Diagnostic EEG System for Viral-induced Epilepsy

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Overview

- Problem Statement & Background
- Client Introduction
- Product Design Specifications
- Head cap and ear clip
- Embedded system and GUI
- Analog front-end
- Future Works
- Reference & Acknowledgements

Problem Statement

- 50 million people are affected by Epilepsy worldwide
- Detection of Epilepsy using EEG is expensive
- Cost can range from $200 - $3000
- Affordable EEG technology
- Create the following components:
  - EEG cap
  - Amplification/filtering of signal
  - Embedded system
  - Graphic User Interface

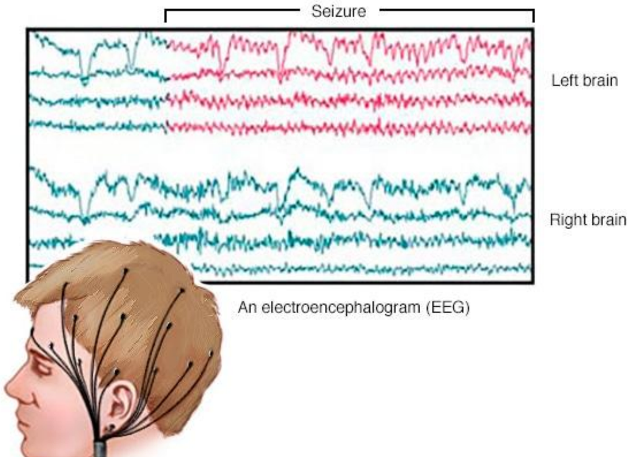

Figure 1: Sample EEG data [1]

Client Introduction

Dr. Brandon Coventry

- Wisconsin Institute for Translational Neuroengineering
- Post doctoral fellow in the department of Neurosurgery
- Neuromodulation within the thalamocortical circuits
  - Optical tools
  - Artificial intelligence

Figure 2: Dr. Brandon Coventry

TECH Collaborators

- Jesse Montoure, M4
  - Neurology
- Tai le, M1
  - Undecided

TECH
TECHNOLOGY, ENTREPRENEURSHIP CHANGING HEALTHCARE

Figure 3: TECH Collaborators

Product Design Specification

- Remain in operation for 3-4 years
- Head cap circumference between 50-64 cm
- Sample at 1kHz with 12-bit resolution
- Able to accommodate 10 different channels
- Cost of complete design under $100

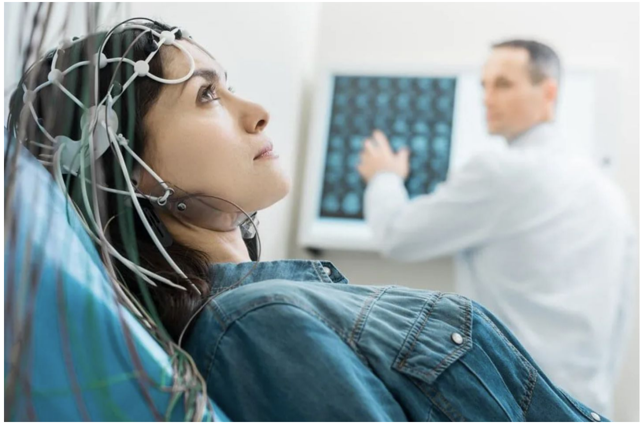

Figure 4: Example EEG Procedure [2]

Design Alternatives

Product	Channel Count	Sampling Rate (Hz)	Bit Depth	Wireless	Cost (USD)
Neurosky MindWave	1	512	12	Yes	130
Muse2	4	256	12	Yes	300
Emotiv MN8	2	128	14	Yes	400
Emotiv Insight	5	128	16	Yes	500
Emotiv EPOC X	14	256	14-16	Yes	1000
Emotiv Flex Saline	32	256	16	Yes	2000
Open BCI Complete Kit	16	125	24	No	2500
Open EEG	2-6	Up to 15.4k	10	No	200-400

Table 1: Summary of Existing Designs

Entire system
$130-$2500

Head Cap and Ear Clip - Previous Fabrication

<u>Head Cap</u>

- ~20g + 40g supports.
- ~$5 printed in TPU.
- Anatomically derived [6].
- S, M, L sizes:
  50, 55, 60 cm head circumference.
- Adjustable for electrodes.
- Space for hair.

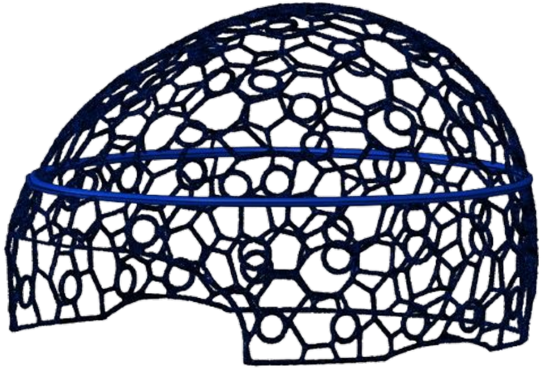

Figure 5: 3D Printed EEG Cap

<u>Ear Clip</u>

- Earclip for reference and driven right leg.
- ~1g ~$0.05.
- Mechanical failure during testing

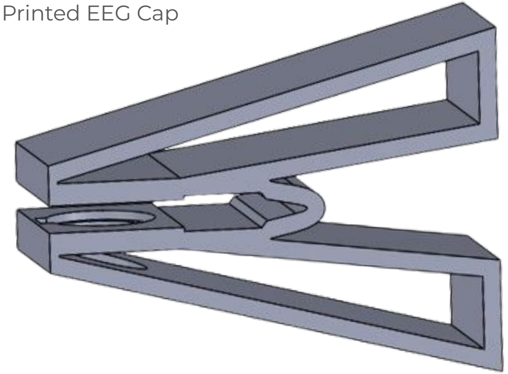

Figure 6: 3D Printed Ear Clip

Head Cap and Ear Clip - Previous Testing

<u>Head Cap</u>

- Mean 6-7% placement error, 2-13% standard deviation.
- Measured expected and actual electrode placement for 10-20 layout from nasion to inion.

<u>Ear Clip</u>

- Mean Borg discomfort value after 10 minutes of 9.75 with a standard deviation of 1.09.

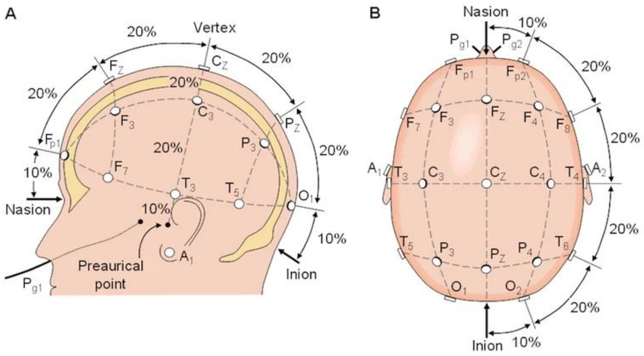

Figure 7: 10-20 EEG Electrode Layout

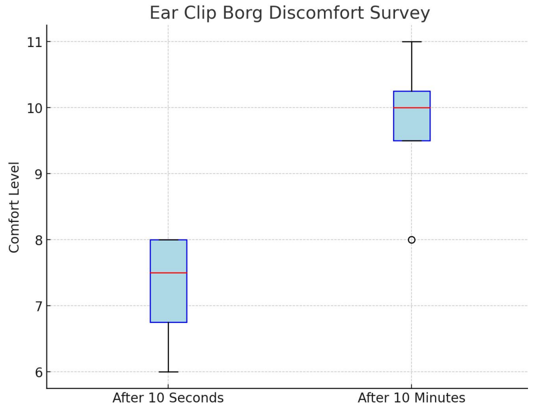

Figure 8: Borg Discomfort Data

Head Cap and Ear Clip - Fabrication and Testing

Head Cap Fabrication:

- Pivot design to fabric design
  - Easier to fabricate
  - Fits range of head sizes
- Secure attachment of all electrodes
- Possibly add chin strap to secure for better signal

New testing methods:

- Test the signal of each electrode while attached to the head cap
- Test on different head/hair types

Ear Clip Fabrication:

- Create more durable design to meet product design specifications
- Secure attachment of electrode

New testing methods:

- Durability testing of both electrode and ear clip
- Include ear clip performance in the testing of both head cap and ear clip

Embedded System & GUI - Fabrication

Embedded System (C)

- Communicate with and control
  - MUX
  - Programmable Gain
- Read data and send to GUI (USB)

GUI (Python)

- Receive data (USB)
- Record Data (excel, txt)
- Live Display data

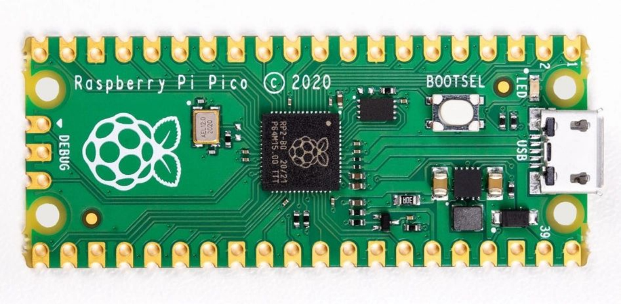

Figure 9: Raspberry Pi Pico [X]

Embedded System & GUI - Evaluation & Testing

Embedded System (C)

- MUX:
  - When given 2+ signals, can it separate them correctly?
- Programmable Gain:
  - Does outputted signal have expected gain?

GUI (Python)

- When 2+ signals does it display them correctly?
- Can run for at least 2 hours?
- Can a novice user navigate the GUI without training?

Previous Work Front-End Circuitry

<u>Designed two different configurations</u>

- INA → Level Shifter → MUX → Bandpass → MCU
- INA → Bandpass → Level Shifter → ADC → MUX → MCU

<u>Routed in Altium</u>

- Included both designs for testing
- Printed via PCBWay ®
- Components Separate

<u>Assembled PCB Board</u>

- Hand-soldered components
- Discovered multiple faulty traces
- One complete channel from INA to MUX functioning

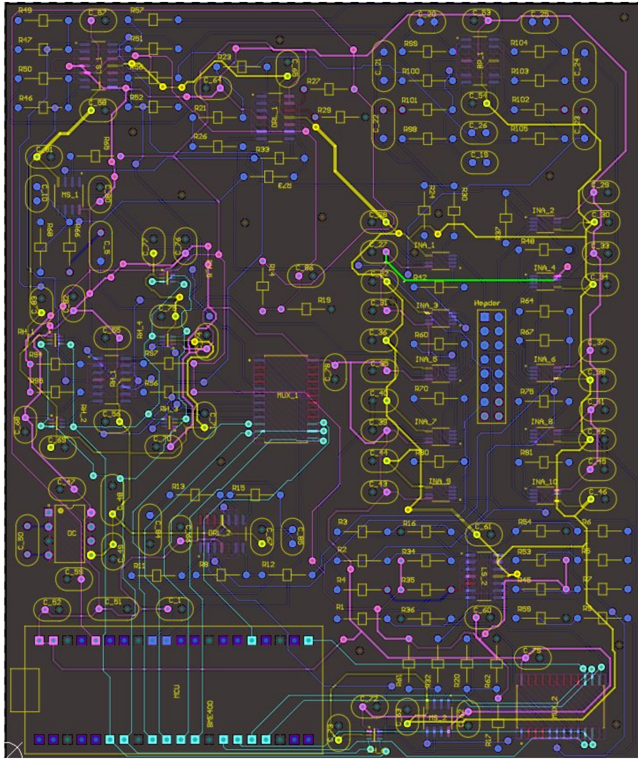

Figure 10: Routed PCB Version 1

Previous Testing Circuitry

Theoretical Passband (0.1-168 Hz)

- Achieved 0.1-200Hz passband
- Within tolerance

Theoretical Gain (6,000 V/V)

- Achieved 3,333V/V
- Combination oscilloscope, wave generator, and component uncertainty

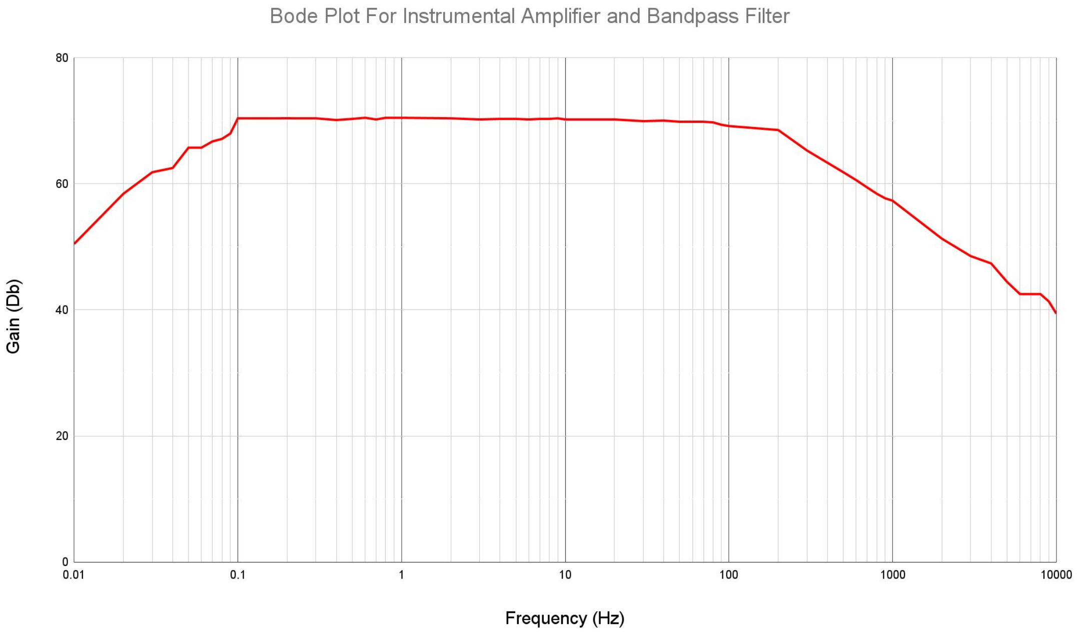

Figure 9: Bode Plot from testing PCB Version 1

Analog Front-end - Fabrication

Circuit Schematic and Routing in Altium

- Select appropriate configuration via testing results
  - Improve gain accuracy
  - Reduce artifacts with MUX
- Surface mount all components

Print PCB

- Oshpark
- Components pre-soldered

Connect Electrodes

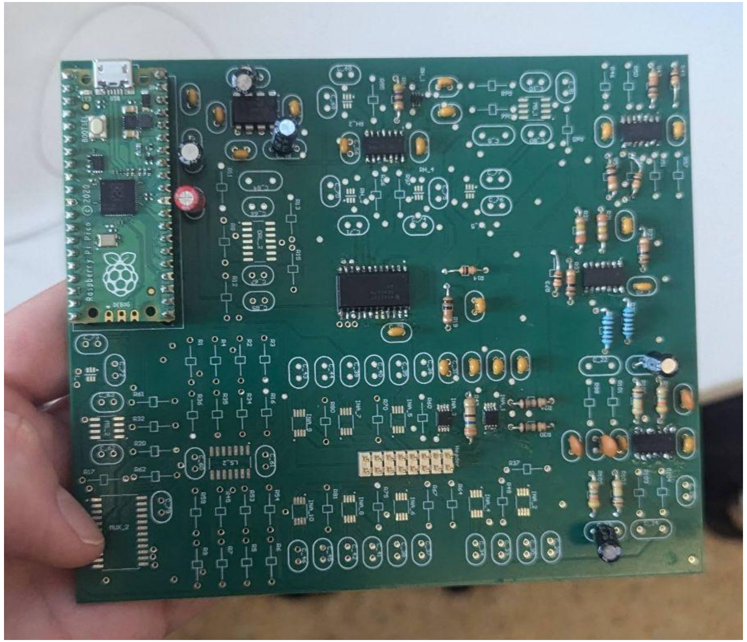

Figure 11: Populated PCB board Version 1

Analog Front-end - Evaluation & Testing

Basic confirmations

- Frequency response
- Ten-channel acquisition
- Baseline drift (<0.5 Hz/s)

Quality quantification

- Signal-to-Noise ratio
- Common mode rejection ratio
- Power supply rejection ratio

Comparison with clinical EEG systems

- Tucker-Davis Technology Bioamplifier

$$x(t) = s(t) + d(t) + \varepsilon(t)$$

Equation 1

$$d(t) = at + b$$

Equation 2

$$\min_{a,b} \sum_{i=1}^{N} [x_i - (at_i + b)]^2$$

Equation 3

$$SNR_{dB} = 10 \log_{10} \left(\frac{\sum_{i=1}^{N} s[i]^2}{\sum_{i=1}^{N} \varepsilon[i]^2} \right)$$

Equation 4

Analog Front-end - Evaluation & Testing

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$$V_{out} = A_d(V_+ - V_-) + A_{cm}\frac{(V_+ + V_-)}{2} + A_p v_p$$

Equation 5

$$CMRR_{dB} = 20\log_{10}\left(\frac{A_d}{A_{cm}}\right)$$

Equation 6

$$PSRR_{dB} = 20\log_{10}\left(\frac{A_d}{A_p}\right)$$

Equation 7

Documentation/Packaging

- Safety precautions
  - Storage environments
  - Powering on/off the device
- Cleaning instructions
- Troubleshooting electrode signal instructions
- Head cap, ear clip, circuit board, and electrodes can be sold in one box

- GUI and Embedded code commented and documented, publicly available via GitHub
- Video and text tutorials for GUI and full prototype
- Vacuum seal around each component to ensure no water damage
- Place each component in foam cut outs to avoid large impacts

Reference

[1] “Epilepsy,” Mayo Clinic, https://www.mayoclinic.org/diseases-conditions/epilepsy/diagnosis-treatment/drc-20350098 (accessed Oct. 3, 2024).

[2] “Can an EEG detect traumatic brain injury?,” Neurodiagnostics Medical P.C., https://neuroinjurycare.com/can-an-eeg-detect-traumatic-brain-injury/ (accessed Oct. 3, 2024).

[3] OPENBCI, “EEG Electrode Cap Kit.” Accessed: Sep. 18, 2024. [Online]. Available: https://shop.openbci.com/products/openbci-eeg-electrocap

[4] Contec, “CONTEC NEW Standard Adjustable Rubber EEG cap For EEG machine KT88-3200,” CONTEC, 2019. https://contechealth.com/products/contec-new-standard-adjustable-rubber-eeg-cap-for-eeg-machine-kt88-3200?variant=43685387469029&currency=USD&utm_medium=product_sync&utm_source=google&utm_content=sag_organic&utm_campaign=sag_organic&srsltid=AfmBOoqbo0xTPKwmFi5n631cKRvb3jyqairhy1mGPAH7mP_eJKc-fyP1e_A (accessed Oct. 04, 2024).

[5] A. McCann, E. Xu, F.-Y. Yen, N. Joseph, and Q. Fang, “Creating anatomically-derived, standardized, customizable, and three-dimensional printable head caps for functional neuroimaging,” bioRxiv, p. 2024.08.30.610386, Jan. 2024, doi: 10.1101/2024.08.30.610386.

[6] “Durometer Shore Hardness Scale Explained | AeroMarine.” Aeromarine Products Inc., 30 July 2020, www.aeromarineproducts.com/durometer-shore-hardness-scale/.

Acknowledgement

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