Submitted to Warsaw Summer School on Advanced Optical Imaging 2024

Low-cost Full-Field Optical Coherence Tomography using a Raspberry-Pi

Taylor Sanderson*[a], Adrian Bradu[a], Ranjan Rajendram[b] and Adrian Podoleanu[a]

[a]*Applied Optics Group, University of Kent, Canterbury, United Kingdom*
[b]*Moorfields Eye Hospital, London, United Kingdom*
#*corresponding author email: tls23@kent.ac.uk*
**Taylor Sanderson*

1. Introduction

Optical Coherence Tomography (OCT) is a non-invasive imaging technique capable of capturing high-resolution, depth resolved images of scattering media [1]. OCT has applications across a wide range of fields from biomedical imaging such ophthalmology and dermatology to non-destructive testing in industrial settings. In ophthalmology, for instance, OCT can be used to assist in early detection of conditions such as diabetic retinopathy, which if not detected and treated in early stages, through regular screening efforts, can cause permanent vision loss [2]. In low-resource and remote settings, access to OCT technology is limited, as conventional OCT systems are bulky in size and prohibitive system costs which often exceed $40,000 [3]. A significant portion of this cost stems from use of specialised or proprietary components and powerful computers for data processing.

Additionally the scanning methods employed, such as flying spot OCT configurations, are also a major contributing factor in the overall cost of an OCT system. An example of this is a flying spot OCT which utilises scanning optics, such as galvanometer scanners, to laterally scan broadband light across the sample. These scanning optics are expensive so hinder cost reduction significantly. Full-Field OCT (FF-OCT) offers a promising approach to cost reduction in OCT, as it forgoes the requirement for scanning optics to capture images of the sample, instead capturing a full en-face view in a single frame. This is achieved by employing a 2D camera in the detection arm of the interferometer, also forgoing the need for spectrometers or photo-detectors giving further cost reduction opportunities. In addition to the high cost of optical components, powerful computers for data processing further drive up system costs. In recent years single-board computers have become more powerful and pose an avenue for cost and size reduction of OCT systems, particularly in cases where image processing can be highly optimised, and have been successfully implemented in spectral domain OCT applications [4].

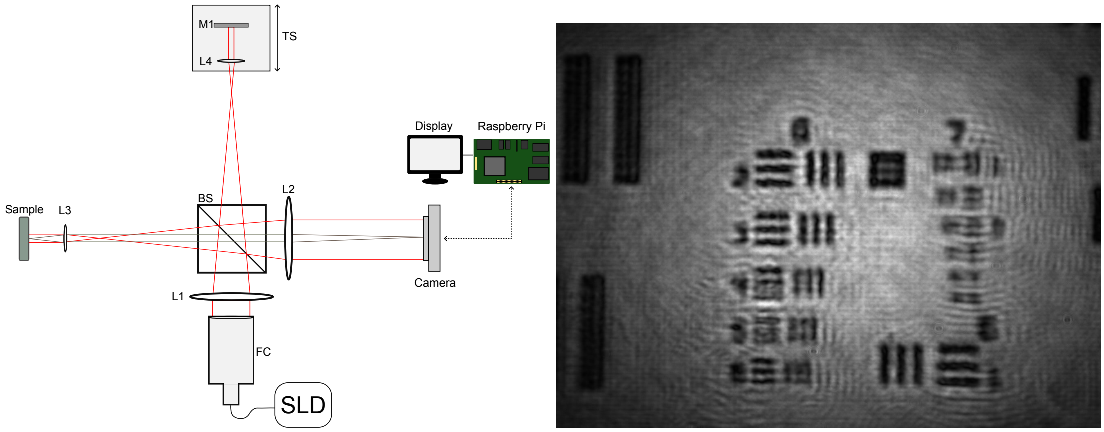
This work aims to address the cost component of OCT to enable better accessibility in low-resource settings and presents a low-cost Full-Field Time Domain OCT (FF-TD-OCT) system. The instrument is designed using a Raspberry Pi single-board computer, a small, affordable, and customisable computing device. It also incorporates a low-cost 2D camera and various off-the-shelf components. This thoughtful combination allows for a substantial reduction in overall costs while still delivering decent-quality images.

2. Methods and results

A schematic of the system is shown in Figure 1(a), and is based on a Linnik interferometer configuration. The optical source is a superluminescent diode (Superlum SLD-381-HP1-DIL-SM-PD), with a centre wavelength $\lambda_0 = 831.1$ nm, and spectral bandwidth of $\Delta\lambda = 16.2$ nm. Considering the spectrum shape Gaussian, a theoretical axial resolution of $\delta z = 18.81$ μm is estimated. Collimated light from the SLD enters the system where magnifying telescopes are formed between lenses L1-L4 for efficient sample illumination and magnification of 7.89x in this configuration. The neutral density filter, M1, is used as an attenuating mirror to decrease returned reference power to approximately that of the sample with a $\approx 4\%$ reflectance at 830 nm. The low-cost camera (Raspberry Pi HQ camera), is operated with the infrared filter removed at a resolution of 1332x990 pixels, and a 120 Hz frame rate. The camera has a pixel size of 1.55x.155 μm and unpacked raw frames are captured with 16-bit depth, bypassing any internal camera processing or compression. The captured image size is 565 x 420 μm.

A Raspberry Pi 5 8gb single-board computer is used to control the capture and process the raw frames. This is achieved using a custom Python programme, where the capture process and a four phase shifting algorithm, Equation 1, has been implemented to extract the OCT signal [5, 6], where a phase shift in the interferogram of $\pi/2$ is introduced between each successive frame. This method is a well adopted approach in FF-OCT to retrieve the phase information and subtract the non phase-shifted background from the image.

$$I = \sqrt{(F_3 - F_1)^2 + (F_4 - F_2)^2} \tag{1}$$



(a) (b)

Fig. 1. (a) Schematic diagram of the low-cost OCT system. FC: fibre collimator, L1, L2: f=150 mm achromatic lenses, L3, L4: f=19 mm achromatic lenses, BS: 50:50 plate beamsplitter, TS: motorised translation stage, M1: absorptive neutral density filter, OD=1.5. (b) An en-face OCT image of a negative USAF 1951 resolution target captured with the low-cost OCT system.

For OCT imaging, the reference arm translation stage is scanned axially using a motorised actuator (Newport LTA-HS, to scan the coherence gate in depth. To characterise the system, a 12.5 mm diameter negative USAF 1951 target was used as the sample, acquiring image in reflection. The captured OCT image, Figure 1(b), shows that the lateral resolution of the system can be discerned from group 6 element 6 of the target, giving an achieved resolution of 4.38 μm. This is larger than the theoretical lateral resolution of 1.54 μm. Multiple factors can lead to this discrepancy. These factors could include misalignment of the system components, optical aberrations within the imaging system, and cross-talk between neighbouring pixels in the imaging sensor.

This work demonstrates the feasibility of a low-cost FF-TD-OCT system, constructed with off-the-shelf components, for increased accessibility of OCT technology in resource limited settings. Future work will focus on miniaturising the system for improved portability and access to remote settings, in addition to replacing the SLD with a higher bandwidth and lower spatial coherence source, such as a Light Emitting Diode (LED). This should enhance the axial resolution, reduce pixel cross-talk and further lower system costs.

3. Funding

University of Kent Global Challenges Doctoral Centre

4. References

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