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TOWARDS THE DEVELOPMENT OF A ELECTRO-ENCEPHALOGRAPHY BASED NEUROPROSTHETIC TERMINAL DEVICE

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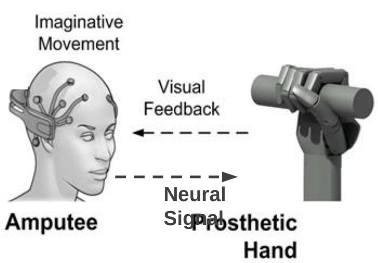
Graphical abstract



Abstract

Brain-Computer Interface (BCI) using Electroencephalography (EEG) enables non-invasive direct control between human brain and machine and opens up new possibilities in providing healthcare solutions for people with severe motor impairment. This paper reviews the recent trends in neuroprostheses and presents a conceptual design for the development of a cost-effective neuroprosthetic hand deploying EEG signals. Towards the development of a brain-computer interface for neuroprostheses, EEG signals are recorded from healthy subjects using the Emotiv Suite Software. The recognition phase and signal analysis are performed using the EEGLab Software. Signal processing is required until clear rhythmic waves are obtained as a command to control a prosthetic hand. A Graphical User Interface (GUI) will be developed using Matlab Software and aided with 3D Animation as a medium of interaction for basic training for the patient before using the prosthetic hand.

Keywords: Brain computer interface, neuroprostheses, electroencephalography

1.0 INTRODUCTION

BCI is a technology where the device records a certain area of brain activities and gives a command to an external device such as robot and prosthesis. There are four methods that record microvolt-level extracellular potentials generated by neurons in the cortical layers; Electroencephalography (EEG), Electrocorticography (ECoG), Local Field Potentials (LFPs), and single-neuron action potential recordings (single units) [1]. Generally, electroencephalography are historically dominated by BCI researchers as providing non-invasive, cheap equipment, excellent resolution, painless, ease of use, portable and no implantation approaches. The input was obtained from EEG mental tasks that include movement of a limb, respiratory, speech, heart and more.

In this paper, our focus of research is to help upper limb amputees to control prosthetic hand developed by our team using non-invasive technique EEG based BCI.

2.0 STATE-OF-THE-ART

Guger *et al.* [2] controlled the prosthetic hand, also known as the terminal device to grasp and release using EEG amplifier, which focused on electrode position C3 and C4 from one healthy subject. The experiment was done with imagery of hand grasp and release by the subject to move the prosthetic terminal device.

Table 1 Comparison of prosthesis hand control using EEG based Brain Computer Interface

Title	Prosthetic Control by an EEG-based Brain Computer Interface (BCI)	Control of an Electrical Prosthesis With an SSVEP-Based BCI	Design on the System of Brain-Computer Interface Driving Neural Prosthesis Hand	Brain EEG Signal Processing For Controlling a Robotic Arm	Towards Brain-Computer Interface Control of a 6-Degree-of-Freedom Robotic Arm Using Dry EEG Electrodes
Authors	Christoph Guger, Werner Harkam, Carin Hertnaes, Gert Pfurtscheller	Gernot R. Müller-Putz, Gert Pfurtscheller,	Xiao-Dong Zhang, Yun-Xia Wang	Howida A.Shedeed, Mohamed F.Issa, Salah M.El-sayed	Alexander Astaras, Nikolaos Moustakas, Alkinoos Athanasiou, Aristides Gogoussis
Years	1999	2008	2009	2013	2013
EEG Data	One healthy subject.	Four healthy volunteers (aged 18–29 years old, two males, and two females	One healthy subject.	A healthy subject, 26 year old, male	34 healthy subjects (25 males, 9 females)
Experiment Sessions	If the person imagined a left movement, then the prosthesis was closed and vice versa.	Four written instructions appeared with a short beep tone in a row on the top of the screen: left, right, open, and close. One of the commands had a different color indicating to the subjects which flickering light need to be focused on.	Data recorded during the hand movement. Subject needs to move four task (arm's free state, arm movement, hand crawl, hand open)	Data recorded during the hand movement. Subject needs to move three task (close, open arm and close hand)	-
Model of Prosthetic					
Device	EEG amplifier	Ag/AgCl electrodes	-	Emotiv	Emotiv
Channel Selected	C3 and C4	O1 and O2	-	AF3,F7,F3 and FC5	-
Prosthesis Movement	Open and close hand	Grasp function (open and closing of the fingers), a wrist rotation (to the left and right).	Arm waiting state, arm movement, hand crawl and hand open	Three movements (close, open arm and close hand)	Pitch, yaw, and roll at the shoulder joint, pitch and roll at the elbow, pitch and yaw at the wrist.
Feature Extraction Method	Adaptive Autoregressive (AAR)	Discrete Fourier transform (DFT)	Power Spectral Density (PSD)	Wavelet Transform (WT), Fast Fourier Transformation (FFT) and Principal Component Analysis (PCA)	-
Classification Method	Linear Discriminant Analysis LDA	-	Support Vector Machine (SVM) and Back Propagation (BP) Neural Network	Back Propagation (BP) Neural Network	-
Classification Accuracy	82.5, 88.75 and 90%.	Between 44% and 88%	-	91.1%, 86.7%and 85.6%	-

For the signal processing concept, this paper used adaptive autoregressive model as the feature extraction method and Linear Discriminant Analysis (LDA) as the classification method. In this project, classification accuracies 82.5, 88.75 and 90% were achieved. Even though the paper is applying imagery to the prosthetic hand, but the imagery data recorded is not accordance with the application.

In 2008, Pfurtscheller and Müller-Putz were study to control two axes electrical hand prosthesis by Steady State Visual Evoked Potential (SSVEP) based BCI concept [3]. Using an SSVEP based BCI, the subject is not required to undergo brain training because the subject does not have to concentrate on the simulation of actions (motor imagery). During experiment, the subject is required to focus on which flickering light need to be focused on and the prosthesis hand will move based on LED positions at prosthesis hand. The signal data was collected from four healthy subjects by using four sintered Ag/AgCl electrode placed at 2.5cm anterior and posterior to electrode positions at O1 and O2. Signal processing was done by using Discrete Fourier Transform (DFT) and online classification was achieved between 44% and 88% accuracies. Although they are successful to control the prosthetic hand but the concept idea of this paper is not practical to apply for the amputee. Due the EEG signal recorded from visual areas of the brain, the subject needs to focus which LED is flickering.

Zhang and Wang presented the BCI by using EEG to control a prosthesis hand with three degree of freedom [4,5]. In this paper, they did not specify their EEG device and electrode channels recorded but the signal data was recorded during the hand movement from one subject. The subject need to perform four tasks (arm's free state, arm movement, hand crawl, hand open) and the prosthesis hand will move based on subject task. Power Spectral Density (PSD) was used as feature extraction method and tested with two types of classification; Support Vector Machine (SVM) and Back Propagation (BP) Neural Network. The results showed that SVM classification had better recognition rate and good classification ability compared to BP Neural Network. This paper used real hand movement signal data to control the prosthesis. Therefore, it is also not practical for the amputee because of the EEG recognition from hand action.

In 2013, a team researcher fom Egypt [6] presented a Brain Machine Interface (BMI) system based on EEG to control robotic arm with three movements (close/open arm and close hand). During the experiment, the signals data was recorded from one healthy subject during the right hand movement. The EEG device was used is Emotiv Epoc and channels selected is AF3 F7, F3 and FC. It shows that AF3 position at the prefrontal cortex and F7, F3 and FC at the supplementary motor cortex of the brain. Data was processed by using three different types of feature extraction method; Wavelet Transform (WT), Fast Fourier Transformation (FFT) and Principal Component Analysis (PCA) to examine the classification accuracy by using BP Neural Network. From the result, Wavelet Transform (WT) has achieved 91.1% which highest than Fast Fourier Transformation (FFT) and Principal Component Analysis (PCA). However the researcher only used data from real hand movements to control the robotic arm. In this case, the upper limb amputee will find difficulties to control the prosthesis due to the different signal in EEG recognition [7].

Astaras *et al*. from Greece also presented their project of BCI [8, 9] to control a robotic arm by using exoskeletel position sensing harness with a dry EEG electrode. 34 subjects was involved for the pilot study which all subjects need to wear BMI harness and the robotic arm was placed at front lower right area from the subject. The purpose of this experimental setup is for qualitative assesment of the BMI. This project is still under development and the BCI headset was planned to integrate into the MERCURY prototype system. The researcher also planned to introduce feedback loop for tactile sensing in future studies. However further studies has not been reported since 2013.

Brain Computer Interface (BCI) is a field of research that is developed to read and control the human brain. This technology allows the disabled to move devices without additional support tools. Paralysed individuals with limited communication capacity can use brainwaves BCI to move prosthetic devices. Although this technology was known, but innovation is still growing rapidly with the modern touch technology as a tactile sensor, adaptive control, haptic which enables the hand to mimic the natural movement. However, until now the system used in the demonstration is still not showing the actual effectiveness and still in early stages. From the review (Table 1), there is no complete study to develop a prosthesis hand by using EEG device in motor imagery. Historically, invasive methods have shown more success in prosthetic control by motor imagery as compared to non-invasive methods [10]. Moreover, the device invented can only be used for specific people, requires training, limited by the range of function and devices [11].

3.0 CONCEPTUAL DESIGN OF A NEURO-PROSTHETIC HAND

We are developing a new neuroprosthetic hand compatible to use with EEG device by improving our past robotic hand designs [12], [13]. The design of the hand will be printed by a 3D printer. Neuroprosthetic terminal device is completed with five fingers full with seven degrees of freedom. It is individually driven by an actuator motor mimicking the human hand movements. This terminal device comes with tactile sensors placed at the fingertip [14], [15]. Basic activities as design requirements for the neuroprosthetic terminal device include touch, grasp and release.

This project aims to develop a neuroprosthetic hand with simple mechanism but effective to perform daily activities for amputee. Figure 1 shows the main system elements of a neuroprosthetic hand with an EEG based BCI. The development of the neuroprosthetic hand focuses on three main criteria: non-invasive technique, high portability and ease of use.

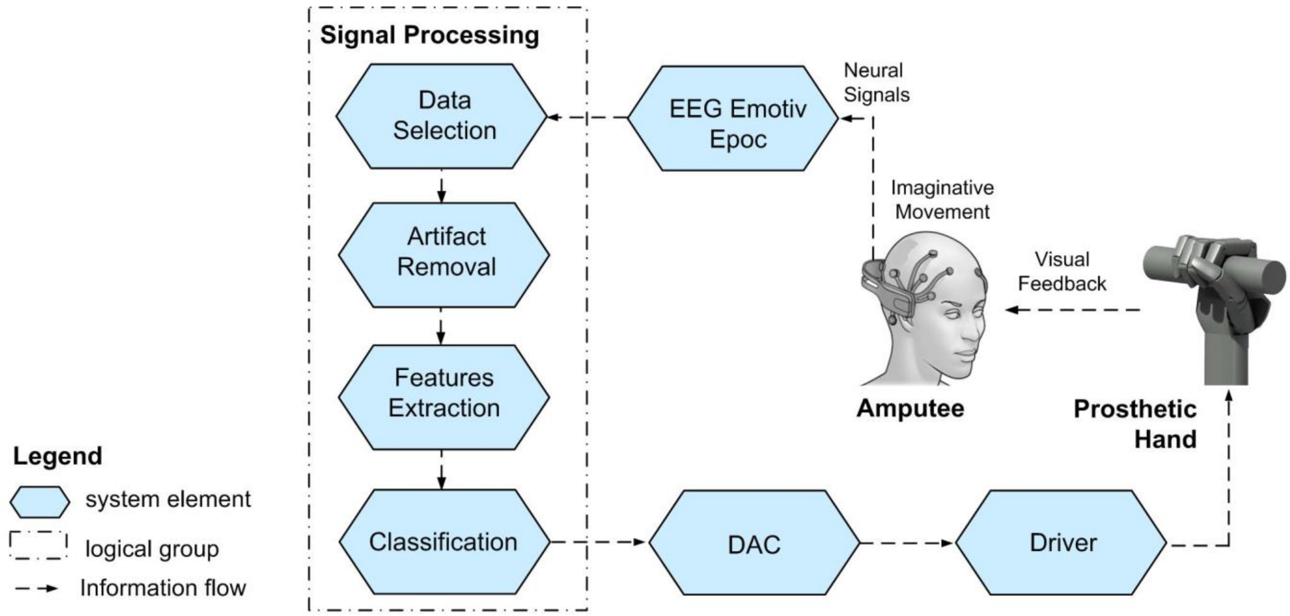


Figure 1 Block diagram of the processes of the system

The system functions by the acquisition of neural signals form the amputee. The data will be processed and stored. The subject will be selected based on the healthy condition with no problems related to brain with a different level of age. Each selected subject will move his or her hands and the result data will be recorded using the Emotiv Testbench Software. They will be given consent of ethic before experiment started. Experiment result will serve as signal sample that will be studied and used for training the amputee later. Subject will sit in front of the display screen in a comfortable position, while monitored by supervisors to help reduce any unnecessary movement, which can interfere with the data collection. However for this experiment, only channels that are related to motor cortex which involves the movement of muscle will be used. EEG Emotiv EPOC 14 Channel with two reference channels used will send a signal to the receiver signal via Bluetooth. Then, the receiver will send a signal in the Workstation for processing the data using a GUI.

The GUI is developed for data acquisition, signal processing and training. If the pattern is detected together with the recorded pattern, GUI system will send a signal to act in EEGBox to move the actuators in neuroprosthetic hand as required. The efficiency of a neuroprosthetic hand system depends on the software developed, hardware that acts as a real time and the neuroprosthetic hand developed. The longer signal recorded from user and many number channels used can affect to the time required for processing the data. Because of these problems, GUI developed must be more stable and efficient for controlling the signal obtained from the brain user.

Raw data obtained from data acquisition cannot be used as a command because there are a lot of artifact signal. Therefore, every signal data obtained will go through a process to eliminate the noise. Before processing the signal, the data must be clean without any artifacts. Several disorders usually occur during EEG recording such as Noise Environment and Physiological Noise. Examples of Environmental Noise as an AC power lines, lighting, wireless device, and a large array of electronic equipment such as computers and laptop displays. The physiological noise can interfere with recording data like Muscle movement (EMG), Cardiac Signal (ECG) and eye blinks (ECOG). A few noises simply eliminated using Automatic Artifact Removal (AAR) through EEGLab. For the muscle movement can be reduced by minimize the body movement of the subject. In addition, special rooms are also required to facilitate the EEG recording. It is also one of the methods to control noise effectively during EEG recording [1]. Every precaution should be taken to reduce the source of noise and easily to filter the noise.

The clean signal data will be converted into a matrix form and saved as a pattern approval in EEGbox database system. This EEGBox data controlled by using the Graphical User Interface (GUI) generated from Matlab Software. In the GUI interface EEGBox, have a training data to be used by the amputee as a supporting training before using the actual prosthetic hand. EEGBox GUI acts as a decision maker to make every movement neuroprosthetic hand depending on the pattern that has been in the program approval inside the database. EEGBox also acts as a real time interface between the GUI software developed by the hardware output as the actuator motor and tactile sensors are used.

4.0 EXPERIMENTAL SET-UP

This project was started in early 2014. This hand is completed with five fingers full with 7 Degree of Freedom. Individually driven by the actuator motor makes more mimic the human hands movement. Figure 2 shows an overview of this project consists of workstation, DAC, EEG Epoc and prosthetic hands.

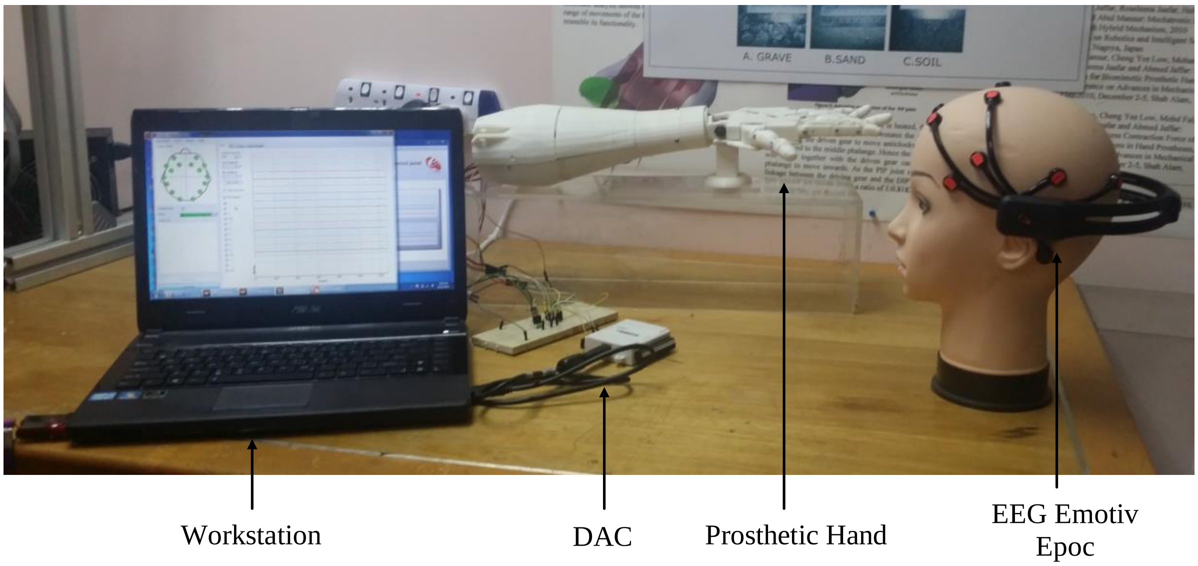


Figure 2 UiTM Neuroprosthetic hand project

5.0 CONCLUSION

Research has shown the advantages of deploying EEG technology to offer new solutions in prosthetic devices. However, until today, EEG based prosthetic devices cannot be found in the market. This shows that this technology is still undergoing a maturing process. In this work, the state-of-the-art is reviewed and a conceptual design for a non-invasive approach for controlling a neuroprosthesis hand using an Emotiv EEG device integrated with a GUI is presented.

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