Volume 3, Issue 3, March 2013 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Speckle Noise Reduction in Ultrasound Images Using Wavelets: A Review

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ABSTRACT- Biomedical images are generally corrupted by speckle noise and Gaussian noise. Speckle noise is multiplicative type whereas other noises like Gaussian noise are additive type. It is difficult to remove multiplicative noise from images. We have presented various techniques for removing speckle noise from images and image enhancement by thresholding using various spatial domain filters and Wavelet analysis on the corrupted images have been discussed. 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. Wavelet analysis represents the next logical step: a windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information. Speckle Noise is the high frequency content in the ultrasound images and can be easily removed using wavelet based thresholding technique. This paper presents study of various techniques for removal of speckle noise from images, used in biomedical applications, such as Spatial and frequency domain filter and a modified algorithm for speckle noise reduction using wavelet based multiresolutional analysis and thresholding function has been proposed incorporating different wavelets such as Haar, Coiflets and Symlets.

KEYWORDS: Speckle Noise, Image Enhancement, Approximation and Detail Coefficients, Multiresolutional Analysis

1. Introduction

In Recent years, many studies have been made on wavelets. An excellent overview of what wavelets have brought to the fields as diverse as biomedical applications, wireless communications, computer graphics or turbulence, is given in [1]. Image enhancement and denoising is one of the most visible applications of wavelets. An image is often corrupted by noise since its acquisition or transmission. The goal of de-noising is to remove the noise while retaining as much as possible the important signal features of an image. Traditionally, this is achieved by linear processing such as Wiener filtering [1]-[3]. A vast literature has emerged recently on signal de-noising using nonlinear techniques, in the setting of speckle noise. The image analysis process can be broken into three primary stages which are pre-processing, data reduction, and features analysis. Removal of noise from an image is the one of the important tasks in image processing. Depending on nature of the noise, such as additive or multiplicative noise, there are several approaches for removal of noise from an image [1]-[2]. Medical images are usually corrupted by noise in its acquisition and Transmission. The main objective of Image denoising techniques is necessary to remove such noises while retaining as much as possible the important signal features. Introductory section offer brief idea about different available denoising schemes. Ultrasonic imaging is a widely used medical imaging procedure because it is economical, comparatively safe, transferable, and adaptable. Though, one of its main shortcomings is the poor quality of images, which are affected by speckle noise. The existence of speckle is unattractive since it disgrace image quality and it affects the tasks of individual interpretation and diagnosis. Accordingly, speckle filtering is a central pre-processing step for feature extraction, analysis, and recognition from medical imagery measurements. Previously a number of schemes have been proposed for speckle mitigation. The rapid increase in the range and use of electronic imaging justifies attention for systematic design of an image processing system and for providing the image quality needed in different applications [2]. The basic measure for the performance of a enhancement algorithm is mean square error or PSNR (Picture Signal to Noise Ratio). However, Quality and compression can also vary according to input image characteristics and content.In image processing, image is corrupted by different type of noises. An appropriate method for speckle reduction is one which enhances the signal to noise ratio while conserving the edges and lines in the image. Filtering techniques are used as preface action before segmentation and classification. On the whole speckle reduction can be divided roughly into two categories. The first one recovers the image by summing more than a few observations of the same object which suppose that no change or motion of the object happened during the reception of observations. Statistical filter like Weiner filter [1] adopted filtering in the spectral domain, but the classical Wiener filter is not adequate while it is designed primarily for additive noise

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suppression [2].To address the multiplicative nature of speckle noise, Jain developed a homomorphic approach, which by obtaining the logarithm of the image, translates the multiplicative noise into additive noise, and consequently applies the Wiener. Adaptive filter takes a moving filter window and estimates the statistical information of all pixels' grey value, such as the local mean and the local variance. The central pixel's output value is dependent on the statistical information. Adaptive filters adapt themselves to the local texture information surrounding a central pixel in order to calculate a new pixel value. Adaptive filters generally incorporate the Kuan filter, Lee filter, Frost filter, Gamma MAP filters [3], [4], [5]. These filters made obvious their superiority measured up to low pass filters, since they have taken into account the local statistical properties of the image. Adaptive filters present much better than low-pass smoothing filters, in preservation of the image sharpness and details while suppressing the speckle noise [6].

Figure 1: Ultrasound Image corrupted by speckle noise

In the process of image denoising using wavelet based transform technique, two-dimensional (2-D) images are transformed from the spatial domain to the frequency domain. An effective transform will concentrate useful information into a few of the low-frequency transform coefficients. An HVS is more sensitive to energy with low spatial frequency than with high spatial frequency.

2. Related Work, Issues and Possible Solutions

Digital image acquisition and processing techniques play an important role in current day medical diagnosis. Images of living objects are taken using different modalities like X-ray, Ultrasound, Computed Tomography (CT), Medical Resonance Imaging (MRI) etc. [1] Highlights the importance of applying advanced digital image processing techniques for improving the quality by removing noise components present in the acquired image to have a better diagnosis. [1] also shows a survey on different techniques used in ultrasound image denoising. [2] has presented the work on use of wiener filtering in wavelet domain with soft thresholding as a comprehensive technique. Also, [2] compares the efficiency of wavelet based thresholding (Visushrink, Bayesshrink and Sureshrink) technique in despeckling the medical Ultrasound images with five other classical speckle reduction filters. The performance of these filters is determined using the statistical quantity measures such as Peak-Signal-to-Noise ratio (PSNR) and Root Mean Square Error (RMSE). Based on the statistical measures and visual quality of Ultrasound B-scan images the wiener filtering with Bayes shrink thresholding technique in the wavelet domain performed well over the other filter techniques.[3] has presented different filtration techniques (wiener and median) and a proposed novel technique that extends the existing technique by improving the threshold function parameter K which produces results that are based on different noise levels. A signal to mean square error as a measure of the quality of denoising was preferred.

3. Speckle Noise Model

Mathematically the image noise can be represented with the help of these equations below:

$$V(x, y) = g[u(x, y)] + \eta(x, y) \quad (1)$$

$$g[u(x,y)] = \iint h(x, y; x', y') u'(x', y') dx' dy' \quad (2)$$

$$\eta(x, y) = f[g(u(x, y))]\, \eta_1(x, y) + \eta_2(x, y) \quad (3)$$

Here u(x, y) represents the objects (means the original image) and v(x, y) is the observed image. Here h (x, y; x', y') represents the impulse response of the image acquiring process. The term ŋ(x, y) represents the additive noise which has an image dependent random components f [g(w)] ŋ1 and an image independent random component ŋ2. A different type of noise in the coherent imaging of objects is called speckle noise. Speckle noise can be modeled as

$$\mathbf{V(x, y) = u(x, y)s(x, y) + \eta(x, y)} \quad (4)$$

Where the speckle noise intensity is given by s(x, y) and ŋ(x, y) is a white Gaussian noise [1]-[3]. The main objective of image-de-noising techniques is to remove such noises while retaining as much as possible the important signal features. One of its main shortcomings is the poor quality of images, which are affected by speckle noise. The existence of speckle is unattractive since it disgraces image quality and affects the tasks of individual interpretation and diagnosis. Recently there have been many challenges to reduce the speckle noise using wavelet transform as a multi-resolution image-processing tool. Speckle noise is a high-frequency component of the image and appears in wavelet coefficients. The availability of an accurate and reliable model of speckle noise formation is a prerequisite for development of a valuable de-speckling algorithm. In ultrasound imaging, however, the unified definition of such a model still remains arguable. Yet, there exist a number of possible formulae whose probability was verified via their practical use. A possible generalized model of the speckle imaging is

$$g(n, m) = f(n, m)u(n, m) + \xi (n, m) \quad (5)$$

Where g, f, u and ξ stand for the observed image, original image, multiplicative component and additive component of the speckle noise basically. Here (*n* , *m*) denotes the axial and lateral indices of the image samples or, alternatively, the angular and range indices for B-scan images. When applied to ultrasound images, only the multiplicative component of the noise is to be considered; and thus, the model can be considerably simplified by disregarding the additive term, so that the simplified version of (5) becomes

$$g(n, m) = f(n, m)u(n, m) \quad (6)$$

Homomorphic de-speckling methods take advantage of the logarithmic transformation, which, when applied its converts the multiplicative noise to an additive one. Denoting the logarithms of g, f *and u* by *gl, fl,* and *ul,* respectively, the measurement model becomes

$$g\,1(n, m) = f1\,(n, m)u1\,(n, m) \quad (7)$$

At this stage, the problem of de-speckling is reduced to the problem of rejecting an additive noise, and a variety of noise-suppression techniques could be evoked in order to perform this task [1]-[14].

4. Image Enhancement And Denoising Techniques

Recently many challenges have been made to reduce the speckle noise using wavelet transform as a multi-resolution image processing tool. Speckle noise is a high-frequency component of the image and appears in wavelet coefficients. One widespread method exploited for speckle reduction is wavelet shrinkage. When multiplicative contamination is concerned; multiscale methods engage a pre-processing step consisting of a logarithmic transform to separate the noise from the original image. It is an ultrasound-based diagnostic medical imaging technique used to visualize muscles and many internal organs, their size, structure and any pathological injuries with real time tomographic images. It is also used to visualize a fetus during routine and emergency prenatal care. Obstetric sonography is commonly used during pregnancy. It is one of the most widely used diagnostic tools in modern medicine. The technology is relatively inexpensive and portable, especially when compared with other imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT). It has no known long-term side effects and rarely causes any discomfort to the patient. Small, easily carried scanners are available; examinations can be performed at the bedside. Since it does not use ionizing radiation, ultrasound yields no risks to the patient. It provides live images, where the operator can select the most useful section for diagnosing thus facilitating quick diagnoses. This work aims to suppress speckle in Ultrasound images. Speckle noise affects all coherent imaging systems including medical ultrasound. Within each resolution cell a number of elementary scatterers reflect the incident wave towards the sensor. The backscattered coherent waves with different phases undergo a constructive or a destructive interference in a random manner. The acquired image is thus corrupted by a random granular pattern, called speckle that delays the interpretation of the image content. In the medical literature, speckle noise is referred as “texture”, and may possibly contain useful diagnostic information. The desired grade of speckle smoothing preferably depends on the specialist’s knowledge and on the application. For automatic segmentation, sustaining the sharpness of the boundaries between different image regions is usually preferred while smooth out the speckled texture. For visual interpretation, smoothing the texture may be less desirable. Physicians generally have a preference of the original noisy images more willingly than the smoothed versions because the filters even if they are more sophisticated can destroy some relevant image details. Thus it is essential to develop noise filters which can secure the conservation of those features that are of interest to the physician. The wavelet transform has recently entered the field of image denoising and it has firmly recognized its stand as a dominant denoising tool. Various spatial domain Filters that are used for removing speckle noise from ultrasound images have been explained below:

A. Median Filter

The best known order statistics filter is the median filter in image processing. The median filter is also the simpler technique and it also removes the speckle noise from an image and also removes pulse or spike noise [4]. Pulse functions of less than one-half of the moving kernel width are suppressed or eliminated but step functions or ramp functions are retained. The median filter considers each pixel in the image in turn and looks at its nearby neighbours to decide whether or not it is representative of its surroundings. Instead of simply replacing the pixel value with the mean of neighbouring pixel values, it replaces it with the median of those values. The median is calculated by first sorting all the pixel values from the surrounding neighbourhood into numerical order and then replacing the pixel being considered with the middle pixel value.

B. Weiner Filter

Wiener filter was purposed in the year of 1942, after N. Wiener. Wiener filter (a type of linear filter) is applied to an image adaptively, tailoring itself to the local image variance. Where the variance is large, Wiener filter performs little smoothing. Where the variance is small, Wiener performs more smoothing. This approach often produces better results than linear filtering. The adaptive filter is more selective than a comparable linear filter, preserving edges and other high-frequency parts of an image. However, wiener filter require more computation time than linear filtering. The inverse filtering is a restoration technique for deconvolution, i.e., when the image is blurred by a known lowpass filter, it is

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possible to recover the image by inverse filtering or generalized inverse filtering. However, inverse filtering is very sensitive to additive noise. The approach of reducing one degradation at a time allows us to develop a restoration algorithm for each type of degradation and simply combine them. The Wiener filtering executes an optimal tradeoff between inverse filtering and noise smoothing. It removes the additive noise and inverts the blurring simultaneously. The Wiener filtering is optimal in terms of the mean square error. In other words, it minimizes the overall mean square error in the process of inverse filtering and noise smoothing. The Wiener filtering is a linear estimation of the original image. The approach is based on a stochastic framework. The orthogonality principle implies that the Wiener filter in Fourier domain can be expressed as follows:

$$W(f_1, f_2) = \frac{H^*(f_1, f_2) S_{xx}(f_1, f_2)}{|H(f_1, f_2)|^2 S_{xx}(f_1, f_2) + S_{\eta\eta}(f_1, f_2)},$$

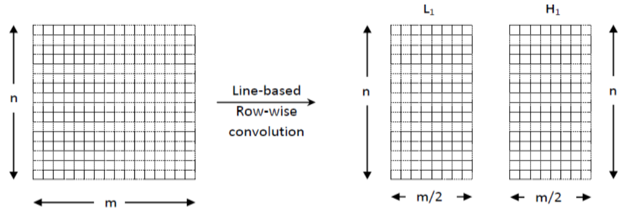
where S_{xx}(f1,f2), S_{nn}(f1,f2) are respectively power spectra of the original image and the additive noise, and H(f1,f2) is the blurring filter. It is easy to see that the Wiener filter has two separate part, an inverse filtering part and a noise smoothing part. It not only performs the deconvolution by inverse filtering (high pass filtering) but also removes the noise with a compression operation (low pass filtering).

C. Homomorphic Filtering

Homomorphic filtering is a generalized technique for signal and image processing, involving a nonlinear mapping to a different domain in which linear filter techniques are applied, followed by mapping back to the original domain. Homomorphic filter is sometimes used for image enhancement. It simultaneously normalizes the brightness across an image and increases contrast. Here Homomorphic filtering is used to remove multiplicative noise. Illumination and reflectance are not separable, but their approximate locations in the frequency domain may be located. Since 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. Illumination variations can be thought of as a multiplicative noise, and can be reduced by filtering in the log domain. To make the illumination of an image more even, the high-frequency components are increased and low-frequency components are decreased, because the high-frequency components are assumed to represent mostly the reflectance in the scene (the amount of light reflected off the object in the scene), whereas the low-frequency components are assumed to represent mostly the illumination in the scene. That is, high-pass filtering is used to suppress low frequencies and amplify high frequencies, in the log-intensity domain.

D. Discrete Wavelet Transform

Previous techniques of thresholding includes filtering in spatial domain, however, in wavelets, the complete analysis is shifted from spatial domain to frequency domain having both time –scale aspects. Wavelet transform (WT) represents an image as a sum of wavelet functions (wavelets) with different locations and scales [17]. Any decomposition of an image into wavelets involves a pair of waveforms: one to represent the high frequencies corresponding to the detailed parts of an image (wavelet function ψ) and one for the low frequencies or smooth parts of an image (scaling function Ø). The Discrete wavelet transform (DWT) has gained wide popularity due to its excellent decorrelation property, many modern image and video compression systems embody the DWT as the transform stage . It is widely recognized that the 9/7 filters are among the best filters for DWT-based image compression. In fact, the JPEG2000 image coding standard employs the 9/7 filters as the default wavelet filters for lossy compression and 5/3 filters for lossless compression. The performance of a hardware implementation of the 9/7 filter bank (FB) depends on the accuracy with which filter coefficients are represented. Lossless image compression techniques find applications in fields such as medical imaging, preservation of artwork, remote sensing etc [4] . Day-by- day Discrete Wavelet Transform (DWT) is becoming more and more popular for digital image compression. Biorthogonal (5, 3) and (9, 7) filters have been chosen to be the standard filters used in the JPEG2000 codec standard. Discrete wavelet transform as reported by Zervas et al., there are three basic architectures for the two-dimensional DWT: level-by-level, line-based, and block-based architectures. In implementing the 2-D DWT, a recursive algorithm based on the line based architectures is used. The image to be transformed is stored in a 2-D array. Once all the elements in a row is obtained, the convolution is performed in that particular row [2] . The process of row-wise convolution will divide the given image into two parts with the number of rows in each part equal to half that of the image. This matrix is again subjected to a recursive line-based convolution, but this time column-wise [2] . The result will DWT coefficients corresponding to the image, with the approximation coefficient occupying the top-left quarter of the matrix, horizontal coefficients occupying the bottom-left quarter of the matrix, vertical coefficients occupying the top-right quarter of the matrix and the diagonal coefficients occupying the bottom-right quarter of the matrix[3] .



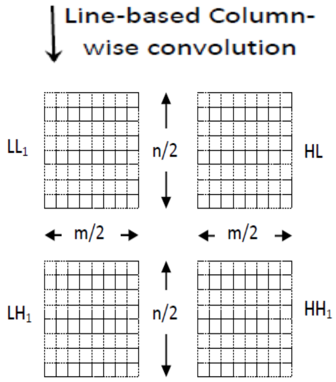


Figure 2: Line based Architecture for DWT

5. Multiresolution Analysis

Wavelet analysis represents the next logical step: a windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information.

Figure 5: Wavelet Transform on a signal

The decomposition process can be iterated, with successive approximations being decomposed in turn, so that one signal is broken down into many lower resolution components. This is called the wavelet decomposition tree.

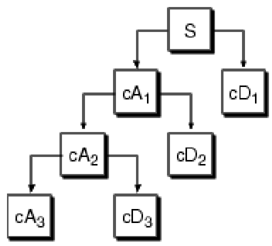


Figure 7: Multilevel Decomposition

Lifting schema of DWT has been recognized as a faster approach

- The basic principle is to factorize the polyphase matrix of a wavelet filter into a sequence of alternating upper and lower triangular matrices and a diagonal matrix.
- This leads to the wavelet implementation by means of banded-matrix multiplications

All the wavelet filters use wavelet thresholding operation for denoising [2], [11], [12].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 hard-thresholding is described as

$$\eta 1\ (w) = wI\ (|\ w\ |> T)$$

Where w is a wavelet coefficient, T is the threshold. The
Soft-thresholding function is described as

$$\eta 2\ (w) = (w - \text{sgn}\ (w)\ T)\ I\ (|\ w\ | > T\ )$$

Where sgn(x) is the sign function of x. The soft-thresholding rule is chosen over hard-thresholding, As for as speckle (multiplicative nature) removal is concerned a preprocessing step consisting of a logarithmic transform is performed to separate the noise from the original image. Then different wavelet shrinkage approaches are employed. The different methods of wavelet threshold denoising differ only in the selection of the threshold.

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6. Conclusion And Future Scope

Lifting schema of DWT has been recognized as a faster approach is used to perform the DWT to factorize the polyphase matrix of a wavelet filter into a sequence of alternating upper and lower triangular matrices and a diagonal matrix to achieve efficient compression. This leads to the wavelet implementation by means of banded-matrix multiplications. Algorithm follows a quantization approach that divides the input image in 4 filter coefficients and then performs further quantization on the lower order filter or window of the previous step. MATLAB software is used to implement the design. Discrete wavelet transform will be applied to construct the detail and approximation coeffients and after multilevel decomposition and filtering, reconstruction image will be created using reconstruction coeffients. In future, work can be done to implement this algorithm of multiresolutional analysis presented in this thesis on other types of medical imaging like CT Scan, MRI and EEG images under various different kinds of noise like speckle noise, gaussian noise, etc. Also, this work could be implemented on an FPGA to built an intelligent model that could be used for denoising in ultrasound images. Work could be done to minimize the constraints and resource utilization on FPGA implementation of this model.

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