Benchtop SS-OCT – layout and performance evaluation

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Abstract — **Optical coherence tomography (OCT) is a non-invasive biomedical imaging technique that provides high speed and high resolution three dimensional and cross sectional images of biological samples, *in vivo* and *in situ*. OCT applications targeting small animals is believed to bring developments in medical techniques, instruments, diagnosis and therapies for a number of human diseases as always have been the case of animal experimentation.**

With the swept source OCT (SS-OCT) system presented in this work, we were able to achieve performance parameters that meet the requirements to image the retina of small animals. Performance characteristics include 105 dB for system sensitivity, a roll-off below 1 dB/mm over 3 mm depth and an axial resolution of 8 µm. We describe the layout and acquisition/processing solutions towards fast imaging of *in vivo* samples.

Keywords— **Swept Source OCT, retina, imaging.**

I. Introduction

Since its first appearance in the early 1990's, Optical Coherence Tomography (OCT) was recognized as a very helpful tool for ophthalmology. Based on the optical interference phenomenon, the OCT is capable of producing high-resolution cross-sectional images of non-homogeneous samples, among which the biological tissue, being particularly tailored to image ocular structures such as the retina. Over the last twenty years, OCT has experienced a fast and steady growth. It now offers a wide range of applications, is clinically very well accepted and is the subject of active research worldwide. The technique and theory behind it – in all possible configurations, being it Time-Domain OCT (TD-OCT), Spectral-Domain OCT (SD-OCT) or Swept-Source OCT (SS-OCT) – is extensively described in the literature [1][2][3][4].

SS-OCT has been appointed as the most promising technology for OCT imaging by offering higher scanning speed, reduced sensitivity roll-off and better overall performance, when associated with balanced detection,[3] in comparison to time and Fourier/spectral domain approaches. OCT systems specifically developed to image small animals, used as physiological models of disease, are fundamental to test and develop new medical therapies. Our group is engaged in the development of a dedicated SS-OCT platform for small animals based on the most recent technological advances. It should allow testing different configurations and explore new concepts. The basic layout has already been presented,[5] along with simulations and preliminary performance evaluation. In this paper, we report recent developments regarding *in vitro* performance and discuss key details with respect to acquisition/scanning synchronism.

II. Experimental Apparatus

A. OCT layout

The basic SS-OCT layout, composed of interferometer, scanning and acquisition system, is schematically depicted in Fig 1. The fundamental blocks of the system are: an Axsun Laser Swept-Source AXP50125-3 1060 nm (Axsun Technologies, Billerica, MA, USA), with central 1060 nm wavelength, 110 nm bandwidth and sweep frequency of 100 kHz; a 400 MSPS multi I/O acquisition board (X5-400M – Innovative Integration, California, USA) with two A/D and two D/A channels, and; an InGaAs balanced amplified photodetector (PDB145C – Thorlabs GmbH, Germany).

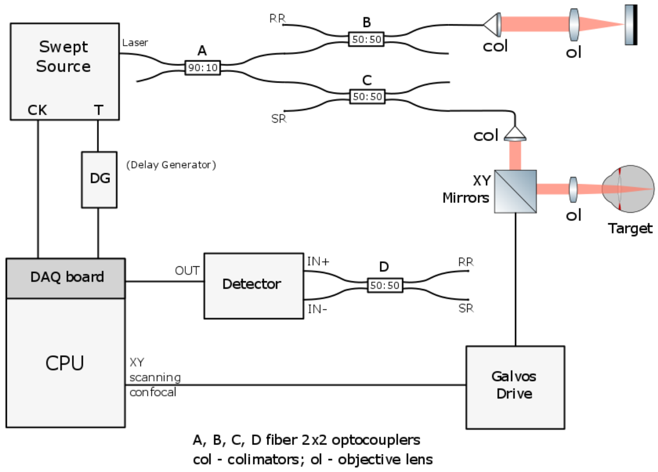

Fig. 1 – Overall SS-OCT Layout

Optical components such as fiber cables, attenuator, couplers, collimators and objectives complete the system.

The scanning, for cross-sectional (B-scan) and volume scans, is ensured by a X-Y galvanometer mirror system which is controlled, respectively, through a precision ramp generator and through a DAC board (National Instruments, Austin, Texas, USA), for the X- and the Y-scans. Digitized fringe data undergoes Fourier analysis to produce individual A-scans and the final OCT images/volumes. These tasks are carried out by dedicated acquisition/control and processing software. Configuration parameters in the software can be tuned according to the needs like the scanning angles, the number of

A-scans per B-scan and the number of B-scans per volume. After acquisition, the whole volume can be stored for posterior analysis or discarded.

B. Software

A customizable software was developed using object-oriented programming (Microsoft Visual C++/IDE) for the 64-bit Microsoft Windows 7 operating system resorting to libraries from Innovative to deal with data acquisition and hardware control.

To perform B- and volume scans, the laser beam must be swept, respectively, along one (X) and two (X-Y) axes by means of a Dual-Axis Scanning Galvo System GVS002 (Thorlabs GmbH, Munich, Germany) controlled by one of the D/A channels, up to a maximum scan angle of 20º in both directions. With the current hardware implementation, 1510 data points are digitalized in 10 µs, which correspond to the number of sample wavelengths outputted by the laser source. This frequency sweep corresponds to the entire A-scan which can be computed owing to the Fourier transform. The number of useful data points is, nevertheless, restricted to 1376, with the remaining ones produced by the dummy clock outputted by the laser source.

The number of A-scans per B-scan and the number of B-scans per volume are only limited by the resolution of the step increments of the galvo system and/or by the acquisition time.

Synchronization between the acquisition and laser emission is paramount for SS-OCT. As such, embedded in the laser source is a Mach-Zehnder interferometer (MZI) to provide the optical clock signal. It allows to sample evenly spaced frequencies event though the output is linearly swept in wavelength (k-space). This signal presents maxima and minima equally spaced in the optical frequency domain (k-space). The difference between two maxima is defined by the free spectral range of MZI. Linearized fringe signals with equal k-spacing can be achieved by clocking the high-speed A/D channel of the acquisition board with the clock provided by the source. The Fourier transform analysis can thus be directly applied on the acquired data. Moreover, the laser source also provides a trigger signal which is connected to the SYNC port of the acquisition board. This signal is responsible for starting the I/O module.

C. Results

The performance of the system was established based on commonly found parameters on the literature [6][7]: sensitivity (S), dynamic range (DR), axial resolution (AR) and depth sensitivity roll-off. Sensitivity is related with the smallest reflectivity, $R_{s,min}$, that can be detected, defined as the signal level when SNR=1.

$$S_{dB} = 10log_{10}\frac{R_s}{R_{s,min}} \tag{1}$$

One way of experimentally measure S is to use a gold mirror (R_s=1). Thus, (1) becomes:

$$S_{dB} = 10log_{10}\frac{1}{R_{s,min}} \tag{2}$$

The sensitivity of the system can be estimated from the ratio between the output from the optimal reflector (the system point spread function, PSF) and that from the noise (no sample), the latter being defined as the standard deviation of the readings, leading to:

$$S_{dB} = 20log_{10}\frac{PSF_{peak}}{\sigma_{noise}} \tag{3}$$

In these conditions, a sensitivity of 105 dB was experimentally determined, allowing to calculate $R_{s,min}$ from (2).

DR regards to the ratio between the maximum and the minimum reflectivity signal that can be measured within the same A-scan. As such, a DR of 60 dB was found for the current setup.

The theoretical value of the axial resolution, in the air and assuming a Gaussian laser beam power spectrum, is given by

$$\Delta z = \frac{2\ln(2)\lambda_0^2}{\pi\Delta\lambda} = 4.51\ \mu m \tag{4}$$

The experimentally determined value, using a gold mirror, is 8.1 µm, though.

Finally, the sensitivity roll-off with depth was assessed over an axial range of 4 mm to find it to be less than 1 dB/mm in the first 2.8 mm and about 3 dB/mm thereafter.

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