Image Denoising of Medical Ultrasound Images using Curvelets

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Abstract: Ultrasound imaging is most extensively used imaging method due to its clinical, inexpensive nature. Unfortunately, the quality of medical ultrasound images is usually restricted owing to a number of factors. The major problem of ultrasound imaging is presence of speckle noise while acquisition. Speckle noise have tendency to decrease the image contrast and distort details of image, thereby degrading the quality and consistency of ultrasound images. Due to these reasons, the difficulty in analysis process increases. Various methods have been used to suppress speckle in ultrasound imaging. Most popular methods are wavelet based transformation and curvelet transformation. Curvelet transform is a higher dimensional overview of the wavelet transform intended to illustrate images at various angles and scales. It is a transform with multi-scale representation through various directions at each extent. This paper presents a novel algorithm for image denoising in medical ultrasound imaging. The proposed algorithm provides an efficient way to use the threshold algorithms to enhance ultrasound images based on curvelet transform and also suppresses noise present in the ultrasound images. The quantitative and qualitative comparisons show that proposed algorithm outperforms other existing algorithms used for medical ultrasound image denoising without blurring the edges and without causing over smoothing of detailed features of the image. The metrics used for evaluation are Coefficient of Correlation (CoC), Edge Preservation Index (EPI), Structural Similarity Index (SSIM) and Signal to Noise Ratio (SNR).

Keywords: Ultrasound imaging, Speckle noise, wavelet, curvelet, CoC, EPI, SSIM, SNR.

Introduction

Over the past many years, several imaging techniques have been invented such as ultrasound, digital radiography, CT scan, SPECT, MRI, spectroscopy and others [1]. These methods provide new clinician data about the internal structure of the human body that has never been existing prior to the field of diagnostic radiology. Out of all imaging techniques, the ultrasound imaging is a popular and inexpensive technique to detect the dynamical activities of organs. This procedure is used for imaging soft tissues in organs like liver, kidney, heart, brain, uterus etc [2]. It is anticipated that ultrasound involve above 30% of all medical imaging procedures. High frequency sound waves and their replicas are utilized in ultrasound imaging procedure.

Speckle Noise

It is a multiplicative noise. Speckle noise is present in many imaging methods such as Medical, Laser, Optical and SAR imagery [3]. This type of noise is caused by the intensity values of the pixels in the image which are multiplied by random values. Speckle noise in image becomes serious issue, due to causing difficulties for image representation. Speckle is formed by consistent processing of backscattered signals from several scattered targets.

$$P(x,y) = a(x,y).b(x,y) \qquad \ldots 1$$

Here, $a\ (x, y)$ is original signal and $b\ (x, y)$ is noise added into signal to get corrupted image $P\ (x, y)$. (x, y) represent the pixel position. Speckle noise follows a gamma distribution and it is given by:

$$F(g) = \frac{g^{\alpha-1}}{(\alpha-1)!a^{\alpha}} e^{\frac{-g}{a}} \qquad \ldots 2$$

wherea^{α} is variance, g is gray level and $F\ (g)$ is Gamma distribution.

Image Denoising

During acquisition, transmission and retrieval, images are often corrupted with noise [4]. Under low lighting conditions, many spots can be speckled in an image taken with a digital camera. Appearance of dots in an image is caused by the real signals getting degraded by noise (unwanted signals). Noise degrades both videos and images. The main idea behind an image denoising algorithm is to remove unwanted signals present in terms of noise [6]. A noisy image is not pleasing to view. Due to this, image denoising is required. Images are contaminated by various types of noise. Ultrasound images are contaminated by speckle noise.

Need of Image Denoising for Ultrasound Imaging

Ultrasound imaging is most widely used imaging technique due to real time imaging [5]. Unfortunately, the quality of medical ultrasound is restricted as a result of various factors, which initiate from physical phenomena underlying the image acquisition. The major problem of ultrasound imaging technique is presence of speckle noise during acquisition. Speckle noise is prone to decrease the contrast of image and give vague details of image, thereby decreasing the quality and consistency of ultrasound. Due to these reasons, there is difficulty in diagnosis.

Curvelet Transform

The curvelet transformation is an overview of the wavelet transform developed to symbolize images at various scales and angles [7]. It is a particular element of the multi-scale geometric transforms of objects. The curvelet transform is numerically tight frames and a multiscale pyramid with several directions and positions at every length scale and needle-shaped elements at fine scales [8]. Curvelets are better than wavelet transform because of following properties:

a) Best illustration of objects with sharp edges.
b) Optimal image reconstruction in many ill-posed problems.
c) Best thin demonstration of wave propagators.

Curvelets are used for demonstration of multi-scale objects. Some examples of curvelets at different scales, orientations and locations are shown in Fig. 1 [9].

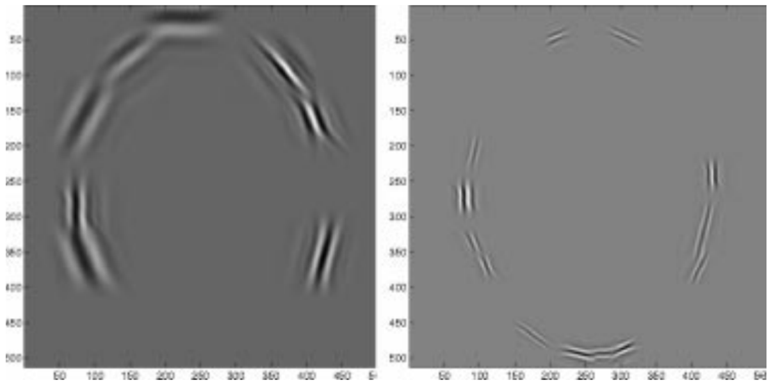

Figure 1: A few curvelets at different scales, orientations and locations

Proposed Algorithm

The proposed work is directed towards the fulfillment of the following objectives:

a. To design an algorithm for image denoising using curvelet transform combined with threshold method Neigh shrink.
b. To compare the results of proposed method with Curvelet Bayes and Curvelet Neigh shrink techniques.
c. To validate the algorithm.

The proposed algorithm for image denoising is as follows:

Step I: Load the noisy ultrasound image.
Step II: Applying Curvelet Transform to ultrasound image.
Step III: Noisy image is decomposed into different layers. Every layer has information of different frequencies bands.
Step IV: Next step is for a Smooth partioning, it divides the layer into small partitions.
Step V: Apply the Adaptive Neigh shrink. This step contains following steps:

a. Let g={set Q dyadic squares}
b. Let Wq={ coefficients of dyadic’s}
c. Let Bij is neighboring window between Wq_i& Wq_j
d. The obtained values from Wq_i & Wq_j will give the shrinked dyadic squares D_i. In the same fashion we will compute all dyadic squares and further these dyadic squares are sent for renormalization.

Step VI: In Renormalization stage, each dyadic square is renormalized via particular method.
Step VII: Reconstruction is done by taking inverse of curvelet transform.
Step VIII: Get final output image.

Flowchart for Proposed Algorithm

In this, an image is loaded with some speckle noise. The noisy image is decomposed into different layers. Then Smooth partioning is performed on image, it divides the layer into small partitions. After this phase, apply the Adaptive Neigh shrink algorithm. In Renormalization stage, each dyadic square is renormalized via particular method. Next reconstruction is done by taking inverse of curvelet transform and get final output image.

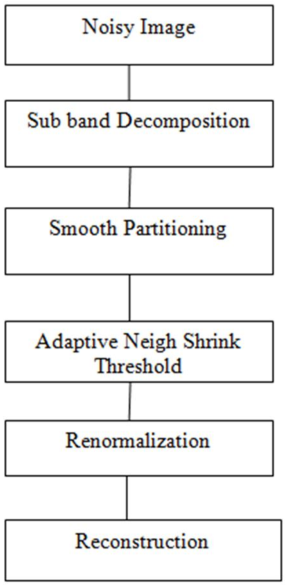

Figure 2. shows the flow of the steps followed for image denoising of ultrasound images using proposed algorithm

Results and Discussions

The medical ultrasound images are successfully denoised using adaptive curvelet transform while preserving edges. The first aim of this thesis work is to propose an algorithm which is simple and effective for image denoising based upon curvelet transformation approach.

To fulfill the second objective, the performance of proposed algorithm for ultrasound images is compared with the results of existing state-of-the-art algorithms. The visual results in figure 3 and figure 4 demonstrate that the proposed algorithm give better visual outcomes in comparison to earlier algorithms. The proposed algorithm significantly increases the quality, while retaining the important details or features of edges. For objective evaluation, quality metrics such as Coefficient of Correlation (CoC), Structural Similarity Index (SSIM), Signal to Noise Ratio (SNR), Edge Preservation Index (EPI) is used.

Edge Preservation Index

Edge Preservation Index (EPI) is calculated as follows [18]:

$$\mathrm{EPI} = \frac{\sum(\Delta x-\Delta\bar{x})(\Delta y-\Delta\bar{y})}{\sum(\Delta x-\Delta\bar{x}))^2(\Delta y-\Delta y)^2)} \qquad \ldots 3$$

where Δx and Δy are the high pass filtered versions of images x and y, obtained with a 3×3 pixel standard estimation of the Laplacian operator. The $\Delta\overline{x}$ and $\Delta\overline{y}$ are the mean values of the high pass filtered versions of Δx and Δy respectively. If the value of EPI is greater, then it provides a good sign of image quality.

Coefficient of Correlation (CoC)

It shows the power and orientation of linear relationship between the original and reconstructed images. If the value of CoC is 1, then there occurs stronger relationship between the original and reconstructed image. Coefficient of Correlation is computed as follows [18]:

$$\mathrm{CoC} = \frac{(x-\bar{x})(y-\bar{y})}{\sqrt{(x-\bar{x})^2(y-\bar{y})^2}} \qquad \ldots 4$$

where $\overline{x}$ and $\overline{y}$ are the mean of the original and denoised image respectively.

Signal-to-Noise Ratio (SNR)

It is defined as ratio between signal powers to noise power of the corrupting signal. It is one of essential statistical parameter for quality measurement of an image or signal. SNR is the ratio of the original signal to noise. SNR is calculated as:

$$SNR = 10\log_{10}\frac{\sigma_j^2}{\sigma_e^2} \qquad \ldots 5$$

where σ_j^2 variance of noise free is reference image and σ_e^2 is variance of error between original and denoised image. The value of signal to noise ratio should be large for good quality image.

Structural Similarity Index (SSIM)

The SSIM is an index that measures the similarity between two images. The SSIM is measured on different window sizes of an image. The resultant SSIM index is a decimal value exists between -1 and 1; in the case of two identical sets of data, output is 1. Let the measure between two windows f and g. This window is common size metric $N \times N$. It can be derived from the formula [19]:

$$\mathrm{SSIM(f,g)} = \mathrm{l(f,g)}^{\alpha}.\,\mathrm{c(f,g)}^{\beta}.\,\mathrm{s(f,g)}^{\gamma} \qquad \ldots 6$$

where $\alpha > 0, \beta > 0, \gamma > 0$

$$\mathrm{SSIM(f,g)} = \frac{(2\mu_f\mu_g + c_1)(2\sigma_f\sigma_g + c_2)}{(\mu_f^2 + \mu_g^2 + c_1)(\sigma_f^2 + \sigma_g^2 + c_2)} \qquad \ldots 7$$

where, μ_f is the average of f, μ_g is the average of g , σ_f^2 is the variance of f, σ_g^2 is the variance of g , μ_{f_g} is the covariance of f and g , C1 = (k1, L)2 and C2 = (k2, L)2 are two variables that stabilize the division with weak denominator and L is the dynamic range of pixel value and by default k1= 0.01 and k2 = 0.03.

Visual results

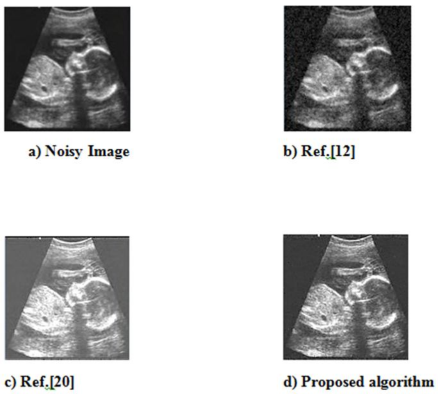

Figure 3: Visual Comparison of image denoising algorithms with proposed algorithm for "Ui1.jpg"

Noisy image of ultrasound is shown in Figure 3(a), yielding the noisy image is then denoised by the different denoising algorithms. The result of Ref. [8] is revealed in Figure 3(b). The result of Ref. [11] is shown in Figure 3(c). After the reconstruction phase, the results of denoised image by proposed algorithm is shown in Figure 3(d).

Noisy image of ultrasound is shown in Figure 4(a), yielding the noisy image is then denoised by the different denoising algorithms. The result of Ref.[8] is revealed in Figure 4 (b). The result of Ref. [11] is shown in Figure 4(c). After the reconstruction phase, the results of denoised image by proposed algorithm is shown in Figure 4(d).

Validation of the proposed algorithm has been done by using a synthetic image' Synth.tif'. Table 1 shows the comparison results for the above metrics values for the image' Synth.tif'.

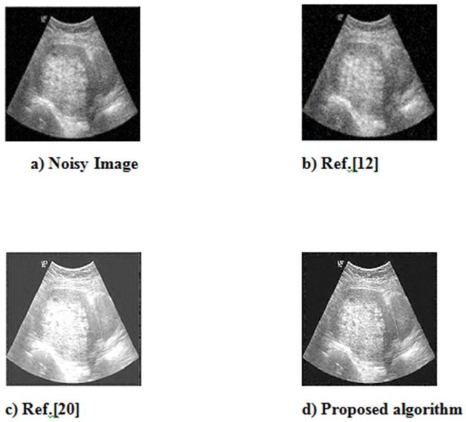

Figure 4: Visual Comparison of image denoising algorithms with proposed algorithm for “Ui2.jpg”

The results from table 1 proved that the values of proposed algorithm for quality metric are higher than the other denoising algorithms. The proposed algorithm outperforms in terms of quality metric in addition to visual quality and increase the quality to a great extent.

Table 1:Image quality measures obtained by various denoising algorithms tested on 128 × 128 synthetic image at three different noise levels (σ = 0.3, 0.35, 0.4)

Method	Quality Measures			
	SNR(dB)	CoC	EPI	SSIM
Speckled input image (σ = 0.3)				
Ref.[8]	22.9275	0.9922	0.8963	0.8081
Ref.[11]	23.1726	0.9923	0.9012	0.8131
Proposed algorithm	23.9127	0.9927	0.9047	0.8140
Speckled input image (σ = 0.35)				
Ref.[8]	21.5114	0.9892	0.8692	0.7651
Ref.[11]	21.9208	0.9853	0.8705	0.7660
Proposed algorithm	22.5339	0.9897	0.8715	0.7678
Speckled input image (σ = 0.4)				
Ref.[8]	20.4839	0.9863	0.8341	0.7262
Ref.[11]	20.7336	0.9865	0.8332	0.7302
Proposed algorithm	21.4275	0.9871	0.8358	0.7333

SNR = signal-to-noise ratio, CoC = coefficient of correlation, EPI = edge preservation index, SSIM = structural similarity index. The SNR is given in dB and the other parameters (CoC, EPI and SSIM) are the unit-less quantities [12].
From table 4.1, it may be observed quantitatively that existing denoising algorithms blurs the resulting images to such an extent that important image details such as edges are suppressed along with speckle. The low values of quality metrics such as EPI and SSIM for these algorithms also support this observation. The proposed algorithm significantly reduce speckle in regions, while maintaining the resolution and sharp features of the original image. The proposed algorithm with high value of SNR, EPI guarantees lower distortion and less interference caused by presence of noise. [12]. Thus, the proposed algorithm provides better image quality. All these results demonstrate that the proposed algorithms are competitive with other state-of-the-art image denoising algorithms.

Conclusion

In this proposed work, an image denoising algorithm for medical ultrasound images using curvelet transform is proposed. The proposed algorithm based on curvelet transform when compared to other traditional denoising methods outperforms these algorithms. The visual results show that proposed denoising algorithm yields significantly better visual quality and better values of SNR, EPI, SSIM and CoC as compared to other algorithms for image denoising. Thus the proposed algorithm preserves all the detail information of the image and suppresses the noise in a better way than other denoising algorithms. Synthetic image is used for the validation purpose. The comparative study of the results for synthetic image between proposed and other denoising algorithms show that the suggested denoising algorithm outperforms other algorithms without over smoothing the image and preserves detail and edge information.

Future Scope

For future work, the other stages of curvelet transformation may be improved to find out the better results. This algorithm can be used in other type of images like Remote sensing images, X-ray images, SAR images etc. Other quality metrics can be used to judge the performance of this algorithm. This algorithm can be used in other modalities to get better quality of the images.

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