

Depth-Resolved Measurements for Non-Invasive Optical Monitoring of the Brain

Research area and its significance to the field

Near infrared spectroscopy (NIRS) is a noninvasive optical modality that is sensitive to the concentrations of oxyhemoglobin (HbO) and deoxyhemoglobin (Hb) in blood. The ability to measure these two molecules is important, because it provides information about oxygen consumption within the body which is relevant for physiological monitoring. An example of its application is for functional studies of brain activation during mental tasks, where neurovascular coupling relates electrical activity in the brain to increased oxygen supply. Another example is in the intensive care unit where it is possible to use NIRS to study oxygen saturation in the brain. Magnetic resonance imaging (MRI) measures parameters similar to NIRS. NIRS is an excellent alternative to this technology, because it is inexpensive, portable, and has higher time resolution than MRI. It can be used in situations where constant monitoring is required. This is especially useful in the hospital setting.

An issue within the field of NIRS is that the light must travel through extracerebral layers before reaching the brain and then must travel back out through extracerebral layers before reaching detectors. Figure 1 illustrates this problem by showing the path that light must take through the extracerebral tissue layer and cerebral tissue layer. The signals experience partial contributions from tissue volumes that are not the main interest. Separation of contributions from different layers can be considered as depth-resolved NIRS, because it is possible to measure signal from the extracerebral layer, the top layer, or from the brain, the deeper layer [1]. The ability to take depth-resolved measurements would be beneficial to all users of this monitoring modality, because it would allow for more accurate readings of signals from the brain.

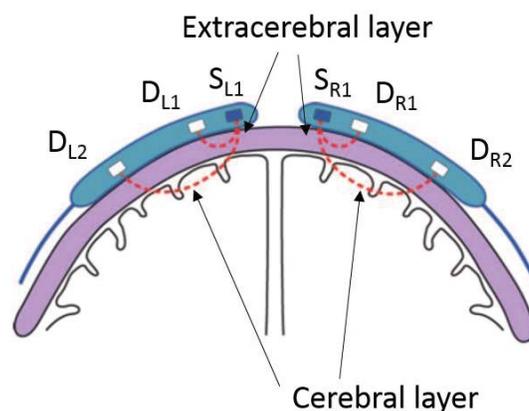


Figure 1. Near infrared spectroscopy probes placed on the left and right sides of the forehead. Light from the sources on the left (S_{L1}) and right (S_{R1}) are measured by the short distance detectors (D_{L1} , D_{R1}) and long distance detectors (D_{L2} , D_{R2}) on either side. The red dotted lines represent the paths of the light. The shorter source/detector distance pairs measure light solely

in the extracerebral layer. The longer source/detector distance pairs measure light that has traveled through both the extracerebral layer and cerebral layer. Adapted from [2].

Methodology/procedures

To address the engineering challenge to separate optical contributions from multiple tissue layers, I plan to use probes for multi-distance data collection. Figure 1 shows that by having a short distance source/detector pair, we can measure the top layer. With the long distance source/detector pair, we can measure the bottom layer but the light in this signal has also propagated through the top layers. By separately measuring the contribution from the top layer, it is possible to separate the two signals through an inversion procedure based on the modified Beer Lambert law for a two-layered medium [1]. This procedure can be summarized as a system of equations that relates changes in light intensity measured for at least two wavelengths to the changes in concentrations of HbO and Hb in the two layers.

I will build probes with multiple source/detector distances ranging from 0.5 to 4 cm to enable measurements at both short and long distances. These probes will be used for NIRS measurements on healthy subjects with a technique called Coherent Hemodynamics Spectroscopy (CHS). Typically, NIRS measurements provide time traces of the concentrations of HbO and Hb. With CHS, a novel hemodynamic model, and experimental protocols that induce small and coherent oscillations in blood pressure, we are also able to relate our measurements to parameters such as capillary transit time, which is inversely proportional to cerebral blood flow, and autoregulation [3]. Autoregulation is the mechanism that maintains constant blood flow in the brain despite changes in cerebral perfusion pressure. This mechanism is often damaged in people who have experienced brain injury. The ability to monitor it allows clinicians to provide a more personalized healthcare treatment based on the needs of the patient. The ability to separate contributions to the signals from different layers will allow us to further refine our methodology and quantify how the propagation of light through extracerebral tissue impacts the measured parameters. This project would be the first of its kind to apply depth-resolved techniques towards NIRS for measuring the parameters computed from Coherent Hemodynamics Spectroscopy.

Significance of project to my scholarly work and degree progress

The proposed project encompasses several key areas relevant to my scholarly work as a PhD student in the biomedical engineering department. First, from the technology point of view, the proposed methodology requires development of the hardware as well as novel software for signal separation. From the science point of view, my design depends on an understanding of the propagation of light through human tissue, a topic of key importance within biomedical optics. From an application point of view, the project will work towards an improved instrument for psychologists and physicians who can enhance their understanding of the human brain by being able to measure signals they know are from the brain and are not altered by partial contributions from other tissue. Upon successful completion of this project, we can

use the techniques developed for collaborations with a hemodialysis unit where there is interest in studying the effects of blood transfusions on the cerebral health of patients. Additionally, there will be collaborations with the neurocritical care unit (NCCU) at Tufts Medical Center where NIRS will be used to monitor patients with issues such as subarachnoid brain hemorrhage and traumatic brain injury.

Grant money

The grant money for this project would be used for purchasing new materials and tools for probe design. Custom designed probes with multi-distance sources are vital to the separation of signals from the extracerebral and cerebral layers. Without the grant money, we will have to use our existing probes that do not have the range of distances we desire to fully characterize the dependence of autoregulation and cerebral blood flow on distance between the source and detector.

References

- [1] F. Fabbri, A. Sassaroli, M. E. Henry, and S. Fantini, "Optical measurements of absorption changes in two-layered diffusive media," *Phys. Med. Biol.*, vol. 49, no. 7, pp. 1183–1201, Apr. 2004.
- [2] S. N. Davie and H. P. Grocott, "Impact of Extracranial Contamination on Regional Cerebral Oxygen Saturation," *Anesthesiology*, vol. 116, no. 4, pp. 834–840, 2012.
- [3] S. Fantini, "Dynamic model for the tissue concentration and oxygen saturation of hemoglobin in relation to blood volume, flow velocity, and oxygen consumption: Implications for functional neuroimaging and coherent hemodynamics spectroscopy (CHS).," *Neuroimage*, Jan. 2014.

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1. Black soft polyurethane sheet (McMaster-Carr, Part Number: 8781K216)- **\$140.28**
 - a. For mounting optical fibers and detectors for probes.
2. Black headbands (Amazon) - **\$15.00**
 - a. For probe attachment around the head.
3. Optical fibers with connectors (Ocean Optics, Product Description: P400-2-VIS-NIR)- **\$200.00**
 - a. For creating light sources in the probes.
4. Optical power meter with sensor (Thorlabs, Part Number: PM120VA)-**\$644.72**
 - a. For measuring power detected between different source/detector distances. The full price of this item is \$1310. This is a tool important for this specific project, but other projects in the lab can benefit from the power meter and cover the additional cost.

Total: \$1000.00