Comparison of Noise Removal Algorithms on Optical Coherence Tomography (OCT) Image

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Abstract— **Automatic Identification of disease through image processing in biomedical field is the norm of modern era. Ophthalmologists have used several invasive and noninvasive techniques for early detection of disease. OCT is one such non-invasive modality that performs high resolution tomographic imaging in biological systems. OCT images are produced containing speckle noise. Noise is a major factor that decreases image quality, hence degrading performance of noise image processing algorithms. It is therefore at highest priority to apply effective method for denoising image, before further processing. In this paper we applied Wavelet denoising, bilateral and wiener filter on an OCT images and discuss benefits and drawback of each algorithms. The effectiveness of each algorithm is compared on basis of Signal to noise ratio SNR, peak signal to noise ratio PSNR and Mean square error MSE.**

Keywords— ***Denoising image, Optical Coherence tomography, Wavelet filtering, Bilateral filtering, Wiener filtering***

I. INTRODUCTION

Optical Coherence Tomography (OCT) is noninvasive biomedical imaging technique that gives high resolution image of biological tissue. Now a days this imaging technique is widely used by ophthalmologist to assist in the diagnosis of disease such as Glaucoma, Macular Edema, Diabetic Retinopathy and many other vision related diseases [1] .The main advantage of OCT over fundus images is that OCT provides layered structure of eye which is handy in early detection of disease as compare to fundus images. Due to its ability to study tissue structure in depth OCT has found its applications in the field of gastroenterology [10], dentistry [11] and intra vascular visualization [12].

OCT imaging technique is based on low coherence interferometer, in which light waves are captured by photo detector after backscattered from tissues of object under observation [2]. There are mainly two types of noises which are introduced in OCT images during the process of image acquisition, short noise and speckle noise. Short noise is also described by Additive White Gaussian Noise (AWGN) which is additive in nature, while speckle noise is multiplicative in nature [3]. To get effective and correct diagnosis of disease, ophthalmologist requires a high quality and detailed image. However, during acquisition process image is corrupted either by thermal energy due to heat produced by image sensors or due to physics-like photon nature of light [4]. Image is acquired by measuring intensity of backscattered light from tissue via Michelson Interferometer using Low Coherence Interferometry. Image formed due to the addition of various crust and troughs of coherent waves produces a grainy representation known as speckle. Noise is pixel in image which shows different values instead of true value of pixel which could alter important meaningful feature use to diagnose disease. Speckle noise is a special type of noise as it carries information about the image, acting as a major degrading factor of an image. Different methods and automated diagnosing algorithms suppress these noises and enhance image for better visualization. Development of these methods are difficult because properties of speckle noise vary from the zero mean, isotropic Gaussian noise [5]. In past researchers had conducted researches to reduce noise from OCT images. Gergesha et al in [3] implemented optimized non orthogonal wavelet (ONW) method for removal of shot noise and Adaptive Laplacian Pyramid Non-linear Diffusion (ALPND) for removal of speckle noise and compare their technique with median and wiener filter. Prabakar Puvanathasan et al in [6] applied combination of Interval type-II fuzzy and anisotropic diffusion method to reduce speckle noise from an OCT of human fingertip and retinal images. Their proposed algorithm abates speckle noise while slight edge blurring.

This paper is divided into four sections. In Section II, we briefly explain denoising algorithms such as wavelet denoising, bilateral filter and wiener filter. In section III, we discuss performance measurement methods such as SNR, PSNR and MSE and evaluate result on basis of these measurements. This is followed by conclusion in section IV.

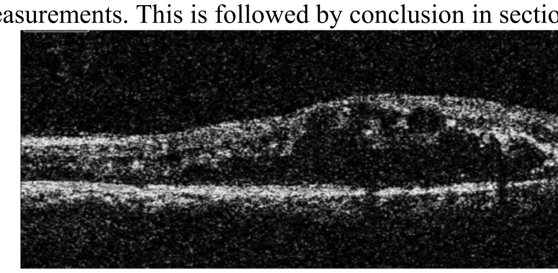

Figure 1 OCT Image of human eye

II. DENOISING ALGORITHMS

A. *Wavelet Denoising*

Wavelet denoising purposed by Mayer et al [5] is a single frame wavelet denoising method in which two different weights are used. This method reduces noise without degrading important structure in an image. The main steps of wavelet denoising algorithm are;

1) Logarithmic transformation is applied on single frame.
2) Dual-tree Complex / Haar Wavelet decomposition is performed.
3) Weight is computed.
4) Coefficients are weighted.
5) Averaging of coefficients is performed.
6) Inverse Wavelet is performed to achieve final result.

The single frame is decomposed by wavelet which yields two different coefficients, approximation coefficient P_i^l and detail coefficient $Q_{i,D}^l$ here D is direction (vertical, horizontal, diagonal) and l is level of decomposition [5].

After calculations, detail coefficient is weighted with weight $G_{i,D}^l$.

$$\hat{Q}_{i,D}^l(x) = G_{i,D}^l(x).\, Q_{i,D}^l(x) \qquad (1)$$

This weighted detail coefficient and approximation coefficient is then averaged and inverse wavelet is performed on averaged coefficient to get final result.

$$Q_D^l(x) = \frac{1}{N}\sum_{i=1}^{N} \hat{Q}_{i,D}^l(x) \qquad (2)$$

$$P^{lmax}(x) = \frac{1}{N}\sum_{i=1}^{N} P_i^{lmax}(x) \qquad (3)$$

Two weights are used in this noise removal algorithm, significance and correlation weight. The significance weight is calculated on single detail coefficient which provided local noise estimation. The correlation weight is calculated on the approximation coefficients which provides information about edges, whether it is preserved or not in current frame.

B. *Bilateral filter*

Bilateral filtering removes noise from image while preserve the edges by mean of nonlinear combination of neighborhood values, this concept was introduced by C. Tomasi et al. [7]. Traditionally, domain filters enforce closeness by applying weights to the pixels value with coefficient whose value decrease with increase in distance. Whereas range filter, are those whose value decrease with decay in dissimilarity. Combining range and domain filter is called bilateral filtering. This filtering is nonlinear because values of these weight coefficients depend upon the intensity value.

A domain filter applied to image I(x) gives an output image defined by $Y(x)$

$$Y(x) = K_d^{-1}(x) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(\xi)\ \ C(\xi, x) d\xi \qquad (4)$$

Here C (ξ, x) is geometric closeness between centered pixel **x** and near point $\boldsymbol{\xi}$. $K_d(x)$ is domain constant.

Range filter is define as

$$Y(x) = K_r^{-1}(x) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(\xi)\ \ S(f(\xi), f(x)) d\xi \qquad (5)$$

Here S$(f(\xi), f(x))$ is photometric similarity between centered pixel **x** and near point $\boldsymbol{\xi}$. $K_r(x)$ is domain and range constant.

Combining equation 4 and 5, we get equation for bilateral filter

$$Y(x) = K^{-1}(x) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(\xi)\ \ C(\xi, x)\, S(f(\xi), f(x)) d\xi \ (6)$$

C. *Adaptive wiener filter*

Wiener filter is used for image restoration and denoising of image on bases of statistical approach. Wiener filter reduce noise on the basis of reduced mean square error. Consider a problem in which image is being corrupted by additive white Gaussian noise

$$y(i,j) = x(i,j) + n(i,j) \qquad (7)$$

Here $y(i,j)$ is a noisy image, $n(i,j)$ is additive white Gaussian noise and $x(i,j)$ is original noise free image. The goal of wiener filter is to obtain linear estimate $\hat{x}(i,j)$of $x(i,j)$ which minimize mean square error [8] given by

$$MSE = \frac{1}{N}\sum_{i,j=1}^{N} (\hat{x}(i,j) - x(i,j))^2 \qquad (8)$$

Where N is number of elements in image $x(i,j)$.

We apply three noise removal techniques, complex wavelet, bilateral and wiener filter on three different OCT image of an eye and then efficiency of each filter is evaluated on the bases of SNR, PSNR and MSE block diagram of implementation process is show in figure 2.

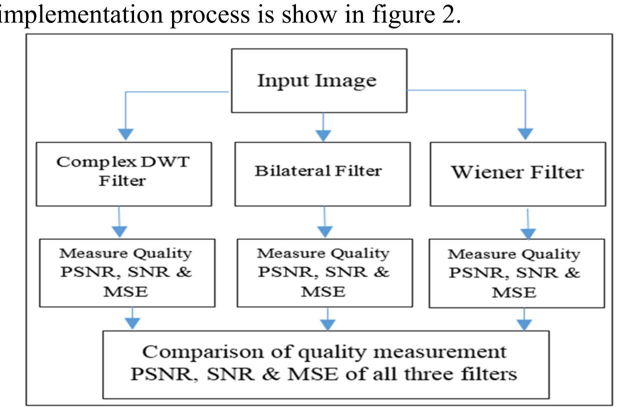

Figure 2 Block diagram of implementation process of comparison

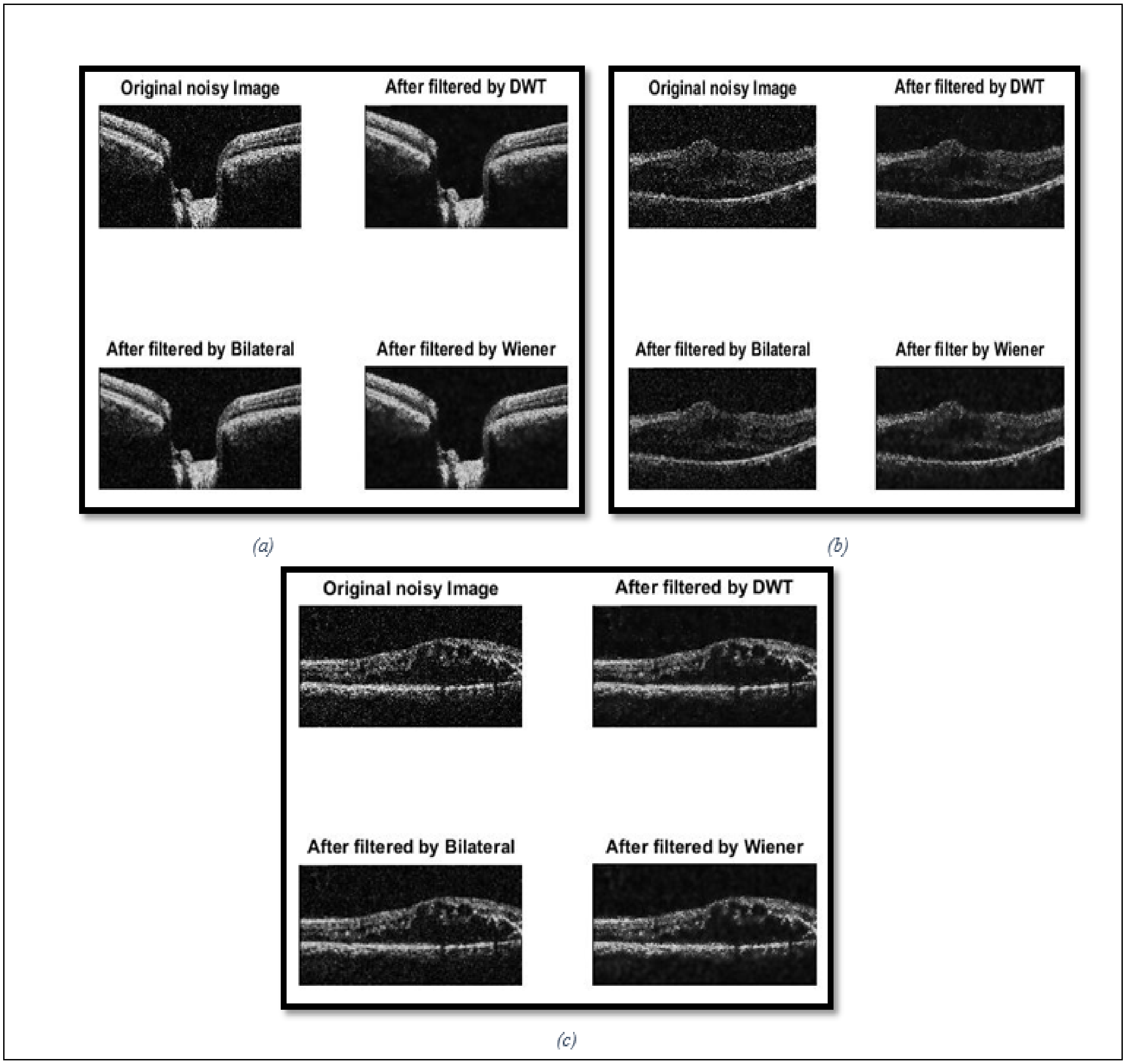

Figure 3 Three different images before and after passing through all three filter (a) image a (b) image b and (c) for image c

III. EVALUATION AND RESULTS

Signal to Noise Ratio: Signal to noise ratio in image processing can be found as

$$SNR = \frac{\sigma(S)}{\sigma(N)} \quad (9)$$

Here σ(N) and σ(S) are standard deviation of noise and noiseless (ideal) signal respectively. In our comparison we calculated SNR of image after passing through complex DWT, bilateral filter and wiener filter separately and compared results shown in Table *1*. From figure 5 it is shown that the SNR values of Complex DWT is higher as compare to bilateral and wiener filter.

SNR Comparison			
	SNR(dB) Complex DWT	***SNR(dB) Bilateral***	***SNR(dB) Wiener***
Image (a)	13.5646	-48.6078	12.4975
Image (b)	9.0897	-49.2697	6.9716
Image (c)	11.3773	-48.9087	9.8007

Table 1 SNR Comparison of DWT, Bilateral and Wiener Filter

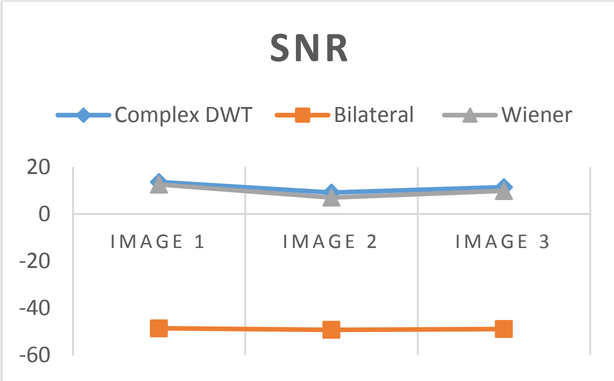

Figure 4 SNR graph

Mean Square Error: Mean Square Error is given by

$$MSE = \frac{1}{NM}\sum_{m=0}^{M-1}\sum_{n=0}^{N-1}[I(m,n) - K(m,n)]^2 \quad (10)$$

Where I (m, n) is denoised image and K (m, n) is *noisy* image. N and M are columns and rows of image respectively. It is calculated by squaring and then taking average of difference between denoised (image after passing through filter) and noisy image [9]. MSE value of different filtered images in shown in table 2. Figure 5 show MSE graph for all three images after applying complex DWT, bilateral and wiener filter. MSE value for complex DWT is least as compare to other two filters.

MSE Comparison			
	MSE Dual Tree Complex DWT	***MSE Bilateral***	***MSE Wiener***
Image (a)	0.1999	5.0522	0.2531
Image (b)	0.2284	2.4060	0.3643
Image (c)	0.2168	3.5410	0.3074

*T*able 2 MSE value of filtered images

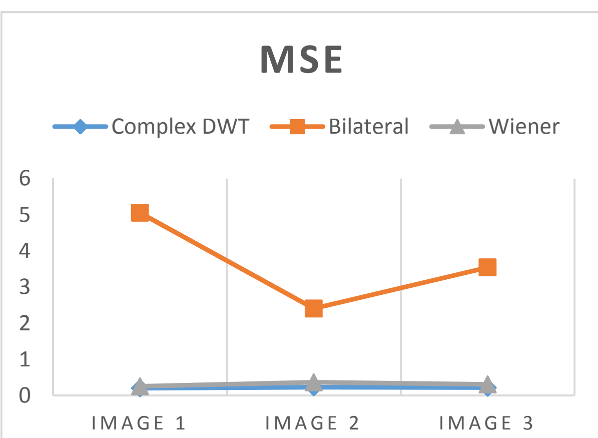

Figure 5 MSE graph

Peak Signal to Noise Ratio: Peak Signal to noise ratio is given by

$$PSNR = 10log\frac{S^2}{MSE} \quad (11)$$

Here S is maximum value of pixel that can be assigned in an image. S=255 for 8 bit image and MSE is mean square error.

It can also be define by ratio between maximum power of signal and power of noise. Decibel (dB) is used to express this ratio. Peak signal to noise ratio of all three images after passing through different filter is shown in Table 3.

PSNR Comparison			
	PSNR(dB) Dual Tree Complex DWT	***PSNR(dB) Bilateral***	***PSNR(dB) Wiener***
Image (a)	-23.0073	-37.0348	-24.0322
Image (b)	-23.5874	-33.8130	-25.6143
Image (c)	-23.3613	-35.4912	-24.8777

Table 3 PSNR values

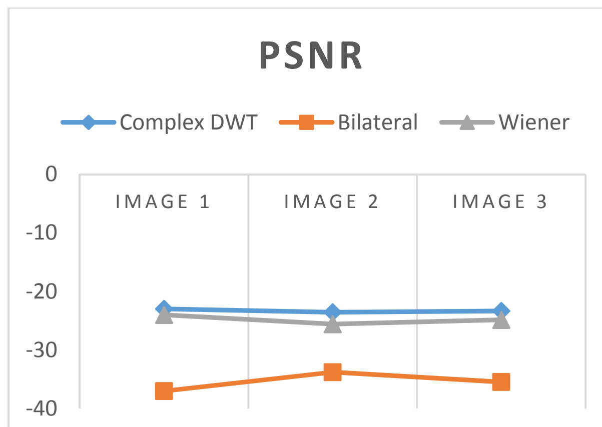

Figure 6 PSNR graph

IV. CONCLUSION

In OCT images, ophthalmologist face problem in correctly identifying disease due to the noise. It is also an obstacle for automatic segmentation of biomedical image for diagnosis of different diseases. The results in section III showed that wavelet (DTCW) denoising filter performed well on all three OCT images. From figure 3 we can note that wavelet denoising filter outperformed remaining two filters and preserve edges of image, while in wiener filter there is blurring at edges which can be seen in figure 3 (b). Bilateral filter performed worst in denoising OCT image. Wavelet (DTCW) filter is best for removing speckle noise and additive white Gaussian noise (AWGN) form OCT images.

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