A brief review on speckle noise reduction techniques for ultrasound images

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ABSTRACT
Speckle noise, typically occurs in coherent imaging systems such as sonar, laser and ultrasound imaging, is an unwanted aftereffect of the image formation process in coherent imaging .Speckle reduction is an important issue for analysis of ultrasound images. In ultrasound imaging system, the presence of speckle results decline in image quality and makes it difficult for human interpretation and diagnosis analysis.Numerous methods for speckle suppression were proposed. In this paper we have given the overview of the speckle noise reduction modelalong with various filters which are commonly used for speckle reduction needed in ultrasound images. As speckle noise is dominated in ultrasound imaging, there is need of de-noising the ultrasound images before segmenting out the tumor regions. As border detection of these tumors should be highly accurate as final results of segmentation are dependent on it. Further we will explore the tumor edge detection and segmentation of infected liver ultrasound images.

Keywords: speckle noise, ultrasound, lee and kuan, frost,, wavelets

1. Introduction

Medical images are mostly corrupted by noise at the time of obtaining and gradually enlarge during transmission. Ultrasonic imaging plays important role in medical imaging procedure,reason behind it is more economical, comparativelysafer, transferable, and adaptable. The objective of image de-noising techniques are necessary in removing such noises while retaining the important signalfeatures. An appropriate method for speckle reduction is one whichenhances the signal to noise ratio while conserving the edges and lines in the image. Filtering techniques are often used before segmentation and classification of images. Ultrasound imaging has to suffer from one main problem that is the poor quality of images which are affected by speckle noise. The existence of speckle is unattractive since it disgrace image quality and automatic interpretation of ultrasound imagesis extremely difficult because of its low signal to noise ratio (SNR) which is due to presence of speckle noise. The specklepattern depends on the structure of the imaged tissues and various imaging parameters[1].

The quality of a medical ultrasonic image is often degraded due to the existence of speckle noise. Speckle which is shown as granular pattern degrades theimage quality of B-scan, makes the low contrast objects, small high-contrasttargets and small differences in image brightness hard to be detected. Therefore,it is important to improve images quality by reducing speckle noise and alsopreserving the tissue structure.

2. Speckle noise modeling

The speckle noise is present in many imaging and vision related applications such as ultrasound imaging, synthetic aperture radar imaging (SAR), digital holography and many more. For correct interpretation of image data it becomes essential to reduce the speckle noise. The speckle noise [2] has complex amplitude given as $a(x, y) = a_R (x, y) + ja_I (x, y)$, where a_R and a_I are zero mean, independent Gaussian random variables for each (x, y) with some variance. The intensity field of speckle noise is given as $n(x, y) = |a(x, y)|^2 = a_R^2 + a_I^2$ .The image observation model [1] for speckle noise reads:

$$I_o (x, y) = I (x, y)* n(x, y) + \eta(x,y) \ldots (1)$$

where I_o (x, y) is the observed speckled noised image; I(x, y) is the original noise free image and n(x, y) is the Gaussian noise with zero-mean and known variance σ_n^2 and η (x, y) is the detector noise which is additive in nature. Assuming detector noise to be zero, the general observation model reads:

$$I_o (x, y) = I (x, y)* n(x, y) \ \ldots\ldots\ldots (2)$$

The B-scan or 2D ultrasound images which are used is medical diagnosis are generated by reflected or transmitted coherent ultrasound waves at unchanged frequencies that interact with different tissue types and give rise to various interference phenomenon leading to speckle noise. The speckle noise present in the acquired ultrasound image may lead to misinterpretation of medical image during diagnosis and therefore, it must be reduced. The speckle noise present in ultrasound image is normally multiplicative in nature and distributed according to Rayleigh's probability density function (pdf) given as follows [3]

$$p(I / I_o) = \frac{I_o}{\sigma^2} \exp(-\frac{I^2}{2\sigma^2}) \ \ldots. (3)$$

Where I_0 is the observed or recorded ultrasound image containing speckle noise; I is the image to be restored ; and σ^2 is the speckle noise variance. Theremoval of additive noise is comparatively easier than removal of multiplicative speckle noise. The various methods available in literature for speckle noise reduction are N-Look Method, spatial averaging and homomorphic filtering . The N-Look process is usually done during data acquisition stage and speckle reduction by spatial filtering is performed on the image after it is acquired. The homomorphic filtering approach operates in logarithmic domain. Irrespective of the methods used to reduce the speckle noise from images, the ideal speckle reduction method must preserve radiometric information and the textural information i.e. the edges between different areas and spatial signal variability. The spatial filters are of two types which are adaptive and non-adaptive. Non-adaptive filters take the parameters of the whole image signal into consideration and leave out the local properties of the terrain backscatter or the nature of the sensor. These kinds of filters are not appropriate for non-stationary scene signal e.g. Fast Fourier Transform (FFT). The adaptive filters accommodate changes in local properties of the tissue backscatter as well as the nature of the sensor. In adaptive filters, the speckle noise is considered as being stationary but the changes in the mean backscatters due to changes in the type of target are taken into consideration. Adaptive filters reduce speckles while preserving the edges and these filters modify the image based on statistics extracted from the local environment of each pixel. Adaptive filter varies the contrast stretch for each pixel depending upon the Digital Number (DN) values in the surrounding moving kernel. In homomorphic filtering approach, the multiplicative speckle noise is first converted to additive noise by taking the logarithm of equation (2), then one of the additive noise model is applied for noise reduction, and finally the speckle reduced image is obtained by taking the exponential of the image obtained in second step. For additive noise removal the various methods available in literature are based on statistical techniques, wavelet based techniques and PDE based diffusion techniques. The popular methods are simple averaging, least mean squares , Weiner filtering , wavelet based de-noising , anisotropic diffusion based techniques.

3.Speckle reduction using some common filters

Speckle filtering techniques: Speckle filtering in the spatial domain is characterized by moving a kernel over each pixel in the image and applying a weighted average calculation using sub region statistics for estimating statistical measures over the defined kernel. Usual kernel window size chosen is odd and ranges from 3×3, to 15× 15. In all these techniques speckle noise model assumed has a multiplicative form.

3.1 Speckle Reducing Anisotropic Diffusion (SRAD)[4]SRAD filter is known as speckle reducing anisotropic diffusion. The SRAD can eliminate speckle without distorting useful image information and without destroying the important image edges. The SRAD PDE exploits the instantaneous coefficient of variation in reducing the speckle. The results which are given below tells the SRAD algorithm provides superior performance in comparison to the conventional techniques like lee, frost, kaun filters in terms of smoothing and preserving the edges and features.

The bilateral filter is technique to smooth images while preserving edges. The bilateral filter is a non-linear technique that can blur an imagewhile respecting strong edges. Its ability to decompose an image intodifferent scales without causing haloes after modification has made itubiquitous in computational photography applications such as tonemapping, style transfer, relighting, and denoising. The key idea of thebilateral filter is that for a pixel to influence another pixel, it shouldnot only occupy a nearby location but also have a similar value.

3.2 Lee and Kuan filters

Lee filter [5]: It is based on multiple-look processing (a.k.a. multi-look processing). Lee filter is a window based approach and depends upon the variance. Lee filters are better at preserving image sharpness and the detail while it suppresses noise. The main disadvantage of Lee filter is that it ignores the speckle noise in the areas closest to edges and lines.

3.3Kuan Filter [6]

The Kuan filter is better than Lee filter as it does not make an approximation on the noise variance within filter window. It just converts the multiplicative noise model in to additive linear form. However, it depends on the ENL from an image to determine a weighting function W and issimilar to Lee filter in functionality. The formula equation for Lee and Kuan has been given below

$$R_{(x,y)} = I_{(x,y)}W_{(x,y)} + I_{(x,y)}(1 - W_{(x,y)}) \qquad 4$$

where I’ x y, is the mean value of the intensity within the filter window and W(x, y) is the adaptive filter coefficient determined using:

$$W_{(x,y)} = \begin{Bmatrix} 1 - \dfrac{C_b^2}{C_1^2 + C_b^2} \; for\ Lee \\ \dfrac{1 - C_b^2 / C_1^2}{1 + C_b^2} \; for\ Kuan \end{Bmatrix} \qquad 5$$

where, Ci is the coefficient of variation of the noised image and Cb is the coefficient of variation of the noise.

3.4 Frost filter

Frost filter [6] is a spatial domain adaptive filter that is based on multiplicative noise order. Frost Filter is an adaptive filter that incorporates the local image statistics in the filtering process assuming a negative distribution for noise. It is used for reducing speckle in the radar images while preserving the texture information. The major limitation of frost filter is that the parameters are adjusted according to variance in each area. If variance is low then the smoothing will occurs. The response of the filter is given by:

$$R_{(x,y)} = \frac{(\sum \mathrm{P}_n * \mathrm{M}_n)}{\sum M_n}$$

Where,

$$M_n = \exp\left(-D * \left(\frac{\delta_n}{\mu_n} \right)^2 * T \right)$$

Pn is the image pixels in the filter window. D is the damping factor, which determines the extent of the potential damping for the image. Typical value of D is 1.Fn is the standard deviation of the filter window. :n is the local mean T is the absolute value of the pixel distance between the centre pixel to its surrounding pixels in the filter window. For a 3×3 filter window the absolute pixel distance with respect to the centre pixel has been defined as

2	1	2
1	0	1
2	1	2

This can be extended for a 5×5 filter window

3.5 Wavelet filter

All the wavelet filters use wavelet thresholding operation for de-noising [7].Speckle noise is a high-frequency component of the image and appears in wavelet coefficients. One widespread method exploited for speckle reduction is wavelet thresholding procedure. The basic Procedure for all thresholding method is as follows:

• Calculate the DWT of the image.
• Threshold the wavelet coefficients. (Threshold may be universal or sub band
adaptive)
• Compute the IDWT to get the denoised estimate.

• There are two thresholding functions frequently used, i.e. a hard threshold, a soft threshold.
The wavelet techniques are widely used in the image processing, such as the image
compression, image de-noising. It has been shown that its performance of image
processing is better than the methods based on other linear transformation. It has beenembedded into the JPEG 2000.
The wavelet de-noising method decomposes the image into the wavelet basis and
shrinks the wavelet coefficients in order to despeckle the image. From the noisy image,global soft threshold coefficients are calculated for every decomposition level. After thethresholding, the image is reconstructed by inverse wavelet transforming and thedespeckled image is derived[7].
After the wavelet transformation, the signal energy will only concentrate on severalwavelet coefficients and the majority of the coefficients will become zeros. Also thefrequency domain filtering based on the DFT could not work well to the piecewisesmooth functions. It has been proved that the simple wavelet de-noising methods couldprovide a almost optimal request to the polynomial piecewise signals.

Table 1: Mathematical expressions of performance metrices

Performance metrics	Mathematical expression	Use
Mean Square Error	$MSE=\frac{1}{MN}\sum_{J=1}^{M}\sum_{K=1}^{N}(X_{j,k}-X'_{j,k})^2$	Measures the quality change between the original image and the de-speckled image
Root mean Square Error	$RMSE=\sqrt{\frac{1}{MN}\sum_{K=1}^{N}(X_{j,k}-X'_{j,k})^2}$	Measure the square root of the squared error averaged over a pixel window. It is the best approximation of the standard error
Signal to Noise Ratio(SNR)	$SNR=10\log_{10}\frac{\sum_{J=1}^{M}\sum_{K=1}^{N}(X^2{}_{j,k}-X'_{j,k})^2}{\sum_{J=1}^{M}\sum_{K=1}^{N}(X_{j,k}-X'_{j,k})^2}$	Compares the level of desired signal with respect to the level of background noise
Peak Signal to Noise Ratio	$PSNR=10\log_{10}\left(\frac{255^2}{MSE}\right)$	Provides the quality of the image in terms of power of the original signal and de-noised signal
Structural Content	$SC=\frac{\sum_{J=1}^{M}\sum_{K=1}^{N}X^2{}_{j,k}}{\sum_{J=1}^{M}\sum_{K=1}^{N}(X_{j,k})^2}$	Measures the similarity between the original and de-noised image
Universal Quality Index	$UQI\,\frac{\sigma\overline{X}\,\overline{X'}}{\sigma_x\sigma_{x'}}\cdot\frac{2\overline{X}\,\overline{X'}}{(\overline{X})^2+(\overline{X'})^2}\,\frac{2\sigma_x\sigma'_x}{(\sigma_x)^2+(\sigma_{x'})^2}$	Measured loss of correlation, luminance distortion and contrast distortion between original image and de-speckled image.
Normalized Cross Correlation	$NCC=\frac{\sum_{J=1}^{M}\sum_{K=1}^{N}(X_{j,k})(X'_{j,k})}{\sum_{J=1}^{M}\sum_{K=1}^{N}(X^2{}_{j,k})}$	Measure the structural similarity between the original image and de-speckled image.
Structural Similarity	$SSIM=\frac{(2\overline{X}\,\overline{X'}+C_1)}{(\overline{X}^2+\overline{X'}^2+C_1)}\frac{(2\sigma_{xx'}+C_2)}{(\sigma_x{}^2+\sigma^2{}_{x'}+C_2)}$	Measures the structural similarity between the original image and the de-speckled image. Its value lies between -1 and +1. C_1 and C_2 are 0.01 and 0.03 dr, respectively, (Where dr is the dynamic range of the intensity)

6. Conclusion

The speckle noise occurs in coherent imaging of objects whenever surface roughness of the image being imaged is of the order of the wavelength of the incident radiation. The existence of speckle noise in the ultrasound image isUndesirable since it disgrace image quality by affecting edges and local details between heterogeneous organs which are the most interesting part for diagnostics. The speckle noise is present in many imaging and vision related applications such as ultrasound imaging, digital holography and many more. For correct interpretation of image data it becomes essential to reduce the speckle noise. In this paper, we have provided a brief introduction to speckle noiseand we have also provided brief review of the filters which are popular and have been discussed be various scholars. In future, we will explore this topic further and will propose an algorithm for speckle reduction in frequency domain techniques..It decreases the computation time. By performing various techniques, it is concluded that the proposed method provides better results than others. It ensure an improvement in the segmentation performance by identifying the boundaries correctly and the speed to processing is also increased. It has also been concluded from literature survey that effective segmentation of ultrasound images need pre-processing step in which there is need of speckle noise reduction as it has been widely found in all ultrasound images especially the ultrasound images of deep organs i.e. Liver, kidney etc. In future we will explore the liver tumor segmentation and will verify the accuracy rate of proposed work in terms of sensitivity and specificity values.

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