Bachelor student project: Incoherent fiber-length measurement

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1 Introduction

Some background information on the problem, as well as relevant starting-point references, are provided below.

1.1 Optical coherence tomography

Optical coherence tomography (OCT) is an interferometric technique that allows high-resolution (~ 5 μm), high-speed, cross-sectional imaging of biological tissues [1, 2]. This has many applications in medical imaging in fields such as ophthalmology, cardiology, and gastroenterology (see Fig. 2), to name just a few. In these fields, OCT can be used to assess the sub-surface structure of tissues to identify or monitor disease markers. In practice, OCT systems are composed of two interferometer arms and many fiber components, see Fig. 1, each of which must be thoroughly characterized to produce optimal images. Failure to length match the two arms results in degraded imaging quality (due to material dispersion) or, in the worst case, a non-functioning setup. However, measuring tens of meters of fiber with millimeter precision/accuracy is tedious, complicated, and risks damaging the components. It is, therefore, very interesting to develop a rapid, systematic, and risk-free method to measure the length of fiber components.

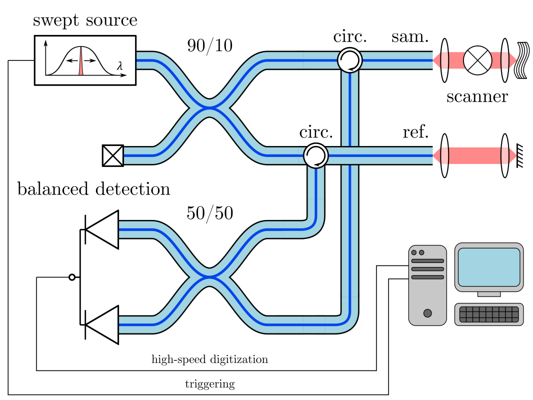

Figure 1: Schematic of an OCT fiber system. All blue segments are single-mode optical fibers that need to be characterized.

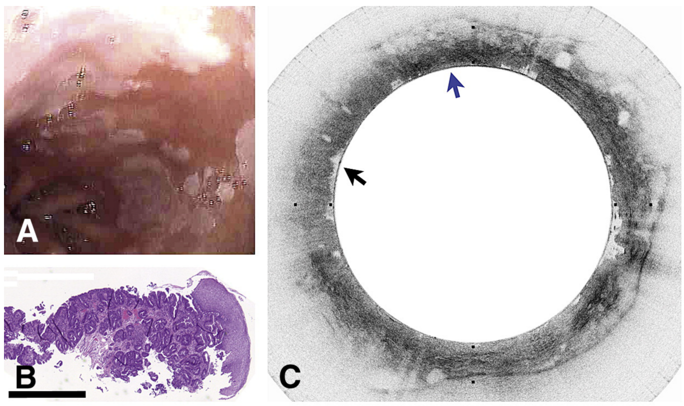

Figure 2: Example OCT image in the esophagus, reproduced from [3]. (A) Image obtained with a conventional video endoscope. (B) Histology slice. (C) OCT cross-section (abnormal tissue indicated by arrows) is used for the early detection of esophageal cancer.

1.2 Existing length measurement techniques

Many methods exist for measuring the length of optical fibers, usually applied to optical fiber networks in telecommunication networks. Moreover, their sensitivity, measurement range, and resolution capabilities are unsuited for the intended application. One such technique is optical time-domain reflectometry (OTDR), which measures the time delay between an input optical pulse and the pulse reflected at the tip of the test fiber [4]. Another technique is optical frequency domain reflectometry (OFDR) which measures the interference between the signal returning from a test fiber and that from a reference fiber as a function of wavelength [5]. However, such methods require expensive components such as pulsed or tunable laser sources and fast high-sensitivity detectors. As such, we aim to develop a related but more cost-effective method.

2 Proposed Work

In this project, we implement phase-detection methods (phase-locked-loops or dual-phase lock-in amplification [6, 7]) to measure the phase shift ($\delta\phi$, see Fig. 3) between the signal transmitted through a reference fiber and a test fiber. This phase offset is proportional to the length difference between the two fibers and the modulation frequency. By varying the modulation frequency using an electro-optic modulator (EOM), it becomes possible to recover the length of the test fiber. While relatively simple in theory, this approach includes many experimental difficulties that the student will need to solve to develop a robust measurement system. The student will first develop the mathematical models relating the phase offset to the length difference and determine which operational parameters allow robust measurements of fiber lengths from 1 to 20 m with millimeter accuracy. They will then construct the experimental setup and assess potential sources of error, overall measurement uncertainty, and repeatability.

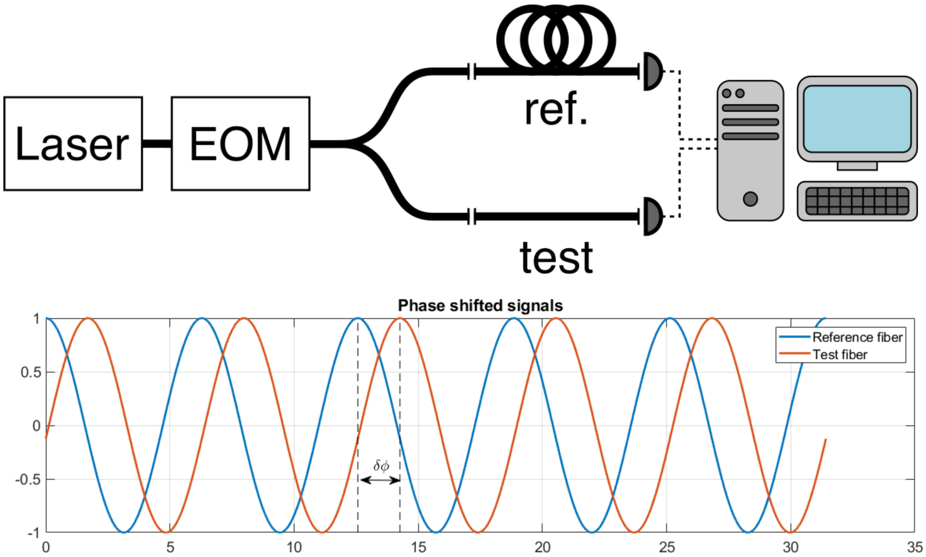

Figure 3: Schematic of the experimental setup (top) and example signal (bottom).

3 Requirements & learning outcome

We are looking for a bachelor's student with knowledge of physics and engineering and an affinity for hands-on experimental work. Some programming experience (Python, Matlab, etc.) is necessary for data analysis. Experience with Labview for system prototyping is beneficial. The student will gain experience in optics, experimental design, and metrology and develop skills in collaboration, scientific writing, and presenting. The expected duration of the internship is three months, but can be adapted based on student needs.

References

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