Common-path OCT using optical delay stair

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We build up a common-path optical coherence tomography (OCT) system using reflected light of sample surface as reference light. As the zero path length reference point has nothing to do with the distance between probe and organ, it can be utilized in endoscopic system. Besides, an optical delay stair is used in this common-path OCT to reconstruct the exact morphology of tissue surface, diminishing the distortion caused by sample surface reference.

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Endoscopic optical coherence tomography (OCT) makes usage of OCT in endoscopically guided biopsy to achieve non-invasive and high-resolution imaging of inner organ *in vivo*, revealing both pathological changes on the surface of mucosa and inside the mucosa, which is essential for early diagnosis[1,2].

OCT is usually based on a low-coherence interferometer consisting of reference and sample arms, and the reflected light from the two arms will interfere when their optical path lengths difference is less than the source coherence length. In endoscopic OCT system, the OCT probe goes into human body through biopsy channel of endoscope, and the distance between probe and organ is variable during imaging, which makes it essential to adaptively adjust the zero path length reference point[3]. Common-path OCT[4–6] with reflected light from probe as reference light is widely used in endoscopic system as its sample and reference arms are common path for achieving dispersion and polarization matching. But its zero path length reference point is unadjustable and it cannot interfere when the distance between probe and tissue is larger than the imaging depth. Tao *et al.*[7] developed a versatile OCT based on alternating reference arm with four mirrors, and a galvanometer scanner was used to switch the reference beam among the four mirrors to get different zero path length reference point. Meng *et al.*[8] developed an enhanced common-path OCT with two reference arms whose optical path length difference was used to adjust the zero path length reference point. In the two setups above, the zero path length reference point is adjustable, but not adaptively, and that makes them unsuitable for endoscopic system. Krstajić *et al.*[9] proposed OCT with tissue surface as the reference arm, whose zero path length reference point has nothing to do with the distance between probe and tissue, but as no separate reference is used, it cannot reveal the morphology of tissue surface.

In this letter, we propose a common-path OCT for endoscopic imaging, which uses tissue surface as imaging reference and an optical delay stair to get the exact position of tissue surface for each A-line scan. Our setup can be used in endoscopic system and the separate reference arm makes sure the presentation of exact morphology of tissue.

The schematic of our common-path OCT is shown in Fig. 1. A superluminescent diode (SLD) (SLD-101S, General Photonics) centered at 1310 nm with 80 nm bandwidth is used as light source. Light emitted from SLD is split into sample light and reference light by 2×2 splitter (splitter 1). The sample light is emitted from a probe with 10 mm working distance and backscattered by tissue surface and deeper tissue. The interference of the two backscattered light is split by 2×1 splitter (splitter 2), part of the light is detected by spectrometer 1, the other part interference with reflected light by optical delay stair and detected by spectrometer 2.

The structure of optical delay stair is shown in Fig. 2. It is composed of 10 glass plates whose thickness is 2 mm each. The steps of the optical delay stair are 3 mm wide each and coated with reflection enhancing film. As the imaging depth of two spectrometers in this

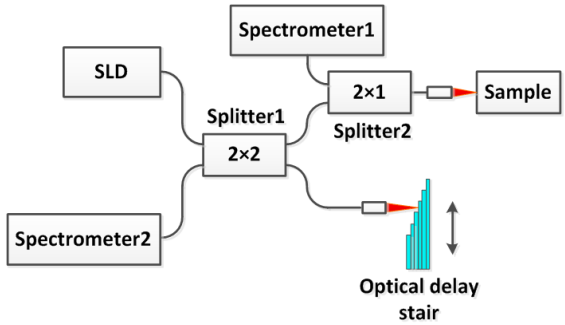


Fig. 1. Schematic of common-path OCT.

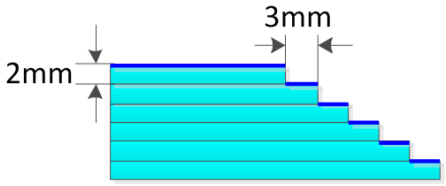


Fig. 2. Structure of optical delay stair.

setup is 2.14 mm, the light reflected from a step will interfere with light backscattered by tissue surface if their optical length difference is less than 2.14 mm, and the precise position of tissue surface can be extracted from spectrum gotten by spectrometer 2 through simple threshold algorithm. In the endoscopic imaging process, the distance between probe and tissue surface (the optical length of sample light backscattered from tissue surface) changes at all times. In this setup, the optical delay stair is put on a translation stage with 5 μm precision and the stage is controlled by hardware which monitors the position of tissue surface. Once the tissue surface disappears in the spectrum obtained by spectrometer 2, the hardware will drive the stage backward or forward, and the reference light will illuminate on the previous step or next step with optical length of reference light decreasing or increasing. The hardware records the precise tissue surface position of each A-line scan, and the exact morphology of tissue can be reconstructed.

Based on the proposed common-path OCT, we performed validation experiments. To verify the effectiveness of optical delay stair in sample morphology reconstruction, a mirror stair with the same structure as optical delay stair is used as sample. The sample stair consists of two mirror steps, each about 3.9 mm height and 3 mm width. To avoid disturbance of sample stair edge, we only performed detection in the center 0.5 mm of each step. Figure 3 shows the upper surface position of sample stair with 25 samples each step. It shows that the position difference of two sample steps is about 3.9 mm which is consistent with the structure of sample.

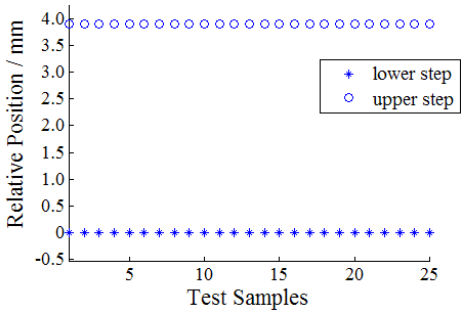
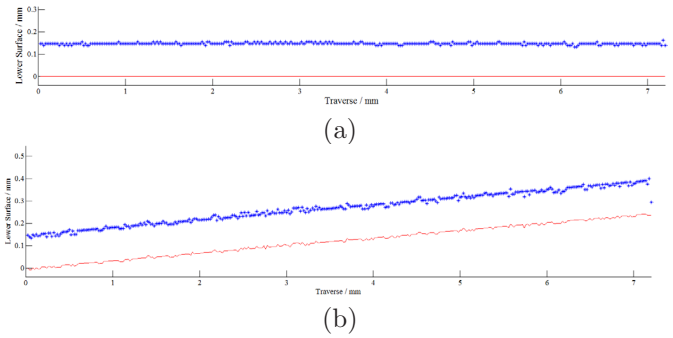


Fig. 3. Distribution of sample surface position.



(a)

(b)

Fig. 4. Distribution of thin plate lower surface: (a) with optical delay stair and (b) without optical delay stair.

A thin parallel plate with 0.14 mm height is used as sample. The plate is put aslant with 5° pitch. The distribution of its lower surface with and without the optical delay stair is shown in Fig. 4. The red line is the fictitious top surface of the thin plate as reference. It can be seen that the morphology of lower surface has the same slope as real after surface reconstruction.

In conclusion, we present a novel common-path OCT for endoscopic system using tissue surface as reference and optical delay stair to reconstruct each A-line scan. Since the zero path length reference point has nothing to do with the distance of probe and tissue, this setup can be used for endoscopic imaging *in vivo*. Besides, the usage of optical delay stair reconstructs the A-line scans, diminishing the distortion caused by common-path setup. The experiments validate the effectiveness of our setup.

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