

Published in final edited form as:

*Electron Lett.* 2009 October 22; 45(22): 1110–1112. doi:10.1049/el.2009.1627.

## Common path optical coherence tomography with fibre bundle probe

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### Abstract

A simple common path optical coherence tomography using a fibre optic bundle as a probe is demonstrated experimentally. The mechanical lateral scans are accomplished outside the specimen, proximal entrance of the fibre bundle, which eliminated the need for moving parts in the distal end of the probe. This feature allows the probe to be made submillimetre in size and easily integrated into surgical tools for intraoperative imaging. The axial and lateral resolutions of the system, and preliminary images of phantom samples, are reported.

### Introduction

Current optical coherence tomography (OCT) adapts various kinds of miniaturised scanning optic probes that can be used in minimally invasive imaging for diagnosing or micro-sensitive image-guided surgery purposes [1-3]. There also have been great efforts to avoid the use of mechanically moving probes for the lateral scans either in high-resolution microscopy [4-6] or in conventional OCT systems to obtain 2-D or 3-D images [7,8]. Some of the previous works that introduced fibre bundle conduits (either rigid or flexible), were taking images using full-field (or wide beam projection) imaging with a 2-D image sensor. Others implemented a remote scanning with the conventional Michelson interferometer type OCT system with directly coupling the beam into the bundle [9,10]. However, because there are large variations of effective index, core size and dispersion properties between fibre bundle pixels, obtaining such an OCT image using a fibre bundle can be difficult and complex. Since common path (CP) OCT obtains the reference at the distal end of the probe, it can overcome the difference between the optical properties between the fibre bundle pixels [11,12]. In this work, we explored an approach for a scanningless probe using common path OCT that can be used for possible applications in endoscopic diagnostic imaging and microsurgery applications.

## Experiment and results

The schematic view of a CP-OCT system with an optical fibre bundle probe is illustrated in Fig. 1. The CP-OCT system comprises a low coherence superluminescence diode (SLD), a  $2 \times 1$  fibre directional coupler, and a spectrometer. We used a broadband  $0.8 \mu\text{m}$  light source with 5 mW output and a high-resolution spectrometer to obtain signal spectra which were subsequently processed for depth imaging. The fibre coupler was used to route the SLD output to an X/Y scanner which was used to scan the beam across the proximal entrance of the fibre bundle. We used 76 mm-long 10 000 and 50 000 pixels fibre optic bundles with a core diameter of  $\sim 10 \mu\text{m}$ . One of the outputs from the fibre coupler was placed at the proximal input of the fibre bundle and was attached to the X/Y scanner for the transverse 2-D scanning. A microscope objective was used to couple the light from the coupler into each fibre pixel. The numerical aperture (NA) and magnification of the objective was 0.25 and 10x, respectively.

The reference plane for the CP-OCT occurs at the distal end of the fibre bundle where a strong Fresnel reflection occurs at the glass–air interface. The computer controls both the spectrometer (connected by USB cable) and the X/Y scanner (connected by GPIB cable) for data collecting and lateral scanning, respectively. We used a US Air Force resolution target, glass slides, and multilayer polymer tapes to evaluate the probe performance.

The axial and lateral responses of selected pixel fibres are shown in Fig. 2. The signal amplitude from a silvered plane (mirror) placed 1 mm away from the tip to avoid detector saturation varies from pixel to pixel both in the axial (Figs. 2a and b) and in the lateral (Fig. 2c) direction. The full width half maximum (FWHM) of the resolved envelope is  $\sim 9 \mu\text{m}$ , which is the source coherence length limited axial resolution for fibre pixels having different amplitudes as in Figs. 2a and b. The irregularity of the fibre bundle is presented with missing and/or damaged fibre pixels from the response in Fig. 2c which is laterally scanned for  $400 \mu\text{m}$  along the fibre bundle with  $1 \mu\text{m}$  steps.

From an *en face* OCT image of the US Air Force test chart in Fig. 3a, we clearly observe the pixilation effect by each fibre core in which the individual pixel limits the lateral resolution of the image. We can also see several partially or totally damaged and/or missing pixels marked with arrows. Fig. 3b shows an A-scan image of two glass slides where the glass interfaces can be clearly seen. A 3-D cross-sectional image of a multilayer polymer tape is shown in Fig. 3c where the boundaries between different layers can be clearly seen. Factors that degrade image quality are the impact of discrete pixilation of fibres, uneven optical characteristics between each core (as compared in Fig. 2), and the coupling loss due to the mismatches in NAs between the fibre bundle (0.55) and the objective (0.25) in the setup (Fig. 1).

## Conclusion

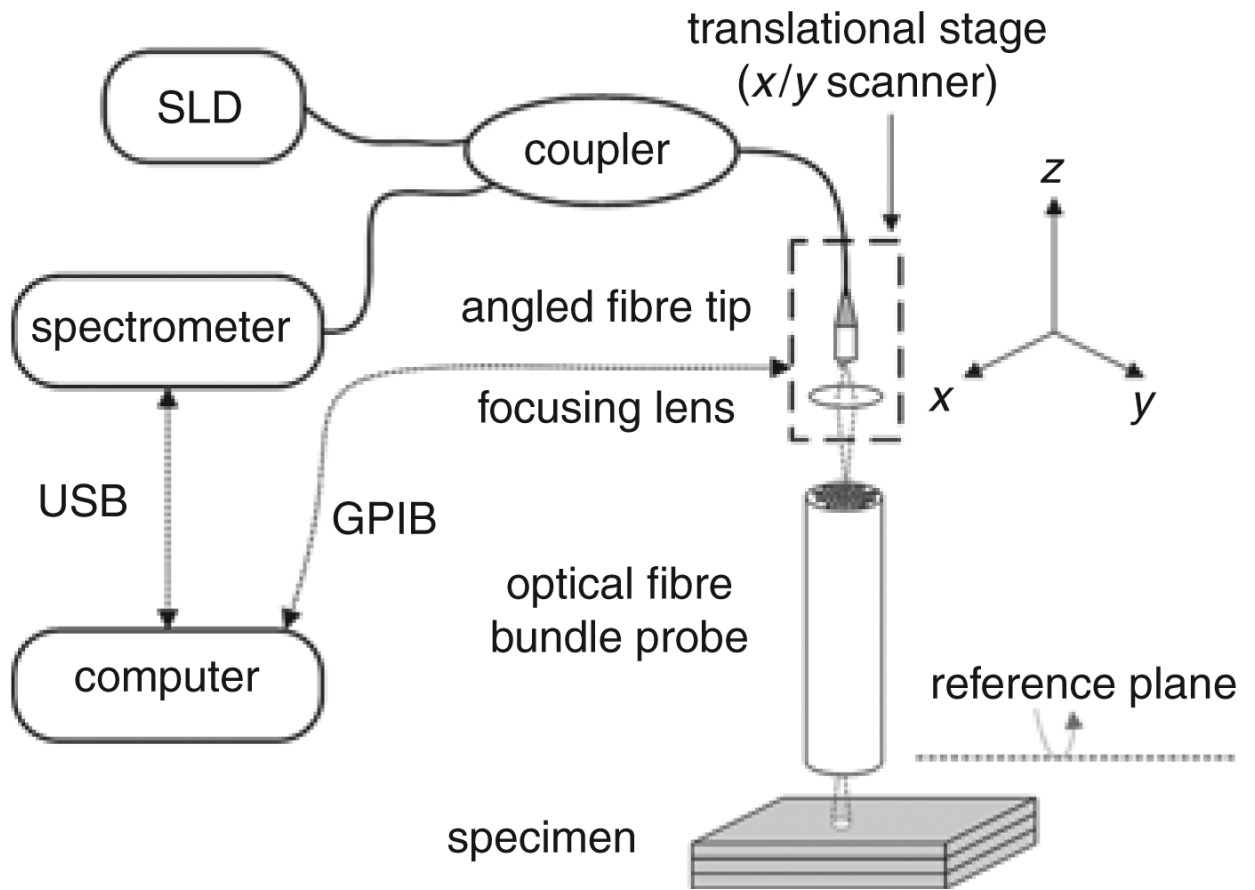
We have experimentally demonstrated a fibre bundle optic probe based common path OCT system that can be used to obtain scanningless OCT imaging at the distal end of the probe for image-guided microsurgery and diagnostic imaging. We were able to achieve axial and lateral resolutions limited by the coherence length of the source and the size of the fibre pixel of the bundle imager, respectively.

## Acknowledgments

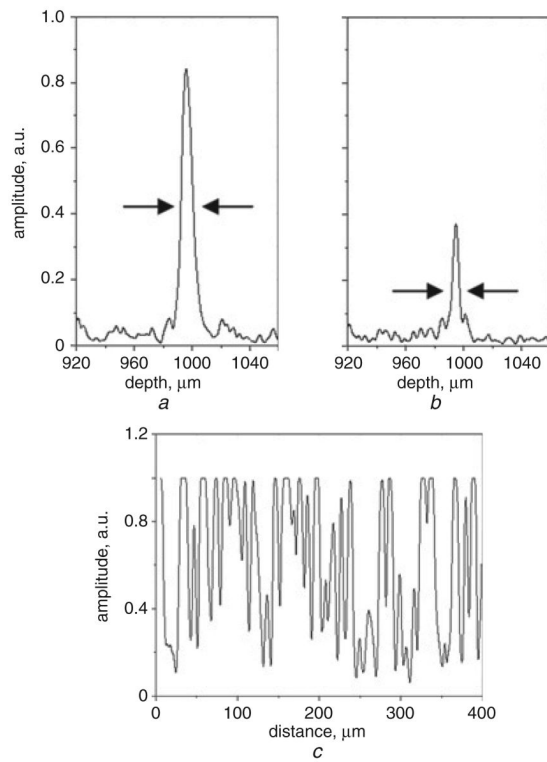
This work was supported in part by NIH grant BRP 1R01 EB 007969-01.

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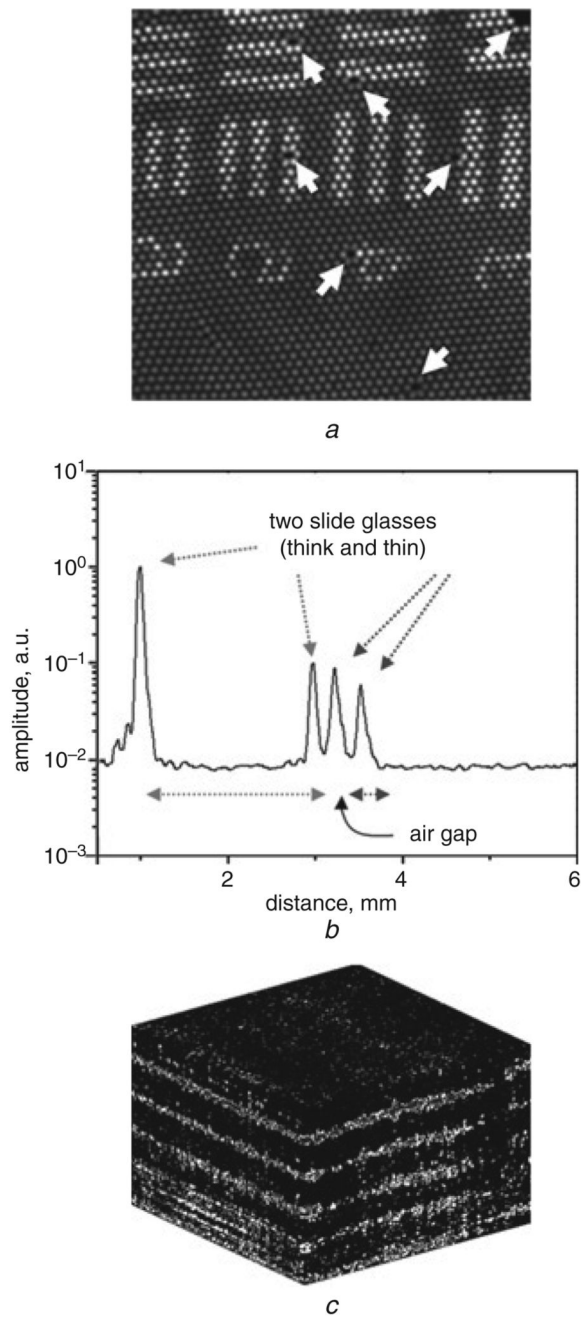
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**Fig. 1.** Experimental setup for FD CP-OCT system with fibre bundle conduit probe



**Fig. 2.**  
Measured different pixel responses from mirror  
*a* Fibre pixel 1 (axial response)  
*b* Fibre pixel 2 (axial response)  
*c* Consecutive fibre pixels (lateral response)



**Fig. 3.**  
 Obtained OCT images  
*a* *En face* image of US Air Force target ( $2 \times 2$  mm)  
*b* A-scan image of two glass slides  
*c* 3-D image of polymer layers ( $0.6 \times 0.6 \times 0.4$  mm)