Electroencephalography (EEG) Minor Traumatic Brain Injury (mTBI) Detection Device

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Project Purpose

Our team set out to create a **portable**, **cost-effective**, and **accessible** device capable of collecting an individual's electroencephalography (EEG) data and providing information that can alert the individual of potential abnormal brain activity indicative of a minor traumatic brain injury (mTBI).

This device would be available for medical professionals in environments outside of a hospital, allowing for basic insight into a person's brain activity.

Potential users:
- Sports team physicians
- Emergency medical professionals

Overall, our goal is to aid medical professionals in their decision-making by providing them with a cost-effective, accessible way to collect information regarding their patients' brain health.

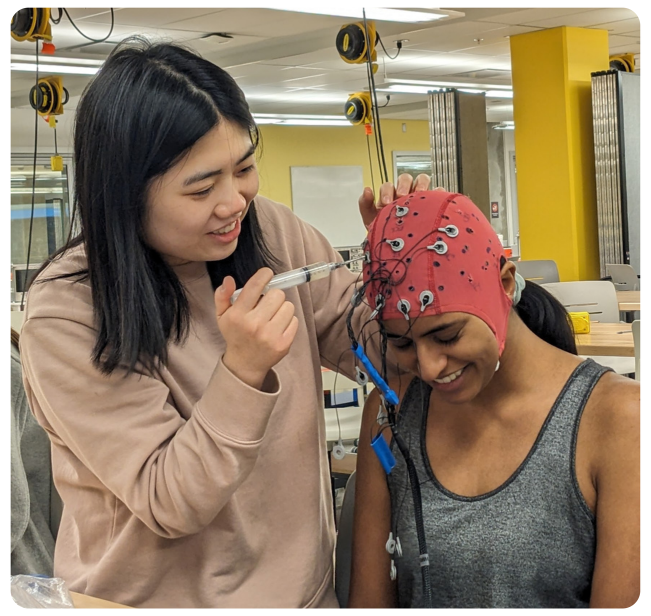

Figure 1: Example Setup

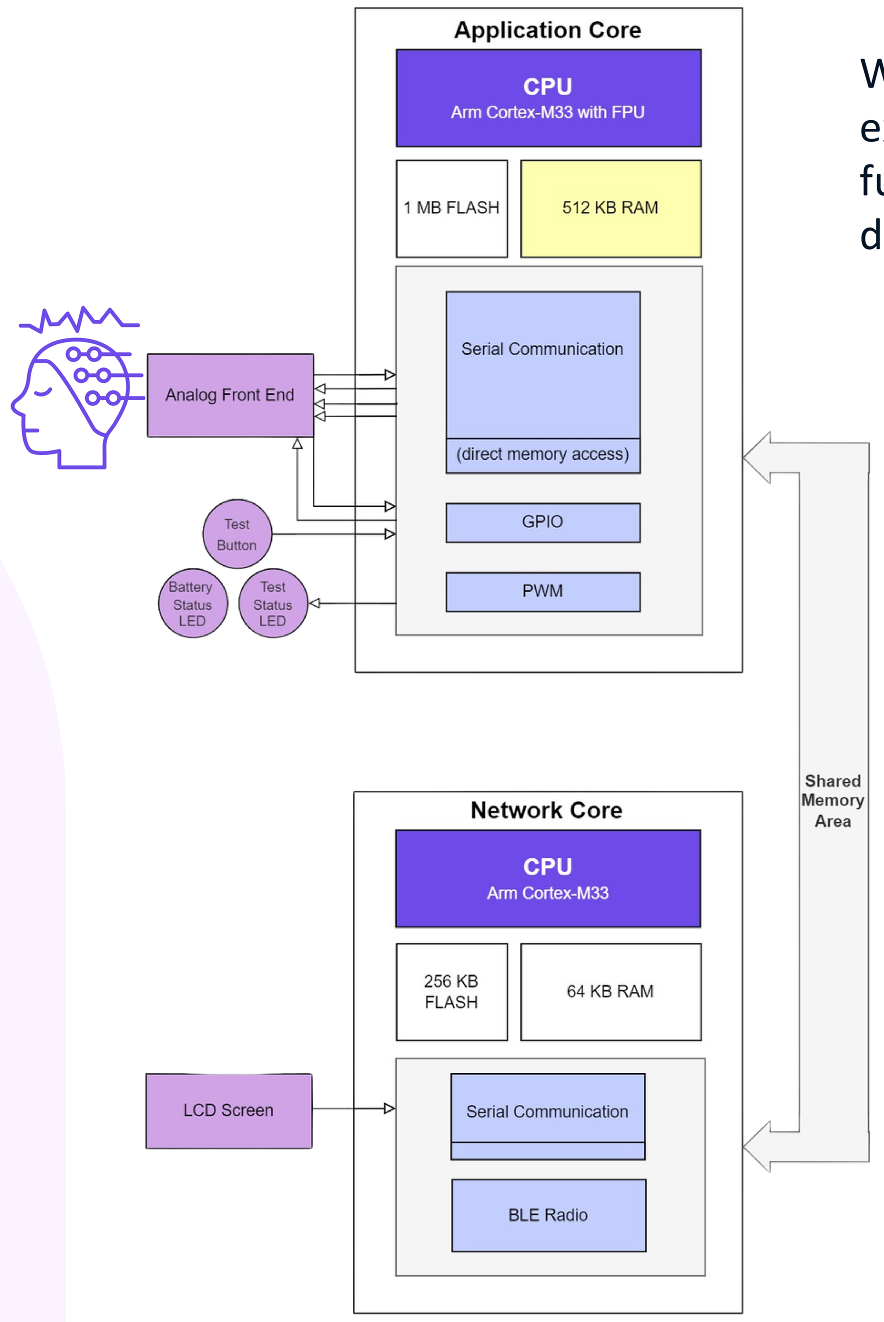

Figure 2: MCU Block Diagram

Firmware

Our multi-threaded firmware is written for a Nordic nRF5340 microcontroller (MCU) using the nRF Connect Software Development Kit (SDK), which is based on the Zephyr Real-Time Operating System (RTOS).

The firmware written for this dual-core MCU consists of four threads:
- A ***State Machine Thread*** which coordinates all of the device's states of operation.
- A ***Data Acquisition Thread*** which interfaces with the Analog Front End (AFE) by collecting data samples over Serial Peripheral Interface (SPI) using EasyDMA. This thread uses custom hardware-agnostic managers that communicate with the drivers.
- A ***Signal Processing Thread*** which cleans the recorded data, extracts features, and computes final EEG values. This thread uses optimized computations defined from CMSIS-DSP.
- A ***Human-Interface-Device Thread*** which outputs to the LCD screen, manages LED colour, and broadcasts results over Bluetooth Low Energy (BLE).

Future Work

- Manufacture our custom AFE board and perform validation tests to compare its performance with the Commercial Off-The-Shelf (COTS) AFE.
- Extract more features using our signal processing algorithm such as coherence and frequency amplitude asymmetry.
- Obtain access to EEG datasets (both normal and mTBI) and use them to train a probabilistic machine learning model for distinguishing between normal and mTBI affected brains.
- Integrate Garmin products with the device such that results broadcasted from the device via BLE to be displayed on a Garmin product.
- Add non-volatile external memory to the custom PCB so that a user's statistics may be saved and compared to future readings.

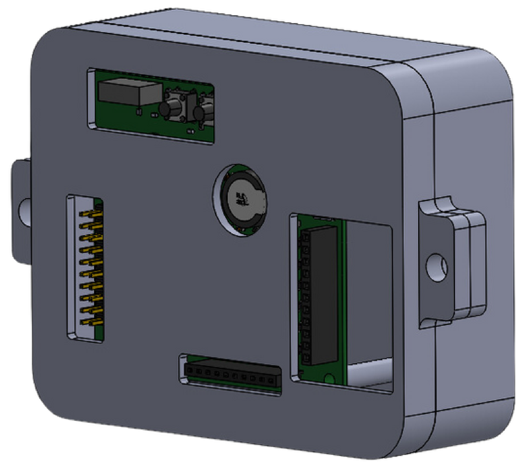

Figure 3: Device Enclosure

Hardware

The hardware component of our project is a custom, 4-layer Printed Circuit Board (PCB) with surface mount technology. The components include:
- A Texas Instruments ADS1299 chip, which is an 8-channel COTS AFE for denoising and amplifying EEG signals.
- A Nordic nRF53 MCU for handling signal processing and communication between components.
- Power management circuitry to regulate the voltage from 4xAA batteries, as well as a low battery sensing circuit.
- An LCD screen for displaying results.
- Status LEDs, a power switch, a buzzer, and control buttons.

We also designed and formally reviewed the schematics for an experimental custom AFE board, which can be explored in future work to further decrease the cost of the device. Table 1 depicts the cost breakdown of each option.

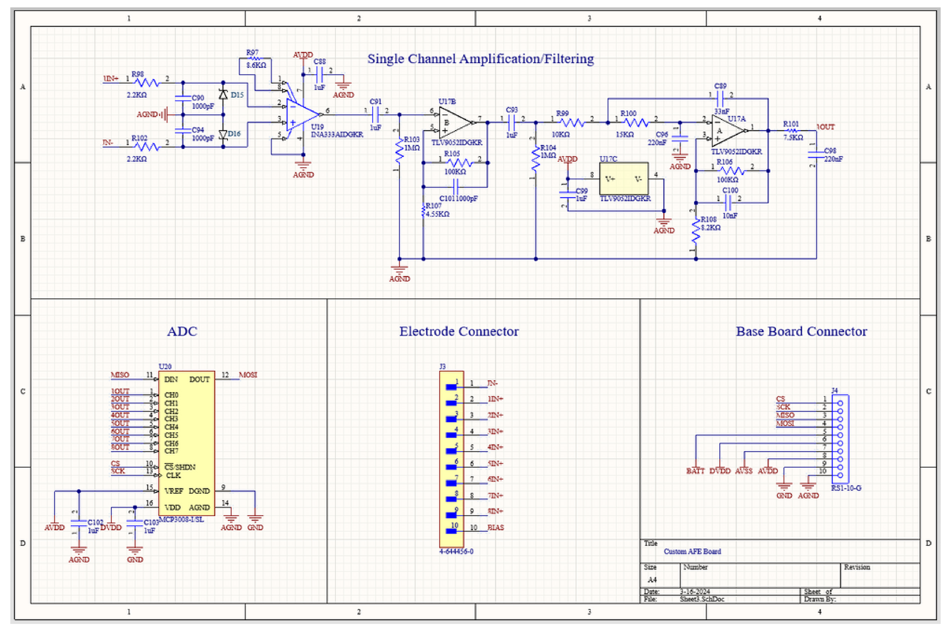

Figure 4a: Custom AFE Board Schematic

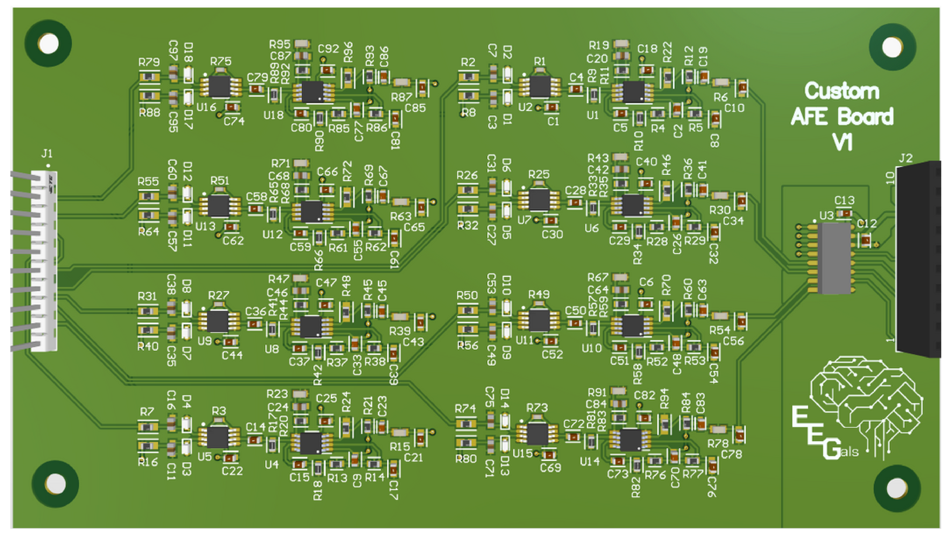

Figure 4b: 3D Rendered Custom AFE Board

Additional hardware includes electrode cables for reading EEG information off the user's head, batteries to power the PCB, and a 3D printed enclosure, as shown in Figure 3.

Product	Cost
OpenBCI Cyton Biosensing Board	$1342 CAD
Custom PCB with COTS AFE	$170 CAD
Custom AFE Board Attachment	$120 CAD

Table 1: Hardware Cost Comparison

Signal Processing

Our signal processing pipeline collects, cleans, and processes EEG data from the user. The algorithm focuses on computing the relative power of each EEG frequency band. The pipeline runs as follows:

- Raw EEG signals are collected via 8 electrodes placed on the user's head according to the International 10-20 System[1] as seen in Figure 5.

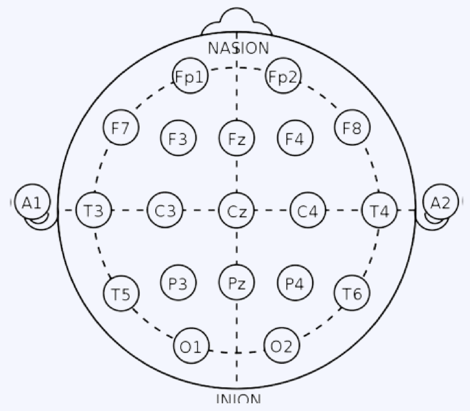

Figure 5: International 10-20 System [1]

- Brain signals travel through copper-shielded cables, which reduce the 60Hz noise interference.
- The AFE amplifies and filters the analog signals at a sample rate of 250Hz
- For each epoch of data (every 2048 samples), the MCU:
  - Transforms the data from the time domain to the frequency domain
  - Computes the power spectral density (PSD) or periodogram of each electrode channel using the Welch method
  - Calculates relative band powers by averaging the Welch periodograms
- The LCD screen displays the relative power for each EEG frequency band

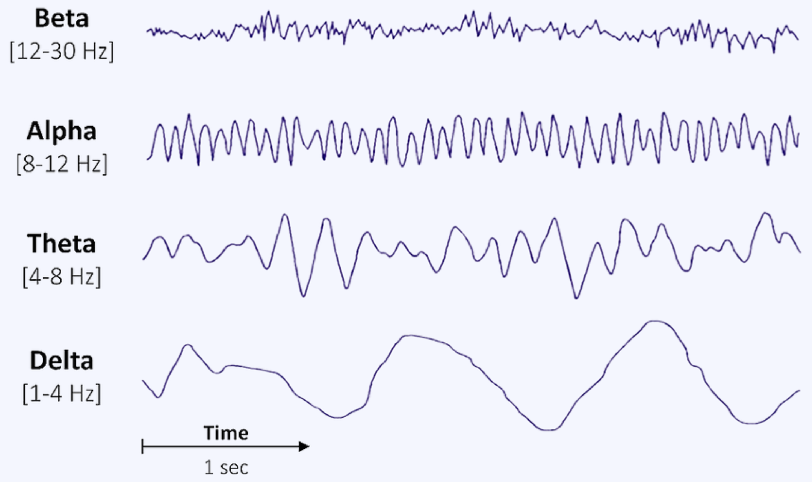

Figure 6: EEG Frequency Bands [2]

Outcome

These results will provide the user with information regarding their brain health. The data can be used by medical professionals to aid their decision-making and determine whether the patient needs further evaluation and treatment in a hospital. As it stands, our project can serve as a development platform in the future as it hosts a suite of sensors, has adequate memory for sophisticated algorithms, provides Bluetooth functionality, and can support professional use.

[1] Electrode locations of International 1-20 system for EEG recording [Online image]. (2010). History. bit.ly/3TzCkU3

[2] Vallat, R. (2018). EEG Signal Frequency Components [Online image]. Dhttps://raphaelvallat.com/bandpower.html