Towards Neuroscience in the Everyday World: Progress in wearable fNIRS instrumentation and applications

Alexander von Lühmann[1,2,*], Bernhard B. Zimmermann[1], Antonio Ortega-Martinez[1], Nathan Perkins[1], Meryem A. Yücel[1,2], David A. Boas[1,2]

[1] Neurophotonics Center, Biomedical Engineering, Boston University, Boston, MA 02215, USA
[2] Athinoula A. Martinos Center for Biomedical Imaging, Department of Radiology, Massachusetts General Hospital, Harvard Medical School, Charlestown, MA 02129, USA
**Corresponding author. Email: avolu@bu.edu*

Abstract: Wearables and machine learning have opened up a new field of research, the Neuroscience of the Everyday World. We present our recent contributions to fNIRS instrumentation (ninjaNirs and ninjaCap) and multimodal analysis (BLISSA^{2}RD and GLM with tCCA).

1. Motivation

Neuroimaging techniques used in contemporary neuroscience research provide great insights into the healthy functioning brain and have led to many advances in characterizing, diagnosing and in developing potential targeted interventions for brain disorder. However, there is still a big gap in our understanding of both healthy and impaired brain function. Part of the reason for this stymied progress is that while we have some understanding of how the brain functions in single-snapshot experiments under restricted lab settings, we do not know how it works in dynamic, complex and multisensory real-world environments – a new field of research that we term the Neuroscience of the Everyday World (NEW). Solving this complex problem requires enabling technologies to continuously track and analyze human brain function and behavior. We present our vision and recent contributions towards wearable neuroimaging instrumentation and multimodal signal analysis: Our wearable open functional Near Infrared Spectroscopy (fNIRS) neuroimaging platform, the ninjaNIRS and ninjaCap, and novel multimodal fNIRS analysis approaches for improved separation of evoked hemodynamic signals and systemic physiology.

2. Recent Progress in Instrumentation and Processing

Wearable neuroimaging: M3BA, ninjaNIRS and ninjaCap

An increasing number of novel fiber less and lightweight wearable fNIRS instruments have been published in recent years [1]. This trend, similarly observable for Electroencephalography (EEG), makes both modalities suitable for Neuroimaging in the Everyday World. We have previously developed **M3BA**, a Mobile, Modular, Multimodal Biosignal Acquisition architecture, for the localized simultaneous hybrid acquisition of fNIRS, EEG and other biosignals [2]. With greatly reduced intermodality crosstalk and high timing precision, the wireless modules provide a scalable stand-alone architecture for high-performance measurements with a low numbers of channels. For whole head imaging, we have recently developed and are disseminating a wearable, fully scalable and modular open source fNIRS system (see **Figure 1**, left) that we named **ninjaNIRS** [3]. It is based on a new compact optode, that consists of one dual wavelength LED (730/850 nm) and one photodiode on a miniaturized printed circuit board that also incorporates a trans-impedance amplifier, analog-to-digital converter, a field programmable gate array (FPGA), and an inertial monitoring unit. The optode acts both as short-separation detector and as longer separation detector for surrounding optodes and has a noise equivalent power of less than 500 fW/√Hz at 730 nm and a dynamic range of almost 140 dB. The system is functional with as little as 2 optodes and can easily be expanded to as many as 128 optodes. We have developed a process to generate completely customizable and individualized flexible head caps, which we named **ninjaCap,** using 3D printing of flexible materials and our established brain atlas software AtlasViewer [4] for mapping of fNIRS optodes and EEG electrode positions to the brain surface. The approach

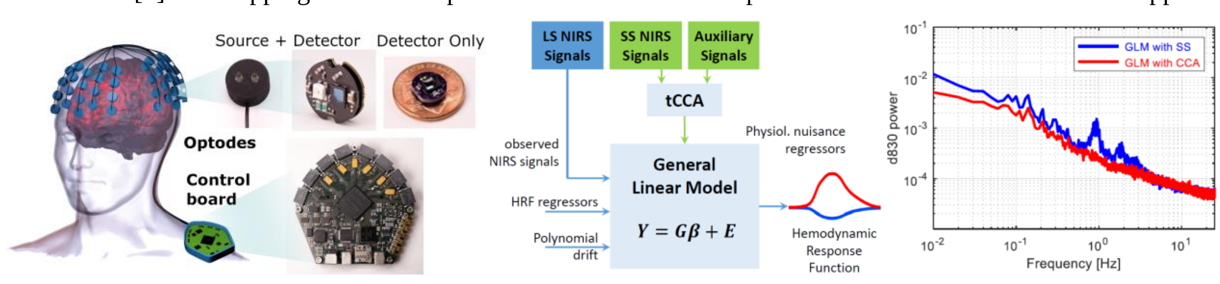

Figure 1: ninjaNIRS optodes and controller (left) and multimodal extension of the General Linear Model with tCCA.

allows the precise placement of sensing elements of any type and shape on the participant's head.

Removing systemic physiology from fNIRS signals using novel multimodal signal processing approaches
The measured fNIRS signal is an integration of the brain signals from cortex as well as the confounding systemic physiological signals from the scalp and vasculature. We have developed a set of methods for the supervised and unsupervised analysis of fNIRS signals based on temporally embedded Canonical-Correlation Analysis (tCCA). CCA is an established method for identifying co-modulating components in multivariate data. **BLISSA²RD** is our multimodal Blind-Source Separation framework for the analysis of fNIRS signals [5] that combines tCCA and a novel Independent Component Analysis to reduce systemic physiological effects of movement. It provides remedies for non-instantaneous and non-constant coupling and correlated noise, improving performance beyond conventional movement artifact correction by simultaneously exploiting fNIRS and accelerometer signals. The supervised analysis of fNIRS signals typically uses a General Linear Model (GLM) to estimate evoked hemodynamic brain responses. Performance can be improved by incorporating short separation (SS) measurements (<10mm) that provide a scalp-only signal that is routinely used to regress out the scalp contamination from the brain signal measured with standard-separation channels [6]. We have recently shown that this approach can be greatly improved further by obtaining optimal nuisance regressors with tCCA [7]. Incorporating short-separation source-detector signals along with any other available physiological signals (Accelerometer, Pulse Oximeter, Respiration, …), the novel **GLM with tCCA** extension improves the rejection of systemic interference, and thus the contrast-to-noise ratio and F-Score significantly over the existing best practice (see **Figure 1**, right). This promises a greater reduction of physiological signal contamination in the fNIRS signals measured in the Everyday World.

3. Vision: Neuroscience in the Everyday World

Combining our abovementioned previous efforts, our vision is to build a portable, miniaturized, lightweight, wearable high-density fNIRS – EEG - Eye-tracking system that permits long duration continuous monitoring of brain activity during movement, perception, and social interaction in real time and in the real world (Figure 2). Using simultaneously acquired video, audio and eye-tracking data, we will develop and validate a novel approach towards continuous and unconstrained decoding and annotation of stimuli and situational context. The probabilistic outputs of cloud-based computer vision services and the eye-tracking data will be used to generate a searchable continuous stream of labels for the bio signals that can be used for context-sensitive data investigation and segmentation to generate cue-based regressors for the data analysis. The output of this detection will also be used as a control signal for the development of adaptive control of the instrument acquisition rate and energy consumption.

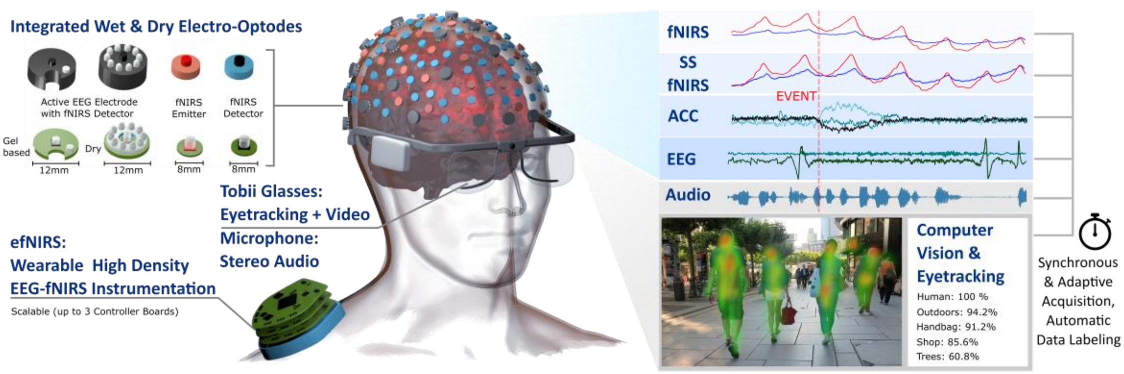

Figure 2: NEW concept. Wearable EEG-fNIRS Eyetracking combined with computer vision for event decoding.

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