A Study on Multi-scale Approach for Despeckling Ultrasound Image

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ABSTRACT
Digital image acquisition and processing technique plays an important role in medical diagnosis. Images of living objects are taken using various modalities such as X-ray, Ultrasound, Computed Tomography (CT), Magnetic Resonance Imaging (MRI) etc. During the acquisition process, various distortions in the images are founded, which will negatively affect the diagnosis process on captured images. There by advanced digital image processing techniques for improving the quality of acquired image by removing noise components present in it becomes important. Among various modalities of medical image acquisition, Ultrasound imaging which is non-invasive in nature and lower acquisition cost is the most used application of high-frequency sound waves to produce diagnostic images. Ultrasound images are degraded by an intrinsic artifact called ‘‘speckle”, which is the result of constructive and destructive coherent summation of ultrasound echoes. This paper discusses different types of filter techniques and multi-scale approach to suppress the speckle noise in ultrasound image.

Keywords
Medical diagnosis, Ultrasound Imaging, Speckle noise, Despeckling techniques.

1. INTRODUCTION
Medical diagnosis identifies the type of disease or condition causing a person's signs and symptoms. Diagnosis becomes a challenging factor due to various distortions. Among imaging, ultrasound which is based on non-ionizing radiation has wide exposure. Ultrasonography (Diagnostic sonography) is an ultrasound-based diagnostic imaging technique used for visualizing internal body structures including tendons , muscles, joints, vessels and internal organs for possible pathology or lesions. Ultrasound refers to sound waves with high frequency (too high for humans to hear) emitted from probes or transducers into the living organism are either reflected back or attenuated by the body. The reemitted sound waves from tissue are converted into an electrical signal. The strength of the signal corresponds to the brightness on the monitor. The converted signals are used to display the distances and intensities of the echoes to form a two-dimensional image. These images can be used in both diagnostic and therapeutic manner to guide interventional procedures (for instance biopsies or drainage of fluid collections).

Ultrasound is effective for imaging soft tissues of the body. Superficial structures such as muscles, tendons, testes, breast, thyroid and parathyroid glands, and the neonatal brain are imaged at a higher frequency (7–18 MHz), which provides better axial and lateral resolution. Deeper structures such as liver and kidney are imaged at a lower frequency 1–6 MHz with lower axial and lateral resolution but greater penetration.

Many different modes of images can be formed using ultrasound. The most well-known type is A-mode (amplitude mode) that scans a line through the body with the echoes plotted on screen as a function of depth. B-mode or 2D-mode image [17] displays the acoustic impedance of a two-dimensional cross-section of tissue. M-mode assesses moving body parts (e.g. cardiac movements) from the echoed sound and Colour mode detects and assesses cell motion, blood circulation using Doppler analysis. Main advantages of Ultrasound imaging are they produce no radiation and are inexpensive. They are excellent for identification of cyst (fluid filled cavities), foreign bodies, liver disease (tumour, chronic liver disease (CLD), liver fibrosis, etc.), obstetric imaging and real time imaging.

Speckle is a particular type of noise which affects all coherent imaging systems such as laser, synthetic aperture radar (SAR), and medical ultrasound images. However, by nature, Ultrasound image contains more speckle noise than any other imaging modality. Noises is initiated in all stages of Image acquisition such as beam forming, signal processing and even during Scan conversion due to the loss of proper contact or air gap between the probe and body. Filtering Techniques and analysis are mostly used to suppress speckles. In this paper, various Image Processing filtering techniques and multiscale approach has been surveyed out for better understanding of despeckling the noise in Ultrasound image.

2. SPECKLE NOISE
Noise is present in image either in additive or multiplicative form. In Additive Noise Model the noise signal that is additive in nature gets added to the original signal to produce a corrupted noisy signal by:

$$w(x,y) = s(x,y) + n(x,y)$$

In Multiplicative Noise Model the noise signal gets multiplied to the original signal. The multiplicative noise model is given by:

$$w(x,y) = s(x,y) * n(x,y)$$

where, s(x,y) is the original image and n(x,y) denotes the noisy values introduced to produce the corrupted image w(x,y) at (x,y) pixel location. Various types of Multiplicative noise seen in digital images are: impulsive or random noise, Gaussian noise, frequency noise and speckle noise [27]. Impulsive noises are introduced when the sensor picks up the saturated image due to improper transmission in signal. Then the value of the pixel may result in high or low. Gaussian noise shows little variation in the image due to sensor gain, low quantization in digitization, etc. Frequency noise is characterized by the interference of a signal which joins the image at a certain frequency. In all cases, noise always implies a sudden change in an image's intensity level.

Speckle noise is multiplicative noise that displays a granular pattern due to the dispersion of the electromagnetic waves caused by the transducer. This noise degrades the fine details and edge definition and limits the contrast resolution by making it difficult to detect small and low contrast lesions in body. Speckle noise has constructive and destructive interference with image which is shown as bright and dark dots.

Speckle noise inherits the property of ultrasound image and reduces the image resolution and contrast, which affects the diagnostic value of this imaging modality [7]. Therefore, despeckling is a very important preprocessing step for filtering speckle [5,26,15] without affecting important features of the image.

3. PERFORMANCE MEASURES

The image quality is measured after the enhancement by comparing with the original image using standard metrics like Mean Square Error (MSE), Root Mean Square Error (RMSE), Signal to Noise Ratio (SNR), and Peak Signal to Noise Ratio (PSNR) [3,25,28]. The peak signal-to-noise (PSNR) and normalized mean square error (NMSE) are used to evaluate the results of the discrete wavelet methods. The SNR is used to evaluate the smoothness, as observed in homogeneous regions of an image (speckle region).

Given a noise-free m×n monochrome image I and its noisy approximation K, MSE is defined as:

$$\mathbf{MSE} = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - K(i,j)]^2$$

$$\mathbf{PSNR} = 10.\log_{10}\left(\frac{MAX_1^2}{MSE}\right)$$

$$= 20.\log_{10}\left(\frac{MAX_1}{\sqrt{MSE}}\right)$$

$$= 20.\log_{10}(MAX_1) - 10.\log_{10}(MSE)$$

MAX_I is the maximum possible pixel value of the image. When the pixels are represented using 8 bits per sample, then MAX_I is 255.

$$\mathbf{SNR} = 10.\log_{10}\left(\frac{\sigma^2 \text{signal}}{\sigma^2 \text{noise}}\right)$$

Where σ is the variance of signal and noise.

4. DESPECKLING TECHNIQUES

In recent years, much interest has been focused on the post-formation filtering methods applied directly in the original images. Different types of image processing and soft computing techniques [1-26]are exist for enhancing the quality of Ultrasound scanned image. This section analyses various de-speckling techniques using Filters, Multi-scale image enhancement and soft computing techniques.

Image processing filters are mainly used for smoothing (low frequencies) the image, or enhancing and detecting edges (high frequencies) in the image. An image can be filtered either in the frequency or the spatial domain.

4.1 Filters

4.1.1. Spatial domain Filters

The spatial domain [27] deals with the image matrix of normal image I, in which a change in pixel position in Image directly projects to a change in 2D or 3D space. Distances in I (in pixels) correspond to real distances (*e.g.* in meters) in S. Image features with high spatial frequency (such as edges) are those that change greatly in intensity over short image distances.

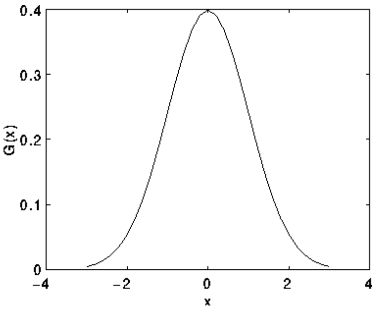
Gaussian averaging, mean, median, Local Region filter, Lee and Diffusion Filter, Wiener filter are applicable to all type of images for reducing speckle noise. These filters are low pass filters that remove the sudden change of intensity value replacing the suspected values with a local average or some similar local measures.

(a) Mean filtering : It is a simple, easy and instinctive method for smoothing images[4] by reducing the noise. It reduces the amount of intensity variation between one pixel and its neighbors. 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. It helps in eliminating pixel values which are unrepresentative of their surroundings. Mostly 3×3 square kernel is used.

(b) Median Filtering : It replace the pixel value with the median of neighboring pixel values[13]. The median is calculated by first sorting all the pixel values from the surrounding neighborhood into numerical order and then replacing the pixel being considered with the middle pixel value.

(c) Gaussian Filter : It is a 2-D convolution smoothing operator[13,27] used to `blur' images and remove detail and noise. It is similar to the mean filter, but it uses a different kernel that represents the shape of a Gaussian (`bell-shaped') hump.

The Gaussian distribution in 1-D has the form:



$$G(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{x^2}{2\sigma^2}}$$

where σ is the standard deviation of the distribution and X the distribution of mean.

(d) Wiener Filter : The Wiener filter can be used to deblur an image and filter out the noise from the corrupted signal. It is based on a statistical approach and linear time-invariant filtering. It minimizes the mean square error between the estimated random process and the desired process in image.

(e) Adaptive Filtering: An adaptive filter is a system with a linear filter that has a transfer function controlled by variable parameters and a means to adjust those parameters according to an optimization algorithm. It preserves edges and other high frequency parts of an image. It works best when the noise is constant-power ("white") additive noise, such as speckle noise.

Eveline Pregitha et al.[6] compared and evaluated the performance of various filters for speckle noise removal in ultrasound fetal image. Out of traditional filters, Adaptive Shock filter gives desirable results in terms of MSE and PSNR. Mohamed Saleh Abuazoum [13] presented an experiment with three filters (Median, Gaussian and Wiener filter) and evaluated the outcomes of medical image de-noising. Their performance is calculated using peak signal-to-noise ratio measure, which shows that Gaussian filter is better than Median and Wiener filter. Bhausaheb Shinde et al.[4] presented, analyzed various filtering techniques like Median Filtering, Adaptive Filtering and Average Filtering, then results are analyzed and compared with standard pattern of noises and quality metrics like Mean, and Standard deviation are used. It was observed that the choice of filtering techniques for de-noising the medical images depends on the type of noise. This study shows that Median filter works better to despeckle noise in Cancer images.

4.1.2. Frequency domain Filters

The frequency domain [27] is a space in which each image value in image I at position S (2D or 3D) represents the amount that the intensity values in image I vary over a specific distance/time related to S. In the frequency domain, changes in image intensity values correspond to changes in the spatial frequency.

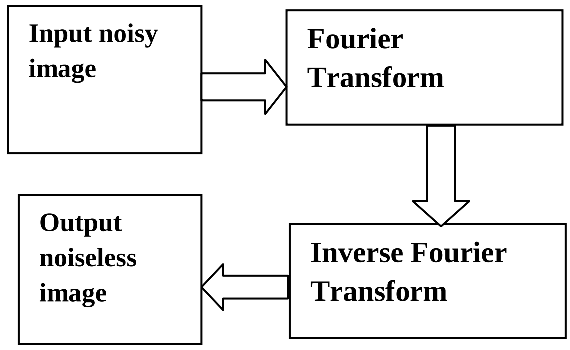


Figure 1: Frequency Domain

Figure 1 shows the frequency filtering process by transforming the image into the frequency domain, multiplying it with the frequency filter function and re-transforming the result into the spatial domain. A signal can be converted from time function (time domain) into a sum of sine waves of different frequencies (frequency domain) using mathematical operators called transforms. Transformation can be done by Fourier series, Fourier transformation, Laplace transform and Z transform.

Fourier Transform:
The operation usually takes an image and a filter function in the Fourier domain[27]. This image is then multiplied with the filter function in a pixel-by-pixel fashion:

$$G(k,l) = F(k,l) * H(k.l)$$

where F(k,l) is the input image in the Fourier domain, H(k,l) the filter function and G(k,l) is the filtered image. To obtain the resulting image in the spatial domain, G(k,l) has to be re-transformed using the inverse Fourier Transform. Lowpass, Highpass, Bandpass, Butterworth filter etc are different types of filters that can be used for despeckling ultrasound images.

(a) A low-pass filter attenuates high frequencies and retains low frequencies unchanged. This results in smoothing the image as the blocked high frequencies correspond to sharp intensity changes.
(b) A highpass filter yields edge enhancement or edge detection in the spatial domain, because edges contain many high frequencies.

(c)A bandpass attenuates very low and very high frequencies (combination), but retains a middle range band of frequencies. Bandpass filtering can be used to enhance edges by suppressing low frequencies and reduce the noise by attenuating high frequencies.

Suganya Devi et al.[25] compared various filtering techniques like Weiner filter, Bayes wavelet filtering and Morphological filtering. Ultimately, the quality of enhanced image is measured by statistical quantity parameters like PSNR, RMSE and ENL (Equal Number of Look). It was found that Morphological filtering performs well. Juan L. Mateo et al. [9] compared algorithms and methods such as Median(Adaptive weight median filtering), Fourier(ideal, butterworth), Wavelet transform and Homomorphic filtering for smoothing existing noise in medical images.

4.2 Multi-Scale Image Enhancement

Multi-scale approaches typically transform the original monochrome image into a multi scale or resolution hierarchy representation. The most common multi-resolution transform is Wavelet transform.

Wavelet transforms

A wavelet [28] is a wave-like oscillation in which its amplitude starts from zero, and it increases or decreases from zero. It is a mathematical function used to divide a given function or continuous-time signal into different scale components. It is used to extract needed information from signals and images. A wavelet transform is the representation of a function by wavelets. Wavelet Transform is a powerful tool of signal used to preserve the edges of image.

Wavelet transforms are classified into discrete wavelet transforms (DWTs) and continuous wavelet transforms (CWTs) [28]. All wavelet transforms will be in the form of time-frequency representation for continuous-time (analog) signals. CWTs operate over every possible scale and translation whereas DWTs use a specific subset of scale and translation values or representation grid. DWT use discrete-time filterbanks. These filterbanks are called the wavelet and scaling coefficients in wavelets.

Discrete Wavelet Transform **(DWT)** [11] of noisy image consist of small number of coefficients having high SNR (signal-to-noise ratio) and large number of coefficients having low SNR. These small coefficients can be thresholded without affecting the significant features of the image. Wavelet thresholding is a signal estimation technique that exploits the capabilities of Wavelet transform for signal denoising. It removes noise by killing coefficients that are irrelevant relative to some threshold. Thresholding the Wavelet coefficients are commonly called Wavelet Shrinkage. Multi scale thresholding is the process of applying a threshold at the high pass components at different scales of the multiresolution decomposed image. Figure 2 shows the stages in wavelet transform for Noise Reduction in Ultra Sound Images [16]:

i. Input Noisy image : Construct Multiplicative noise model
ii. Wavelet transformation of noisy image
iii. Estimation : Calculate variance of noise, weighted variance of signal , threshold value of all pixels and sub band coefficients
iv. Take inverse DWT to do the despeckling of Ultrasound images.
v. Output denoised image

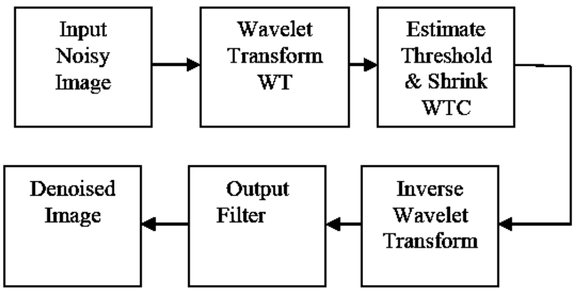


Figure 2 : Image despeckling using Wavelet Transform

1. *Discrete Wavelet transform* [20] : The noisy image is read as input and are recursively divided into 4 quadrants by applying low-pass and high pass spatial filtering along horizontal and vertical directions.

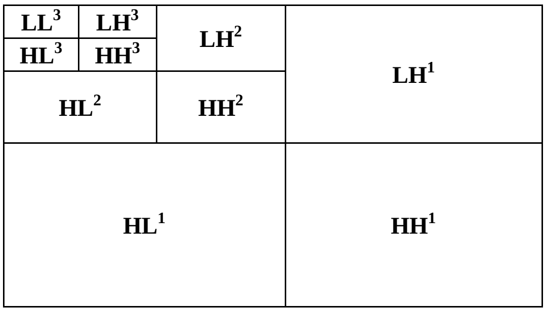


Figure 3: 3 level -Discrete Wavelet Transform

1, 2, 3 - decomposition level, H - High Frequency Bands, L - Low Frequency Bands

One level of the transform:

The DWT of a signal x is calculated by passing it through a series of filters [28]. First it is passed through a low pass filter with impulse response g resulting in a convolution of the two:

$$y[n] = (x*g)[n] = \sum_{k=-\infty}^{\infty} x[k]g[n-k]$$

Then the signal is decomposed simultaneously using high-pass filter h. The h produces the detail coefficients and g produces approximation coefficients. The two filters that are related to one another are called quadrature mirror filter. While filtering half of the samples are discarded.

$$y_{low}[n] = \sum_{k=-\infty}^{\infty} x[k]h[2n-k]$$

$$y_{high}[n] = \sum_{k=-\infty}^{\infty} x[k]g[2n-k]$$

The filter outputs are then sub sampled by 2 with the sub sampling operator $\downarrow$ and the above summation is written as

$$y_{low} = (x*g)\downarrow 2$$

$$y_{high} = (x*h)\downarrow 2$$

Wavelet coefficients are obtained on each level. Then the noise variances are estimated from noisy image and threshold values are calculated using various threshold selection rules or shrinkage rules. Next soft or hard thresholding functions are applied to noisy coefficients. Finally the inverse DWT are performed to reconstruct the denoised image.

Cascading level and Filter banks:

The above decomposition is repeated further [28] and the approximation coefficients at each level is decomposed with high and low pass filters and then down-sampled. It is represented as a binary tree with nodes representing a sub-space with a different time-frequency localisation. The tree is called as a filter bank.

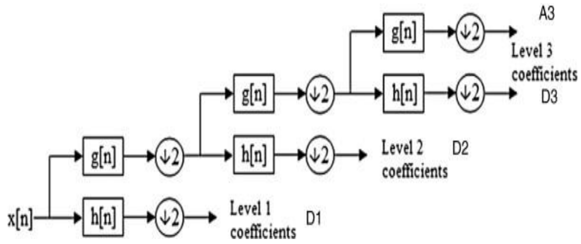


Figure 4 : 3 level – Filter bank

At each level, the signal is decomposed into low and high frequencies. During decomposition process the input signal must be a multiple of 2^n where n is the number of levels.

2. ***Wavelet Thresholding*** *:* Threshold plays an important role in the denoising process [20]. It finds an optimum threshold value. A small threshold value will retain the noisy coefficients whereas a large threshold value leads to the loss of coefficients that carry image details. The two types of thresholding techniques used for denoising are:
Hard Thresholding*:* Hard threshold will suppress or retain procedure and is more intuitively appealing. Sometimes pure noise coeffiecients may pass the hard threshold. It is mainly used in medical image processing.

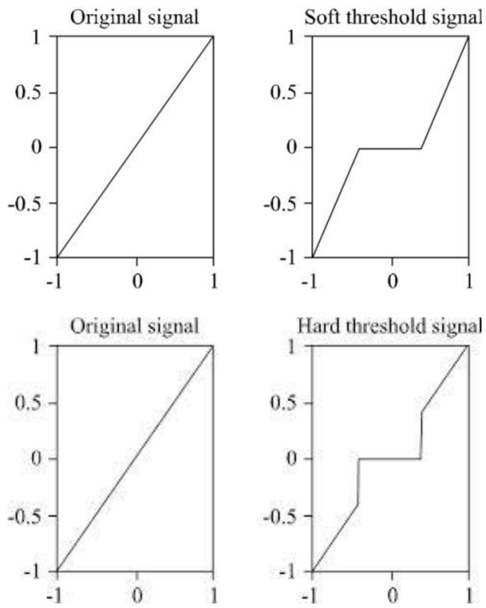


Figure 5 : Original and Hard & Soft thresholded signal

Soft Thresholding**:** Soft threshold shrinks coefficients above the threshold in absolute value. The false structure in hard thresholding can be overcomed by soft thresholding. Important features characterized by large wavelet coefficient across scales are identified.

3. ***Wavelets*** *Haar wavelet* [14, 28] is a sequence of rescaled "square-shaped" functions which allows a target function over an interval to be represented in terms of an orthonormal function basis. *Daubechies Wavelet* - Ingrid Daubechie wavelet is the first wavelet family which has set of scaling function which is orthogonal [20]. This wavelet has finite vanishing moments. Daubechies wavelets have balanced frequency responses but non-linear phase responses. Daubechies wavelets are useful in noise removal of image processing because of its property of overlapping windows and high frequency coefficient spectrum reflect all high frequency changes. Daubechies family wavelets are written as dbN, where N is the order, and db is the "surname" of the wavelet. The db1 wavelet is the same as Haar wavelet. The Haar, Daubechies, Symlets and Coiflets are compactly supported orthogonal wavelets. These wavelets along with Meyer wavelets are capable of perfect reconstruction. The Meyer, Morlet and Mexican Hat wavelets are symmetric in shape.

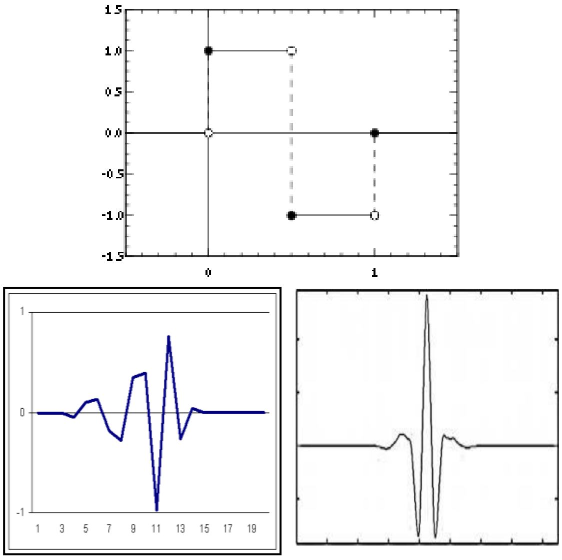


Figure 6 : 1st –Haar , 2nd –Daubechies & 3rd –Coifelts Wavelets

Mariana Carmen Nicolae et al. [12] described the wavelet transform that gives better result than median and homomorphic Wiener filtering methods for despeckling ultrasound images. In order to realize a fair comparison, the same analysis for three frequency values is used. Sudha et al.[24] presented DWT Discrete wavelet-based thresholding scheme for noise suppression in ultrasound images. Quantitative and qualitative comparisons of the results are obtained to demonstrate the higher performance for speckle reduction. Jaspreet kaur et al.[7] presented a study on various techniques for speckle noise removal in biomedical applications, such as Spatial and frequency domain filter, wavelet based multiresolutional analysis (Haar, Coiflets and Symlets) and thresholding function. Anutam et al.[3] compared filters and various wavelet based methods and showed that wavelet based Bayes shrinkage method outperforms other methods in terms of PSNR and MSE.

4.3 Soft Computing Techniques

Soft computing principles like Artificial Neural Networks (ANN), Genetic Algorithms (GA) Fuzzy Logic (FL) and other soft computing techniques are used in designing algorithms for speckle noise reduction in medical ultrasound images. Alamelumangai et al.[1] presented a novel memetic based approach to optimize neuro fuzzy system for reducing this speckle noise in sonogram images. The system uses a 5 layer feed forward neural network with 5 input parameters representing the 5×5 window pixel. These are the fuzzy values which are optimized by memetic algorithm (MA) and fed into the system as input parameters. Alamelumangai et al.[2] proposed another efficient method for diagnosing the breast cancer cells in women . The Fuzzy C-Means clustering system identifies various important artifacts, such as cyst, tumor and micro calcifications. Their system suppresses speckle noise and further extended to FCM class 2 non-homogeneous images. Manpreet Kaur et al. [10] showed that three layer feed forward neural network and its optimization with particle swarm optimization (PSO) changes the weights to achieve minimum mean square error in the image yields better results than the Back propagation algorithm. To measure the quality of image, statistical parameters such as MSE and PSNR are calculated.

5. FUTURE RESEARCH

This study describes various filtering techniques that have been applied so far. Despeckling techniques needs to balance the image pixel intensity between noise suppression and loss of information, which is something that experts are very concerned about. It is, therefore, desirable to keep as much important information as possible in image. The majority issue of speckle reduction techniques concerns about affecting the quality of the processed images. Most of the despeckling filtering algorithms are empirically estimated. It does not enhance the edges, but only inhibit smoothing near the edges.

Almost different evaluation criteria such as MSE, PSNR, SNR, etc. are used for evaluating the performance of despeckle filtering. Therefore additional quantitative criteria like texture analysis and classification, image quality evaluation metrics, and visual assessment by experts could be investigated in future.

6. CONCLUSION

The study focused on different filtering techniques and soft computing algorithms that are currently used to suppress speckle noise in medical ultrasound images. The comparative study of noise suppression methods leads a way to identify new methods to enhance noise-free synthetic image for diagnosis than the existing one. The quantitative performance measures must be computed to show better solution.

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