A Review on Despeckling of Medical Ultrasound Images

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Abstract

Ultrasound imaging is a widely used imaging system for medical diagnosis due to its safe and noninvasive nature. However, the presence of speckle noise in the ultrasound image degrades its usefulness. Speckle noise in US B –mode images appears as granular structure formed by constructive or destructive interference of back scattered echoes. Speckle noise causes to reduce image contrast and resolution, thereby reducing the diagnostic value of this technique. Several methods have been introduced for despeckling of ultrasound images. This paper presents a review on some significant works proposed for despeckling of medical ultrasound images.
Keywords: Ultrasound Image, B Mode Image, Speckle, Despeckling

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I. Introduction

In Medical diagnosis, ultrasound imaging plays a vital role due to its safe and noninvasive nature. As compared to other image modalities, ultrasound imaging provides real time images with low cost thereby, it is widely used for observing growth status of fetus in pregnant woman and diagnosis of lesions of abdominal organs especially kidney and liver. However, the presence of speckle noise deteriorates the image quality and thereby, the diagnosis value. Therefore, despeckling is an important prerequisite to preserve image quality of ultrasound images. Many algorithms have been proposed for despekling of ultrasound images.

II. Despeckling

In 2009, J. L. Mateo et al. [1] has compared some of the different methods used to remove speckle noise present in the ultrasound images. Fourier filtering method uses Fourier transform and inverse Fourier transform to provide better quality images. Since it uses only one parameter, it is simple. In Adaptive weighted mean filtering method, a mean filter with weights which decreases from the center of the window to the outer limits is used to remove speckle noise. This method eliminates less noise and some Image details may be lost. Wavelet filtering method eliminates certain frequencies in order to remove noise there by eliminating some image details also. In Homomorphic filtering method, the multiplicative noise is converted into additive by log transformation function and Fourier Transform is used to remove the noise.

In 2010, Tay PC et al. [2] proposed an iterative technique based on the squeeze box filter (SBF) which reduces speckle noise by suppressing outliers as a local mean of its neighborhood. The image pixel outliers are defined to be local minimums and local maximums determined from a 3×3 window. Each outlier is replaced by a local mean computed from a window centered on the outlying pixel. The outlier pixel value is not used in computing the local mean. After all the outliers are replaced by the local means, the iteration is carried out until convergence is attained. The quality of image in terms of contrast enhancement, structural similarity and segmentation result is improved by the SBF. Although an effective speckle reduction is achieved, the SBF provides some artifacts in the form of blurred edges and irregular intensity pattern around edges.

In the same year, Ashish Khare et al. [3] introduced an algorithm based on Daubechies complex wavelet transform for speckle removal. Firstly, strong edges are detected by using imaginary component of complex scaling coefficients and then shrinkage is applied on magnitude of complex wavelet coefficients in the wavelet domain in order to detect non-edge points. Since the shrinkage depends on the statistical parameters of complex wavelet coefficients of noisy image, it is adaptive in nature. The shrinkage was applied only on the magnitude of wavelet coefficients, thus making it as simple and preserving the phase and the shape of the object in image. However there exists a trade-off between the smoothness and the edge preservation.

In 2011, G.G. Bhutada et al. [4] proposed a method that utilizes features of wavelet and curvelet transform to denoise defferent regions of an image. In this method, variance approach is used to identify homogeneous, non-homogeneous and neither homogeneous nor non-homogeneous regions. The edgy information that may be lost by wavelet approach is extracted back by denoising it with curvelet transform. The directional information is restored by Curvelet denoising. But it adds additional fuzzy edges in homogeneous region. This method combines adaptive fusion of denoised images obtained from WT-TNN and curvelet transform.

In 2012, Parrilli S et al. [5] proposed a Wavelet-based despeckling technique. In the wavelet domain, the noise can be removed by properly suppressing or thresholding the small coefficients that are likely due to noise. In this, it first performs a 2-D wavelet transform, then modifies the noisy coefficients using a shrinkage function and finally performs a 2-D inverse wavelet transform. Some details in the images may be lost along with noise by applying this method.

In the same year, G. Andria et al. [6] proposed an algorithm to denoise the ultrasound images using linear filtering of only the vertical and diagonal details of the image. The details are obtained via the first-level 2-D wavelet decomposition. The linear filtering is performed with a Gaussian filter with a kernel size that depends on the amplitude of the speckle noise.

In 2014, G Umamaheswari et al. [7] proposed an adaptive window hybrid median filter for denoising of medical ultrasound images. The size of the window of the hybrid median filter is selected based on the image region. The sobel edge operator is used to differentiate between the smooth and edge regions. A window size of 3*3 is used if the center pixel is identified as an edge pixel and otherwise a window size of 5*5 is used.

In the same year, Meriem et al. [8] proposed a multiplicative regularization method through an adaptive window whose shapes, sizes and orientations vary with the image structure. It doesn't perform smoothing uniformly. Instead, the despeckling is achieved in preferred orientations, more in homogeneous and less in detailed ones to preserve region boundaries.

Norashikin Yahya et al. [9] proposed a subspace-based speckle reduction technique. In this method, the multiplicative speckle noise is converted into additive via logarithmic transformation. Then, it decomposes the vector space of the noisy image into signal and noise subspaces. Image enhancement is achieved by nulling the noise subspace and estimating the clean image from the remaining signal subspace. Linear estimation is used to minimize image distortion while maintaining the residual noise energy below some given threshold.

S. Bama et al. [10] proposed a speckle reduction method in the curvelet domain with coefficient modelling and diffusion filtering of the coefficients. An un-decimated Átrous based curvelet transform of the image is computed. Maximum A posteriori Probability (MAP) estimation is used to determine the shrinkage function for the curvelet transformed coefficients. Perona Malik Anisotrpic Diffusion filter (PMAD) is used to filter a part of the curvelet coefficients and the estimated shrinkage function is used to model the rest of the coefficients. Diffusion (PMAD) is a type of scale space transformation of the image and preserves the significant contents of the image while reducing image noise. In this, each individual image is formed by convolving the image and the diffusion filter successively. This process preserves the key information in the original image and removes the speckle noise.

In 2015, Ju Zhanga et al. [11] proposed an algorithm based on the wavelet transformation and fast bilateral filter. The wavelet coefficients of noise-free signal is modeled as generalized Laplace distribution and speckle noise is modeled as Gaussian distribution. The Bayesian maximum a posteriori estimation is used to obtain the wavelet shrinkage function. High-pass component of speckle noise in the wavelet domain is suppressed by the shrinkage function. The fast bilateral filter is used to suppress speckle noise in the low frequency component.

In the same year, Xiaowei Fu et al. [12] proposed an adaptive DTCWT-based image despeckling method using the quantum-inspired adaptive threshold function. This method uses coefficients in the dual-tree complex wavelet transform (DTCWT) domain to develop a new quantum-inspired thresholding function. The developed threshold is further incorporated into a Bayesian framework to perform adaptive image despeckling.

M. A. Gungor et al. [13] developed an object-based tool for wavelet thresholding to reduce speckle noise. The tool is formed by using Waterfall model. Both conventional and new wavelet filtering techniques can be applied by this tool. In this tool, the image is decomposed into four lower resolution components; LL (approximation coefficients), LH (horizontal detail coefficients), HL (vertical detail coefficients) and HH (diagonal detail coefficients). The wavelet coefficients are determined by the following equations:

$LL=g(n)*[g(n)*Image|_{n=2k,k\geq0}]|_{n=2k,k\geq0}$ (1)

$LH=h(n)*[g(n)*Image|_{n=2k,k\geq0}]|_{n=2k,k\geq0}$ (2)

$HL=g(n)*[h(n)*Image|_{n=2k,k\geq0}]|_{n=2k,k\geq0}$ (3)

$HH=h(n)*[h(n)*Image|_{n=2k,k\geq0}]|_{n=2k,k\geq0}$ (4)

The g(n) and h(n) mean low pass decomposition filter and high pass decomposition filter respectivel.

Ju Zhang et al. [14] compared despeckle filters for the breast ultrasound images. They compared eleven despeckle filters classified as local adaptive filter, anisotropic diffusion filter, multi-scale filter, nonlocal means filter, and hybrid filter. They converted multiplicative speckle noise into additive noise by using logarithmic transformation before filtering. They used Rayleigh distribution before logarithmic transformation and Gaussian distribution after logarithmic transformation for modeling the speckle noise. The quality of image is measured by blind image quality metric (NIQE).

Deep Gupta et al. [15] proposed a despekling method based on discrete ripplet transform (DRT) and nonlinear bilateral filter (NLBF). The DRT is a new image representation approach with the different features of anisotropy, localization, directionality, and multiscale. The ripplet transform is higher dimensional generalization of the curvelet transform and is applied to provide effective representation of the noisy coefficients. The DRT coefficients are thresholded by using soft and NeighShrink thresholding algorithms and their performance is evaluated. Bilateral filter is applied to the noisy ripplet coefficient to improve the denoising efficiency and preserve the edge features effectively. In bilateral filtering, the pixel values are replaced by a weighted sum of the pixels in a local neighborhood. The weights are determined by the spatial distance of the pixel around the neighborhood and the intensity distance around the neighborhood of a pixel. This filtering is achieved by the cascading two Gaussian filters; domain filter and range filter respectively. The edge preservation in despeckled image is evaluated by using Pratt's figure of merit (FOM) and edge keeping index (EKI).

In the same year, Hyun Ho Choia et al. [16] proposed an image fusion-based denoising method for speckle removal. The image fusion technique develops the image for input through decomposition, fusion and reconstruction of the image. Firstly, the 2 input images are decomposed into sub images with high frequency and low frequency through the DWT techniques. Then, the new input image is formed by combining the key information for each input image. Wavelet based image fusion is performed by the sub image element containing details and features of the original image .The fusion process combines the complimentary information via multiple modality images.

J. Nithya1 et al. [17] proposed a curvelet transform based denoising method. In this approach, firstly the image is decomposed into sub bands. Then each sub band is partitioned into a block of an appropriate scale and the block is renormalized to a unit scale. Finally, the digital ridgelet transform is applied to each block. The curvelet coefficients are analysed to eliminate the noisy coefficients by setting a threshold. The image can be reconstructed by repeating the same process in the reverse order.

In 2016, Sedigheh Ghofrani [18] proposed an adaptive filter based on non-sub sampled shearlet transform (NSST). A log transformed image is modeled as Nakagami distribution. In NSST, Bayesian shrinkage is used to find optimum threshold values in transform domain. He has effectively compared the performance of two methods that remove speckle noise in spatial domain and transformed domain by using Peak signal to noise ratio (PSNR), mean square error (MSE), structural similarity (SSIM), edge keeping index (EKF), noise variance (NV), mean square difference (MSD), and equivalent number of looks (ENL). In this approach, two filters that works in spatial domain based on Nakagami distribution and in transform domain based on NSST are applied to remove speckle noise.

In the same year, Nagashettappa Biradar et al. [19] proposed extreme total variation bilateral (ETVB) filter for despekling of echocardiographic image. This algorithm utilizes prior knowledge of noise free image. The noise free image and noisy image are used as input to the extreme total variation bilateral filter. The regularization term of total variation are replaced with bilateral filter.

III. Discussion

Different types of despeckling methods have been proposed yet. Some of the methods are first order static filtering, homomorfic filtering, wavelet filtering, wavelet and linear filtering, wavelet and nonlinear filtering, complex wavelet filtering, corvelet transform based filtering, and replet transform based nonlinear filtering.

First order static filter is based on first order statics such as mean, median etc. It is applied in the spatial domain of an image. The performance of these methods depends on the size of the window. In homomorphic filtering, multiplicative speckle noise is converted into additive noise and it is modeled as additive white Gaussian noise. Wavelet based methods utilizes wavelet transform and inverse wavelet transform. Wavelet of any suitable family can be chosen according to the applications. Suitable shrinkage function can be used for thresholding. Most commonly used shrinkage functions are MAP estimation, Bayesian shrinkage, MMSE estimation and Bayes estimation. Wavelet based filtering can be improved by combining it with linear or nonlinear filtering. Limitations of discrete wavelet transform can be overcome by using complex wavelet transform. Instead of wavelet transform, latest methods utilizes curvet transform and replet transform. A combined method of wavelet and curvelet transform has been proposed. A method combining Replet transform and nonlinear filtering such as bilateral filtering has also been proposed.

The speckle noise can be modeled appropriately according to the applications. Due to its multiplicative nature, most of the papers model it as Raleigh distribution. It is relatively a simple model. In homomorphic filtering, speckle noise is modeled as Gaussian or Laplace distribution after logarithmic transformation. Other distributions such as Nakagami distribution, Gamma distribution, Fisher-Tippett distribution, Mixture Gaussian distribution have also been used for modeling speckle noise.
The performance of each method can be evaluated by using different evaluation metrics such as Peak Signal to Noise Ratio (PSNR), Mean Square Error (MSE), Structural Similarity (SSIM), Noise Variance (NV), Mean Square Difference (MSD), Equivalent Number of Looks (ENF) and Blind Image Quality Metric (NIQE). The edge preservation in despeckled image is evaluated by using Pratt’s figure of merit (FOM) and Edge Keeping Index (EKI).

IV. Conclusion

These all techniques removes speckle noise. But some artifacts in the form of blurred edges and irregular intensity pattern are retained in the reconstructed image. Some diagnostic information appearing as speckle are also removed by these methods. Most of the methods assume speckle as zero mean white Gaussian distribution after logarithmic transformation. This assumption makes them irrelevant in terms of performance. So the homomorphic filtering can’t be used effectively for despeckling. Use of down sampling operation in DWT causes shift invariance and makes it difficult to preserve original image discontinuities in wavelet domain. Also, DWT is inefficient to provide phase information. The application of DWT should be replaced by another method. However, as compared to other methods wavelet based methods are simple and effective. Since Complex wavelet transform contains phase information also, it can be a good replacement for wavelet transform

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