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Contrast improvement for swept source optical coherence tomography image of sub-surface tissue

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ABSTRACT

Swept source optical coherence tomography (SSOCT) is an attractive biological imaging technology due to its advantages of simple setup and high imaging speed. As the light intensity attenuated rapidly in high scattering biological tissues, the contrast of OCT image will drop with depth. In this paper a new method was introduced to compensate the attenuation of imaging contrast in SSOCT. The interference signal was divided into two channels of analog to digital converter (ADC) with a splitting ratio of 1:5. The higher level signal in one channel was used to reconstruct deeper structure of tissue and the lower level signal in the other channel was used to reconstruct surface structure of tissue. Low-frequency signals in one channel were filtered by a high pass filter and then combined with the signal in the other channel to obtain a high contrast image in both surface and deep area of tissue. Human finger and porcine airway imaging obtained with the system show that the contrast of SSOCT images can be improved in deeper region of tissue.
Keywords: Swept source optical coherence tomography, contrast improvement, attenuation compensation

1. INTRODUCTION

Optical coherence tomography (OCT) is an emerging biomedical optical imaging modality capable of high-resolution cross-sectional imaging in biological tissue[1]. With a swept source optical coherence tomography (SSOCT) system based on a frequency swept narrow-bandwidth light source, the high imaging speed of up to multi-MHz can be achieved [2,3].

OCT obtains the internal microstructure of biological tissues by detecting back reflected/scattered light from the object. However, due to the turbid and heterogeneous nature of tissues, the incident light will drop drastically when it penetrates into the biological tissue resulting in a decayed contrast with imaging depth [4]. In ultrasound imaging the signals were compensated based on its propagation time, which represented the depth information of image [5]. Due to the much faster speed of light than that of sound, a different compensation method need be proposed for OCT. Chang et al. analyzed the A scan signal and constructed a compensational curve to compensate the OCT signal attenuation [6]. An enhancement algorithm for OCT skin images and improved the quality of the images in the structures at deeper levels was proposed by Hojjatoleslami et al. [7]. Zhang et al. built a dual-band FD-OCT system and developed an algorithm for compensating depth-related discrepancy and attenuation [8]. Anderson et al. proposed a method of performing extraction of optical scattering parameters and attenuation compensation [9,10]. To compensate for light attenuation and enhance contrast in OCT images, Girard et al. prestent a series of algorithms that can be applied to both time and spectral-domain OCT images [11].

In this paper, a new attenuation compensation method for SSOCT is proposed. In SSOCT the higher frequency signal represented the signal in deeper depth with stronger attenuation in biological tissues. In our setup, the interference signal was split into two channels of an ADC with a splitting ratio of 1:5. The lower level signal was used to reconstruct surface structure of tissue. In the higher level channel, the high frequency signal passing through a highpass filter was used to reconstruct deeper structure of tissue to display the details in the deeper areas more clearly. By combining the low

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frequency signal in lower level channel and high frequency signal in higher level channel, the contrast of OCT imaging is improved.

2. METHODS

Fig. 1 shows the SSOCT system. A swept source (Axsun Technologies, Inc, USA) with a center wavelength of 1310 nm, a bandwidth of 108 nm, a sweep frequency of 50 kHz and an output power of 20 mW was used as the light source. The light was split into the sample arm and the reference arm by a 90:10 coupler. The light back-scattered/back-reflected from the reference mirror and sample arm were redirected by two circulators and detected by a balanced detector. The detected signal was divided into two channels of an ADC (ATS9360, Alazar) by a directional coupler with the ratio of 1:5. The higher level signal in ChB was filtered by a high pass filter so that the signal intensity in ChB is close to that in ChA. Because the higher frequency signal experiences stronger attenuation, signal in ChB was used to reconstruct structure in deeper tissue and signal in ChA was used to reconstruct structure of tissue surface. The signals in two channels were combined in real-time after digitized by the ADC.

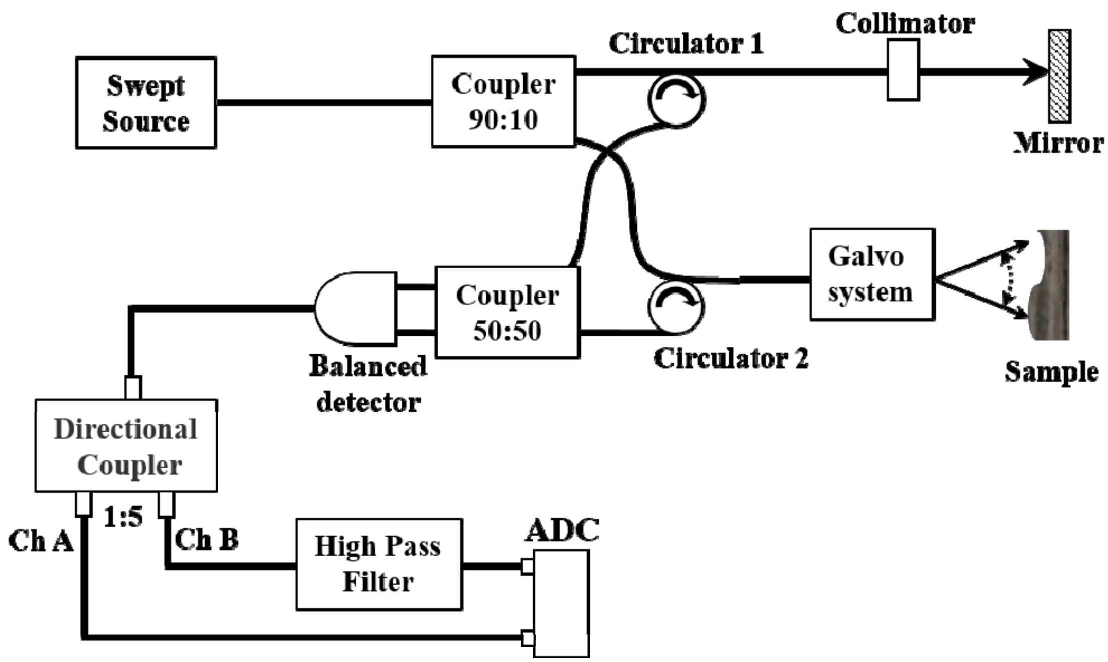

Fig. 1 Schematic of the SSOCT system, ADC: analog to digital converter

3. RESULTS

Human finger was imaged to test the capability of our system to improve the image contrast. As shown in Fig.2(A), the contrast of OCT image before compensation dropped with depth and the structural information in deep area was lost. As illustrated in Fig.2(B), OCT image after compensation shows an obvious enhancement of contrast in deep area.

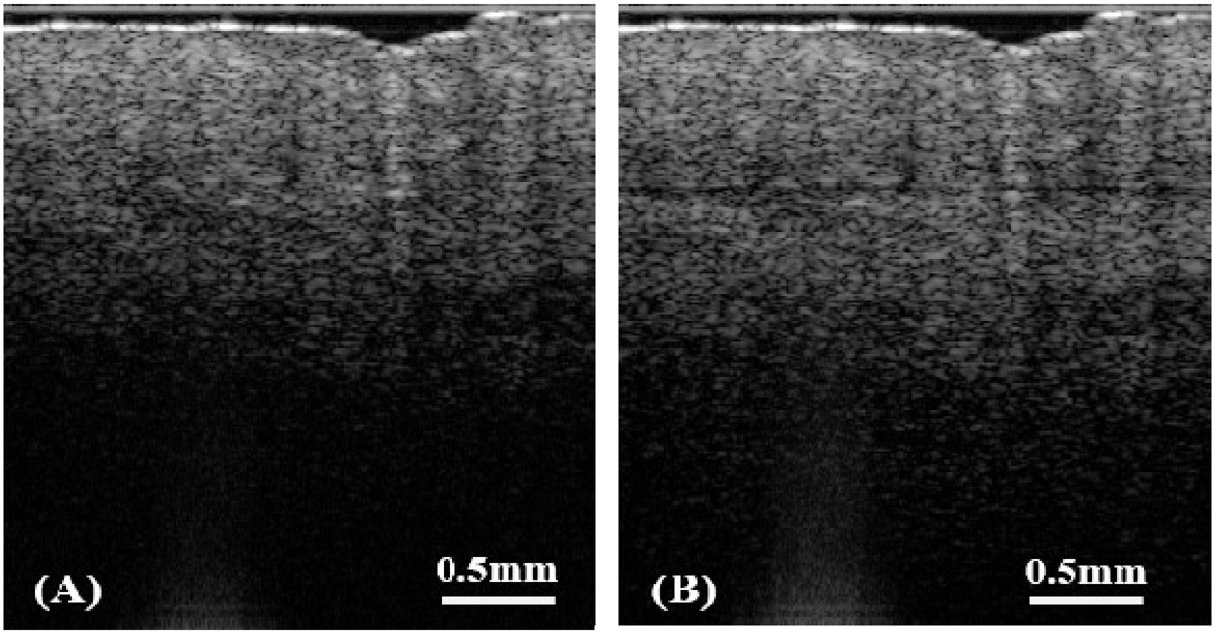

Fig.2 Images of human finger before (A) and after (B) compensation

Porcine upper airway imaging shown in Fig.3 demonstrated that this method can improve the quality of OCT image effectively.

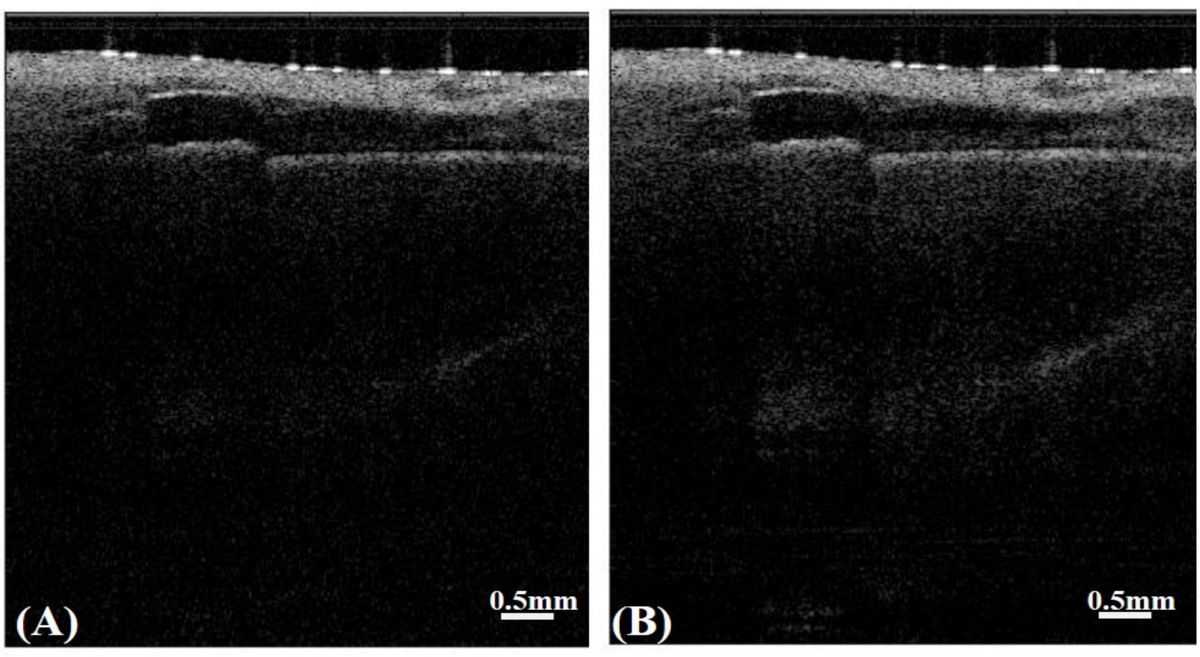

Fig.3 OCT image of porcine upper airway before (A) and after (B) compensation

4. DISCUSSION

In SSOCT, high frequency signal are strongly attenuated in biological tissues, Fig.4 shows an average curve of 1000 A-line curves in an OCT image of human skin obtained by SSOCT.

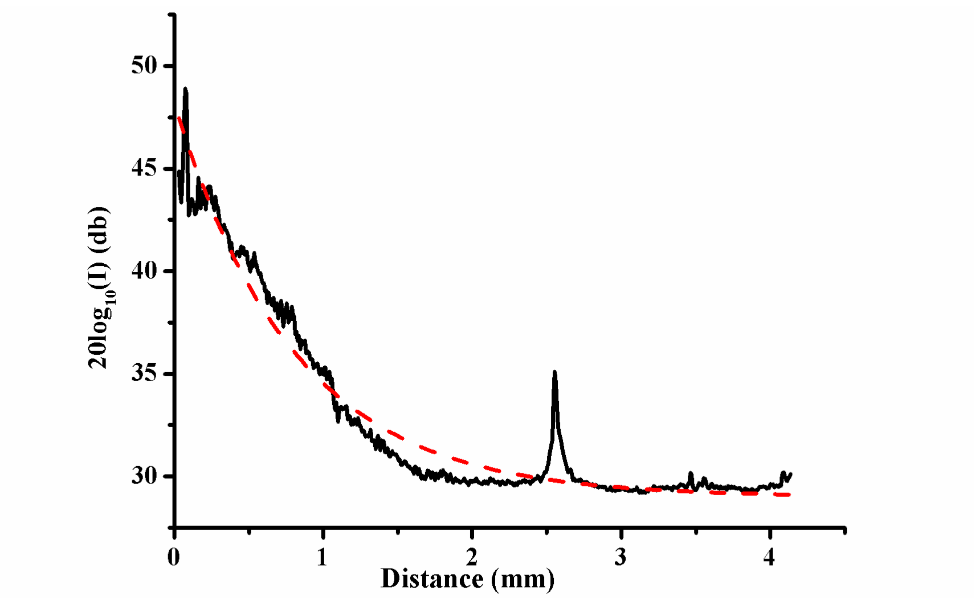

Fig.4 The average curve of 1000 A-line curves in an OCT image of human skin.

In SSOCT, signal could be compensated in frequency domain since frequency of interference signal corresponds to depth in the sample. By using a high pass filter to filter the low frequency signal, OCT image is reconstructed with the left high frequency signal. Fig.5 shows the frequency response curve of the used high pass filter with a cut-off frequency of 13MHz.

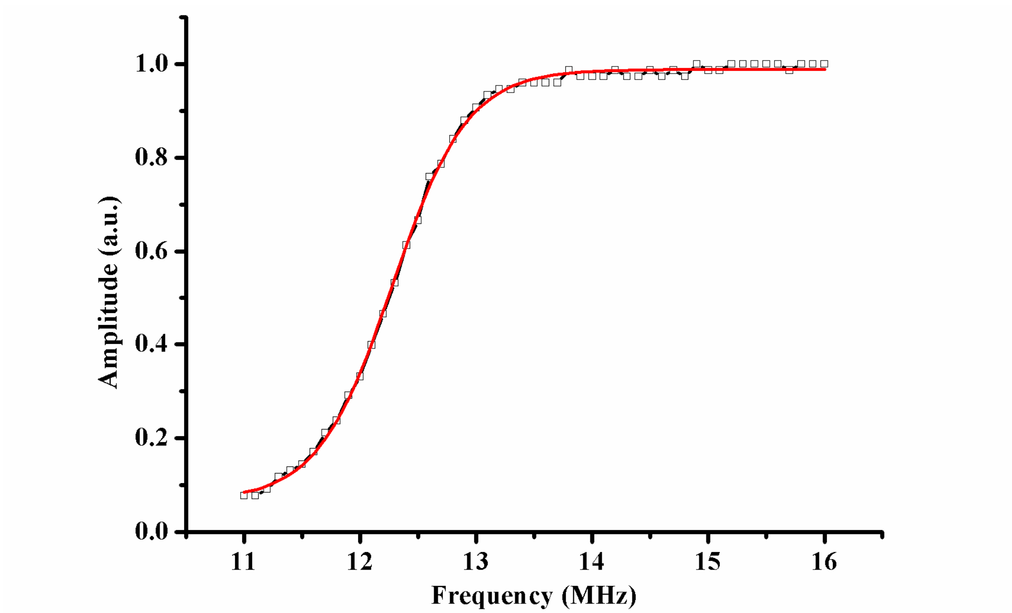

Fig.5 Frequency response curve of high pass filter

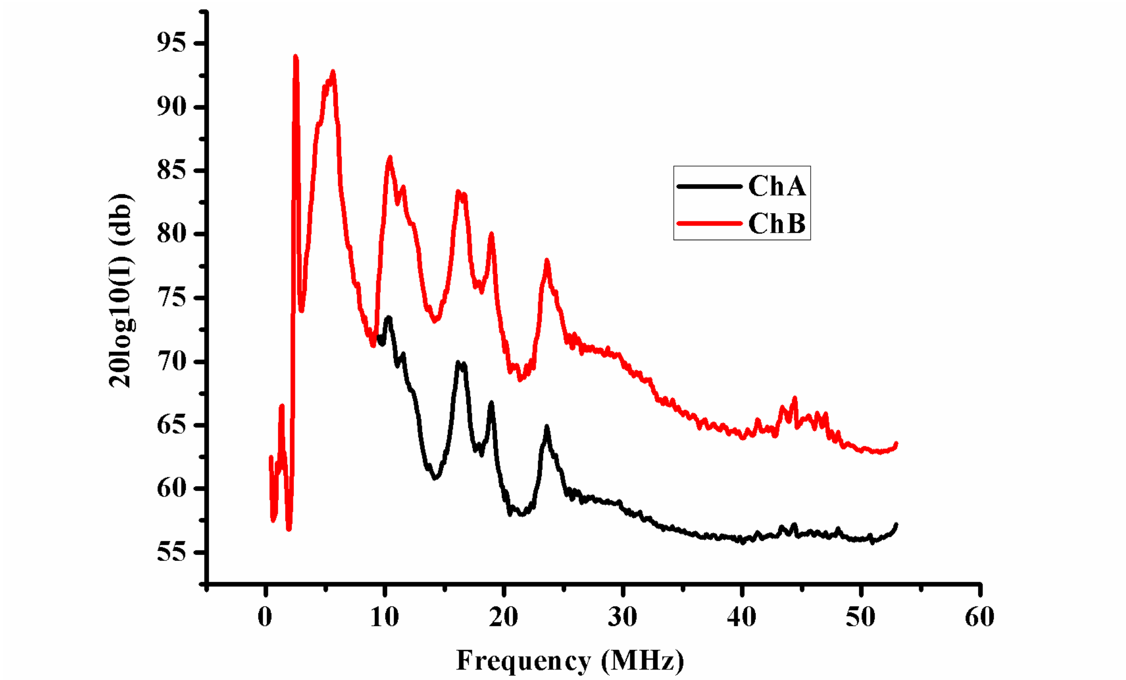

Fig.6 The average intensity of A-line signal

Fig.6 shows the comparison of average intensity of the signal in ChA and ChB.

Conclusions

In summary, a new compensation method to improve the OCT imaging contrast in highly scattering tissue is presented. Due to the strong attenuation of light in tissue, the imaging contrast in the deeper area is significantly weaker than that in surface area. With the presented dual channel based compensation method, the contrast of OCT images was enhanced in deeper region. Human finger and porcine upper airway imaging demonstrated that high quality image can be obtained with this simple and cost-effective method.

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