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Implementation of Some Speckle Filters on Digital Image and OCT Image

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Abstract— ***Optical Coherence Tomography (OCT) technology introduces speckle, an insidious form of multiplicative noise. Reduction of speckle noise is one of the post processing techniques to increase the quality of OCT images. Some of the existing speckle denoising filters were applied on digital image and on OCT image and their performances are compared in this paper. The objective evaluation of both the types of images was performed using various image metrics like peak signal to noise ratio, root mean square error and image quality index. The obtained results have been presented by filtered images, statistical tables and graphs.***

Keywords — Optical Coherence Tomography, Speckle Noise, Speckle denoising filters, PSNR, RMSE, IQI.

I. Introduction

Diagnostic imaging has become a phenomenal tool for medical diagnosis. The available technologies like Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) can provide non-invasive images of the human body. These techniques however, cannot generate high resolution images because of their physical limitations. To overcome this limitation, optical imaging has been being actively developed with the ultimate goal of high resolution ultrafast in-vivo imaging. One such technology is, Optical Coherence Tomography (OCT) a method for imaging the internal structure of biological tissue in vivo with micron resolution. OCT is based on the coherence properties of light. It enables the real-time, in situ visualization of tissue microstructure without the need to excise and process a specimen as in conventional biopsy and histopathology. One of its main limitations is the presence of speckle noise which obscures small and low-intensity features. "Coherence" in OCT technology introduces speckle, an insidious form of noise which degrades the quality of OCT images. Speckle arises as a natural consequence of the limited spatial-frequency bandwidth of the interference signals measured in optical coherence tomography (OCT) [1]. In images of highly scattering biological tissues, speckle has a dual role as a source of noise and as a carrier of information about tissue microstructure. There are different techniques developed to remove the speckle from the OCT image [2].

OCT images, as well as all other imaging modalities that involve a coherent light source, are affected by speckle noise. Speckle, arising from constructive and destructive interferences of the backscattered waves appears as a random granular pattern [1] that significantly degrades image quality and complicates further image processing tasks, like image segmentation and edge detection.

II. Speckle Noise

Speckle noise is a common phenomenon in all coherent imaging systems such as Ultrasound and Synthetic Aperture Radar imaging [3,4,9]. Speckle noise in OCT occurs due to the reflection of a laser beam from a rough surface which has a distinctive granular or mottled appearance. It is known to have Rayleigh distribution. Speckle is well modeled by a multiplicative noise. Multiplicative noise is a signal dependent form of noise whose magnitude is related to the value of the original pixel. It is a random signal where the average amplitude increases with the overall signal intensity[4,5]. It appears as bright specks in the lighter region of the image. It can be modeled as a pixel value multiplied by the random value. Speckle noise can be modeled as:

$$Y(x, y) = S(x, y).N(x, y) \qquad (1)$$

where Y, S and N represent the noisy data, signal and speckle noise, respectively. In order to change the multiplicative nature of the noise to additive one, a logarithmic transformation is applied to the image data [6,7]. Taking logarithm of the both sides of equation (1), leads to:

$$f(x,y) = s(x,y) + e(x,y) \qquad (2)$$

where f, s and e represent logarithms of the noisy data, signal and noise, respectively.

III. Types of Speckle Filters

A. Frost Filter

The Frost filter [8] replaces the pixel of interest with a weighted sum of the values within the n x n moving window. The weighting factors decrease with distance from the pixel of interest. The weighting factors increase for the central pixels as variance within the window increases. This filter assumes multiplicative noise and stationary noise statistics. It strikes a balance between averaging and the all-pass filter. In this case, the balance is achieved by forming an exponentially shaped filter kernel that can vary from a basic average filter to an identity filter on a pointwise, adaptive basis. Again, the response of the filter varies locally with the coefficient of variation. In case of low coefficient of variation, the filter is more average-like, and in cases of high coefficient of variation, the filter attempts to preserve sharp features by not averaging.

B. Lee Filter

The Lee filter[9], developed by Jong-Sen Lee, is an adaptive filter which changes its characteristics according to the local statistics in the neighborhood of the current pixel. The Lee filter is able to smooth away noise in flat regions, but leaves the fine details (such as lines and textures) unchanged. The Lee filter is designed to eliminate speckle noise while preserving edges and point features in radar imagery. Based on a linear speckle noise model and the minimum mean square error (MMSE) design approach, the filter produces the enhanced data. It uses small window (3×3, 5×5, 7×7). Within each window, the local mean and variances are estimated. The distinct characteristic of the filter is that in the areas of low signal activity (flat regions) the estimated pixel approaches the local mean, whereas in the areas of high signal activity (edge areas) the estimated pixel favors the corrupted image pixel, thus retaining the edge information. It is generally claimed that human vision is more sensitive to noise in a flat area than in an edge area. The major drawback of the filter is that it leaves noise in the vicinity of edges and lines. However, it is still desirable to reduce noise in the edge area without sacrificing the edge sharpness.

C. Anisotropic Diffusion(AD)

Anisotropic diffusion filters usually apply spatial regularization strategies. There are two representatives of anisotropic diffusion processes. They are called edge-enhancing anisotropic diffusion and coherence-enhancing anisotropic diffusion. The first one offers advantages at noisy edges, whereas the second one is well-adapted to the processing of one-dimensional features. In anisotropic diffusion [10] filter it is necessary to extract a family of derived images of multiple scales of resolution in order to be able to identify global objects through blurring. Anisotropic models do not only take into account the modulus of the edge detector, but also its direction. In the anisotropic diffusion method, the gradient magnitude is used to detect an image edge or boundary as a step discontinuity in intensity.

D. Wiener Filter

There are two methods: (i) Fourier- transform method (frequency-domain) and (ii) mean- squared method (spatial-domain) for implementing Wiener filter [11,12]. The former method is used only for complete restoration (denoising and deblurring), whereas the later is used for denoising. In Fourier transform method of Wiener filtering, normally it requires a priori knowledge of the power spectra of noise and the original image. But in mean-squared method no such a priori knowledge is required. Hence, it is easier to use the mean-squared method for image denoising. Wiener filter is based on the least-squared principle, i.e. the filter minimizes the mean-squared error (MSE) between the actual output and the desired output. Image statistics vary too much from a region to another even within the same image. Thus, both global statistics (mean, variance, etc. of the whole image) and local statistics (mean, variance, etc. of a small region or sub-image) are important. Wiener filtering is based on both the global statistics and local statistics. Wiener filtering estimates the original data with minimum mean-squared error and hence, the overall noise power in the filtered output is minimal.

IV. IMAGE METRICS

The quality of an image is examined by objective evaluation as well as subjective evaluation. For subjective evaluation, the image has to be observed by a human expert. The human visual system (HVS) [13] is so complicated that it is not yet modeled properly. There are various metrics used for objective evaluation of an image. Some of them are Mean Squared Error (MSE) , Root Mean Squared Error (RMSE), and Peak Signal to Noise Ratio (PSNR) [14, 15]. RMSE is an estimator in many ways to quantify the amount by which an noisy image differs from noiseless image. PSNR is the ratio between possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. Higher PSNR value provides higher image quality. The universal Image Quality Index (IQI) [15,16] is modeled by considering three different factors: (i) loss of correlation, (ii) luminance distortion and (iii) contrast distortion and they are represented in equation (6). It ranges between 0 and 1 and the optimum value of 1 is achieved only when □ $_f$ □= □ $_{\hat{f}}$.

$$MSE = \frac{\sum_{x=1}^{M}\sum_{y=1}^{N}(\hat{f}(x,y) - f(x,y)^2}{M \times N} \quad (3)$$

$$RMSE = \sqrt{MSE} \quad (4)$$

$$PSNR = 10.log_{10}(\frac{1}{MSE})db \quad (5)$$

$$\text{IQI} = \frac{\sigma_{f\hat{f}}}{\sigma_f\sigma_{\hat{f}}}.\frac{2\bar{f}\bar{\hat{f}}}{(\bar{f})^2+(\bar{\hat{f}})^2}.\frac{2\sigma_f\sigma_{\hat{f}}}{\sigma_f^{\,2}+\sigma_{\hat{f}}^{\,2}} \quad (6)$$

TABLE I: CALCULATED VALUES OF IMAGE METRICS LIKE RMSE, PSNR AND IQI FOR BOTH DIGITAL AND OCT IMAGE.

	Digital Image			**OCT Image**		
	RMSE	**PSNR**	**IQI**	**RMSE**	**PSNR**	**IQI**
Frost	6.5937	31.75	0.9989	4.3619	35.34	0.5664
Lee	5.5732	33.21	0.9997	3.3685	37.58	0.5733
Anisotropic Diffusion	5.598	32.60	0.9999	3.6593	36.86	0.5026
Wiener[3*3]	5.1358	33.92	0.9999	2.3151	40.84	0.5750
Wiener[5*5]	6.0016	32.57	0.9998	2.8186	39.13	0.4739
Wiener[7*7]	6.2057	32.27	0.9995	3.1724	38.10	0.4614

V. RESULTS

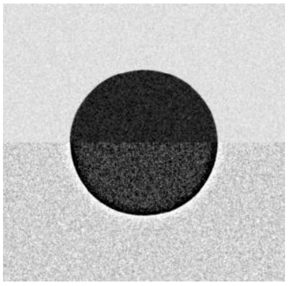

Fig. 1 Digital Image

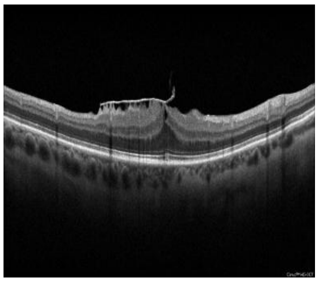

Fig. 8 OCT Image

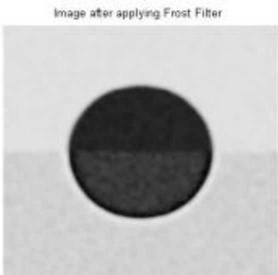

Fig.2 Frost filter

Fig. 9 Frost filter

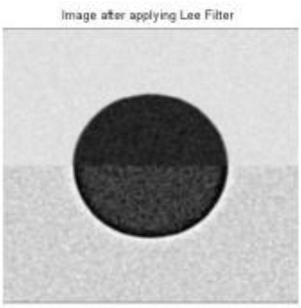

Fig. 3 Lee filter

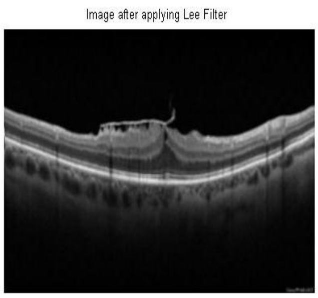

Fig 10. Lee filter

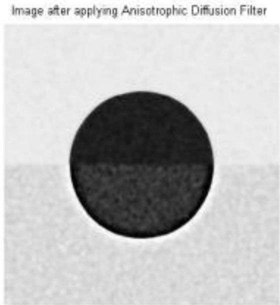

Fig. 4 Anisotrophic filter

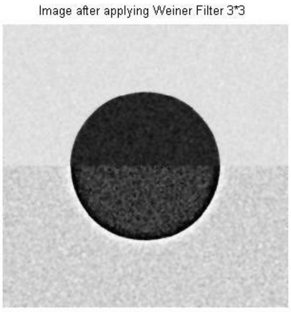

Fig 5 Wiener filter[3*3]

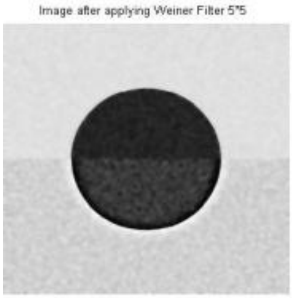

Fig. 6 Wiener filter[5*5]

Fig. 7 Wiener filter[7*7]

Fig. 11 Anisotrophic filter

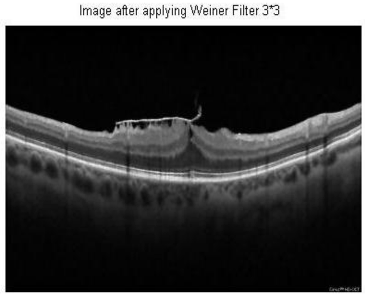

Fig. 12 Wiener filter[3*3]

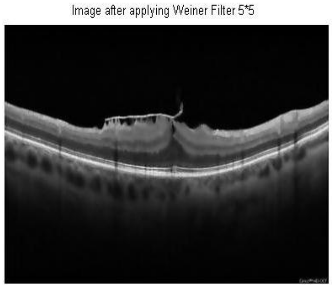

Fig.13 Wiener filter[5*5]

Fig. 14 Wiener filter [7*7]

The experiments were carried out on a Core i3; 2.4 GHz processor with 4GB RAM using MATLAB R2009. Existing speckle filters like frost, lee, anisotropic diffusion, and wiener filter with different mask size of 3*3, 5*5 and 7*7 was used. Fig. 1 and Fig.8 are the digital and synthesized OCT images which contain speckle noise. Fig. 3 to Fig. 7 represents the denoised digital images. Fig. 9 to Fig. 14 represents the denoised OCT images. The digital image and the OCT images that are used for the experiments are two dimensional images. Table 1 gives the comparison between the denoised digital image and the denoised OCT image through the image metrics root mean square error (RMSE), peak signal to noise ratio (PSNR) and Image Quality Index IQI. Table 1 shows the comparison of the speckle filters with respect to the image metrics and it indicates that calculated RMSE values of OCT images are less when compared with digital images. However as the PSNR values for OCT images are high but the filtered OCT images are smoothened. As IQI values for the OCT images are less, it indicates that the speckle filters reduces the contrast level of the filtered image. A good filter shows lower RMSE, higher PSNR and higher value of IQI which usually guarantees better subjective evaluation of the denoised image. Fig 15 gives the graphical representation of the performance of speckle denoising filters on digital image with respect to various image metrics. Similarly, Fig16 gives the graphical representation of the performance of speckle denoising filters on OCT image with respect to various image metrics. Similar work [17] was carried on order statistics filters and the denoised OCT image had more blurring effect.

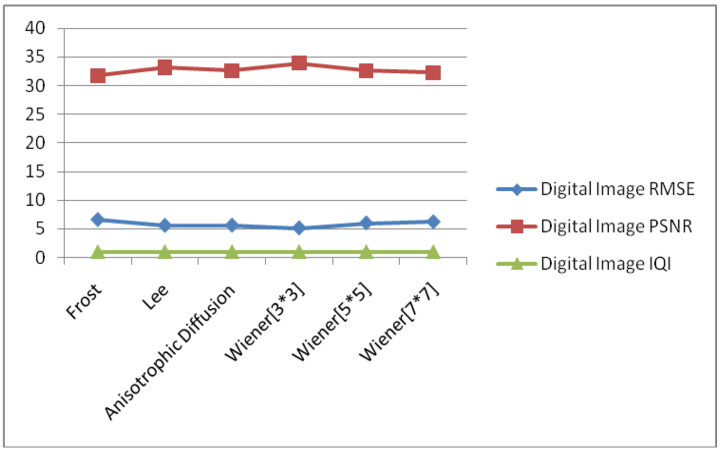

Fig15: Comparison between the performances of filters for a digital image.

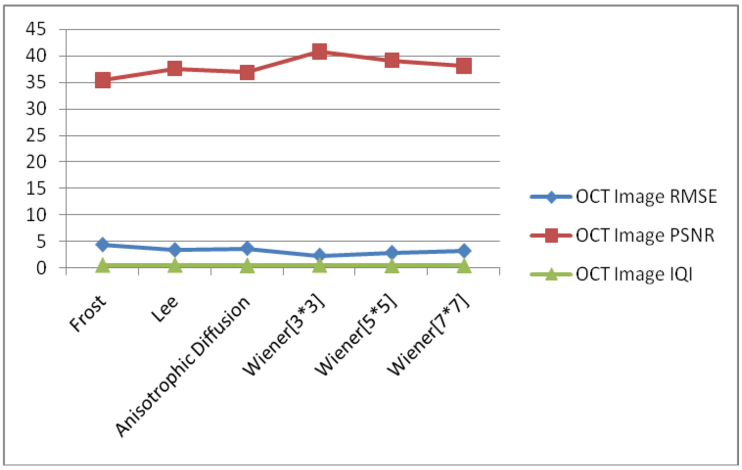

Fig16: Comparison between the performances of filters for an OCT image.

VI. CONCLUSION

In this work a digital image and a synthezied OCT image with speckle noise was used. The existing speckle filters were used for reducing the speckle noise. The results are evaluated through the image metrics like root mean square error, peak signal to noise ratio and image quality index. It is also evident from the figures that the speckle filters had smoothened the images with blurring effects. However, Wiener filter with a 3x3 kernel has the lowest RMSE and highest PSNR values in both digital image and OCT image and the IQI value for digital image was almost close to 1 which ensures that the subjective evaluation of the image is high whereas for the OCT image it was less, thereby it does not guarantee a good subjective evaluation of the OCT image for human visual system. Hence future work can be proposed to denoise the speckle effects of an image through wavelet transform which might reduce the smoothening and blurring effect by maintaining low RMSE value and high PSNR and IQI values.

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