One new method for OCT image denoising based on wavelet transform

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Optical coherence tomography (OCT) suffers from random noises which degrade contrast of image, these noises can not effectively be wiped off by filtering technique. Characteristics of random noises were discussed and analyzed, noise influences were identified on image. The method of wavelet transform is presented for image denoising. The result shows that the method can reduce image noises.

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Optical coherence tomography (OCT) is an emerging noninvasive imaging technique, which is developed rapidly in recently years. It was used to perform high resolution cross sectional in vivo and in vitro imaging of microstructure in transparent as well as nontransparent biological tissue by low coherence interferometric technique. Micron and submicron scale high resolution, high sensitivity imaging makes OCT attractive for clinical applications in diagnosis of disease, especially optical biopsy. Currently, optical coherence tomography has found an increasing number of diagnosis applications. Now OCT has been applied to imaging the tissue of eye, skin and dentistry[1−4].

As in any other imaging modality, OCT images are affected by different existing sources of random or structured noises, such as high scattering of tissue, nonlinearity of photo electricity detector and scanning movement, which degrades contrast and resolution of images of dense biological tissue. In this paper, origins of noises and influence on imaging are discussed, by using of wavelet transform technique, noises can be reduced, the resolution is improved.

There are lots of noises which influence image quality in OCT system, including speckle, scanning noise, source side lobe, source noise and circuit noise. In an interferometer, signal noise is increased by mechanical instabilities that cause uncertainties in the path delay between the interfering beams. Quantum or shot noise arises in the photoelectric detection of light. Thermal noise adds to the signal power incident on the detector and to the signal as the photocurrent is amplified and processed by analog electronics. Quantization error is caused by discrete thresholding of the signal during the analog-to-digital conversion process. The sources of noises are tissue, scanning movement, light source and circuits.

The reasons are complex about the speckles. Speckles arise due to a coherence superposition of backscattered light waves from different scattering point or areas of a sample containing densely packed scattering particles[5,6]. There are abundant scattering particles in biological tissue. When near infrared light from a coherence source illuminates scattering particles, the spherical wave which encircles scattering particles is radiated. The light wave, received by photodetector, contain single scattering light as well as multi-scattering light, back-scattered light. Scattering is a relatively complex phenomena. Single scattering light from different particles interferes and superposes, multi-scattering light superposes incoherently. the detected signal by heterodyne detector is an interference signal of the scattering light component and reference light. The current intensity of detector is $|i_{T,sb}| + K_c < i^2_{T,ms} >^{\frac{1}{2}}$, the first term is current contributed by single scattering light, the second term corresponds to the multi-scattering light, K_c is scale coefficient. Signals are detected and imaged, when optical path length difference is within the coherence length of the source. The scattering light, which optical length difference is $n\pi\overline{\lambda}$, produce salternating current which phase difference is $n\pi$, so interfering forming speckle.

Speckle noise in OCT images is a structured noise, which coexists with signal, discarding this noise in image poses many difficulties. Speckle makes edge detection and thickness measurements difficult.

By moving the scanning system in reference arm for lognitudinal scanning, a Doppler shift is introduced to the reference beam, causing a heterodyne interferometric signal centered at the Doppler frequency. The frequency is $f_D = {}^{2\nu}/_{\lambda}$, so avoiding direct current (DC) component and low frequency noise. The signal bandwidth is influenced by the scanning velocity. The bandwidth of band-pass filter is determined by the signal bandwidth, and selected to ensure high resolution and sensitivity, the best bandwidth is $2\Delta f$, $\Delta f = {}^{2\pi\nu}/_{L_c}$. The bandwidth of system should be wider than the signal bandwidth for longitudinal resolution, differentiating the two peaks of which distance is L_c in depth.

If the scanning velocity is not constant, the Doppler shift will change, the center frequency of signal will be excursion also. Image signal is interfered, noises appear on image. When the frequency excursion goes beyond the bandwidth, signal intensity is weakened, the bright or dark lines come out in rows or column of image.

Some light source spectra have multi-module. Figure 1(a) shows the emission spectrum of superluminescent diode (SLD) source, according to the data sheet of the manufacturer. The non-Gaussian shape of the spectrum is caused by the internal structure. Figure 1(b) shows the coherence envelope of the source[7,8]. There are two peaks of the spectrum, the signal envelope peaks appear in points of which the optical length difference is nonzero, side lobe degrades the contrast of image and blusr the image, so it is difficulty to observe the details of tissue structure in deep layer.

OCT images are affected by all kinds of noises.

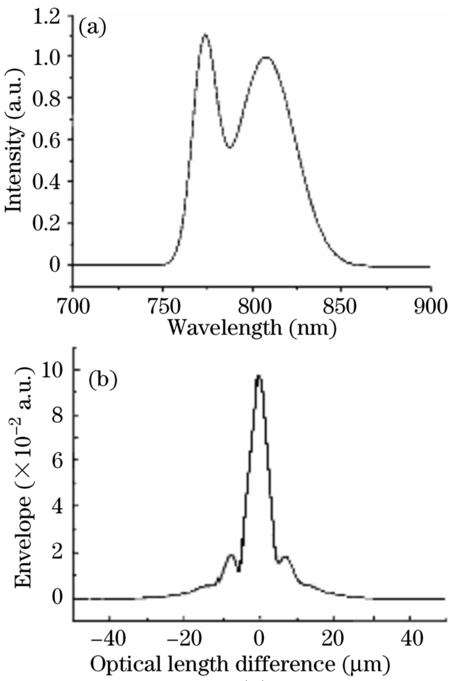

Fig. 1. SLD emission spectrum(a) and coherence envelope of broadband SLD (b).

Different noise has different impact on image. Denoising is important to improve the imaging quality for distinguish the microstructure of different tissues on image. How to optimize OCT image, most researchers were interested in physics mechanism, instrumentation and practical applications. As the research goes on, they realized that some of the problems may not be easily solved by physical methods. More people think of processing image to solve the noise problems. So far several techniques have been introduced to reduce noise, either based on spatial compounding , frequency compounding, or on digital signal-processing algorithms[4,9]. The mean, median and hybrid median filters are used for denoising. The rotating kernel transformation, information expansion and maximum entropy are applied in the specific problem[9,10]. These methods proved to be successful techniques in noisy and low constrast image, however they are limited in OCT image.

Wavelet transform, comparing with traditional denoising methods, localizes signal in time and frequency domain, the basis function is dilated over many scales. Wavelet transform is multi-resolution representation of signals and images. They decompose signals and images into multiscale details. This special treatment of noises by wavelet transform is very attractive in image filtering.

Two-dimensional wavelet transform is used in image multiresolution analysis. The wavelet transform domain noise filtration technique is based on the fact that sharp edges have large signal over many wavelet scales, and noise dies out swiftly with increasing scale. Assumsing the orginal image is L', wavelet transform decomposes image into a series of bandwidth, the first decomposing of image is

$$[\mathrm{LL1}, \mathrm{LH1}, \mathrm{HL1}, \mathrm{HH1}] = \mathrm{dwt2}(L'), \qquad (1)$$

the second decomposing of image is

$$[\mathrm{LL2}, \mathrm{LH2}, \mathrm{HL2}, \mathrm{HH2}] = \mathrm{dwt2}(\mathrm{LL1}), \qquad (2)$$

where LH1, LH2 are horizontal high frequency detail component in mage; HL1, HL2 are vertical high frequency detail component in image; HH1, HH2 are diagonal high frequency component in image; LL1, LL2 are low frequency component in mage; dwt2 denotes two dimension discrete wavelet transform. Figure 2(a) shows one scale decomposing, Fig. 2(b) shows two scale decomposing, L and H represent low and high frequency component. Noises in row distribute in LH1 and LH2;noises in column distribute in LH1and LH2; high frequency random white noises distribute in HH1 and HH2.

The high resolution image $L2$ reconstructed by wavelet inverse transforms is

$$L2 = i\mathrm{dwt2}(\mathrm{LL2}, \mathrm{LH2}, \mathrm{HL2}, \mathrm{HH2}). \qquad (3)$$

The high resolution image $L1$ reconstructed by wavelet inverse transforms is

$$L1 = i\mathrm{dwt2}(\mathrm{LL1}, \mathrm{LH1}, \mathrm{HL1}, \mathrm{HH1}). \qquad (4)$$

Speckle and side lobe are colored noises, which confined to some scales. The scanning noise that has very low frequency, is concentrated at two small scales. Filtering noise from an image relies on the variations in scale of the wavelet transform data of the signal. Most noise power is confined to small scales; the reduction of signal at small scales reduces noise preferentially. Through the wavelet transform of image, a threshold is used to process coefficients before the image is reconstructed.

OCT image is decomposed by biorthogonal wavelet in two scales. Figure 3(a) is original image of human finger tip, Fig. 3(b) is filtered image. Figure 4(a) is original image of the cartilage, Fig. 4(b) gives filtered image. The detail of image becomes distinct, features are easily retained and not degraded. The definition and contrast of image are improved. Results show that this new filtering technique can remove the noise from the images. A close-up view shows that the wavelet domain filter technique is more effective.

Features that are the same size as noise are suppressed because they are not distinguished from the noise. The noise near a sharp edge is not removed as effectively as the noise in the smooth regions of an image.

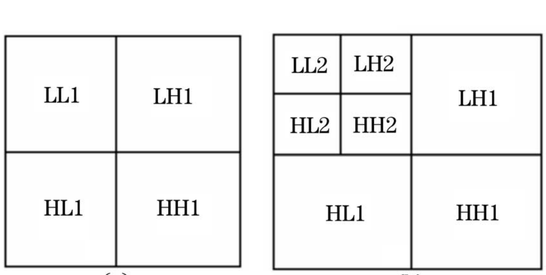

Fig. 2. Wavelet transforms of image.

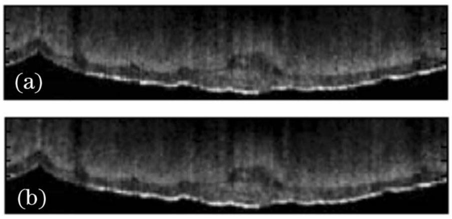

Fig. 3. OCT image of human finger tip *in vivo*.

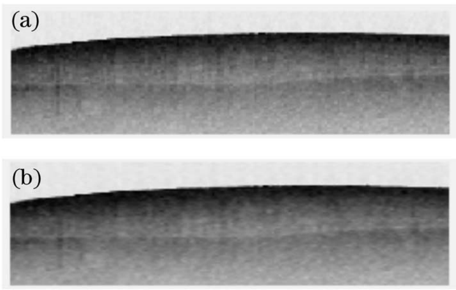

Fig. 4. OCT image of the cartilage.

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References

1. D. Huang, E. A. Swanson, C. P. Lin, J. S. Schuman, W. G. Stinson, W. Chang, M. R. Hee, T. Flotte, K. Gregory, C. A. Puliafito, and J. G. Fujimoto, Science **254,** 1178 (1991).
2. E. A. Swanson, J. A. Izatt, M. R. Hee, D. Huang, C. P. Lin, J. S. Schuman, C. A. Puliafito, and J. G. Fujimoto, Opt. Lett. **18,** 1864 (1993).
3. M. E. Brezinski and J. G. Fujimoto, IEEE J. Sel. Top. Quantum Electron. **5,** 1185 (1996).
4. G. J. Tearney, S. A. Boppart, B. E. Bouonaetal, M. E. Brezinski, N. J. Weissman, J. F. Southern, and J. G. Fujimoto, Opt. lett. **21,** 543 (1996).
5. M. Pircher, E. Gotzinger, R. Leitgeb, A. F. Fercher, and C. K. Hitzenberger, J. Biomed. Opt. **8,** 565 (2003).
6. J. M. Schmitt, S. H. Xiang, and K. M. Yung, J. Biomed. Opt. **4,** 95 (1999).
7. C. K. Hitzenberger, A. Baumgartner, and A. F. Fercher, Opt. Commun. **154,** 179 (1998).
8. J.-Y. Lu, J. Q. Cheng, and B. D. Cameron. Proc. SPIE **4619,** 300 (2002).
9. K. Yu, L. Ji, L. Wang, and P. Xu, Opt. Express **9,** 24 (2001).
10. J. Rogowska and M. E. Brezinski, Phys. Med. Biol. **47,** 641 (2002).