Speckle Noise Reduction in Ultrasound Images – A Review

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***Abstract*— Ultrasound imaging is a widely used and safe medical diagnostic technique, due to its non-invasive nature, low cost and capability of forming real time imaging. Ultrasound imaging uses high-frequency sound to image internal structures by differing reflection signals produced when a beam of sound is projected into the body and bounces back at interfaces between the structures. However the usefulness of ultrasound imaging is degraded by the presence of signal dependant noise known as speckle. The speckle pattern depends on the structure of the image tissue and various imaging parameters. Speckle noise present in ultrasound image affects edges and fine details which limit the contrast resolution and make diagnostic more difficult. There are two main purposes for speckle reduction in medical ultrasound imaging (1) to improve the human interpretation of ultrasound images (2) despeckling is the preprocessing step for many ultrasound image processing tasks such as segmentation and registration. A number of methods have been proposed for speckle reduction in ultrasound imaging. The objective of this paper is to give an overview of speckle reduction in ultrasound imaging**

Keywords — Ultrasound image, Speckle noise, despeckling, kidney, filters.

I. INTRODUCTION

Ultrasound diagnosis differs from radiologic diagnosis in that there is no ionizing radiation involved. This is also called as ultrasound diagnosing. Ultrasound can be used for medical imaging, detection, measurement and cleaning. Ultrasound imaging is used for diagnosis provides the internal structure of the body to detect eventually diseases or abnormalities tissues. Ultrasound imaging plays crucial roles in medical field to estimate kidney size, position, appearance and helps to detect structural abnormalities as well as the presence of cysts, stones, cancer, congenital anomalies, swelling, blockage of urine flow etc. But presence of speckle noise and low contrast in ultrasound images, detection of kidney is a difficult as well as challenging task. Speckle is a granular noise that inherently exists in and degrades the quality of the active radar, synthetic aperture radar (SAR)and medical ultrasound images.

Speckle noise present in ultrasound image affects edges and fine details which limit the contrast resolution and make diagnostic more difficult.

Speckle noise is a multiplicative noise which is difficult to remove the multiplicative noise as compared to additive noise. So speckle noise is converted to additive noise by applying log transformation. Thus, speckle noise can be removed from ultrasound image. Several experiments were conducted to evaluate the proposed despeckling model. The performance metrics used are (i) Peak Signal to Noise Ratio (PSNR) and (ii) Denoising Time. PSNR is a quality measurement between the original and a denoised image. The higher the PSNR, the better is the quality of the compressed or reconstructed image. Denoising time denotes the time taken for the algorithm to perform the despeckling procedure.

Considering internal organ as kidney, kidneys are retroperitoneal organs, located near the middle of the back, just below the rib cage, one on each side of the spine. Many people are affected by chronic kidney failure due to diabetes mellitus and hypertension etc. Worldwide research indicates that one out of 10 adults has kidney problems and by 2015 it is estimated that about 36 premature deaths due to kidney disease will happen [3]. Since kidney function impairment can be life threatening, diagnosis of the disorders and diseases in the early stages is crucial. Ultrasound is one of the non-invasive low cost widely used imaging techniques for diagnosing kidney diseases.

Ultrasound image is adaptable, transferable and comparatively safe, but this type of image consists of full of acoustic interferences (speckle noise) and artifacts. Speckle is a complex phenomenon, which degrades delectability of target organ and reduces the contrast. It affects the human ability to identify normal and pathological tissue.

II. RELATED WORK

In [1], kidney ultrasound imaging is used to estimate kidney size and position, and help to diagnose structural abnormalities as well as the presence of cysts and stones. However, due to the presence of speckle noise in these, performing the segmentation methods for the kidney images were very challenging and therefore, deleting the complicated background will speed up and increases the accuracy of the segmentation process. Therefore, this study proposes an automatic Region Of Interest (ROI) generation for kidney ultrasound images. Firstly, for speckle noise reduction the techniques such as median filter, Wiener filter and Gaussian low-pass filter are applied. Then texture analysis is performed by calculating the local entropy of the image, continued with the threshold selection, morphological operations, object windowing, determination of seed point and last but not least the ROI generation will be done. This method has performed on several kidney ultrasound images with different speckle noise reduction techniques and different threshold value selection. Based on the result, it shows that for median filter, threshold value of 0.6 has given the highest TRUE ROIs which are 70%. For Wiener filter, threshold value of 0.8 has given highest TRUE ROIs which are 80% and for Gaussian low-pass filter, threshold value of 0.7 has given highest TRUE ROIs which are 100%. As the result of experiment, for longitudinal kidney images, out of 120 images, 109 images generate true ROI (91%) and another 11 images generate false ROI (9%). For transverse kidney images, out of 100 images, 89 images generate true ROI (89%) and 11 images generate false ROI (11%).

Thus, texture analysis by using entropy filter is better compared to range filter and standard deviation filter. By choosing Gaussian low-pass filtering for speckle noise reduction technique with the threshold value of 0.7 can be applied to the rest of the images. It can be used to automatically detect the seed point of the kidney and successfully generate true kidney ROI until 89%. The generation of true ROI is used as the preprocessing methods for any other segmentation techniques. This ROI generation can make the next image processing methods faster as some part of the original image has been cropped.

In [2], the image processing can be used to automatically detect the centroid of human kidney. The software MATLAB consists of speckle noise reduction, Gaussian filter, texture filter and morphological operators which are used for image segmentation in order to extract important features. For the result, median filter has been chosen as speckle noise reduction techniques as it is faster and detect kidney centroid better compared to wiener filter, wavelet filter and speckle noise anisotropic diffusion (SRAD) filter. This software can detect centroid up to 96.43% of accuracy. The detected centroid used in the ultrasound machine can be used as segmentation tool to reduce human errors and time. It can also be used to detect the kidney's contour automatically and time taken to process will be less.

In further research, improvement can be made by selecting another better filter, as well as by investigation the morphological operation in finding the optimum values for detecting a more accurate kidney centroid.

In [3], the variation in kidney sizes can be associated with different kidney diseases. However, the precision and accuracy of the result is low due to the manual measurement that is highly dependent on the skill and experience of the doctor. Hence an automatic measurement system is used to measure the kidney size automatically from ultrasound image. First, samples of kidney ultrasound image are collected and analyzed. Then, programming algorithm which is a combination of noise filtering method such as Gabor filter, Wiener filter, and sharpening methods are used to suppress the speckle noise on the ultrasound image while preserving the fine details. The kidney is then segmented from the image using Level set method in which the zero level set is evolved to minimize the overall energy function depending on the gradient flow. Comparison of pixel value is used to determine the maximum and minimum point which is utilized to find the length, width, and thickness. At last, volume of the kidney is calculated using ellipsoid formula.

Thus, it is possible to improve the quality of kidney ultrasound image by reducing the speckle noise and enhancing the boundary by implementation of automatic segmentation method using the level set method to partition the kidney from the ultrasound image. Testing and optimizing process are done continuously to ensure the robustness of the algorithm until the satisfied result is obtained.

In future, a better segmentation method can be used to partition the kidney without the need of a very clear image from ultrasound machine.

In [4], an algorithm is described for cleaning speckle noise in ultrasound medical images. Mathematical Morphological operations are used in this algorithm. This algorithm is based on Morphological Image Cleaning algorithm (MIC) designed by Richard Alan Peters II. The algorithm uses a different technique for reconstructing the features that are lost while removing the noise. For morphological operations it also uses arbitrary structuring elements suitable for the ultrasound images which have speckle noise.

Thus, the MMIC is the best algorithm for cleaning speckle noise which also preserves features in the image. The image cleaned by this algorithm could be used as an input for other image processing tasks such as segmentation, feature extraction, classification etc.

In [5], the kidney volume is considered as the most precise indicator of kidney size. However, it is not widely used clinically as its measurement is difficult due to the complex kidney shape. A method is used to evaluate the normal kidney volume in young Korean men by using Multi-Detector Computed Tomography (MDCT). The materials and methods are used to review MDCT data of young Korean men (113 patients). After data processing, the volume and length of the kidneys are measured. Further, body parameters (height, body weight, body-surface area, and total body water) and laboratory data are collected. Glomerular Filtration rate (GFR) is calculated using Cockcroft-Gault (CG) equation. Thus, the kidney volume measured with MDCT is correlated well with body parameters, and is useful to predict renal function.

Thus, the kidney volume is a better indicator of body parameters and predictor of renal function than kidney length, suggesting that kidney volume is more useful than kidney length in clinical field.

The kidney volume is more reliable index of kidney size than kidney length, and measurement of kidney volume with MDCT is useful method. Hence, MDCT facilitates measurement of kidney volume and enables to use it in clinical field.

In [6], medical image processing image denoising has become a very essential exercise all through the diagnose. In ultrasound images, the noise can restrain information which is valuable for the general practitioner. A wavelet-based thresholding method is used for noise suppression in ultrasound images. Quantitative and qualitative comparisons of the results obtained by the wavelet-based thresholding method achieved from the other speckle noise reduction techniques demonstrate its higher performance for speckle reduction.

A context-based model is introduced for adaptive threshold selection within a wavelet thresholding framework. The estimations of local weighted variance with appropriately chosen weights are used to adapt the threshold. The proposed thresholding technique outperforms all the standard speckle filters, Wiener filter Visu shrink, and Bayes shrink methods.

However, by visual inspection it proves that the denoised image does not suffer with no degradation in sharpness, while removing a substantial amount of noise.

III. NOISE MODELS

A. Model of speckle noise[7]

An inherent characteristic of ultrasound imaging is the presence of speckle noise. Speckle noise is a random and deterministic in an image. Speckle has negative impact on ultrasound imaging, Radical reduction in contrast resolution may be responsible for the poor effective resolution of ultrasound as compared to MRI. In case of medical literatures, speckle noise is also known as texture. Generalized model of the speckle is represented as

$$g(n,m) = f(n,m) * u(n,m) + \xi(n,m) \qquad (1)$$

Where, $g(n,m)$ is the observed image, $u(n,m)$ is the multiplicative component and $\xi(n,m)$ is the additive component of the speckle noise. Here n and m denotes the axial and lateral indices of the image samples.

For the ultrasound imaging, only multiplicative component of the noise is to be considered and additive component of the noise is to be ignored. Hence, equation (1) can be modified as

$$g(n,m) = f(n,m) * u(n,m) + \xi(n,m) - \xi(n,m)$$

Therefore, $$g(n,m) = f(n,m) * u(n,m) \qquad (2)$$

B. Noise in Ultrasound Images[7]

Ultrasound imaging system is widely used diagnostic tool for modern medicine. It is used to do the visualization of muscles, internal organs of the human body, size and structure and injuries. Obstetric sonography is used during pregnancy. In an ultrasound imaging speckle noise shows its presence while doing the visualization process.

C. Medical Ultrasound Speckle Pattern [8]

Nature of Speckle pattern depends on the number of scatters per resolution cell or scatter number density. Spatial distribution and the characteristics of the imaging system can be divided into three classes:

1) The fully formed speckle pattern occurs when many random distributed scattering exists within the resolution cell of the imaging system. Blood cells are the example of this class.

2) The second class of tissue scatters is no randomly distributed with long-range order [8].

3) The third class occurs when a spatially invariant coherent structure is present within the random scatter region like organ surfaces and blood vessels [8].

IV. VARIOUS METHODS

Several different methods are used to eliminate speckle noise, based upon different mathematical models of the phenomenon.

A. Multiple-look processing

Multiple-look processing, averaging out the speckle noise by taking several "looks" at a target in a single radar sweep. The average is the incoherent average of the looks.

B. Adaptive and Non-Adaptive Filters

Adaptive and non-adaptive filters on the signal processing (where adaptive filters adapt their weightings across the image to the speckle level, and non-adaptive filters apply the same weightings uniformly across the entire image). Such filtering also eliminates actual image information as well, in particular high-frequency information, and the applicability of filtering and the choice of filter type involves tradeoffs. Adaptive speckle filtering is better at preserving edges and detail in high-texture areas (such as forests or urban areas). Non-adaptive filtering is simpler to implement, and requires less computational power, however.

There are two forms of non-adaptive speckle filtering: one based on the mean and one based upon the median (within a given rectangular area of pixels in the image). The latter is better at preserving edges whilst eliminating noise spikes, than the former is. There are many forms of adaptive speckle filtering, including the Lee filter, the Frost filter, and the Refined Gamma Maximum-A-Posteriori (RGMAP) filter.

C. Filtering Techniques

1) Median Filter: Median filter, one of the nonlinear filter types is created by replacing the median of the gray values of pixels into its' original gray level of a pixel in a specific neighbourhood. Median filter can help in reducing speckle noise as well as salt and pepper noise. The noise-reducing effect of the median filter depends on the neighbourhoods' spatial extent and the number of pixels involved in the median calculation.

2) Wiener Filter: Wiener filter inverts the blurring and removes the additive noise simultaneously by performing an optimal tradeoff between inverse filtering and noise smoothing. Besides, Wiener filtering is optimal in terms of the mean square error, where it minimizes the overall mean square error in the process of inverse filtering and noise smoothing. Wiener filtering is also a linear estimation of the original image. The Wiener filter in the frequency domain is as in equation (3):

$$w(f1, f2) = \frac{H^*(f1, f2) S_{xx}(f1, f2)}{|H(f1, f2)|^2 S_{xx}(f1, f2) + S_{\eta\eta}(f1, f2)} \quad (3)$$

Where $S_{xx}(f1, f2)$, $S_{\eta\eta}(f1, f2)$ are respectively power spectra of the original image and the additive noise, and $H(f1, f2)$ is the blurring filter.

3) Gaussian Low-pass Filter: Gaussian Low-pass filtering has been used for removing the speckle noise in US images. Gaussian filter has similar function as median filter but it uses different kernel, which has the bell-shaped distribution. The equation (4) for Gaussian filter is:

$$g(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{x^2}{2\sigma^2}} \quad (4)$$

σ in the equation (4) is the standard deviation of the distribution, and also the degree of smoothing. The larger the value of σ, the filtered image is smoother.

D. Texture Analysis

Texture analysis is important in characterizing regions in an image by their texture content and it is helpful when objects in an image are more characterized by their texture than by intensity, and traditional thresholding techniques cannot be used effectively. When certain values either range, standard deviation or entropy of the image are calculated, they will provide information about the local variability of the intensity values of pixels in the image, thus the texture can be characterized.

E. Wavelet based speckle reduction methods

The wavelet based speckle reduction method usually includes (1) logarithmic transformation (2) wavelet transformation (3) modification of noisy co efficient using shrinkage function (4) invert wavelet transform and (5) exponential transformation. This method can be classified into three groups.

1) Thresholding Methods: The wavelet coefficients smaller than the predefined threshold are regarded as contributed by noise and then removed. The thresholding techniques have difficulty in determining an appropriate threshold.

2) Bayesian estimation methods: This Method approximates the noise free signal based on the distribution model of noise free signal and that of noise. Thus, reasonable distribution models are crucial to the successful application of these techniques to medical ultrasound imaging.

3) Coefficients correlation methods: This is an undecimated or over complete wavelet domain denoising method which utilizes the correlation of useful wavelet coefficients across scales. However this method does not rely on the exact prior knowledge of the noise distribution and this method is more flexible and robust compared to other methods.

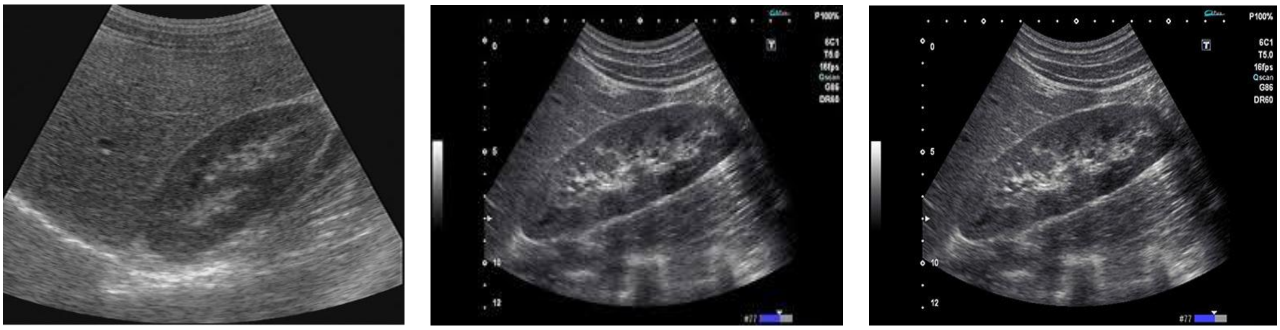
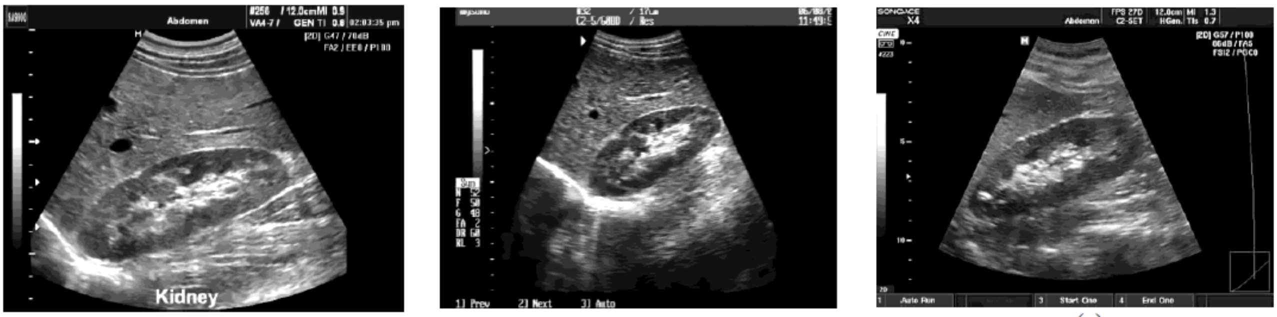


Fig. 1. Shows the sample of ultrasound images (courtesy from Google Image)



(a) (b) (c)

Fig. 2. Shows the output images after speckle reduction (courtesy from Google Image)

V. CONCLUSION

Thus, while developing an efficient and robust denoising method for ultrasound images one has to take into account number of factors. The choice of despeckling filter and speckle model plays an important role in the design of speckle reduction methods and it differs from application to application. Most commonly preferred models and filters were discussed with its merits and demerits in this paper.

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