Design of an Electroencephalography Measurement System
Part 1: High Level Design

2426234

Muaawiyah Dadabhay

ELEN4006: Measurement Systems

08 April 2024

Abstract

This report outlines the development of a single-channel Electroencephalography (EEG) measurement system tailored for controlling a robotic exoskeleton orthotic hand through brain signals, aimed at aiding individuals with hand disabilities, such as paralysis. It delves into the design of the EEG measurement system, including visual representations, analysis of data, design criteria, examination of existing solutions, and a high-level Bentley model design. The design process is summarised, commencing with the amplification of brain signals received from a designated sensor using an instrumentation amplifier. Subsequently, the signal is refined through a band-pass filter to isolate relevant frequencies, followed by the application of a digital notch filter to eliminate power interference. Finally, the processed signal is displayed via an OLED interface. Furthermore, the report offers insights into the sensor selection process. Through a weighted evaluation, a dry AgCl (Silver Chloride) electrode sensor is chosen as the optimal choice for integration into the measurement system.

University of The Witwatersrand

School of Electrical and Information Engineering

1. Introduction

The World Health Organisation (WHO) estimates the global population of people with disabilities to be 100 million [1]. With rapid technological advancements in biomedical engineering [2], cost-effective solutions are essential for addressing the needs of disabled individuals worldwide. This report focuses on equipping patients suffering from hand disabilities, often due to paralysis, with a robotic exoskeleton orthotic hand controlled via brain signals. An Electroencephalography (EEG) measurement device captures brain electrical signals [3], transmitting them to a brain-computer interface (BCI) for controlling the bionic hand [4]. This report outlines the high-level design of a single-channel EEG measurement device for quantifying specified signals required to operate the bionic hand based on brain activity. Sections to follow include graphical representations of the system in Section 2, analysis of measured variables in Section 3, design specifications in Section 4, exploration of existing solutions in Section 5, formulation of a high-level system design in Section 6, and a sensor selection process in Section 7.

2. Measurement System Application

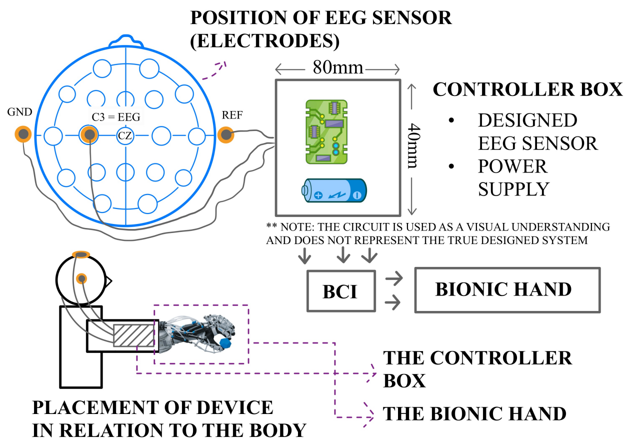
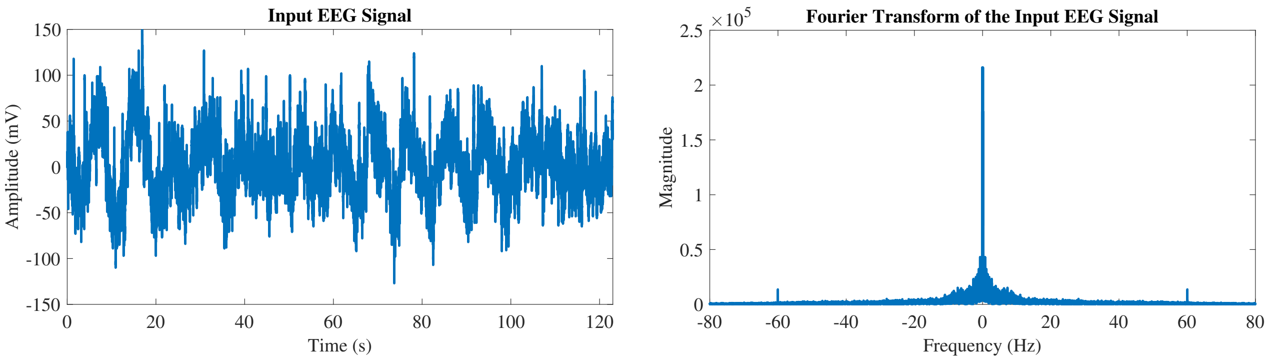


Fig. 1: Graphical depiction of the Measurement System.

An EEG measurement device detects brain electrical activity via scalp electrodes [3]. Regions for motor function are targeted in the intended design application, capturing neural oscillations in mu and beta frequency bands [5]. These bands are associated with event-related synchronisation (ERS) and desynchronisation (ERD) during motor tasks, crucial for Brain-Computer Interface (BCI) systems [6]. ERS, characterised by increased power or synchronisation of oscillatory activity, occurs during motor task preparation and execution, while ERD, characterised by decreased power or desynchronisation, occurs during active movement or motor imagery tasks [6]. A single-channel electrode configuration placement follows a path from the head to a 3D-printed box, accommodating arm movement. Cable length considerations derive from average human body male measurements

[7], ensuring optimal performance. Users with thick or long hair may need to shave for better electrode-scalp contact. The measurement box, depicted in Figure 1, houses the EEG instrument, with the box constructed from Polylactic Acid (PLA) material suitable for medical-grade devices [8]. A rechargeable battery pack meets power needs, with temperature considerations designed for typical human body ranges [9].

3. Analysis of the Measured Variable



(a) Time Domain Representation of EEG Signal (b) Frequency Domain Representation of EEG Signal

Fig. 2: Time and Frequency representation of a measured EEG signal respectively.

Utilising an EEG motor movement/imagery dataset [10], samples representing potential input signals for the measurement device were extracted. Figure 2 illustrates an EEG signal captured during alternating fist movements over a two-minute period in both time and frequency domains. Signal analysis, conducted using MATLAB and the EEGLab toolbox, focused on the C3 region electrode placement as shown in Figure 1 of Section 2. From the dataset, a subset of twenty-five patients was selected to compute average maximum and minimum values for both time and frequency domains. The average maximum and minimum voltages in the time series are 205.400 μV and -164.08 μV, respectively, while in the frequency domain, voltages range from 79.99 Hz to -80.00 Hz. Further examination of the frequency domain indicates a significant concentration of signal magnitude between approximately -20Hz to +20Hz, aligning with the mu (8–12 Hz) and beta (13–30 Hz) channels associated with motor function [6]. This observation confirms the relevance of the input signal to motor activities.

4. Design Specifications

The design specifications for the measurement device are detailed in Table I below, accompanied by their respective justifications. These specifications will serve as reference points for success criteria.

TABLE I: Design Specifications of the Measurement System

Specification	Value	Justification
Variable Range (μV)	-180.00 to 225.00	Derived from the mean maximum value calculated from the EEG dataset in Section 3, with an additional 10.00% to accommodate unexpected events. The specified values are rounded for simplicity.
Supply Voltage (V)	9.00	A 9.00V rechargeable battery will power the system, offering convenience and environmental benefits by eliminating the need for frequent battery replacements. Considering that most micro-controller units (MCUs) accept 5V input [11], a DC Buck converter will reduce the voltage supply if an MCU is utilised.
Output Voltage (V)	0.00 to 5.00	The maximum input voltage most micro-controllers are able to receive is 5V [11].
Bandwidth (Hz)	0.00 to 100.00	Derived from the mean maximum value calculated from the EEG dataset in Section 3, with an additional 10.00% to accommodate unexpected events. The specified values are rounded for simplicity.
Accuracy (%)	90.00	Factoring in Potential Drift.
Operating Temperature	0.00 to 45.00	The considerations are based on typical humans body temperature [9] since the system will be placed on a person's arm (Figure 1). Usage under extreme environmental temperatures is not recommended, as this factor is not accounted for in the design.
Price (R)	$<$ 2500.00	Kept in-line with existing solutions as discussed in Table II

5. Review of Existing Solutions

TABLE II: Summary of Existing Solutions on the Market

Device Name	Overview	Pros	Cons	Cost
EEG Click [12]	Single-channel EEG device. Includes a high-sensitivity circuit for weak electrical impulses amplification and has a bandwidth of 0.00Hz to 100.00Hz.	- Easy to use and accessible - High sensitivity by using an instrumentation amplifier	- Not suitable for clinical examination - Limited electrode compatibility	$\approx R1115$
NeuroSky EEG: TGAM [13]	Capable of analyzing various EEG metrics. Uses dry electrodes, suitable for portable applications.	- Easy to use and accessible - Low power consumption (3.3V)	- Not suitable for clinical examination	$\approx R2500$

Table II above provides a summary of existing solutions available on the market for EEG measurement devices. This overview aims to assist the design of the measurement device.

6. Proposed High-Level Solution

The proposed high-level solution shown in Figure 3 and utilises the Bentley Model approach.

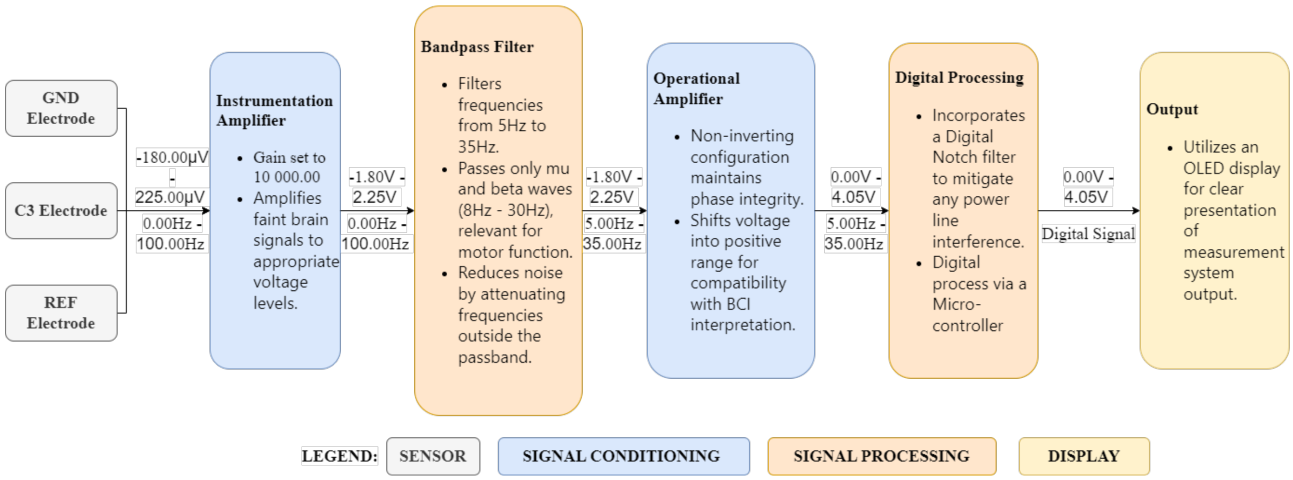


Fig. 3: Block Diagram Representation of High-Level Solution.

7. Sensor Selection

TABLE III: Summary of EEG Sensor Specifications

	Type	Potential Drift (mV/10min)	DC Offset (mV)	Cable Length (mm)	Lifespan (Years)	Price (R)	Score
Weighting	3.00	8.00	6.00	3.00	2.00	2.00	24.00
AgCl Cup [14]	Dry	0.10	<2.00	1500.00	0.50	233.70	22.67
Gold Cup [15]	Dry	5.00	<30.00	1500.00	0.50	204.50	18.00
Tin [16] [17]	Dry	10.01	<500.00	1200.00	-	243.00	13.33
AgCl Sintered [18]	Wet	0.15	<0.15	1000.00	-	705.45	13.00
Legend							
Unacceptable	Ideal	Acceptable					

Table III shows a comparison of three EEG electrode sensors as well as the sensor selection process. In terms of sensor choice, dry electrodes offer convenience. Lower potential drift and DC offset ensure longer usage and accuracy. An optimal cable length enhances user comfort and mobility as mentioned in Section 2. A longer lifespan and reasonable price contribute to a cost-effective design lessening financial burden. A weighted approach was used to evaluate the sensors with the selected input sensor being the AgCl (Silver Chloride) Cup electrode.

8. Conclusion

This report presents the high-level design of an EEG measurement system intended for integration into a larger system aimed at assisting paralyzed patients in controlling a bionic hand. Through analysis of existing solutions and sensors, a dry AgCl electrode sensor was selected as the input sensor for the measurement system.

References

[1] O. Prabhune and P. P. Rege, “SpeakingEyes: Enabling Paralyzed People to Communicate,” in *2019 IEEE 16th India Council International Conference (INDICON)*, Rajkot, India, 2019, pp. 1-4. DOI: 10.1109/INDICON47234.2019.9029026.

[2] L. G. Griffith and A. J. Grodzinsky, ”Advances in Biomedical Engineering,” *JAMA*, vol. 285, no. 5, pp. 556–561, 2001. DOI: 10.1001/jama.285.5.556.

[3] M. Teplan, “Fundamentals of EEG measurement,” *Measurement Science Review*, vol. 2, no. 2, pp. 1-11, 2002.

[4] G. Schalk, D. J. McFarland, T. Hinterberger, N. Birbaumer and J. R. Wolpaw, “BCI2000: a general-purpose brain-computer interface (BCI) system,” *IEEE Transactions on Biomedical Engineering*, vol. 51, no. 6, pp. 1034-1043, June 2004. DOI: 10.1109/TBME.2004.827072.

[5] S. Bhattacharjee, R. Kashyap, T. Abualait, S. H. Annabel Chen, W. K. Yoo, and S. Bashir, “The role of primary motor cortex: more than movement execution,” *Journal of Motor Behavior*, vol. 53, no. 2, pp. 258-274, 2021.

[6] H. Yu, S. Ba, Y. Guo, L. Guo, and G. Xu, ”Effects of motor imagery tasks on brain functional networks based on EEG Mu/Beta rhythm,” *Brain Sciences*, vol. 12, no. 2, p. 194, 2022.

[7] C. C. Gordon et al., “Anthropometric Survey of U.S. Personnel: Summary Statistics,” Interim Report, March 1989.

[8] V. DeStefano, S. Khan, and A. Tabada, “Applications of PLA in modern medicine,” *Engineered Regeneration*, vol. 1, pp. 76-87, 2020.

[9] E. F. J. Ring, H. McEvoy, A. Jung, J. Zuber, and G. Machin, “New standards for devices used for the measurement of human body temperature,” *Journal of Medical Engineering & Technology*, vol. 34, no. 4, pp. 249-253, 2010.

[10] G. Schalk, D. J. McFarland, T. Hinterberger, N. Birbaumer, and J. R. Wolpaw, ”BCI2000: A General-Purpose Brain-Computer Interface (BCI) System,” *IEEE Transactions on Biomedical Engineering*, vol. 51, no. 6, pp. 1034-1043, 2004.

[11] R. H. Kumar, A. U. Roopa, and D. P. Sathiya, ”Arduino ATMEGA-328 microcontroller,” *Int. J. Innov. Res. Electr. Electron. Instrum. Control Eng.*, vol. 3, no. 4, pp. 27-29, 2015.

[12] Microe, ”EEG Click”, (n.d.), Available at: https://docs.rs-online.com/6d2f/A700000006877304.pdf.

[13] NeuroSky, ”TGAM”, 2011, Available at: https://cdn.hackaday.io/files/11146476870464/TGAM%20Datasheet.pdf.

[14] CNSAC, ”Silver/silver chloride (Ag/AgCl) Cup Electrodes”, 2021, Available at: https://www.cnsac-medshop.com/wp-content/uploads/2021/04/Silver-silver$_{c}hlorid_{e}eg_{c}up_{e}lectrodes.pdf$.

[15] CNSAC, ”Gold Cup Electrodes”, 2020, Available at: https://www.cnsac-medshop.com/wp-content/uploads/2021/04/Silver-silver$_{c}hlorid_{e}eg_{c}up_{e}lectrodes.pdf$.

[16] Bio-medical, “Tin Disc Cup Electrode”, (n.d.), Available at: https://bio-medical.com/tin-disc-electrode.html

[17] P. Tallgren, S. Vanhatalo, K. Kaila, and J. Voipio, ”Evaluation of Commercially Available Electrodes and Gels for Recording of Slow EEG Potentials,” Clin. Neurophysiol., vol. 116, no. 2, pp. 799-806, 2005. DOI: 10.1016/j.clinph.2004.10.001.

[18] BES DataTech, ”Pallet and Disc Sintered AgCl Electrodes”, [Online], Available at: https://besdatatech.com/pallet-and-disc-sintered-agcl-electrodes/, [Accessed: April 6, 2024].