A Multimodal Brain Monitor

ELECOMP Capstone Design Project 2022-2023

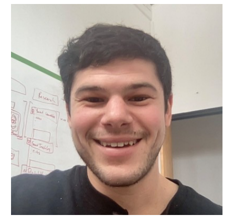
Sponsoring Company:

EchoWear
1005 Main Street, Pawtucket, RI, 02860
https://echowear.org/

Company Overview:

EchoWear is a MedTech startup founded in 2016, at the Wearable Biosensing Lab, translating high-risk technologies into a series of commercial digital health products. Since its conception, EchoWear has consistently maintained its focus in finding ways to translate human needs into health technology research that can drive commercialized solutions in the areas of digital health, wearable devices, and patient-centered care. EchoWear works closely with medical experts from Lifespan Hospital and Butler Hospital, enabling us to understand and meet the clinicians needs early in our design process.

Technical Director(s):



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Project Motivation:

The motivation of this work is to improve the quality of insights immediately available to a neuro-specialist trying to detect early mild cognitive impairment (MCI) and assess its future trajectory. The first step of this project is to develop an initial prototype multimodal wearable headband brain monitoring system. This system is envisioned as a textile-based brain monitoring technology that combines the monitoring of brain's blood oxygenation response (using functional near infrared spectroscopy; fNIRS) and electrical activity (using electroencephalography (EEG)).

Existing functional imaging technologies are limited by exposure to ionizing radiation (SPECT, PET), susceptibility to motion (fMRI), contraindications for patients with metallic implants (fMRI), and relatively high purchase and running costs (all). In contrast, fNIRS and EEG are promising brain monitoring tools that are portable, inexpensive, and easy to use. fNIRS uses a grid of NIR light sources and detectors to measure the hemodynamic changes (the concentration changes of the oxyhemoglobin (HbO) and deoxyhemoglobin (HbR)) in the cortex, while EEG measures electrical activity on the scalp.

The new brain monitoring device needs to be user friendly. Most existing devices require significant preparation time, including measuring head circumference, putting on the cap, integrating electrodes, measuring the quality of skin-electrode contacts, calibrating the system, and cleaning the scalp after testing. Another challenge is patient comfort. Some of the existing products use rigid bumpy electrodes that are uncomfortable and often irritate patients. Busy medical providers need a brain monitoring device that not only takes advantage of fusing fNIRS and EEG but also is simple to use, requires minimal preparation time, and incorporates digital cognitive measures for real-time assessment of cognition and neural activity.

This project is in collaboration with RI Hospital (as a research partner), Darlington Fabrics (as a textile manufacturing partner), and a textile designer (as an expert consultant).

Anticipated Best Outcome:

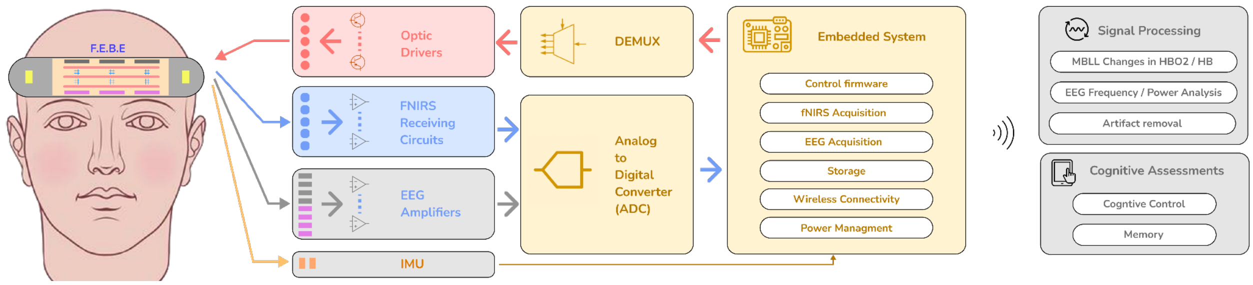
Outcome 1: *A miniaturized electronics module for fNIRS-EEG data acquisition*: The entire electronics will be embedded into a single flexible printed circuit board (PCB) consisting of analog and digital circuits including an embedded system for acquiring fNIRS and EEG signals.

Outcome 2: *Methods for processing fNIRS, EEG, and Head Motion Data*: The data acquisition system will acquire and send the raw data wirelessly to a computer where the signal processing algorithms will be applied on time-series data.

Project Details:

The goal of this project is to develop and test the initial feasibility of a multimodal wearable headband brain monitoring system for detection of mild cognitive impairment (MCI) by medical providers. The wearable headband will consist of multi-channel brain sensors to detect changes in blood oxygenation (functional near infrared spectroscopy; fNIRS), electrical activity (electroencephalography; EEG), and head motion while people perform cognitive tasks. The goal is to develop a usable prototype and determine feasibility of use in younger adults, cognitively normal older adults, and MCI patients to ultimately improve early detection of MCI due to neurodegenerative disease.

F·E·B·E, is a smart textile-based headband that is targeted to monitor multimodal brain biomarkers, including the hemodynamic response and EEG, in conjunction with cognitive assessments. Our innovation enables the early detection of MCI in older adults, informing prevention and treatment efforts. Based on our initial market analysis, we identified medical providers such as neuropsychologists and neurologists as the primary users.



Hardware/Electrical Tasks:

The analog frontend circuit for fNIRS is divided into two components - one for light emission and the other for acquiring the signals from the photodetectors. Stable current drivers will be designed to maintain the proper intensity for three dual wavelengths at high consistency within the allowable range. One of the well-known challenges for the fNIRS concerns the poor signal quality in darker skin tones. To address this issue, we plan to make the light's intensity adaptive to the skin tone. We will incorporate a skin tone detection system within the band. This will be fed back to the control system to adjust the light's optimum intensity for high-fidelity fNIRS data acquisition.

For EEG electrodes, we will integrate a skin impedance checking circuit that can be triggered during the configuration of the band. The design of an embedded system will require a selection process within several system-on-chip (SoC) processors. We will develop a firmware that will send control signals to the light sources current drivers through a demultiplexer. On the receiving side, the detected fNIRS and EEG signals will pass through two corresponding receiving circuits to condition, amplify, and filter the analog signals that will be fed to an analog-to-digital converter (ADC). The digital signals from ADC will go to the embedded system for storage and communication. The system will be powered using a rechargeable Lithium Ion battery. A recharging circuit will be a part of the PCB.

For fNIRS the sensors will use fiber optic stripes will be woven into the substrate, the terminal end will be connected to a thin-film flexible printed circuit board (PCB) to employ an SMD (surface mounted device) based component including front end analog interface. For the source, a dual or multi wavelength will be selected based on the absorption spectra of two important chromophores HbO2 and Hb for the fNIRS brain imaging. For the receiver, a photodetector will be integrated into the woven substrate using photosensitive patches. As our aim is to make the fNIRS modular, it is imperative to ensure integration between the textile material and flexible PCB is stable and simple to connect.

Firmware/Software/Computer Tasks:

We will develop a firmware for the embedded system that will send control signals to the light sources current drivers through a demultiplexer. On the receiving side, the detected fNIRS and EEG signals will pass through two corresponding receiving circuits to condition, amplify, and filter the analog signals that will be fed to an analog-to-digital converter (ADC). The digital signals from ADC will go to the embedded system for storage and communication. The system will be powered using a rechargeable Lithium-Ion battery. A recharging circuit will be a part of the PCB.

For fNIRS data, we will apply the modified Beer-Lambert Law (MBLL) to convert the optical signals into the concentration changes of HbO2 and Hb. Signals from EEG electrodes closer to the eyes will represent electrophysiological artifacts such as eye blinks, eye movements, and other facial muscle activities. IMU data will carry head motion information We will use independent component analysis (ICA) and Kalman filters to remove artifacts, and motion noise digital filters will be applied to remove the electromagnetic noise such as 60Hz. The data will be stored in time-series log files with timestamps and annotations (required during the feasibility study).

Composition of Team:

2-3 Electrical Engineers

1-2 Computer Engineer

Skills Required:

Electrical Engineering Skills Required:

- Designing and developing components such as printed circuit boards (PCB), processors, memory modules, and network components.
- Interpreting datasheets of electrical components such as LEDs, photodiodes, embedded processors, etc.
- Knowledge of RF hardware systems and testing equipment.
- Experience with analog electronics and MOS transistors.
- Testing hardware prototypes and analyzing and interpreting performance data.
- Generating analytic and performance reports for presentation and revision.
- Excellent written and verbal communication skills.
- Ability to work independently.
- Good troubleshooting and problem solving skills.

Computer Engineering Skills Required:

- Designs and implements algorithms for firmware.
- Ability to create technical documents describing firmware usage.
- Oversee firmware development process from design to creation.
- Manage updates and provide support.
- Alter existing software based on the needs from the company.
- Firmware programming (e.g., C, C++, or Python).
- Familiar with wireless communication protocols such as Bluetooth or MQTT.
- Interfacing with the analog electronics via busses
- Excellent written and verbal communication skills.
- Meticulous attention to detail.
- Ability to work independently.
- Good troubleshooting and problem-solving skills.

Anticipated Best Outcome's Impact on Company's Business, and Economic Impact

In the long run, F·E·B·E is envisioned as a clinical product that can be used by clinicians such as neuropsychologists and neurologists who can detect the early onset of MCI. We will have a working prototype of an integrated fNIRS/EEG headband and neurocognitive assessment system with preliminary feasibility data from patients with mild cognitive impairments (MCI) with our clinical partner at RI Hospital.

The design of F·E·B·E as a product will demand modern skills in STEM areas and partnering with manufacturing companies. We will recruit new fresh talents with skills in engineering (electrical, computer, and biomedical, and textile engineering), computer science, and textile designers.

Broader Implications of the Best Outcome on the Company's Industry:

A significant number of people with MCI develop Alzheimer's disease and dementia. In the US, there are 6.5 million people living with AD or AD-related dementia. This is where F·E·B·E can make a big difference. F·E·B·E will help detect cognitive impairments in early stages. Individuals and their family can access early interventions.