Denoising Of Intravascular Ultrasound Images: A Comparative Study

Ruchita Gupta¹, Harjeet Kaur², Nidhish Tiwari³

¹Assistant Professor, Electronics & Communication Department, Global Institute of Technology & Management, Farrukhnagar, Gurgaon (Haryana)
²Associate Professor, Electronics & Communication Department, International Institute of Management, Engineering & Technology, Jaipur (Rajasthan)
³Associate Professor, Electronics & Communication Department, Jagannath Gupta Institute of Technology, Jaipur (Rajasthan)

Abstract—The major objective of the image Enhancement techniques is to emphasize & sharpen the features of images for better display & investigation. Medical images are affected by the Mixed Noise, which is the combination of Speckle & Gaussian Noise. Mixed Noise is an inherent property of Intravascular Ultrasound Imaging (IVUS) & it is generally tends to deteriorate the image quality, thereby reducing the diagnostic value of this medical imaging modality. As a result the noise reduction filtering is considered to be an important & essential procedure to be used, whenever IVUS image is used for atherosclerotic lesions assessment. In this paper, wiener filtering is used to reduce the mixed noise in IVUS Image. This method reduces the noise & hence the quality of the image is enhanced. Experimental results show a significant improvement in removing the mixed noise present in the IVUS Image by giving better PSNR & MSE values.

Keywords—Image Enhancement, Mixed Noise, Speckle Noise, Gaussian Noise, Wiener Filter, PSNR, MSE.

I. IMPORTANCE OF ULTRASOUND IMAGING

Image denoising is a procedure in digital image processing aiming at the removal of noise, which may corrupt an image during its acquisition or transmission, while retaining its quality. Image denoising still remains the challenge for researchers because noise removal introduces artifacts and causes blurring of the images. Medical ultrasonography is one of the popular techniques for imaging diagnosis and is preferred over other medical imaging modalities because it is noninvasive, portable and does not provide any harmful radiations. The disadvantage of ultrasonography is the poor quality of images, which is due to the presence of Mixed Noise.[8]

II. INTRODUCTION OF IVUS IMAGES

Intravascular ultrasound (IVUS) is a medical imaging methodology using a specially designed catheter with a miniaturized ultrasound probe attached to the distal end of the catheter. IVUS is a medical imaging technique for studying atherosclerotic disease.

It produces cross-sectional images of blood vessels that provide quantitative assessment of the vascular wall, information about the nature of atherosclerotic lesions as well as plaque shape and size. Automatic processing of large IVUS data sets represents an important challenge due to ultrasound speckle. An IVUS image is very grainy due to heavy speckle noise. The speckle noise prevents not only the medical interpretation of the IVUS image, but also the processing of medical images for computer-aided diagnoses (CADs)[1].

III. NOISE IN IVUS IMAGES

Speckle is a granular 'noise' that inherently exists in and degrades the quality of the active radar and synthetic aperture radar (SAR) 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. A speckled image is commonly modeled as:

\[ v = f + n \]

Where \( f = \{f_1, f_2, f_3, \ldots, f_n\} \) is a noise-free ideal image, \( V = \{v_1, v_2, v_3, \ldots, v_n\} \) speckle noise and \( u = \{u_1, u_2, u_3, \ldots, u_n\} \) is a unit mean random field.

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[12].

437
Gaussian noise represents statistical noise having probability density function (PDF) equal to that of the normal distribution, which is also known as the Gaussian distribution. In other words, the values that the noise can take on are Gaussian-distributed.

The probability density function \( P(z) \) of a Gaussian random variable \( z \) is given by:

\[
P(z) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(z-\mu)^2}{2\sigma^2}}
\]

Where \( z \) represents the grey level, \( \mu \) the mean value and \( \sigma \) the standard deviation.

Principal sources of Gaussian noise in digital images arise during acquisition e.g. sensor noise caused by poor illumination and/or high temperature, and/or transmission e.g. electronic circuit noise. In digital image processing Gaussian noise can be reduced using a spatial filter, though when smoothing an image, an undesirable outcome may result in the blurring of fine-scaled image edges and details because they also correspond to blocked high frequencies. Conventional spatial filtering techniques for noise removal include: wiener filtering, mean (convolution) filtering, median filtering and Gaussian smoothing.

IV. MODEL OF SPECKLE NOISE

The speckle noise model may be approximated as multiplicative and is given by:

\[
I(i,j) = R(i,j) u(i,j) + \alpha(i,j)
\]

Where \( I(i,j) \) is the noisy image and \( R(i,j) \) denotes the intensity of the image without speckle, \( u(t) \) and \( \alpha(t) \) are the multiplicative and additive components of the speckle noise respectively. When applied to ultrasound images, only the multiplicative component \( u \) of the noise is considered, hence, \( I \) can be considerably simplified by disregarding the additive noise term. This leads to the following simplified model (2):

\[
I(t) = R(t) u(t)
\]

Where \( t(i,j) \) is the spatial coordinates of the current pixel[10].

V. NEED FOR DENOISING

Thus, speckle & gaussian are considered as the dominant source of noise in ultrasound imaging and should be processed without affecting important image features. The main purposes for mixed noise reduction in medical ultrasound imaging are:

1. To improve the human interpretation of ultrasound images – mixed noise reduction makes an ultrasound image cleaner with clearer boundaries.
2. Denoising is a preprocess step for many ultrasound image processing tasks such as segmentation and registration – noise reduction improves the speed and accuracy of automatic and semiautomatic segmentation & registration[11].

VI. DENOISING OF IVUS IMAGES

The Wiener filter is a filter used to produce an estimate of a desired or target random process by linear time-invariant filtering an observed noisy process, assuming known stationary signal and noise spectra, and additive noise. The Wiener filter minimizes the mean square error between the estimated random process and the desired process.

The goal of the Wiener filter is to filter out noise that has corrupted a signal. It is based on a statistical approach. Typical filters are designed for a desired frequency response. However, the design of the Wiener filter takes a different approach. One is assumed to have knowledge of the spectral properties of the original signal and the noise, and one seeks the linear time-invariant filter whose output would come as close to the original signal as possible. Wiener filters are characterized by the following:

1. Signal and additive noise are stationary linear stochastic processes with known spectral characteristics or known autocorrelation and cross-correlation
2. The filter must be physically realizable/causal.
3. Performance criterion: minimum mean-square error (MMSE)

Figure 1 shows the block diagram of wiener filter that represents the prediction problem. The input signal, \( w[n] \) is fed into a predictor with tap-weights \( a_i \). The output of the predictor is \( x[n] \).

\[
\begin{align*}
& w[n] \\
& \rightarrow G(z) = \sum_{i=0}^{N} a_i z^{-i} \\
& \rightarrow x[n] \\
& \rightarrow s[n]
\end{align*}
\]

Figure 1: Block Diagram of Wiener Filter

It compares \( x[n] \) to desired signal denoted as \( s[n] \). The difference between these two signals is error signal, \( e[n] \). The idea behind the Wiener Filter is that we can select the optimum tap-weights \( a_i \) such that the error signal is minimized.
Types of Minimization:

The most common, and most mathematically method to minimize the mean-square error of the signal. That is, to minimize the average expected error, not any individual error value. A cost function $J$ as the expectation of error squared:

$$ J = E[e[n]e^*[n]] $$

Where $e^*[n]$ is the complex conjugate of system $e$.

To minimize cost function, the gradient of the cost function, and the point where the gradient is identically equal to zero:

$$ \nabla J = 0 $$

It is the vector gradient instead of the single-dimensional derivative, because eventually signals are become more complicated vectors.

VII. PERFORMANCE EVALUATION

The performance of wiener filter is evaluated quantitatively for IVUS Image with speckle & Gaussian Noise using the Quality Metrics like Peak signal to noise ratio (PSNR) & Mean Square Error (MSE).

Peak signal-to-noise ratio (PSNR), is the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. Because many signals have a very wide dynamic range, PSNR is usually expressed in terms of the logarithmic decibel scale.

PSNR is most easily defined via the mean squared error (MSE). Here X is original IVUS Image and Y is noisy image, MSE is defined as:

$$ MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [X(i,j) - Y(i,j)]^2 $$

The PSNR is defined as:

$$ PSNR = 10 \cdot \log_{10} \left( \frac{MAX^2}{MSE} \right) $$

Here, MAX is the maximum possible pixel value of the image. When the pixels are represented using 8 bits per sample, this is 255. More generally, when samples are represented using linear PCM with B bits per sample, MAX is $2^B - 1$.

VIII. EXPERIMENTAL RESULTS

The experimentation is carried out on IVUS Images using wiener filter.

In TABLE I the PSNR & MSE values of the denoised image are presented. Comparing the values of PSNR & MSE for degraded & enhanced Image with different gaussian noise & constant speckle variance.

<table>
<thead>
<tr>
<th>Speckle Noise</th>
<th>Gaussian Noise</th>
<th>PSNR</th>
<th>MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.01</td>
<td>23.0932</td>
<td>25.4429</td>
</tr>
<tr>
<td>0.1</td>
<td>0.04</td>
<td>19.5173</td>
<td>21.8673</td>
</tr>
<tr>
<td>0.1</td>
<td>0.08</td>
<td>17.4364</td>
<td>19.6392</td>
</tr>
<tr>
<td>0.1</td>
<td>0.1</td>
<td>16.6957</td>
<td>18.8829</td>
</tr>
<tr>
<td>0.1</td>
<td>0.4</td>
<td>12.8393</td>
<td>14.8151</td>
</tr>
<tr>
<td>0.1</td>
<td>0.8</td>
<td>11.5865</td>
<td>13.5586</td>
</tr>
</tbody>
</table>

In TABLE II the PSNR & MSE of the denoised results are presented. Comparing the values of PSNR & MSE for degraded & enhanced Image with different speckle variance & constant gaussian noise.

<table>
<thead>
<tr>
<th>Speckle Noise</th>
<th>Gaussian Noise</th>
<th>PSNR</th>
<th>MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>0.1</td>
<td>16.9948</td>
<td>19.0771</td>
</tr>
<tr>
<td>0.04</td>
<td>0.1</td>
<td>16.9033</td>
<td>18.9805</td>
</tr>
<tr>
<td>0.08</td>
<td>0.1</td>
<td>16.6990</td>
<td>18.8605</td>
</tr>
<tr>
<td>0.1</td>
<td>0.1</td>
<td>16.6805</td>
<td>18.8710</td>
</tr>
<tr>
<td>0.4</td>
<td>0.1</td>
<td>16.0933</td>
<td>18.6293</td>
</tr>
<tr>
<td>0.8</td>
<td>0.1</td>
<td>15.6437</td>
<td>18.3733</td>
</tr>
</tbody>
</table>

The original noise free IVUS image, noisy image with speckle variance 0.01 and the denoised image by wiener filter are shown in Figure 2.
Apart from PSNR & MSE measures, visual quality of the denoised image is usually used for calculating the denoising results. In Figure 3 the original IVUS Image, noisy image with speckle variance 0.03 and the denoised image by wiener filter are shown.

By comparing the denoised results using wiener filter in Figure 2, Figure 3 & Figure 4.

It can be concluded that wiener filter gives better PSNR & MSE value for enhanced image in comparison to degraded image. It shows in TABLE I & TABLE II.
IX. CONCLUSION

In this paper the experimentation is carried out on IVUS image using wiener filter for denoising the image.

The performance analysis of the experiment is done in terms of calculating PSNR & MSE values. The wiener filter is effective in removing speckle & gaussian noise and preserving edges. The denoising method using wiener filter gives better PSNR & MSE values for enhanced image in comparison to degraded image.

REFERENCES


