Low cost speckle reduction method for OCT B-scan imaging

Julien Camard[*a], Manuel Jorge Marques[a], Marie-Claire Aquilina[b], Giuseppe Silvestri[b], Darren Griffin[b], Adrian Podoleanu[a]
[a]Applied Optics Group, School of Physics and Astronomy, Division of Natural Sciences, University of Kent, CT2 7NH, Canterbury, UK; [b]Evolution, Reproduction, and Genome Organisation Group, School of Biosciences, Division of Natural Sciences, University of Kent, CT2 7NJ, Canterbury, UK

ABSTRACT

The most successful methods for speckle reduction in Optical Coherence Tomography (OCT) are based on deformation of the wavefront used in scanning. Here, a simple method is presented where the wavefront is distorted by lateral translation of the lens between the 2D galvo-scanner and sample. The report demonstrates that the method can be implemented with a small, fast piezoelectric transducer. Up to 33% improvement in speckle contrast ratio (SCR) of B-scan OCT images is demonstrated.

Keywords: Optical Coherence Tomography, speckle reduction, low cost, oocyte, embryo, animal, image processing

1. INTRODUCTION

Optical coherence tomography (OCT) provides optical sectioning of a scattering sample as a result of the low coherence of a broadband laser source. The degree of coherence, although limited, gives rise to speckle, an optical phenomenon resulting from the interference of photons multiply scattered by the sample within the coherence gate. Speckle distorts the wavefront of the returning wave and appears as bright or dark spots in OCT images. As a result, boundaries between biological layers can be blurred.

Because speckle changes over time in a live sample, averaging of B-scan OCT images can reduce the speckle contrast, as long as the imaged region changes faster than the total acquisition time. Whether this is the case is difficult to estimate *a priori*.

A method for speckle reduction based on fast beam deflection in a direction perpendicular to the B-scan plane was reported[1]. Another method consists in moving the assembly of launcher, plus 2D scanner and lens laterally over the sample[2]. In both cases, the wavefront is distorted and averaging of images enables angular compounding. Focus shifting by sample stage translation was also suggested[3] but involves image registration and it is slower.

In this paper, a simpler technique is evaluated by using a piezoelectric transducer attached to the single small lens between the 2D galvo-scanning head and the sample. The lens is translated in a direction orthogonal to the plane of simultaneously acquired B-scan OCT images, which are then averaged to produce a single composite B-scan. We call this method Lens Translation and averaging (LTav)-OCT.

*jgac2@kent.ac.uk; research.kent.ac.uk/applied-optics/

2. SPECTROMETER-BASED OCT SETUP

The setup diagram is shown in Figure 1. To achieve a high axial resolution, a supercontinuum source (SuperK EXR9, NKT Photonics) is used. It is coupled to a filter box, providing an emission bandwidth centred at 830 nm with a full width at half maximum (FWHM) bandwidth of 150 nm. The FWHM axial resolution of the OCT system was measured to be 2.8 µm. The sample arm is mounted vertically to accommodate biological samples mounted on microscope slides.

The beam is scanned over the sample by a fast scanner, FS (Galvoline) and a high-numerical aperture achromatic lens, L (Edmund Optics 7.5mm achromat.). OCT interference spectra are detected and buffered by a commercial spectrometer, S (Wasatch Ph. Cobra S-800) and transferred via Camera Link bus to a digitiser (NI-DAQ PCI-e 1437). An in-house LabVIEW software implements Complex Master-Slave (CMSI)[4] processing and enables easy visualisation and saving of B-scans.

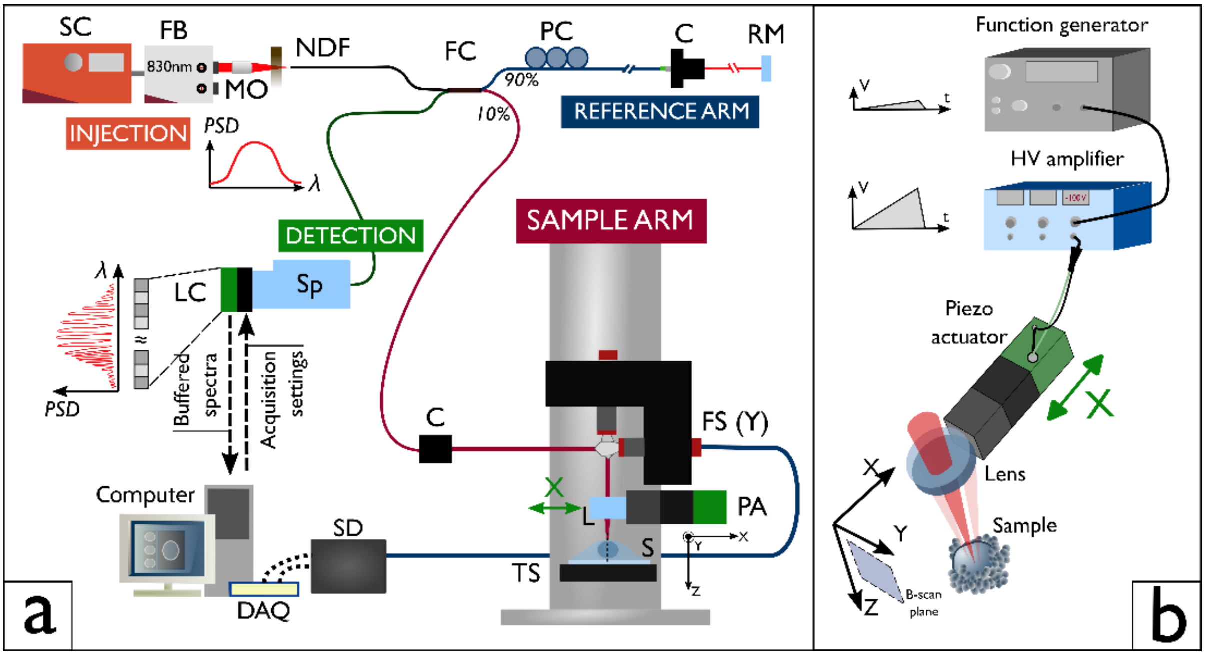

Figure 1. (a) Diagram of SD-OCT set-up. SC: Supercontinuum source, FB: Filtering box, MO: Microscope objective, NDF: Neutral density filter, FC: Fibre coupler, PC: Polarization controller, C: Fibre collimator, RM: Reference mirror, FS: Fast scanner, PA: Piezo actuator, S: Sample, TS: Translation stage, Sp: Spectrometer, LC: Line Camera, DAQ: Digital acquisition board, SD: Scanner driver. The sample lens (L) is attached to the piezo actuator (PA) with degrees of freedom along X and Y. (b) Lens Translation (LT) mounting and driving. The X-axis piezo stack is driven by a function generator and a high-voltage (HV) amplifier. B-scans are produced in the YZ plan, where Y is the fast lateral scanning direction.

3. LTav-OCT OPERATION

The imaging lens, L, was glued at the end of a piezoelectric actuator, PA (PN5FC3, Thorlabs). The piezo was driven along the X axis direction (orthogonal to the B-scan plane) with a voltage varying from 0 to 150 V DC, corresponding to a 7 µm lateral lens translation. A B-scan was acquired every 0.7 µm lens translation step. 11 B-scans were obtained and averaged.

A pig oocyte was imaged following the LTav-OCT method described above. A single B-scan is compared with the B-scans in Fig. 2, shown for two sets: (i) a first set, obtained by averaging 11 B-scans only and (ii) a second set, obtained by adding registration before averaging using Fiji's StackReg plugin[5].

To quantify the speckle reduction with LTac-OCT, the speckle contrast ratio (SCR) was evaluated for 3 distinct regions of interest (ROI). The SCR is defined as the standard deviation σ_A of the intensity in a given uniform area of the image divided by the mean intensity I_A evaluated over the same area:

$$SCR = \frac{\sigma_A}{\langle I_A \rangle}$$

4. RESULTS

As it can be seen in Fig. 2, the SCR is reduced by 25.5%, 33.3% and 23.6% when LTav is applied, for ROI 1,2 and 3 respectively; and by 24.5%, 28.3% and 23.3% when frame registration is applied before averaging. The registration does not seem to bring any additional improvement, which can be explained by the fact that the lens motion is along X and registration was performed in the YZ plane.

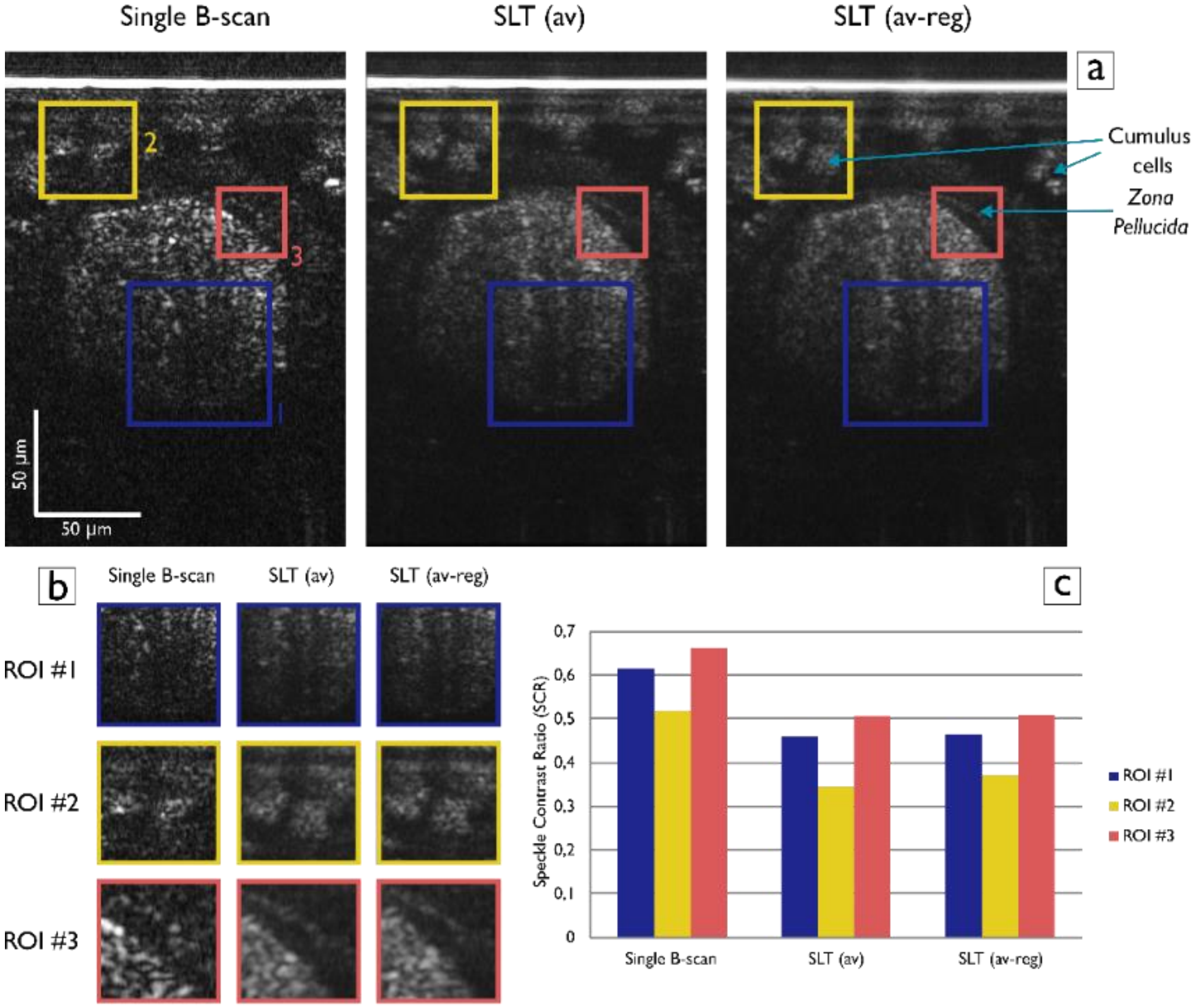

Figure 2. (a) B-scans of a porcine pig oocyte. From left to right, single B-scan, LTav-OCT B-scan and LTav-OCT B-scan after image registration with StackReg. 3 ROI are defined within the coloured square. (b) Detail of ROI for the 3 B-scans (c) Speckle Contrast Ratio (SCR) calculated in each ROI for all B-scan.

5. CONCLUSION

LTav-OCT is an efficient method to improve the quality of OCT B-scans. The assembly is compact and lightweight. Further work is necessary to determine with precision the optimal translation amplitude that can be applied to the lens to modify speckle without compromising lateral resolution. This could Finally, LTav-OCT can be applied to the two other axes to improve further the overall aspect of OCT volumes.

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