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A New Nonlinear Anisotropic – Wiener Method for Speckle Noise Reduction in Optical Coherence Tomography

Ahmed H. Samak
Ass. Professor of computer science, Department of Mathematics, Faculty of Science,
Menofia University, Egypt

ABSTRACT

Removing noise from the original medical image is still a challenging research in image processing. This paper presents a new method for speckle noise reduction in Optical coherence Tomography (OCT). Stationary wavelet transform (SWT) is employed to provide effective representation of the noisy coefficients. Nonlinear Anisotropic filtering of the Details coefficients improves the denoising efficiency and effectively preserves the edge features while wiener filter improves to denoising approximate coefficients.

The performance of the proposed method is compared with Nonlinear Anisotropic filter, Wiener filter, Lee filter and Frost filter and analyzed based on the peak signal-to-noise ratio (PSNR).

Keywords: image denoising; wavelet transform; Optical coherence Tomography; Nonlinear Anisotropic filter.

1. INTRODUCTION

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.

Over the past few decades, technological advancements in optical devices and laser technology have given birth to a novel non-invasive optical biomedical imaging technique called optical coherence tomography (OCT).

OCT is an imaging technology that allows for in vivo, non-invasive high-resolution, two- or three dimensional cross-sectional imaging of the morphology of partially transparent and highly scattering biological tissues on a microscopic level [1]. The axial OCT resolution can range from 0:5 mm to few micrometers, while the penetration depth in biological tissue is limited to 1:5 to 2mm. Hence, OCT is uniquely suited for performing non-invasive optical biopsy of biological tissues such as skin, cornea, retina, arterial plaques, cervical and gastro-intestinal epithelium, etc.

The system diagram presented in figure1 representing the noise model in OCT imaging system. S(x; y) is the noise free OCT image, f(x; y) is the noise observation of s(x; y), m(x; y) and n(x; y) are the speckle and additive noise [2].

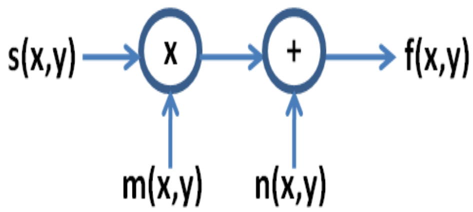


Figure1: Noise model in OCT imaging system.

In the past, extensive research has been conducted both in the fields of medical imaging and remote sensing for suppressing speckle noise. Many methods have been developed to improve the image quality degraded by speckle noise. Several speckle-reduction procedures are described by [3]. In this work, speckle reduction techniques in OCT are classified into four categories: polarization diversity, spatial compounding, frequency compounding, and digital signal processing. These categories can be summed into either numerical image processing algorithms, or alternative detection schemes of the OCT system design. Polarization diversity, spatial compounding, and frequency compounding are based on modification to the OCT system design.

A wavelet based soft thresholding technique has been previously applied to OCT images corrupted by speckle noise [4]. It computes the undecimated wavelet transform and applies soft thresholding to the horizontal, vertical, and diagonal sub bands. The threshold is obtained using the statistics of the wavelet coefficients. The wavelet based technique described in [4] does not reduce the image sharpness significantly but the execution time for the algorithm is about 7 min using Matlab implementation.

Modified Lee and Kuan adaptive filters have been applied to SAR speckle reduction [5]. Anisotropic diffusion is another digital algorithm that has been previously applied for speckle noise reduction in OCT images. For example, in references [6, 7] the gradient of the image is used for the calculation of the diffusion coefficient with no consideration to the actual noise present.

Bo Chong and Yong-Kai Zhu proposed a novel speckle noise reduction algorithm in OCT. The algorithm is based on block-matching 3D filter modified by morlet wavelet decomposition. Original OCT image data transformed by logarithmic compression is decomposed into 10 components by morlet wavelet for three levels. Each component is proposed by a suited BM3D filter and the output image is reconstructed by wavelet reverse transformation [8].Mashaly, A.S. and et al presented an adaptive mathematical morphological filter is proposed to reduce the speckle noise in SAR images [9].

In this paper a novel speckle noise reduction in OCT algorithm is proposed as discuss in the next sections.

2. The Proposed Nonlinear Anisotropic – Wiener Filter In Wavelet Domain (NA-W)

Wavelets are orthogonal basis functions that delve data into different spatial-frequency components. The delineating capability of wavelet leads to better discrimination between the noise and the signal. Hence, they are successfully exploited in developing efficient denoising algorithms that also lessen the blurring effect [10]. Discrete wavelet transform (DWT) is an implementation of the wavelet transform using a discrete set of wavelet scales and translations [11].

There are several modifications of DWT corresponding to the choice of basis functions. One of these modifications is the stationary wavelet transform (SWT). The multi-resolution property in SWT is achieved by up-sampling the filters at each level of decomposition [12]. In this work, the Stationary wavelet transform (SWT) is employed to provide effective representation of the noisy coefficients. Then Nonlinear Anisotropic filtering of the Details coefficients improves the denoising efficiency and effectively preserves the edge features. Anisotropic Diffusion is a nonlinear filtering method that encourages diffusion in the homogeneous region while inhibits diffusion at edges. The diffusion is described by [13]

$$\frac{\partial l}{\partial t} = div\left[c(\|\nabla I\|)\nabla I\right];$$

$$I(t=0) = I_0$$

Where div is the divergence operator, $\|\nabla I\|$ is the gradient magnitude of the image I , $c(\|\nabla I\|)$ is the diffusion coefficient or the diffusivity function and I_0 is the original image. If the function $c(\|\nabla I\|)$ is constant for all image locations, the diffusivity function $c(\|\nabla I\|)$ is a monotonically decreasing function of the gradient magnitude. In the anisotropic diffusion method the gradient magnitude is used to detect an image edge or boundary a step discontinuity in intensity.

In the other hand wiener filter improves to denoising approximate coefficients. The Wiener Filter is a noise filter based on Fourier iteration. The coefficients of a Wiener filter are calculated to minimize the average squared distance between the filter output and a desired signal.

In its basic form, the Wiener theory assumes that the signals are stationary processes. However, if the filter coefficients are periodically recalculated for every block of *N* signal samples then the filter adapts itself to the average characteristics of the signals within the blocks and becomes block-adaptive. A block-adaptive (or segment adaptive) filter can be used for signals such as speech and images that may be considered almost stationary over a relatively small block of samples [14]. The filter input–output relationship is given by:

$$\hat{x}(m) = \sum_{k=0}^{p-1} w_k y(m-k)$$
$$= w^T y$$

where m is the discrete-time index, y^T is the filter input signal, and the parameter vector w^T is the Wiener filter coefficient vector.

3. Results and discussion

Simulations are carried out in MATLAB in order to study the performance of the proposed method using synthetically speckled and medical OCT images. The performance of the proposed method is compared with Wiener filter [14] ,Lee filter[5] , Nonlinear Anisotropic filter[7] , and Frost filter[15].

The results of OCT image filtering carried out separately using Wiener, Lee filter , Nonlinear Anisotropic filter , and Frost filter , then, the proposed (NA-W) filter (Biorthogonal 6.8, Daubechies 2 and Symlets 8) were analyzed based on the peak signal-to-noise ratio (PSNR) and given in the figures 2 , and figure 3.

The numerical results shows that the best type of wavelet family used for speckle reduction in OCT images is Daubechies of order 2 It gives the highest PSNR value compared with the other type of wavelets. And Figure 4 shows that our method give more good performance in increasing PSNR in comparison with Wiener, Lee filter , Nonlinear Anisotropic filter , and Frost filter.

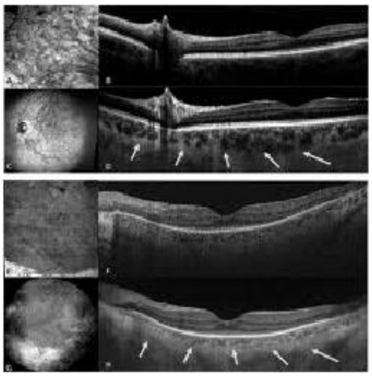
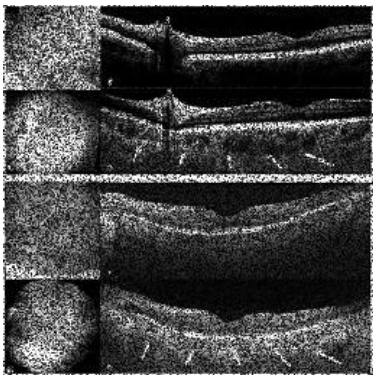
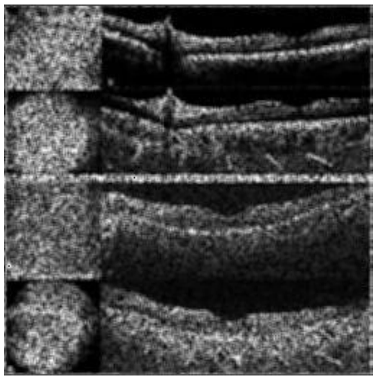
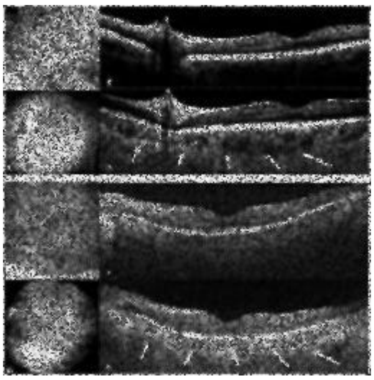
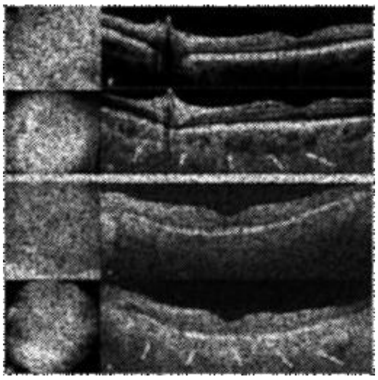
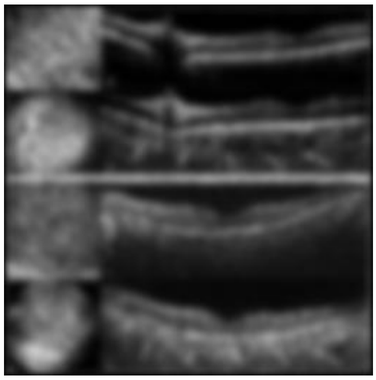
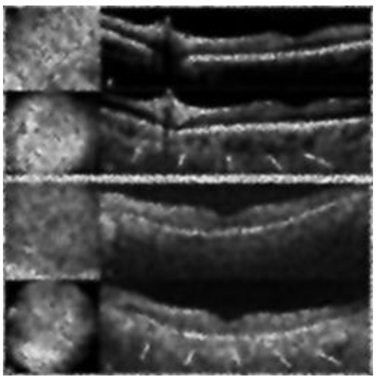
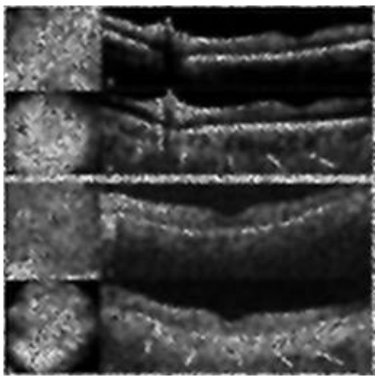
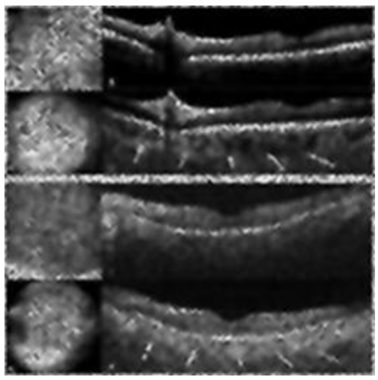
The original image	The corresponding noisy image for a speckle noise standard deviation of 0.3	Denoised images obtained using the lee filter
		
Denoised images obtained using the Winner filter	Denoised images obtained using the Frost filter	Denoised images obtained using the Nonlinear Anisotropic filter
		
Denoised images obtained using the proposed method using db2 wavelet family	Denoised images obtained using the proposed method using sym8 wavelet family	Denoised images obtained using the proposed method using Biorthogonal 6.8 wavelet family
		

Figure 2: Qualitative comparison of the despeckling performance of the various methods of the OCT image 1

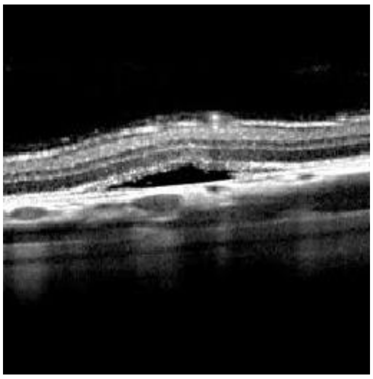
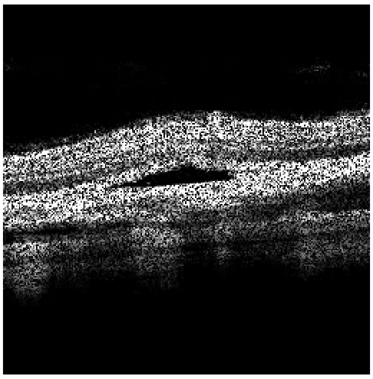
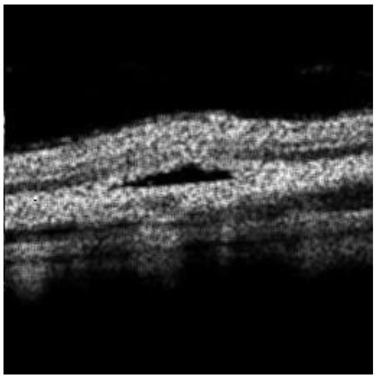
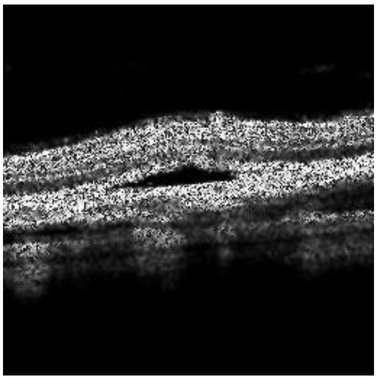
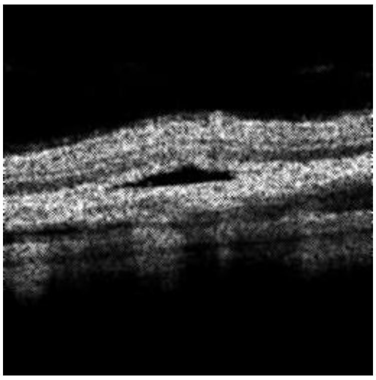
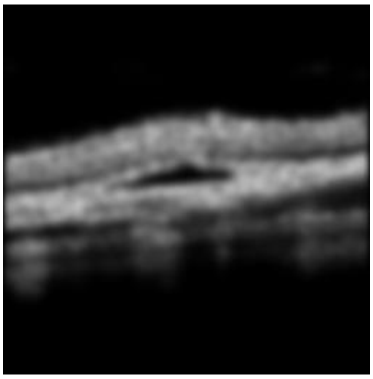
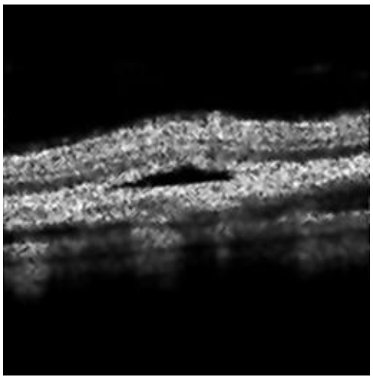
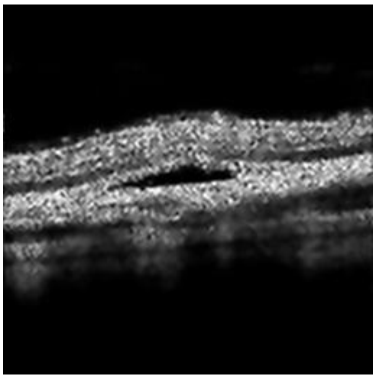
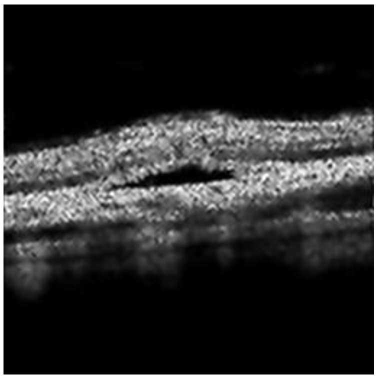
The original image	The corresponding noisy image for a speckle noise standard deviation of 0.3	Denoised images obtained using the lee filter
		
Denoised images obtained using the Winner filter	Denoised images obtained using the Frost filter	Denoised images obtained using the Nonlinear Anisotropic filter
		
Denoised images obtained using the proposed method using db2 wavelet family	Denoised images obtained using the proposed method using sym8 wavelet family	Denoised images obtained using the proposed method using Biorthogonal 6.8 wavelet family
		

Figure 3: Qualitative comparison of the despeckling performance of the various methods of the OCT image 2

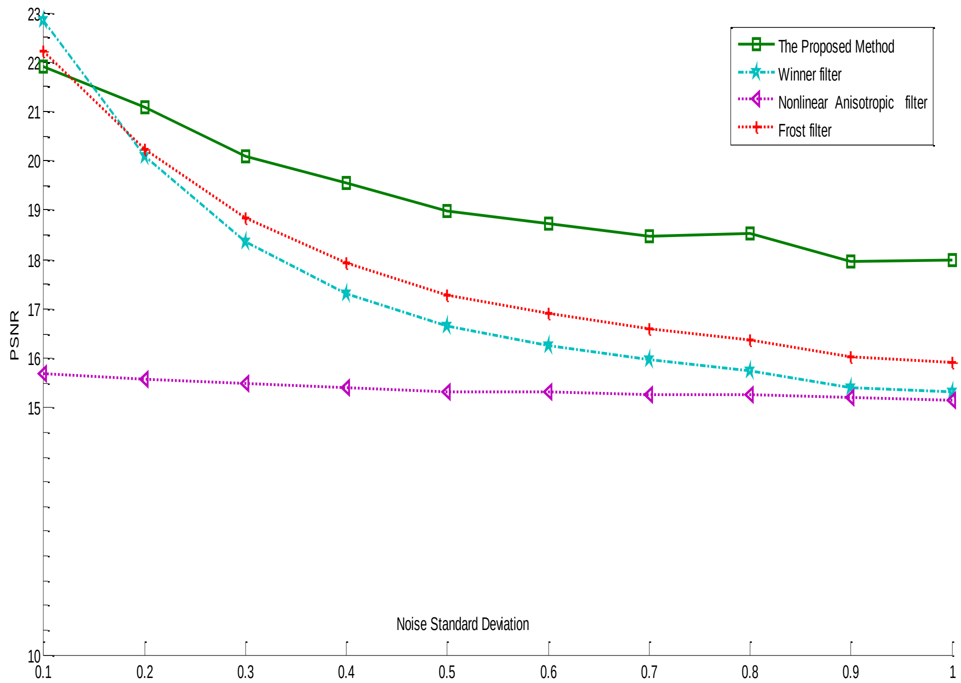


Figure 4 comparisons between the proposed method with Wiener, Lee filter, Nonlinear Anisotropic filter, and Frost filter

The proposed method is also computationally fast. To illustrate this, the average CPU time for different OCT images used in our simulation (carried out on an Intel Core 2 Duo CPU 1.83 GHz computer with 4.00 GB RAM) are shown in Table 1 for the various methods.

Table 1: The averages CPU time of the proposed method in comparison with others methods.

Method	Average processing time (in seconds)
Frost filter	5.195
Nonlinear Anisotropic	2.186
Lee filter	7.694
Winner filter	1.898
our method	3.795

4. Conclusion

This paper presented a new efficient method for Speckle Noise Reduction in OCT. Stationary wavelet transform is employed to provide effective representation of the noisy coefficients then the Nonlinear Anisotropic filtering of the Details coefficients improves the denoising efficiency and effectively preserves the edge features while wiener filter improves to denoising approximate coefficients.

The result shown that our method give more good performance in increasing PSNR and decreasing CPU time than standard speckle reduction filters, such as the Nonlinear Anisotropic filter, Lee filter ,Frost filter and Wiener filters.

5. References

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