Multiple reference optical coherence tomography for smartphone applications

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A novel, compact optical sensing and imaging platform can be used for affordable next-generation, smartphone-based personal and point-of-care applications.

As a multifunctional clinical diagnostic and monitoring technique, optical coherence tomography (OCT) has become a well-established tool in many areas, including ophthalmology, dermatology, gastrointestinal endoscopy, intravascular imaging, and oncology. OCT is a low-coherence, interferometric-based imaging modality that can be implemented using either time-domain (TD) or frequency-domain (FD) methods in which the interference signals generated by combining reference signals with light scattered by the target are detected. Early OCT systems are based on TD technology, and they use a bulky scanning reference arm optical delay to sequentially generate the axial scans (A-scans). TD systems require an inherently long acquisition time due to the moving reference mirror. This restricts the scan frequency to a few hundred A-scans/sec. That, in turn, limits the utility of this technique for high-speed applications, especially in ophthalmology and intravascular imaging. Modern OCT systems are based on FD technology. They can achieve hundreds of thousands of A-scans/sec. However, current OCT systems based on conventional TD and FD technologies are large and require expensive optical and electronic peripherals. Furthermore, the need for accurate alignment of complex optics makes them impractical in the point-of-care (POC) and personal care environments.

Recently, the unprecedented spread of mobile and smartphone technologies and innovative applications to address health priorities have created the new field of electronic health (eHealth), also known as mobile health (mHealth). Smartphone-based sensor technology for personal and POC applications is emerging as a very promising area of research. Recent developments in smartphone technology offer high-end computing power, storage, and connectivity that create new opportunities to integrate a wide range of medical sensor technologies to measure the user’s vital parameters such as heart rate, respiration rate, glucose, and body temperature. In addition, medical imaging technology developers are scrambling to create technologies that integrate with popular smartphone platforms for personal and POC applications. Recently, applications of smartphone-based devices have been growing quickly in imaging and bioanalytical areas such as immunoassays, lateral flow assays, electrochemical sensing, surface plasmon resonance-based biosensing, microscopy, ultrasound imaging, flow cytometry, and colorimetric detection.

This has all led to increasing interest in developing a cost-effective, compact, and easy-to-use OCT platform based on

Figure 1. Experimental setup of a multiple reference-optical coherence tomography (MR-OCT) system compared to a typical CD/DVD pickup head (PUH). (a) A typical CD/DVD PUH. (b) Experimental configuration of the MR-OCT system based on a bulk optics configuration. SLD: Superluminescent diode. L1-L3: Lenses 1-3. BS: Beam splitter. PM: Partial mirror, VCA: Voice coil actuator. RM: Reference mirror. D: Distance between PM and RM. S: Scan range. TD: Total depth scan range.

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smartphones for personal care and POC diagnostics that can enable rapid and accurate diagnosis and monitoring with reduced cost and time. Integrated optics-based FD-OCT is one emerging technology that has the potential to provide a small form factor and to be more cost-efficient. However, integrated optics technology is not yet well-established for commercial applications. Several technological difficulties need to be overcome in the field of integrated optics. First, the insertion losses in an integrated optics system are considerably larger compared to fiber or micro-optics systems. Second, coherent systems are extremely sensitive to reflections. These artifacts can drastically affect system sensitivity and imaging performance. The commercial availability of robust and low-cost integrated optics-compatible light sources and array detectors is another issue.

To address the smartphone trend, we are proposing a multiple reference OCT (MR-OCT) based on a miniature optical delay that uses a single miniature actuator (such as a piezoelectric transducer, voice coil, or a vertical scanning micro-electromechanical system) and a partial mirror to generate the recirculating optical delay for an extended A-scan range. Our proposed MR-OCT architecture promises to fit into a robust, cost-effective design that can be largely solid-state. It can be implemented by the same optics and process technologies used to produce CD/DVD ROM pick-up head (PUH) technology to address a variety of high-volume applications. Modern CD/DVD PUH technology integrates various optics and mechatronic devices, such as light sources, actuators, objective lenses, beam splitters, and optoelectronic integrated circuits in a small form factor platform similar to the optics of a Michelson interferometer-based TD-OCT system. Figure 1 shows our experimental MR-OCT setup compared to a CD/DVD PUH that costs less than $10 to address a variety of high-volume, depth-resolved sensing and ranging applications where high-speed is not important. We achieved the depth scanning by using a miniature re-circulating optical delay based on a voice coil motor actuator and a partial mirror. The actuator was extracted from a CD optical pick-up head and can provide an A-scan rate of 50Hz to 600Hz with an axial displacement of ~60μm. Figure 2 shows a prototype MR-OCT sensor setup based on a smartphone platform consisting of four main modules: an MR-OCT-based optical sensor module, an analog font end, a digital front end, and a smartphone using the Android operating system.

To demonstrate the imaging performance of our proposed MR-OCT system, we performed ex vivo imaging of the anterior chamber of a rat’s eye and layered cellophane. The corresponding images in Figure 2 are compared with a commercial-grade swept-source OCT (Thorlabs OCS1300SS with a 16kHz A-scan rate). We believe our multiple reference optical delay-based OCT platform features one of the most compact, affordable, and simple designs among similar OCT systems developed to date. This technique is simple and robust. The interferometric part of the MR-OCT system could be implemented as a very small device comparable in size and complexity to the optical pick-up unit of a DVD player and at a fraction of the cost of conventional OCT systems. In addition, it would have a moderate A-scan rate and performance for resource-limited applications. Furthermore, the moderate scan speed of MR-OCT does not demand high-specification computational platforms. Low-cost mobile systems are sufficient for its instrumentation and computational needs.

In summary, we are introducing the concept and design of a smartphone-based MR-OCT platform that promises to fit into robust and cost-effective designs. It will be virtually solid state and use optics typical of those used in CD/DVD ROM technology. The affordable and small form factor design of MR-OCT makes it easy to integrate with a wide range of low-cost POC devices such as a derma scope, fundus camera, or otoscope.

Our future work will focus on developing a more compact, low-cost, low operating power and robust MR-OCT platform based on micro optics devices and advanced photonic integration technology with the flexibility to address a variety of high-volume applications in fields such as mobile personal health monitoring and biometric security.

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