Speckle Noise Reduction in Ultrasound Images

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Abstract- Ultrasound imaging is a widely used medical imaging modality because it is safe, allows real-time visualization of moving structures, and is relatively inexpensive. But the major issue with ultrasound images is the presence of speckle noise, which is an inherent limitation of ultrasound images. Various filters are used to reduce the speckle noise and to enhance the quality of the image. This work focuses on the study of various filters used for image enhancement.

Keywords- Denoising Filters, Digital Image Processing, Image Enhancement, Qualitative Metrics.

I. INTRODUCTION

Ultrasound is a widely used medical imaging modality. The use of ultrasound has expanded enormously over the last two decades, largely due to the fact that it is safe, allows real-time visualization of moving structures, suitable for many clinical applications, and is relatively inexpensive. However, like all imaging modalities, ultrasound is still subject to a number of inherent artifacts that compromise image quality and impair diagnostic utility. Medical images are usually degraded by noise during image acquisition and transmission process. But the most important is ‘speckle’, which is an inherent limitation of ultrasound images. Speckle reduces image contrast and detail resolution, and makes it difficult to identify abnormal tissue patterns (or texture) that may indicate disease. The main purpose of the noise reduction technique is to remove speckle noise by retaining the important feature of the images.

A. Speckle Noise

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 [2]

\[ g(n,m) = f(n,m) \cdot u(n,m) + \xi(n,m) \] ........................(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 [3]:

\[ g(n,m) = f(n,m) \cdot u(n,m) + \xi(n,m) \] ........................(2)

Speckle noise degrades the quality of the ultrasound image. Thus it is necessary to remove speckle noise from the image to enhance its quality. Various techniques used for speckle noise reduction are discussed below.

B. De-noising filtering techniques

De-noising filtering techniques includes various filters that are used for removing noise from the images. Input to the filter is a noise polluted image and output is a filtered (denoised) image. Filtering of the image is done on the basis of various formulas used in different filters. Denoising filtering techniques are broadly classified into two categories which are basic filtering and homomorphic filtering.

1) Basic Filtering: Basic filters use mathematical formulae for filtering noise from the images. Some basic filters used for the purpose of speckle noise reduction in ultrasound images are median filter, weiner filter, lee filter etc.

2) Homomorphic Filtering: Homomorphic filtering technique is one of the important ways used for digital image enhancement, especially when the input image is suffers from poor illumination conditions. This filtering technique has been used in many different imaging applications, including biometric, medical, and robotic vision. Homomorphic filtering works in frequency domain, by applying a high-pass type filter to reduce the significance of low frequency components. [8] It simultaneously normalizes the brightness across an image and increases contrast. Here homomorphic filtering is used to remove multiplicative noise. Illumination and reflectance combine multiplicatively, the components are made additive by taking the logarithm of the image intensity, so that these multiplicative components of the image can be separated linearly in the frequency domain. [9]

C. Image Enhancement

Image enhancement is basically improving the interpretability or perception of information in images for human viewers and providing ‘better’ input for other automated image processing techniques. The principal objective of image enhancement is to modify attributes of an image to make it more suitable for a given task and a specific observer. During
this process, one or more attributes of the image are modified. There exist many techniques that can enhance a digital image without spoiling it. The enhancement methods can broadly be divided into two categories which are spatial domain and frequency domain. In spatial domain techniques, we directly deal with the image pixels. The pixel values are manipulated to achieve desired enhancement. In frequency domain methods, the image is first transferred in to frequency domain. It means that, the Fourier Transform of the image is computed first. All the enhancement operations are performed on the Fourier transform of the image and then the Inverse Fourier transform is performed to get the resultant image.

D. Quantitative Metrics

Quality of an image is a characteristic of an image that best measures the perceived image degradation. Quantitative metrics are quantitative measures that automatically predict the perceived image quality. Commonly used quantitative metrics are described below.

1) Signal-to-noise ratio (SNR): Signal-to-noise ratio (SNR or S/N) is a measure used in engineering that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise. Signal-to-noise ratio is defined as the power ratio between a signal (meaningful information) and the background noise (unwanted signal): 

\[ \text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}} \]  

(3)

2) Peak Signal to Noise Ratio (PSNR): The term peak signal-to-noise ratio (PSNR) is an expression for the ratio between the maximum possible value (power) of a signal and the power of distorting noise that affects the quality of its representation. The PSNR is usually expressed in terms of the logarithmic decibel scale.

\[ \text{PSNR} = 10 \log_{10} \frac{L^2}{\text{MSE}} \]  

(4)

where MSE is Mean Square Error and is computed as:

\[ \text{MSE} = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} (X(i,j) - Y(i,j))^2 \]  

(5)

where ‘X(i,j)’ is the original image and ‘Y(i,j)’ is the noised image.

3) Correlation Coefficient(r): A measure that determines the degree to which two variable's movements are associated. The correlation coefficient varies from -1 to +1. Correlation Coefficient(r) is defined as:

\[ r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2} \sqrt{\sum (y_i - \bar{y})^2}} \]  

(6)

where \( x_i \) is the intensity of the \( i \)-th pixel in image 1 and \( y_i \) is the intensity of the \( i \)-th pixel in image 2. \( \bar{x}_m \) is the mean intensity of image 1 and \( \bar{y}_m \) is the mean intensity of image 2.

4) Edge Performance Index (EPI): EPI stands for Edge Performance Index, which can be mathematically stated by the following formula:

\[ \text{EPI} = \frac{\sum_{i,j} (f(i,j) - m_1)(y(i,j) - m_2)}{\{(f(i,j) - m_1)^2 + (y(i,j) - m_2)^2\}} \]  

(7)

where ‘F(i,j)’ and ‘Y(i,j)’ are the edge map images of the original image f(i,j) and the distorted image y(i,j) respectively. ‘m_1’ and ‘m_2’ are the mean of the edge maps of original and the distorted images respectively.

II. RELATED WORK

Rangaraju, K.S. et al. (2012) [1] in paper “Quantitative Image Quality Assessment-Medical Ultrasound Images” have described that quality of an image is a characteristic of an image that best measures the perceived image degradation. When it comes to image quality assessment there are two types of assessment which are subjective Image Quality Assessment and Objective Image Quality Assessment.

Paulo J. S. G. Ferreira (2001) [5] in paper “Sorting Continuous-Time Signals: Analog Median and Median-Type Filters” has discussed the analog median filter and other ranked-order filters. The analog median filter is defined in terms of the (unique) non increasing left-continuous sorting. The rate of convergence of the digital median filter to the analog median filter is discussed and related to the signal sampling period, the duration of the filter window, and the smoothness of the input signal. This paper introduces the concept of noise width and studies the effect of additive and multiplicative noise at the output of the analog median filter in terms of the noise width and the smoothness of the input signal.

Michailovich, O.V. et al. (2006) [6] in paper “Despeckling of Medical Ultrasound Images” have elaborated the concept of speckle noise. Speckle noise is a phenomenon that accompanies all coherent imaging modalities in which images are produced by interfering echoes of a transmitted waveform that emanate from heterogeneities of the studied objects. Although speckle noise is a random process, it is not devoid of information. A new method for improving the performance of homomorphic despeckling methods has been presented in this paper.

Abraham, B.A. et al. (2011) [7] in paper “Speckle Noise Reduction Method Combining Total Variation and Wavelet Shrinkage for Clinical Ultrasound Imaging” have described the importance of ultrasound imaging. A new speckle reduction method and coherence enhancement of ultrasound images based on method that combines total variation (TV) method and wavelet shrinkage is discussed. In this method, a noisy image is decomposed into sub bands of LL, LH, HL, and HH in wavelet domain.

Sarode, M.V. et al. (2011) [3] in paper “Reduction of Speckle Noise and Image Enhancement of Images Using Filtering Technique” have described various filtering techniques used for speckle noise removal. Reducing noise from the medical image...
images, satellite images etc. are a challenge for the researchers in digital image processing. Medical images, Satellite images are usually degraded by noise during image acquisition and transmission process. Maini, R. et al. (2010) [2] in paper “A Comprehensive Review of Image Enhancement Techniques” have described that enhancement algorithms offer a wide variety of approaches for modifying images to achieve visually acceptable images. The choice of such techniques is a function of the specific task, image content, observer characteristics, and viewing conditions. Image Negative is suited for enhancing white detail embedded in dark regions and has applications in medical imaging. Power-law transformations are useful for general purpose contrast manipulation. Log Transformation is useful for enhancing details in the darker regions of the image at the expense of detail in the brighter regions the higher-level values.

Kaur, J. et al. (2013) [4] in paper “Speckle Noise Reduction in Ultrasound Images Using Wavelets: A Review” have explained that Biomedical images are generally corrupted by speckle noise and Gaussian noise. Latest domain in the field of Image denoising and compression is using wavelet analysis. Multiresolutional image analysis using wavelets is the latest modification in the field of image enhancement and denoising. Saleh, S.A.M. et al. (2012) [8] in survey “Mathematical Equations for Homomorphic Filtering in Frequency Domain: A Literature Survey” have described that homomorphic filtering technique is one of the important ways used for digital image enhancement, especially when the input image is suffers from poor illumination conditions. This filtering technique has been used in many different imaging applications, including biometric, medical, and robotic vision. Homomorphic filtering works in frequency domain, by applying a high-pass type filter to reduce the significance of low-frequency components.

Joy, J. et al. (2013) [10] in paper “Denoising Using Soft Thresholding” have presented a comparative study of different wavelet denoising techniques. The principal work on denoising is done by Donoho, which is based on thresholding the DWT of the signal. The method relies on the fact that noise commonly manifests itself as fine-grained structure in the signal, and WT provides a scale-based decomposition.

Jain, A. et al. (2011) [12] in paper “A Full-Reference Image Quality Metric for Objective Evaluation in Spatial Domain” have presented a new full-reference image quality metric for objective assessment in spatial domain. Quantitative measurement of image quality is presently an active area of research with the growing development in image acquisition and processing systems. The central idea for objective assessment of image quality is to develop a metric whose mathematical assessment is consistent to that of subjective assessment by human observation.

Yen, E.K. et al. (1996) [11] in paper “The Ineffectiveness of the Correlation Coefficient for Image Comparisons” have stated that Pearson’s linear correlation coefficient is widely used for comparing images. Pearson’s correlation coefficient (r) is widely used in statistical analysis, pattern recognition and image processing. Typically, the correlation coefficient is used to compare two images of the same object taken at different times. The r value indicates whether the object has been altered or moved.

### III. SIMULATION RESULTS

Simulation results of various filters in matlab are shown below:

![Fig.1 Denoising of Ultrasound image corrupted by Speckle Noise of Variance of 0.1.](image)


### IV. CONCLUSION

The median filter is a simple technique and it removes the speckle noise from an image and also removes pulse or spike noise but the main disadvantage is the extra computation time needed to calculate median. Wiener filter performs little smoothing where the variance is large and performs more smoothing where the variance is small. The Lee filter is based on the approach that if the variance over an area is low or constant, then the smoothing will be performed. The main disadvantage is that it tends to ignore speckle in the areas closest to edges and lines. BayesShrink is based on homomorphic filtering technique. The goal of this method is to minimize the Bayesian risk. On the whole, BayesShrink produces better quantitative and qualitative results as compared to other filters.
REFERENCES


