SUBDERMAL EEG MEASUREMENT SYSTEM FOR THE CONTROL OF A BIONIC HAND – PART 1

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Abstract: This work presents a novel approach to addressing motor disabilities through the development of a measurement system utilizing sub-dermal or sub-scalp electroencephalogram electrodes for controlling bionic prosthetic hands. The investigation delves into capturing, conditioning, and processing electroencephalogram signals to identify motor imagery tasks within a Brain Computer Interface. Research into existing solutions was performed. Identification of suitable sensors and proposing a high-level system solution was carried out. The UNEEG SubQ 24/7 sensor was chosen as the most suitable sensor. Signals from the sensor would undergo amplification, filtering, and processing to be useful to the Brain Computer Interface.

Key words: BCI, EEG, sensor, signal-conditioning, sub-scalp

1. INTRODUCTION

Brain-Computer Interfaces (BCIs) are a modern solution to challenges associated with motor disabilities by enabling communication between the brain and external prostheses [1]. In the context of this project, the focus is on developing a measurement system utilising sub-dermal or sub-scalp electroencephalogram (EEG) electrodes for controlling a bionic prosthetic hand. This system would be targeted at individuals who would not want to wear a large EEG headband and have a bigger budget. This system would capture and analyse EEG signals which are voltage waveforms [2]. These signals would be used to identify motor imagery tasks. These signals would need to be conditioned and processed to ensure the signals can be used by the bionic hand.

Individuals with motor disabilities or amputations face difficulties in controlling traditional prosthetic devices [3]. A method of control for bionic prostheses would be Electromyographic (EMG) sensors. The muscle contractions used to control EMG bionic prostheses are not intuitive muscle contractions for the task the prosthesis should be performing which requires extensive rehabilitation [3]. This highlights the need for a more intuitive and efficient means of control. Using EEG technology, the proposed solution enables users to generate commands by simply imagining specific hand gestures, such as a fist closure [4].

This report discusses the application and design specifications of the EEG-based measurement system for bionic control. The subsequent sections will analyse existing solutions, explore and identify the correct sensor for the application and suggest a high-level solution for the system.

2. DESIGN OF MEASUREMENT APPLICATION

The measurement system will measure signals from the brain via EEG. These signals would be depicted as voltage waveforms [2]. The voltage waveforms are obtained from an EEG electrode placed sub-dermally. Sub-dermal electrode placement is a new field that has mainly been researched for long-term epilepsy monitoring [2]. The EEG signal obtained from the electrode would need to go through processing which would involve filtering, transient removal, and eye blinking artefact removal to ensure only the hand movement signal is acquired [4]. Once the movement signals are acquired, they would be processed by a control system to determine what the movement of the hand would be.

2.1. Literature Review

In an article, Haneef, *et al,* speak about different sub-scalp or sub-dermal EEG electrodes that could be viable sensors for the measurement system [2]. The article discusses five different sub-scalp electrodes. The sub-scalp electrodes in this article are currently being used and researched for long-term epilepsy monitoring. However, despite being used for epilepsy monitoring, they still measure EEG signals and could therefore be adapted to be used for BCI implementation. Haneef *et al* tabulate specifics of each of the electrodes discussed.

In a paper by Mahmoodi, *et al*, the feasibility of a single-channel EEG to control a bionic prosthetic is discussed [4]. Mahmoodi explains how the Readiness Potential (RP) is shown on EEG moments before the individual imagines movement or physically moves. The RP signals are detected over the midline motor area of the brain from the "Cz" position on a 10-20 EEG layout [5]. Mahmoodi *et al* placed the electrode over the midline to detect movement from either side of the brain with a low-cost impact. In this study filtering and multiple denoising methods are applied to the signals to single out movement signals.

2.2. Design Considerations and Requirements, Assumptions and Constraints

The main considerations would be the electrode placement on the individual, which electrode to use, what would be measured from the electrode and how this signal would be conditioned to make it usable. The specific type of electrode is a consideration as it would affect the signal that is obtained from the brain. The sampling frequency and accepted bandwidth of the microprocessor would also be a consideration of the design as this would limit the signal processing, therefore the choice of microprocessor is also a consideration of the design. The requirements for this system would be a single-channel EEG electrode, as well as conditioning signals to be used for BCI application. The system would also need to be portable to be worn daily by the patient, and therefore weather and temperature resistant for daily climates.

Accurate and trustworthy information on sensors is difficult to obtain which makes defining the specifications of the sensor difficult. New technology that is not fully available to the public is a constraint. Other constraints would be that signals would need to be classified as EEG signals as well as the placement of the electrode to identify the motor imagery tasks. The system would be required to be powered and wearable for extended periods while the

BCI-enabled prosthesis is used. A practical assumption is that EEG electrodes whose intended use is for epilepsy monitoring would suffice as sensors for a BCI as the voltage waveforms outputted would be useful in the system. The choice of microcontroller in the design would be a constraint to the signal processing element of the system.

2.3. Annotated Diagram of the Measurement System

In Figure 1 below the measurement system is shown. The electrode is placed sub-dermally under the individual's scalp. This electrode is connected to a microprocessor which performs digital signal processing on the voltage waveform obtained from the electrode. This would be the point at which the data could be displayed for investigation of the signals to fix problems with the system. The power supply of the system would be kept in the housing with the microprocessor. This power supply would be a rechargeable lithium-ion battery between 7-12 V with a buck converter to regulate the voltage.

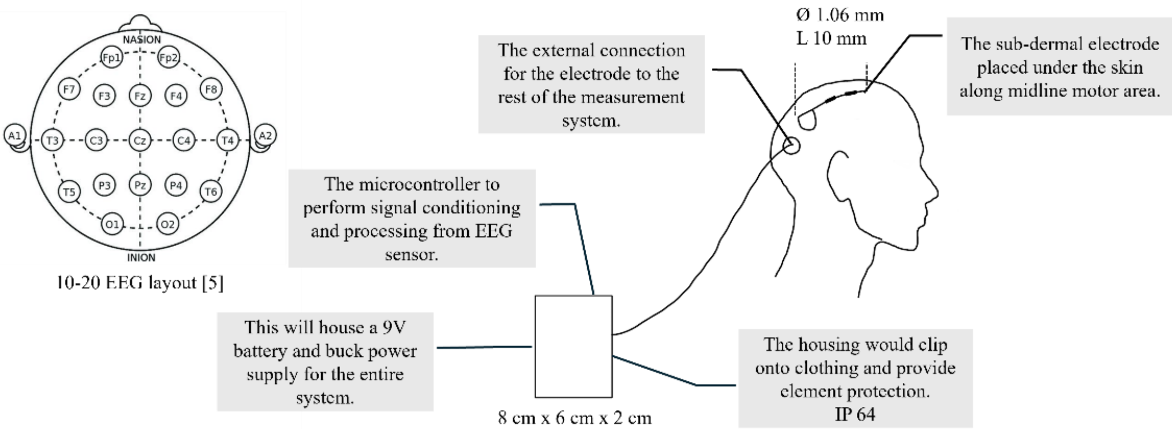

Figure 1: Annotated diagram of the measurement system.

3. ANALYSIS OF MEASURED VARIABLE

The plots below were plotted using data from the BNCI Horizon 2020 database (dataset number 11) [6] [7] [8]. "This data was collected from one subject with a high spinal cord lesion controlling an EEG hybrid BCNI to operate a neuro-prosthetic device." This motor imagery data is taken from the Cz electrode on a 10-20 EEG layout and sampled at 200 samples per second. The Cz electrode is on the midline motor area [4]. This electrode placement is chosen as it would be an accurate representation of data as RPs would be identified from both sides of the brain [4] .

When a fast Fourier transform (FFT) is performed on the time-series representation of the signal, Figure 2c, a bandwidth of 0 Hz to 100 Hz is seen. EEG signals are traditionally bandlimited excluding frequencies below 0.5 Hz and above 100 Hz [9]. In Figure 4 this is shown. Using the '*obw*' function in MATLAB it is seen that the occupied bandwidth identified by 99% of the signal's power is 83.2442 Hz. Maximum and minimum voltages should range between ± 0 – 200 µV.

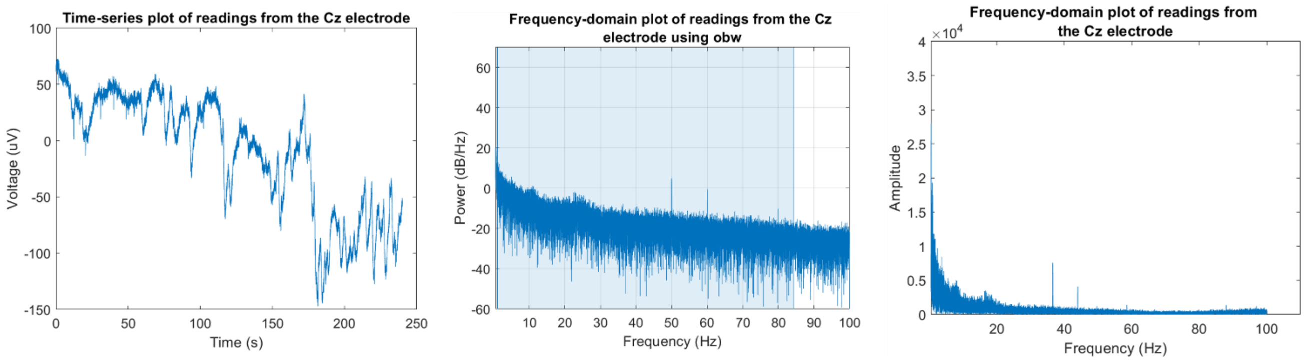

Fig 2a: Time series plot

Fig 2b: Power Spectral Density plot 'obw'

Fig 2c: Frequency domain plot 'fft'

Figure 2: Time and Frequency Plots of the expected input signal.

4. DESIGN SPECIFICATIONS

The typical voltage range of neural signals is from 0 to 200 microvolts [10]. The widest range of inputs for the BCI and microprocessor would be 0 to 5 volts. The 99% power definition of bandwidth in Figure 2b shows that the effective bandwidth would be 83.24 Hz, however, the bandwidth of all four EEG bands are encompassed by 0.5 to 100 Hz [9]. Accuracy would be important so that the correct motor imagery signals are detected. Little research has been conducted on EEG systems without the BCI component. A 5% discrepancy in signals would still allow for the correct potentials to be identified. A study on motor imagery and BCI usage showed a 96.54% accuracy with machine learning models [11]. An individual would want to make use of this system while they are using their bionic prosthetic, therefore the battery life should last longer than a working day with enough power to use before and after work. A time of 10 hours is estimated as sufficient. For sufficiently accurate analogue to digital conversion, the sampling rate of EEG systems is generally 2.5 times the highest frequency of interest [9]. Since no frequencies above 80 Hz would be deemed useful for detecting RPs a sampling frequency of 200 Hz is chosen. This would meet the Nyquist sampling criteria [12]. An IP rating of IP64 would be appropriate to protect electronics from possible rain showers or dusty environments.

Table 1: Table showing the Specifications of the Measurement System.

Specification	Variable
Input voltage range	+/- 0-200 µV
Output voltage range	0V – 5V
Bandwidth	0.5 Hz to 100 Hz (99.5 Hz)
Accuracy	± 5% error
Battery Life	+ 10 hours
Sampling Frequency	+ 200 Hz
IP rating	IP 64

5. REVIEW OF EXISTING SOLUTIONS

The existing solutions above are all headband solutions with the possibility for a BCI link. The Emotiv Insight and B-Alert x10 would be the best options. The Emotive Insight's downside would be the slower sampling rate. The B-Alert x10's downside would be the shorter battery life and lack of sensor information.

Table 2: Table showing a comparison of existing solutions.

Solution	**Emotiv Insight** [13]	**NeuroSky MW2** [14]	**Zeto EEG Headset** [15]	**B-Alert x10** [16]	**Enbio 8** [17]
Channels	5 channels and 2 Ref	1 Channel and 1 Reference	19 channels	9 channels	8 channels
Sensor type	New three-prong gummy sensor	passive biosensors	soft flex electrodes		gel or dry electrodes
Connection	Bluetooth Low Energy	Bluetooth	WiFi	Bluetooth 2.4	WiFi or USB
Dynamic range (input)	8400uV (pp)			1000 uV to 2000uV	
Sampling rate	128 samples/second per channel	512 Hz	500 Hz	256 samples/second	500 samples/second
Resolution	16 bits		24 bit	16 bit	24 bit
Frequency Response	0,5 Hz - 43 Hz	3 Hz - 100 Hz	0,003Hz - 250Hz	0,1 Hz - 67 Hz	0 Hz - 125 Hz
Filtering	5th order Sinc filter, digital notch at 50 Hz and 60 Hz			0,1 Hz HPF Firmware, 67 Hz LPF Hardware	
Battery size	Internal Lithium Polymer battery, 480mAh	AAA battery	Lithium-ion	Lithium-ion (650mAh)	Lithium-ion
Battery life	20 hours	8 hours	5-6 hours	8 hours	6,5 hours
Cost	$499,00	$129,00	Price per use		

6. PROPOSED HIGH-LEVEL SOLUTION

The system will take in a neural signal from an electrode placed sub-dermally. These signals (in the order of microvolts) will then be amplified to obtain a usable signal for the microprocessor. An instrumentational amplifier would be used to produce a very large gain. The signals will then be transported with low-latency cables to a micro-processor where digital filtering is performed. The microprocessor will also process the signal and allow for a display port where the signal can be tested for troubleshooting.

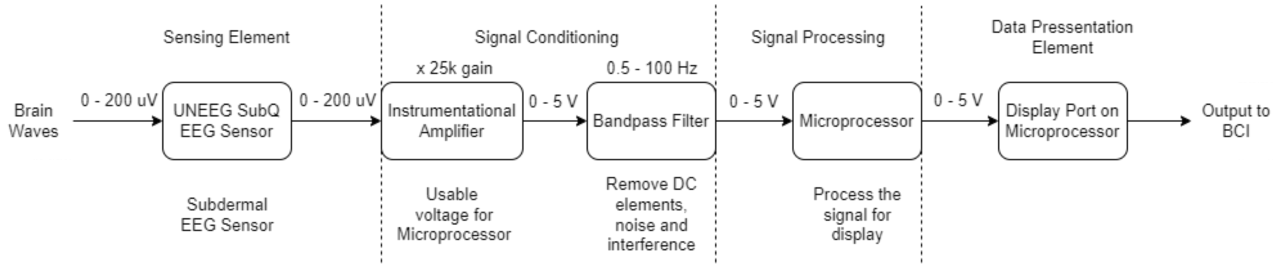

Figure 3: Bentley's model of the measurement system.

7. SENSOR SELECTION

The sensors in Table 3 are chosen as they are all sensors that are inserted sub-dermally [2]. As many of the sensors on this table are being developed at the forefront of innovation in their field, information is not freely available. These sensors are still shown to be effective at producing EEG signals and are therefore still considered. The sensor of choice from the table above is the 24/7 EEG SubQ by UNEEG Medical [18]. This sensor fulfils all the specifications for the system. The SubQ system is well-documented and is chosen over traditional semi-dry electrodes as subdermal placement is a priority. The electrode would require minimally invasive surgery [2]. This device would have less interference with hair and different moisture contents but less information and limited spatial sampling [2]. The bandwidth, battery life and sampling frequency would all fit within the specifications. This device is a single-lead sensor with multiple contact points however only one channel would be used for the measurement system. A subdermal device would also be more aesthetically pleasing and easier to wear for patients who want to mitigate stigmas around larger devices.

Table 3: Table comparing subdermal EEG sensor options. [2] [24] [25]

Company	**UNEEG Medical** [18]	**Epi-Minder** [19]	**Neuroview Technology** [20]	**Wyss Centre** [21]	**Precisis** [22]	**SOENIA** [23]
Sensor	24/7 EEG SubQ	Minder System	Neuroview	Epios	Easee	Ultimate EEG
Channels	1 lead with 3 contact points	1 lead with 4 contact points	1 lead with 3 contact points	Each trident - 8 contacts, up to 32 contacts	5 platelet contacts	1 lead with up to 8 contacts
Electrodes	Platinum/Iridium				Laplace electrode	Platinum
Sampling Frequency	207Hz	250Hz	256 Hz	250 Hz	250 Hz	1000 Hz
Bandwidth	0.5-48Hz					
Accuracy	over 10% at 50 µV for all freq within 1 Hz to 48 Hz		98% sensitivity, 99% specificity			
Battery Life	24 h rechargeable	24 h rechargeable	3 years, internal	24 h rechargeable	> 3 years, internal	24 - 48h

8. CONCLUSION

This report serves to assess the possible specifications for a subdermal EEG measurement system for the control of a BCI. This report provides a high-level overview of the possible solution including a Bentley's model diagram of the system. A comparison of existing solutions and possible sensors is completed. These aid in the design of the specifications for the system. In conclusion, a subdermal EEG electrode called the 24/7 EEG SubQ by UNEEG Medical is chosen. The signals from this sensor will go through signal conditioning and processing which will later be used to control a BCI-enabled bionic hand.

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