# Speckle Reduction in the Wavelet Domain for Image with Optical Coherence Tomography

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***Abstract***

Optical Coherence Tomography (OCT) is high resolution medical imaging system which is obtaining image inside biological objects with non-destructive method. OCT system is based on Michelson interferometer with a reciprocating mirror in the reference arm and a biological object in the sample arm. The obtained image from OCT suffers from a granular or mottled image, called speckle. These speckles severely hinder the application of automated data analysis. We propose effective speckle reduction method that uses wavelet transform. With wavelet domain image, Wiener filtering and thresholding are performed. Finally speckle reduction experiment for Misgurnus mizolepis skin image is shown.

***Keywords*** **: optical coherence tomography, speckle, wavelet, Wiener filter.**

## I. Introduction

Optical coherence tomography (OCT) is a new medical diagnostic imaging system which is obtaining cross-sectional image of the inside of biological object with high resolution[1].

OCT system is based on Michelson interferometer with two parts. One is reference arm which is composed of ODL (optical delay line) with reciprocating mirror. The other is sample arm which places biological object. The incident light from light source from SLD is splitted with half power each and the splitted lights travel reference and sample arm. The combined light from reflected reciprocating mirror and sample arm provides interferometric data which keep different depth information along the biological object. Namely, interferometric data is obtained when reflected lights from each arms have same optical path length between the reciprocating mirror and tissue in the biological object. The obtained data is an interferometric cross-correlation, $\overline{R_{is}}(\triangle l)$, where $\triangle l$ is optical path length difference between the arms. Furthermore, $\triangle l$ can be divided into $\triangle l_g$ and $\triangle l_\phi$ i.e. group delay and phase delay respectively. Thus, the $\overline{R_{is}}(\triangle l)$ can be represented as

$$\widetilde{R_{is}}(\triangle l_g, \triangle l_\phi) = R_{is}(\triangle l_g)e^{-jk_0 \triangle l_\phi} \qquad (1)$$

where, $k_0$ is the center wavenumber of the light source. As can be seen in (1), interferometric cross-correlation is expressed as the product of the complex envelope of the interferometric cross-correlation, $R_{is}$, and a complex exponential carrier[1].

The group delay term in (1) has information of biological tissue. It can be extracted by demodulation. And a complex exponential carrier is measured by Doppler frequency $f_0$,

$$f_0 = \frac{2s}{\lambda_0} \qquad (2)$$

where $s$ is the velocity of a reciprocating mirror and $\lambda_0$ is center wavelength of light source. Fig. 1 shows our previous fiber based OCT system[2]. Light go through fiber based Michelson interferometer, and detected form of electrical current by photodetector. This current goes into the pre-amp and is converted into voltage. And voltage signal is directed into a bandpass filter to remove noise. After the processing, the voltage signal only contains the modulated pattern which has meaningful information of biological object. Doppler frequency in (2) determines the specifications of analog signal processing part such as center frequency of bandpass filter and demodulating speed.

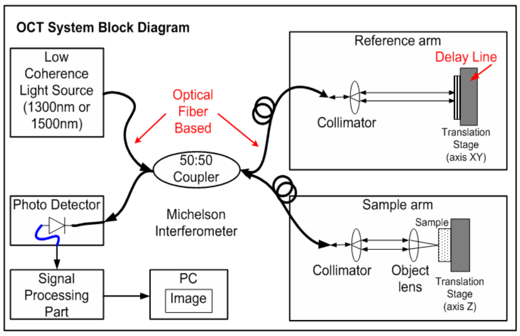



Fig. 1 Fiber based OCT system.

The obtained image from OCT suffers form a granular or mottled image, called speckle. This unwanted phenomenon, speckle, results from random interference between reflected waves that are mutually coherent. These speckle severely hinder the application of methods for automated data analysis, such as feature extraction, segmentation, and visualization [1, 3].

## II. Speckle Reduction Method

As one of effective speckle reduction method, processing speckled image in the transformed domain is popular. After specific processing such as filtering and thresholding in the transformed domain, desired image can be obtained by inverse transform. Application of signal transform aims at revealing properties of a signal that are not accessible in the spatial domain. These properties must be suitable signal representation for speckle reduction. Many image features consist of high frequency components with low spatial extension and of low-frequency components with large spatial extent. The wavelet transform is intended to provide a variable signal representation for this type of image features. Characteristic signal features are efficiently captured and transformed into a small number of large coefficients while the noise spreads out as small coefficients. This different properties of the transform coefficients related to noise makes it possible to define a separator for thresholding the transform coefficients.

2-D wavelet transform of function $f(x,y)$ of size $M \times N$ is given by

$$W_\phi(j_0,m,n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y)\phi_{j_0,m,n}(x,y) \qquad (3)$$

$$W_\psi^i(j,m,n) = \frac{1}{\sqrt{MN}} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \psi_{j,m,n}^i(x,y) \quad (4)$$

where $j_0$ is an arbitrary starting scale and the $W_\phi(j_0,m,n)$ coefficients define an approximation of $f(x,y)$ at scale $j_0$, and $W_\psi^i(j,m,n)$ coefficients add horizontal, vertical, and diagonal details for scales $j \geq j_0$, so, $i = \{H, V, D\}$ are each horizontal, vertical, and diagonal details respectively.

First, we apply 2-D wavelet transform to the speckled image. Continually we apply 2-D Wiener filtering to the approximation $W_\phi(j_0,m,n)$. This aims at decreasing of small granular speckles by smoothing image. 2-D Wiener filter filters an intensity image that has been degraded by additive noise with constant power. It uses a pixel-wise adaptive Wiener method based on statistics estimated from a local neighborhood of each pixel. 2-D Wiener filter estimates the local mean and variance around each pixel as follows. The local mean and variance, respectively, are given by

$$\mu = \frac{1}{NM} \sum_{n_1,n_2 \in \eta} a(n_1,n_2) \quad (5)$$

$$\sigma^2 = \frac{1}{NM} \sum_{n_1,n_2 \in \eta} a^2(n_1,n_2) - \mu^2 \quad (6)$$

where $a(n_1,n_2)$ is input pixel, and $\eta$ is the $N \times M$ local neighborhood of each pixel. Given the local mean and variance, output pixel $b(n_1,n_2)$ is determined by

$$b(n_1,n_2) = \mu + \frac{\sigma^2 - v^2}{\sigma^2}(a(n_1,n_2) - \mu) \quad (7)$$

where $v^2$ is the noise variance. If the noise variance is not known, noise variance uses the average of all the local estimated variances.

Second, we apply 2-D wavelet transform to the level one approximation $W_\phi(j_0,m,n)$, and each details $W_\psi^i(j_0,m,n)$, $i = \{H, V, D\}$ are divided into $L \times L$ sub-windows. This process is conducted until enough level $j = 0,\cdots,l-1$ that the discrimination between information and speckle is possible. Also, we apply sub-windowing to $W_\phi(l-1,m,n)$. After that, we apply thresholding to all sub-windows as in (8).

$$W_\psi^i(m,n) = \begin{cases} W_\psi^i(m,n) \times 0.1 & ,|W_\psi^i(m,n)| \leq T \\ W_\psi^i(m,n) \times 2 & ,|W_\psi^i(m,n)| > T \end{cases} \quad (8)$$

where $T$ is threshold value.

In thresholding, if wavelet coefficients are smaller than threshold value, we decrease coefficients with a weight of 0.1. These decreased coefficients are regarded as speckle that is a source of noise. However, It is inappropriate to make these coefficients zero. Because these nonzero coefficients have some information for the reconstruction of processed image.

One the other hand, if coefficients are larger than threshold value, we increase coefficients with a weight of 2 in order to emphasize those useful informations. Threshold value given by (9) is very important parameter which distinguishes useful information from noise[4, 5].

$$T = |\text{Median}(S_{ij})| \times 1.7 \, , i,j = 1,2,\cdots L \quad (9)$$

where, $S_{ij}$ is wavelet coefficients of a sub-window, $i$ and $j$ is horizontal and vertical length of $L \times L$ sub-window respectively. The absolute median value of a sub-window is needed before calculating threshold value. The threshold value is adopted as an absolute median value multiplied by 1.7. This constant is an experimental optimum value. Finally, we reconstruct image by conventional 2-D inverse wavelet transform. The reconstructed image still suffers from the mottled patterns that is caused during the calculating process of sub-block Wiener filtering to the approximation image of one-level wavelet transform. The block based operation to the decimated approximation $W_{\phi}(j_0,m,n)$ with Wiener filter can produce mottled patterns. Thus, the Wiener filter that is used before is applied again for better visualization. As a result, final enhanced image can be obtained.

## III. Experiments

We extracted Misgurnus mizolepis skin shell lateral image from our OCT system as shown in Fig. 2.

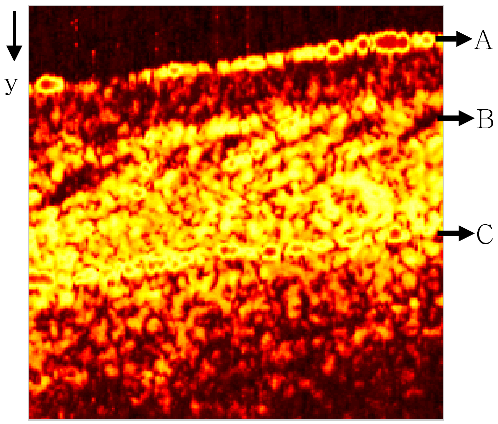



Fig. 2 Misgurnus mizolepis skin OCT image obtained with SLD (central wavelength: 1300nm, spectral bandwidth: 50nm, size: 256×256 pixels).

Misgurnus mizolepis is a kind of mudfish. In Fig. 2, A is the epidermal tissue, B is a form of cell structures, and C is an another structure of muscle tissue. The scanning direction is marked as y.

In Fig. 2, we can observe many speckles, a kind of granularity. These speckles degrade image quality, and hinder the identification of the inner structure. We apply proposed speckle reduction method. First, we applied one-level wavelet transform. Wiener filtering to the approximation of one-level wavelet coefficients was performed. In this experiment, we use Wiener filter that have sub-block size of 5×5. Subsequently we apply 8-level wavelet transform ($l=8$) and conduct thresholding for the details in all levels and approximation of the last level. We used Daubechies-4 type wavelet basis function. The sub-window size for thresholding is 7×7. Finally, we apply inverse wavelet transform and Wiener filtering. We get the result image as shown in Fig. 3.

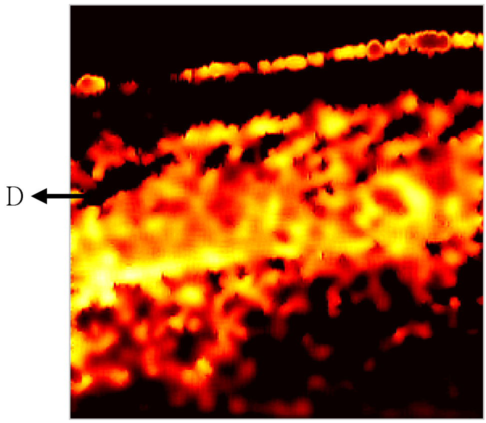
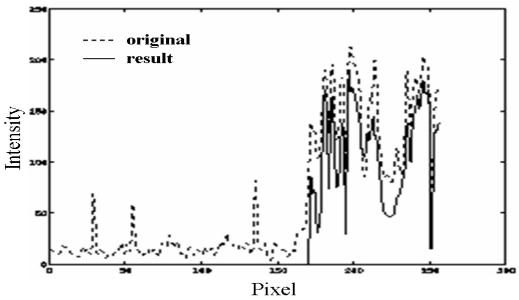


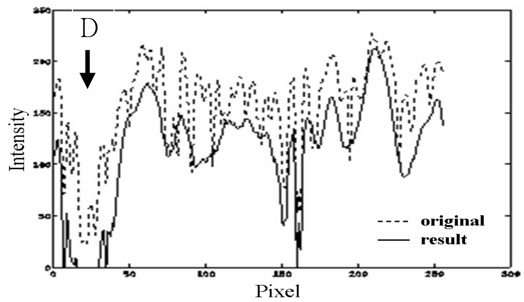

Fig. 3 Result image using proposed speckle reduction method (sub-block size of Wiener filter is 5×5, sub-window of thresholding is 7×7).

We can observe resulting image with reduced speckles. Although we can observe damaged epidermal tissues, the enhanced image can distinguish inner cell structures easily, such as epidermal tissues, cell shapes, and structure under them. Furthermore the image becomes smooth without loss of intensity.

Fig. 4 is 1-D intensity plots of original and result image. Fig. 4(a) and Fig. 4(b) correspond to the 25th and 115th row of image. In Fig. 4, we can observe the processed solid line against the dotted line, such as reduced high frequency component and enhanced edge. In Fig. 4(b), the valley marked as D is the same position as D in Fig. 3. The valley in result image becomes more clear than the original.




(a)




(b)

Fig. 4 1-D comparison between original and processed image. (a) 25th row, (b) 115th row.

## IV. Conclusion

We discuss speckle reduction method in the wavelet domain. Wiener filtering in one-level approximation and proper thresholding in wavelet domain reduce speckles and enhance OCT image information effectively. The result image clearly distinguishes the structure of biological. as well as keeping the edges and shapes of inner structures. We will trying to further work for an adaptive parameterization with general performance indexes.

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