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Wide-field Hemodynamic Neuroimaging of Rodents using a Modified openSFDI Build

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Abstract: We modified and combined an open-source spatial frequency domain imaging (openSFDI) build with laser speckle imaging (LSI) into a widefield rodent cortical hemodynamic imaging system. Here, we present system specifications and in-vitro phantom measurement results.

Introduction

Spatial frequency domain imaging (SFDI) is a diffuse optical imaging technique that utilizes structured illumination to quantify tissue's optical properties, specifically absorption ($\mu_{a)}$ and reduced scattering (μ_s') coefficients. In comparison to point-based diffuse optical methods (e.g., near-infrared spectroscopy), SFDI offers mapping of optical properties, and subsequently concentrations of hemoglobin (HbR) and deoxy-hemoglobin (HbO_2) and physiologically relevant parameters such as oxygen saturation (StO_2). Recent studies have employed SFDI to image wounds and wound healing processes such as burns, skin graft, and diabetic foot ulcers [1,2].

However, SFDI utilization in neuroimaging has been limited. A few notable studies used SFDI to measure in-vivo optical properties and cortical hemodynamics of rodents, often through a cranial window prep. These studies mainly aimed to quantify changes in optical properties and hemodynamic responses to specific brain-related diseases such as epilepsy, migraine, ischemic stroke, and Alzheimer's disease [3-6]. More information regarding these studies can be found in a recent review paper on SFDI by Gioux *et al*. [7].

Previously, we reported on a multimodal mesoscopic imaging system combining SFDI and laser speckle imaging (LSI) for rodents [8]. This system enabled fast (14 Hz for SFDI, 60 Hz for LSI) imaging of cerebral hemodynamics during cardiac arrest and resuscitation. Here, we describe a small-animal wide-field optical neuroimager build based on the openSFDI platform described by Applegate *et al.* [9]. This system incorporates LSI as a second modality with a co-registered FOV (10mm x 10mm) with the SFDI images, facilitating the quantitative mapping of the cortical hemodynamics with measurements of HbR, HbO2, StO2, and cerebral blood flow. Below, we describe system specifications and performance characterization measurements using silicone phantoms.

Methods and Results

1) System design specifications:

The SFDI design (Fig. 1A) is adapted from the openSFDI build guide with a few modifications. The illumination setup includes mounted LED modules from Thorlabs at 660, 780, and 850 nm (M660L4, M780LP1, M850L3, and LEDD1B, Thorlabs, NJ, USA) and appropriate dichroic mirrors. In addition, we utilized a long-coherence-length 633 nm laser (SureLock RO, Coherent, CA, USA) for LSI illumination, with laser light expanded using an aspheric lens and homogenized using a diffuser. To achieve similar FOVs for both modalities, we used the same CMOS cameras (BFS-U3-32S4M-C, FLIR, OR, USA) and lens (50mm VIS-NIR #67-717, Edmund Optics, NJ, USA) combinations for both SFDI and LSI. Here, a dichroic mirror, lens spacers, and notch and line filters were also used to ensure that both cameras have similar FOVs of ~10 mm x 10 mm with 1200 x 1200 pixel resolution, which is a typical size of a mouse cranial window preparation.

We used an Arduino UNO (Rev3, Arduino, MA, USA) to trigger the DMD (LC4500-NIR-EKT, Keynote Photonics, TX, USA) and LED light sources. The output signal from the DMD is then used to trigger the camera's acquisition. The computer is the master controller that starts and stops the Arduino's triggering sequence using LabVIEW (LabVIEW 2020 64-bit, NI, TX, USA) through serial communication. We chose a 10 ms exposure time for both the DMD and the cameras with a delay of 10 ms to avoid dropping frames. The detailed triggering schematic

can be found below in Fig 1B. The system can currently achieve a 50 Hz total frame rate with minimal dropped frames (1 in 15000 frames), resulting in an effective ~2.78 Hz for SFDI (at two spatial frequencies with 3 phases: 0 and 0.3 mm^{-1}) and 50Hz for LSI.

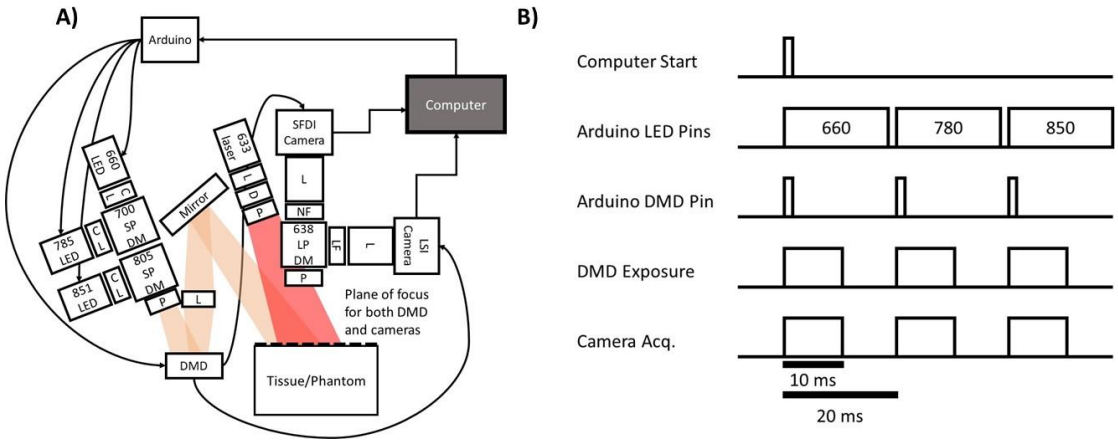

Fig 1. A) Design of the system and B) its triggering scheme.

2) Phantom measurements:

We performed a comparison study with a commercial SFDI (Reflect RS, Modulim, CA, USA) device using four silicone phantoms made in-house, imaged at 0 and 0.3 mm^{-1} spatial frequencies. Results for 660 and 850 nm are shown below in Fig 2. The neuroimaging system in its current state can achieve a high correlation with a commercial device (R^2 = 0.99). The percentage error for μ_a ranges from -20.0 to -1.4% (or -0.0061 to -0.00032 mm^{-1}), while that of μ_s' ranges from 0.8 to 7.0% (or 0.019 to 0.12 mm^{-1}). Note that for μ_a, the percent error is largest at low μ_a values.

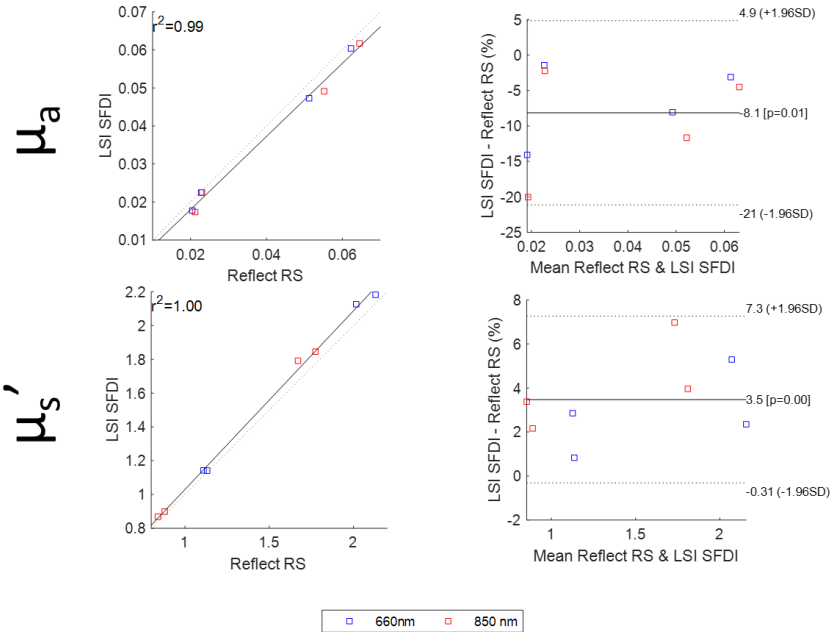

Fig 2. Phantom measurements comparison with a commercial SFDI device at 660 and 850 nm. Correlation and Bland-Altman plots are displayed from left to right, respectively.

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