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Evaluation of Common Path Optical Coherence Tomography in Specific Applications

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Abstract: This paper evaluates the application of common path optical coherence tomography (OCT) in three applications: distance sensing, handheld imaging and dynamic OCT. © 2025 The Author(s)

1. Introduction

Optical coherence tomography (OCT) is a well-established, non-invasive volumetric tissue imaging technique, used both for medical diagnosis and non-destructive imaging of biological and industrial samples. It employs low-power broadband or sweeping infrared light sources, such as SLDs [1]. OCT is most widely-used in ophthalmology, but there are many other applications of interest where OCT interferometry can be utilized, such as proximity sensing, or studying and diagnosing disease in other biological tissue. OCT is an interferometric technique, requiring that the light source is split into a reference path and an object path, with the beam in the object path, returning from the sample, recombined with the reference path prior to the detector. In modern Fourier-domain OCT systems, depth information from the sample is encoded in the spectrum of the broadband or wavelength-swept light, with interference leading to modulations in the spectrum corresponding to different optical path differences (OPDs) between the reference beam path and the object beam returned from a particular depth layer within the sample. The maximum detectable OPD is typically a few millimeters (with maximum sensitivity close to zero OPD) and so the reference and object path lengths must be closely matched. Most OCT interferometers employ a dual path optical structure, such as a Michelson interferometer, where the reference and object beams travel along physically separate paths, either in air or in fiber. While this has a number of advantages, including the ability to easily vary both the length of, and optical power in, the reference path, there are some applications where common path (CP) OCT may be preferable. In this case, the reference and object arms follow the same optical path for all or most of their length. As well as leading to more compact optical set-ups, with fewer optical components, CP-OCT has other potential advantages, particularly in reducing instabilities or polarization changes that arise from separated optical paths, particularly where the paths are long or in optical fiber. In this paper we evaluate three cases where CP-OCT or partial CP-OCT may have significant benefits: ultra-thin OCT distance sensors, compact manually-scanned OCT probes, and dynamic OCT.

2. Fiber based common path OCT for tissue proximity sensing and manually-scanned imaging

OCT-based optical fiber sensors can provide proximity detection (for example to the surface of delicate tissue) over a range of several millimeters. They can be integrated with surgical tools, particularly for the retina, to provide surgical guidance and improve safety by avoiding accidental tissue damage [2]. Methods for building and testing sub-mm diameter sensors, utilizing commercially-available 125 μm single mode fiber fused with a beam expanding coreless fiber and a small section of focusing graded index multimode fiber, have been developed and are detailed in [3], where probes with an axial resolution of 20 μm and a usable range of 2 mm were achieved. Gold sputtering at the distal end provides a medium-independent partial back-reflection which serves as the reference beam, allowing the probes to be used common-path. This allows interchange of different length probes without adjustment of the length of the reference arm. The sensor was evaluated with a 1060 nm swept laser source, sweeping over a 100 nm bandwidth at 100 kHz. Following spectral shaping and adjustment of non-linearities in the laser sweeping, the proximity length from the probe to the surface is determined by locating the first A-scan peak, and this is displayed visually or as an audible signal conversion.

A modified version of the fiber probe described above was mounted in a 3D printed holder and linked via a 2x2 fiber coupler to a broadband SLD centered at 840 nm (with 50 nm bandwidth) and a custom-build spectrometer running at 7.5 kHz, forming a low-cost CP spectral domain OCT system. In this case the end of the probe was not gold-sputtered, and the reference signal was derived from the intrinsic back-reflection from the end of the fiber. The probe was then manually translated over samples and, based on analysis of image speckle decorrelation, images were reconstructed with automatic compensation for variations in manual scanning speed. Fig. 1(a) shows an

example of an image of an infra-red viewer card acquired with a the manually-scanned CP OCT probe (a), compared with an image of the same sample acquired with a conventional scanning, non-CP OCT system, also at 840 nm, depicted in (b).

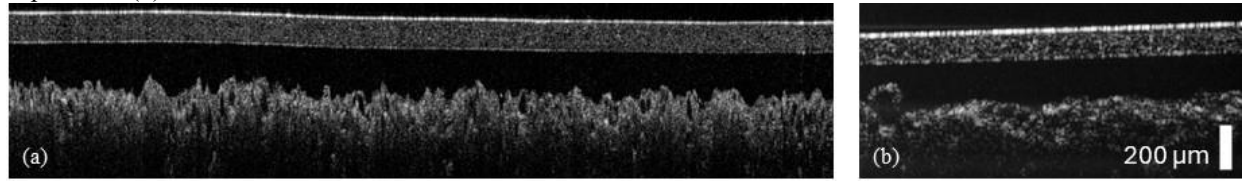


Fig. 1 Example OCT images of infra-red viewer card, consisting of semi-transparent layer (top), air gap (middle) and fluorescence material (bottom), using (a) CP manually-scanned OCT and (b) conventional, mechanically scanned non-CP OCT.

3. Free space partial common path OCT for biological tissue imaging

Dynamic OCT [4] is an emerging technique that uses the time variation of OCT signals to distinguish different components of tissue. Due to small-scale motion (e.g. Brownian motion) within tissue, speckle grains and the phase within the OCT image vary over timescales of milliseconds to a few seconds. A time-series of OCT images acquired of the same sample over several seconds can therefore be analyzed to provide additional image contrast beyond conventional structural OCT. However, any small disturbance to one arm of the OCT interferometer will also lead to a time-varying signal, generating a spurious dynamic signal, suggesting that CP would be beneficial. To investigate this, a spectrometer-based CP OCT system is illustrated in Fig. 2(a), using a broadband 850 nm SLD, and an 80-20 fiber optic coupler. In the object arm, a beamsplitter is used to create a separate reference beam entirely in air, i.e. the fiber portion of the optical system is all common-path. For comparison purposes, the system also includes a second reference path which does include a fiber-portion, as in a typical OCT system. Fig. 2(b) shows the phase stability of the common path (CP) versus non-common-path (NCP) while the fiber is moved, using the signal from a mirror. Fig. 2(c,d) show phase-based dynamic OCT (as described in [4]) images from a grape using NCP and CP, respectively, with the NCP showing much higher background signal.

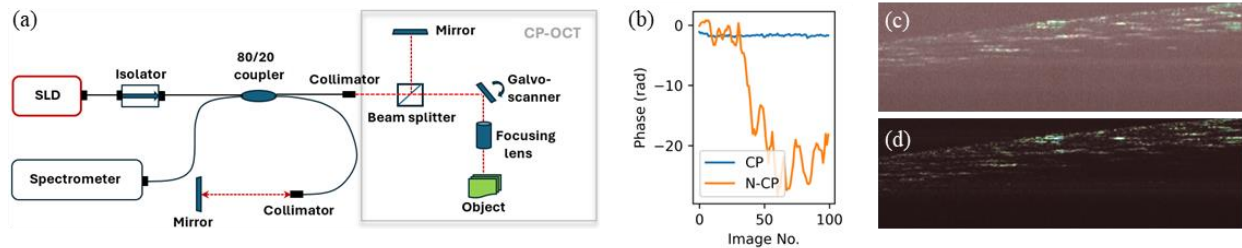


Fig. 2.(a) Setup of common path (CP) and non-common path (NCP) OCT for biological tissue imaging, (b) difference in phase stability between CP and NCP; (c) dynamic image of grape using NCP; and (d) using CP.

4. Acknowledgements

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5. References

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