2 are the means and σ_1 and σ_2 are the standard deviations of the images being compared is the covariance between them. SSIM has values between 0 to 1, when it is equal to 1 images are structurally equal.

IX. RESULT AND DISCUSSION

In this section, the obtained results from the applied method are presented and discussed in details that are more significant. To find out the best ideal speckle noise filter technique for ultrasound medical images with particularly preserving image contents, information, important details, edges, features and more. The enhancement of ultrasound medical images will allow for better clinical diagnosis acquire close information imaging for internal parts and organs of human's body. Thus, best-selected ideal filter significantly has the following features:

I. The ideal filter has the ability of preserving the core contents of the original image including information, important details, edges, features, segmentation, etc.

II. Selected ideal filter's ability to eliminate speckle noises is highly effective and efficient toward achieving significantly enhanced results of ultrasound medical images.

III. The ideal selected filter has good and considerable result values based on different applied evaluation functions such as MSE, PSNR, and SSIM. Where, the comparison was carried out with real dataset images.

1. Quantitative Evaluation

In this section, three real and specified datasets (ultrasound medical images) are used for numerical experimentation. The first ultrasound image is known as (Convex_Pros_Live) with the depth of (10.0). The second dataset image is a (Convex_Pros_Live) with the depth of (16.0). While, the third ultrasound image is a (Convex Prosonic) with a depth of (8.0). These images are utilized with the proposed algorithms in order to remove speckle noises for better clinical diagnosis.

In Tables (2), Table (3), and Table (4) below, significant result values based on different applied filters are presented. Specifically (Median filter, Hybrid Median filter, Lee_Diffusion filter, Kuan filter, Frost filter, Lee Filter, Kuan, and Diffusion filter. The values from the Mean Square Error (MSE) function, the Peak Signal to Noise Ratio (PSNR), and Structural Similarity Index Metric (SSIM) are calculated and measured.

Table (2) summarize the quantitative results values from three evaluation functions which are (MSE), (PSNR), and (SSIM) with using a 3 *x* 3 window size. These functions have been applied to the results obtained by several specified speckle noises removal filters. Based on the gained values, hybrid median and median filters are ideal filters to obtain a more smooth and effective result. Both filters are able to balance between removing speckle noises on an ultrasound medical image, while preserving image contents and features. The performance and affection of other filters including Lee_Diffusion filter, Kuan filter, Frost filter, Lee Filter, and **A**nisotropic Diffusion filter are illustrated. Each filter has come particular quantitative values, which indicate clearly the performance of each filter on the utilized images.

Table 2: Quantitative evaluation of the filters using a 3x3 window size on the first image

Type of filter	MSE	PSNR	SSIM
Hybrid Median	4.793	45.513	0.993
Median Filter	4.866	44.401	0.991
Lee_Diffusion	6.220	42.344	0.978
Frost	8.157	41.167	0.982
Lee Filter	16.564	38.090	0.975
Kuan	18.750	37.552	0.967
Anisotropic Diffusion Filter	33.216	35.522	0.98

Table (3) also shows a summary of quantitative numerical values of the mean square error, peak signal to noise ratio, and structural similarity index metric measured functions. These values illustrate the performance of the applied filters quantitatively. Based on the presented results, there are changes in the obtained values with respect to the type of filter applied. It is seen that median filters were capable of gaining the best in comparison to other filters.

Table 3: Quantitative evaluation of the filters using a 5*x*5 window size on the second image

Type of filter	MSE	PSNR	SSIM
Hybrid Median	4.042	45.971	0.979
Median Filter	4.356	43.032	0.961
Lee Filter	20.589	38.129	0.960
Kuan	20.637	37.997	0.9616
Lee_Diffusion	21.249	37.792	0.896
Frost	32.988	26.989	0.921
Anisotropic Diffusion Filter	41.013	35.672	0.942

Table (4) presents the quantitative results values for the third utilized ultrasound image with a 7 *x* 7 window size. The values from the three applied the Mean Square Error (MSE) function, the Peak Signal to Noise Ratio (PSNR), and Structural Similarity Index Metric (SSIM) are measured. The measured values show the performance of the selected filters. Based on the collected results, there are various changes in gained, these changes are depending on the type of applied filter. Where, median filters in comparison to other filters obtain the best results.

Table 4: Quantitative evaluation of the filters using a 7*x*7 window size on the third image

Type of filter	MSE	PSNR	SSIM
Hybrid Median	6.572	42.962	0.976
Median Filter	6.622	42.930	0.966
Lee Filter	20.589	38.129	0.960
Kuan	18.183	38.544	0.9432
Lee_Diffusion	23.543	32.093	0.786
Frost	41.355	21.126	0.879
Anisotropic Diffusion Filter	43.189	26.031	0.664

2. Qualitative Results

In order to show closely the effectiveness of the proposed and applied algorithms and best ideal selected filter, a qualitative comparison part is presented. This part of experiments is carried out to show the difference between original images with speckle noises and after applying several specified filters. Based on the observation of the gained results as shown in Table 5 and Table (6). The qualitative result for ultrasound images after filtering are more sharp and enhanced. In addition, the qualitative results from hybrid median and median filters are the most smoothed in compare to other filters. Thus, from evaluation and observation on the output results of speckle ultrasound images, along with this comparative analysis, it can be clearly seen that hybrid median and median filters are more efficient methods of smoothing speckle ultrasound medical images. Where these methods are more effective and more capable of removing noises toward more accurate clinical diagnosis.

Table 5: Qualitative results for applied filters on speckle ultrasound medical images

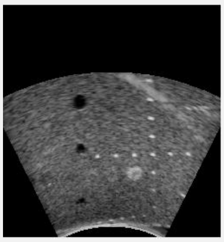
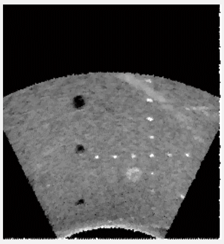
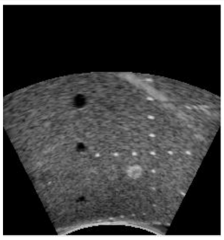
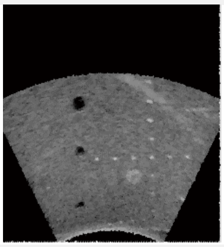
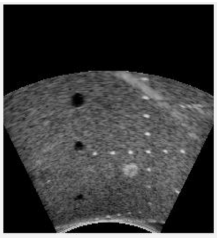
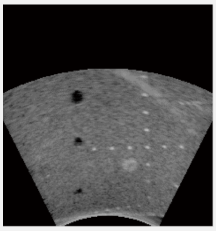
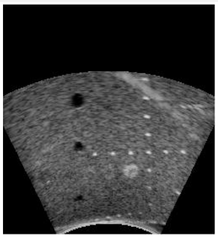
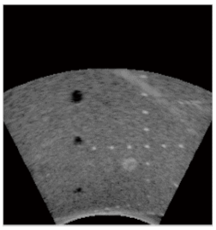
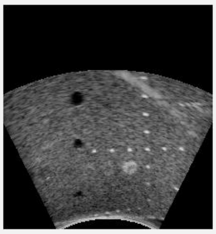
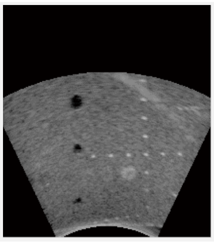
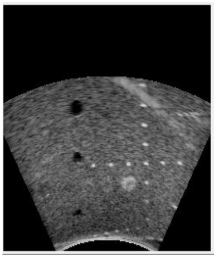
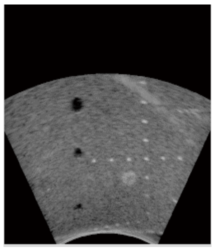
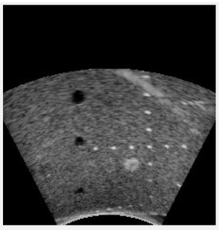
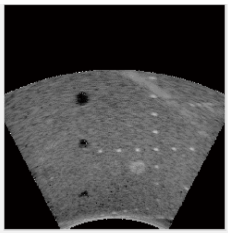
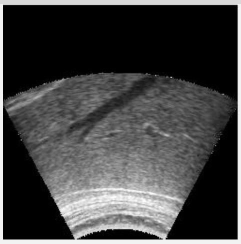
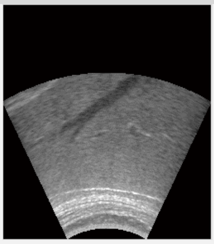
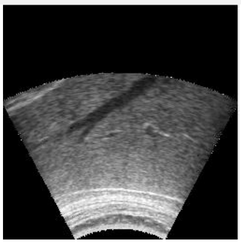
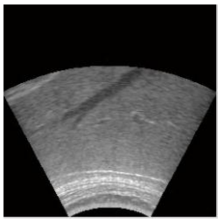
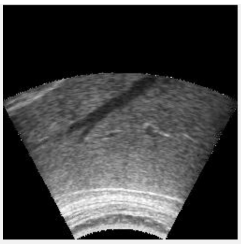
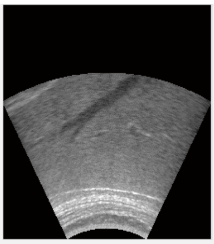
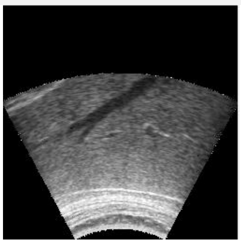
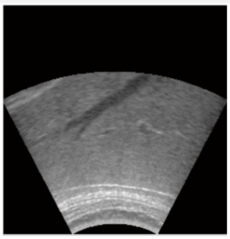
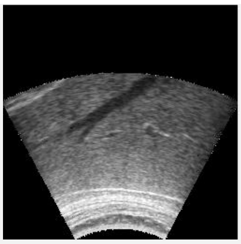
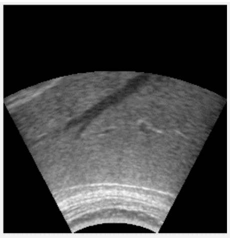
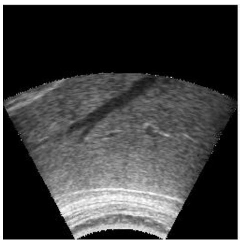
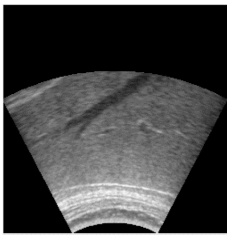
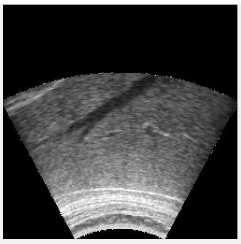
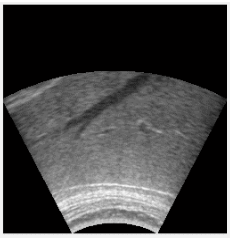
Type of filter	Original Image	Image After Filtering
Hybrid Median		
Median Filter		
Lee_Diffusion		
Frost		
Lee Filter		
Kuan		
Anisotropic Diffusion Filter		

Table 6: Qualitative results for applied filters on speckle ultrasound medical images

Type of filter	Original Image	Image After Filtering
Hybrid Median		
Median Filter		
Lee_Diffusion		
Frost		

Lee Filter		
Kuan		
Anisotropic Diffusion Filter		

X. CONCLUSION

This paper presented a method of speckle noise reduction in medical ultrasound imaging using an effective and optimized post-processing combination technique. The method consists of three significant stages, where Stage (1) is mainly developed to select the datasets (speckle ultrasound images) before proceeding to the next stage. In Stage (2), the optimized post-processing approach algorithm is being proceeded as an improved reduction part, where multiple filters are proposed to be applied to real dataset images such Median filter, Hybrid median, Frost filter, Lee_Diffusion filter, Kuan, and more in order to remove the speckle noise on the medical ultrasound images. While, Stage (3) is an evaluation approach, where three main evaluation functions are applied, which are the Mean Square Error (MSE) function, the Peak Signal to Noise Ratio (PSNR), and Structural Similarity Index Metric (SSIM) to test the performance and affection of the filters as well as achieve comparative analysis among utilized images. The ideal filters among this approach (median and hybrid median) shows, higher Signal to noise ratio, higher structural similarity index metric closer to one, and lower mean square error.

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