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Novel software package to facilitate operation of any spectral (Fourier) OCT system

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Abstract: We present a novel software method (master-slave) to facilitate operation of any SDOCT system. This method relaxes constraints on dispersion compensation and k-domain re-sampling in SDOCT methods without requiring any changes in the hardware used.

OCIS codes: (120.0120) Instrumentation, measurement, and metrology; (120.3890) Medical optics instrumentation; (120.4290) Nondestructive testing; (110.4500) Optical coherence tomography

OCT methods employing SD (FD) interferometry are now the norm in the OCT field, having introduced considerable improvements over the time-domain variant, namely in terms of acquisition speed and signal-to-noise ratio [1–3].

Despite these improvements, there are several disadvantages which hinder the use of these methods in OCT. Firstly, the acquired spectra need to be represented in a uniformly sampled domain so that the FFT operation can be carried out successfully. Normally, this is achieved by employing sophisticated and costly hardware and software methods to re-sample the acquired spectra in the correct domain [4].

An issue shared by both SD and FD methods is that of the need for dispersion compensation in the interferometer. Uncompensated dispersion between the two arms of the interferometer causes chirping of the channeled spectra, which in turn affects the sensitivity and resolution of the OCT measurements [5]. Dispersion compensation methods may prove difficult to implement, depending on the specificities of the OCT system in question, and they normally increase the complexity and cost of a new OCT system [5].

Master-slave interferometry (MSI), a technique invented by researchers at the University of Kent and first reported in 2013 [4], addresses all the issues listed above by performing a comparison of the acquired spectra against a previously acquired set of spectra $\widetilde{CS}_{\text{mem}}$ from the same system (placed in the computer's memory). The channeled spectra in this set are acquired at increasing, but regularly spaced, optical path differences (OPDs) in the interferometer. Since both the stored set and the newly acquired spectra derive from the same optical interferometer, with the same sampling parameters and the same dispersion imbalance between its two arms, the result of such comparison is unaffected by non-uniform sampling and chirping caused by uncompensated dispersion [5,6]. Moreover, direct rendering of *en-face* images is possible by performing the comparison against a single stored channeled spectrum.

However, the first iteration of MSI presented some shortcomings: the axial range and resolution of the OCT system were dictated by the channeled spectra stored in the set $\widetilde{CS}_{\text{mem}}$. Higher-resolution OCT systems therefore required very high precision positioning stages in the reference arm, and the operation to store the channeled spectra in $\widetilde{CS}_{\text{mem}}$ could become a lengthy one if a long axial range was necessary. Phase instabilities also dictated that the comparison result needed to be averaged over several lags, which harmed the axial resolution of the system [7]. Additionally, the comparison operation relied on a numerical cross-correlation which was implemented using two or three FFT operations, thus requiring a considerable amount of computing power. Hence, early implementations of the MSI algorithm were done using GPU processing [8].

In 2016, a new version of the MSI algorithm was reported by Rivet *et al.* [7]. Labeled complex-domain Master Slave interferometry (CMSI), this method addressed the shortcomings listed in the previous paragraph, while retaining all the advantages inherent to the original MSI algorithm. Only a small subset of channeled spectra $\bar{C}S_{\text{mem}}$ obtained at the master stage is necessary to infer the whole set $\widetilde{CS}_{\text{mem}}$ needed for the comparison operation

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at the slave stage, removing the need for high precision translation stages in the reference arm. Additionally, the spectra present in the inferred set $\widetilde{CS}_{\text{mem}}$ are represented in the complex domain, hence it is possible to extract the phase information from the OCT measurements, which is important in a number of functional extensions, such as polarization and angiographic measurements.

In this communication, we present a software solution that brings the CMSI algorithm to any spectrometer or swept-source based OCT system. No hardware changes are necessary, and the software package can be installed and configured remotely on any PC. In this way, the user does not need to perform any steps to eliminate the complexity introduced by dispersion-compensating procedures and/or by the nonlinearities in laser tuning (FD) or in the spectrometer (SD). This software takes full control of the main parts of a flying-spot OCT system, namely the interferometer and the scanning head.

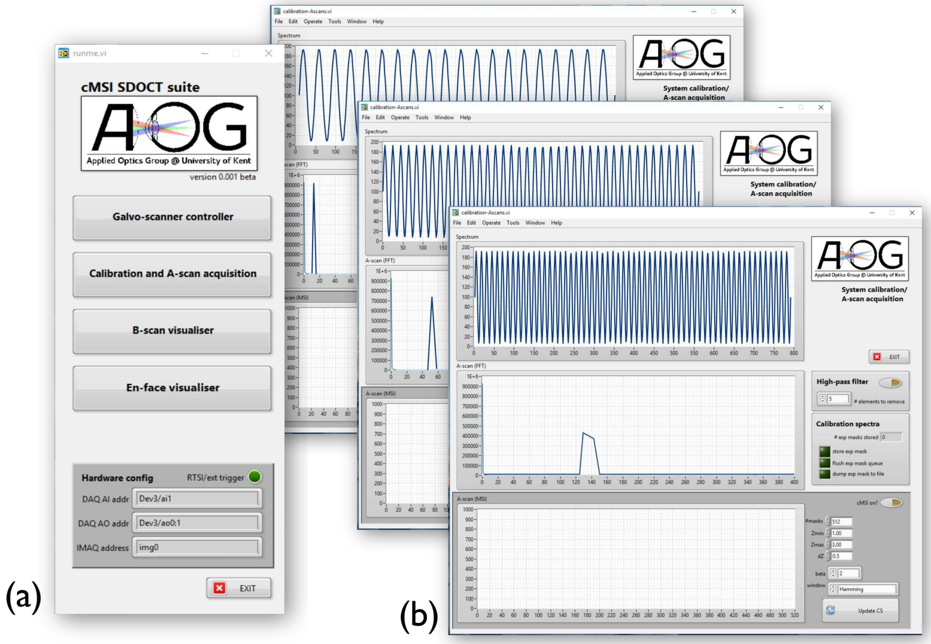
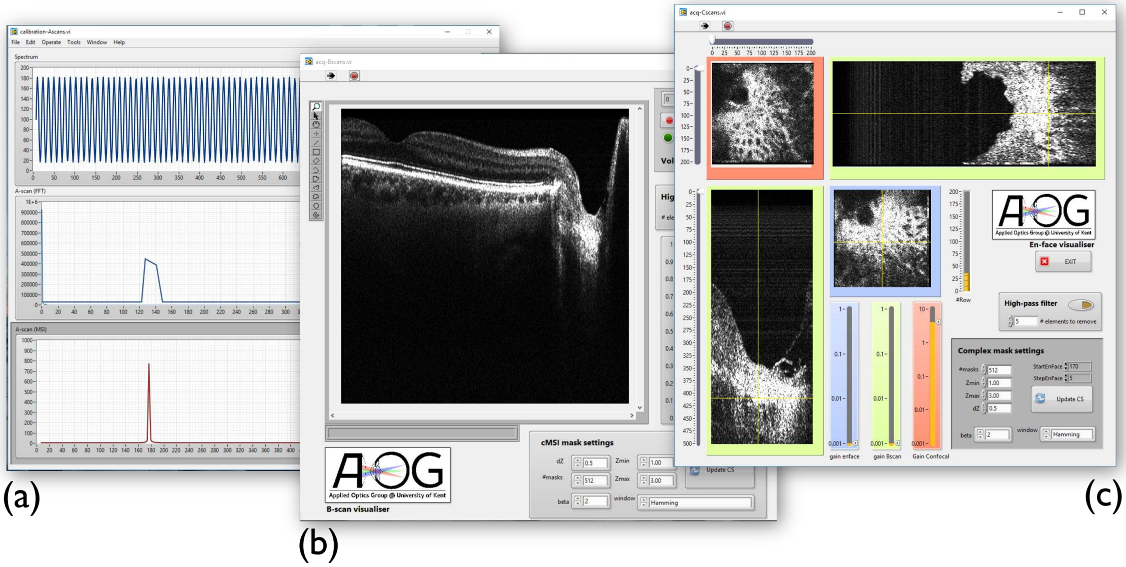

DAQ AI addr: Dev3/ai1
DAQ AO addr: Dev3/ao0:1
IMAQ address: img0
elements to remove: 5
exp masks stored: 0
#masks: 512
Zmin: 1.00
Zmax: 3.00
dZ: 0.5
beta: 2
window: Hamming

Fig. 1. Screenshots of the CMSI SD-OCT software package in operation. **(a)** option selector (main screen); **(b)** calibration (master stage) and A-scan visualisation interface, showing the calibration procedure, involving the acquisition of three (any number above and including 2 can be chosen) CS into the calibration set $\overline{CS}_{\text{mem}}$.

The various graphical user interfaces of the software package, termed "CMSI SD-OCT suite", are shown in Figures 1 and 2. The main program allows the user to perform the acquisition of the small set of channeled spectra $\bar{CS}_{\text{mem}}$ (the number of spectra can be 2 or more, as represented in Figure 1 (b)). The OPD values which yield the various modulation frequencies need not be determined exactly, only the step between them needs to be known with sufficient precision. After this calibration step has been carried out (master stage), the A-scan for new incoming spectra can be computed with either an uncorrected FFT or with the CMSI protocol, as shown in Figure 2 (a).

Once this procedure is carried out, the user can then run the OCT system in imaging mode (Figures 2 (b) and 2 (c)), where several different B-scan and *en-face* C-scan visualizations are allowed, as well as a pseudo-confocal representation (obtained from a projection along the depth axis of many C-scans).

Further work has been started into extending the package to full-field OCT solutions.



cMSI mask settings
dZ 0.5
Zmin 1.00
#masks 512
Zmax 3.00
beta 2
window Hamming

High-pass filter
5 # elements to remove

Complex mask settings
#masks 512
Zmin 1.00
Zmax 3.00
dZ 0.5
StartEnFace 170
StepEnFace 5
beta 2
window Hamming

Fig. 2. Screenshots of the CMSI SD-OCT software package in operation under the slave stage. **(a)** A-scan visualisation interface, after the calibration procedure has been completed. The red trace on the bottom plot denotes the A-scan carried out with the CMSI procedure, whereas the middle plot (blue trace) denotes the same A-scan carried out with the FFT procedure (no re-sampling); **(b)** B-scan imaging mode (example image); **(c)** *en-face* C-scan imaging mode with B-scan representation and pseudo-confocal image (obtained from a projection along the depth axis of many C-scans).

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