Brain Computer Interface controlled Soft Finger Exoskeleton for Rehabilitation – Reality and Virtual Control Analysis

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Abstract

Brain Computer Interface (BCI) machine in this project is developed with Rehabilitation hand to enhance and amplify the motor function feedback for the subject to strengthen then connection between the muscle activation and brain activities in order to recover their paralyzed motor function. In this paper, the highlight will be on Reality and Virtual Control analysis of the BCI machine accuracy in control for 10 different subjects. The classifiers LDA and ESD will be used in the BCI machine. The EEG coverage area is F7, F8, FC5, FC6, F3 and F4. The aim of the project is to have a system that is controlled by Electroencephalogram (EEG) BCI that improves Neuroplasticity Brain activation for Rehabilitation of Stroke Patient on Finger-hand paresis. The BCI analysis is focused on temporal information features extraction. The outcome of the project achieved overall control accuracy for manual control is 40\% and for auto control is 30\% in online BCI, which is promising.

Keywords: Exoskeleton, Rehabilitation, Brain Computer Interface, Real-time processing, Reality and Virtual Control

I. Introduction

BCI controlled machine for rehabilitation is the form of the physio rehabilitation and neuro rehabilitation. There are 15 million people suffer from the affection of stroke annually worldwide (Ang, K, 2013). Referred to statistical report from World Heart Federation, 6 million of the stroke patient died and 5 million of them suffer from disability (World Heart Federation, 2017). Therefore it is essential to provide rehabilitation as early as possible for the stroke survivors in order to recover and get back to their daily function. There are research shows promising results in recovering basic motor function for the BCI machine hand orthosis rehabilitation showing 50\% of the patients obtain improvement and changes in clinical testing (Shindo, K. et al, 2011).

Spectrum information, spatial information and temporal information are compiled and mixed in the EEG raw data signal which is extractable. Temporal information focus on the signal changes over-time due to event and thoughts changes. Spectrum
and spatial information are based on the frequency changes of the signal over-time (Lotte, F., 2014) With classification output obtained from the BCI system the field des-vice able to reacts based on the classification output from the subject thoughts.

Therefore, in the part of the paper the research will be focused on the reality control on the rehabilitation hand and virtual control for the game session for the training before approaching to the rehabilitation hand control.

II. Methodology

A. Brain wave recording

In brain wave recording, the subject is required to sit on a comfortable chair with hand rest provided for comfort and reduce injury during the operation. Total of 10 sessions is included in this section, each session consists of 5 trails. Subject will be instructed which finger to move or rest the finger physically and imaginary based on the video display in front of the subject. The video consists of ‘Move’ and ‘Rest' instruction visually and audibly 5 seconds each and repeated for 6 times. Subject is required to wear the EEG on the head; the electrodes will be placed correctly.

The data recorded for training purpose is pre-processed using Emotiv Simulink exporter and the raw signal is filtered using Bandpass filter of Frequency 4 – 30 Hz, Stopband attenuation is 60dB and Passband attenuation is 1dB. Hence the output of this stage is pre-filtered raw data of the EEG signal.

B. EEG Signal processing

In this stage, the system focused on signal analysis and processing for signal identification. Two important steps are applied in this stage which is Features Extraction such as ERP, FFT, Channel Band Power and difference between electrodes. As shown in table 1.

| Modal Set | Features holds                        |
|-----------|---------------------------------------|
| 1         | ERPset, Energy                        |
| 2         | Differences of ERPset, Energy         |
| 3         | Differences of ERPset, ERPset         |
| 4         | FilterSet, Energy, Differences of ERPset |
| 5         | FilterSet, Zero Crossing Rate, Differences of ERPset |

ERP is the average data calculated using the same trails of the recorded raw data. Using this method, the difference of the event from the EEG raw data signal can be
determined. The actual EEG raw data can be long and messy and required higher
order of matrix to perform intensive calculation.
Fast Fourier Transform (FFT) able to determine the mental state of the signal
recorded from EEG. The obtain signal from brain wave recorded is pre-processed to 4
– 30 Hz which are Alpha, Beta and Theta band is co-existed in the raw signal. Using
FFT the raw data obtain can be filtered to 3 different frequency band in time domain
manner to analyze the feature of ERP which reduce the mixture of the signal for
simplified analysis.
CBP analyze the obtained raw signal in positive region by squaring all the data. The
strength of the signal can obtain using CBP features to understand the strength of the
electrodes obtain at different segment.

C. Classification Prediction
Classification used to identify the obtain features vector into classes that is usable for
field-end devices. The output of the classification results will be +1 or -1 for deciding
the class of the features obtain. Features calculated and acquired is required to be
tabulated into series of the table form with class estimated. Matlab classification
Learner tools is used for modal training for high level identification and
classification. The output of the data depends on the features tabulated in the table for
classification learner.

D. Actuators Control
In this stage, the output of the classification is the decisive action input for the
actuators control. There are 2 actuators is required to control in order to finish the
BCI training, which are (1) Virtual Actuators and (2) Real-Life Actuators.
Virtual Actuators

In virtual control, the subject required to play redesigned ‘Simon Said’ that have 5
buttons that represent each fingers movement to ‘Move’ (Press) and ‘Rest’ (Release)
as shown in figure 2. In this session of the training, the subject requires to achieve the
gaming scoring up to 90% before proceeding to Real-Life actuators control.
Real-Life Actuators

Real-Life actuators control uses the rehabilitation hand that is soft-exoskeleton design as shown in figure 3. In this session, the stroke hand will be placed in the rehabilitation hand device to perform training to ensure the control is robust.

Hardware Design and Implementation Rehab Hand

Circuit Design

Figure 4 shown the circuit design of the rehabilitation hand that control the servo motors to perform flexion and relax the finger based on the output of the BCI system. The servo motors are controlled by servo controller SC08A. SC08A is controlled by Arduino Nano instructions. Arduino Nano is receiving instructions from BCI system. SC08A takes in the power requires by Servo Motors which is 7V that’s controlled by buck boost converter connected before SC08A. This design regulated the current and voltage requires by the Servo Motors without causing power shortage to the microcontroller.
Figure 5 shows the design of the rehab hand glove that perform flexion and relaxation of the finger for the rehabilitation. Using basic mechanisms of leveling and positioning barring, the flexion and relaxation of the finger can be achieved. Nylon string secured on the palm of the glove will be connected to servo horn that would perform actuation while the servo motors actuates. When the nylon string tension, finger flexes and elastic band tensed, where when the servo motors releases the nylon string tension, finger relaxes and elastic band naturally recurred back to its natural state.

Rehabilitation Hand uses leather glove and PVC fixed joint to perform the flex and relax of the finger movement using servo motor pull. The subject requires to wear it in full to the tip of the glove to provide optimal rehabilitation of the fingers. The straps underneath the 3D printed components box is required to strap the box on the subject have firmly and gently. Ensure the stroke hand is sit firmly on the PVC stand to ensure low vibration during rehabilitation.

Figure 6 shows the working principle of the overall system in a visual manner. First, the subject requires to wear the Emotiv EEG headset on the head and make sure the connection of the electrodes is well connected. The subject will then perform imagination or motor execution on the finger they wanted to move. All the raw signal data will be collected using Emotiv EEG headset electrodes in terms of micro-voltages. The Emotiv EEG headset is built-in with Bluetooth and come with Bluetooth dongle, hence all the data obtain each 1/128 second will be transmitted wirelessly towards computer for further processing.
Second, the obtained data from Emotiv EEG headset will be performing processing such as feature extraction and classification. Feature extraction such as Difference of ERP, ERP, FFT Filter set, Energy and ZCR is extracted. Classification Learner using supervised machine learning to train the modal for output class predict based on the features extracted from the EEG headset. The focus approaches are using LDA and ESD for classification, due to testing and analysis that will be discussed in chapter 5.2 Quadratic Discrimination Analysis (QDA) and SVM is eliminated because of low accuracy of performance. The output of the classification results is decisive and numeric for field end device controlling.

Lastly, the obtain action control word from classification results will be sent as the command to control the rehabilitation to execute which finger under which event. Same apply to the Simon Said virtual training on the computer.

Online GUI – BCI system

Figure 7 shows the BCI system user interface that’s comprehend the real-time monitoring and system control. The user interface able to monitor the current 6
electrodes input raw data of the subject brain waves and prediction output of the finger controlling event that is executing to the system. The system uses two classifier approved class to execute the event. The finger that’s the system controlling will be displayed in the user interface as well. The user interface able to connect to another interface that is usable for the operator or researcher.

Testing of the proposed design

In this chapter, there are 5 tests will be executed for the project to determine the efficiency of the system on different people that with different background. There are 10 subjects participate the training and testing of the project, table 2 shows the names, age, gender and general description of the subjects participate in the project training.

| ID | Age | Gender | Comments |
|----|-----|--------|----------|
| 1  | 23  | Male   | - Engineering Background, Final Year Student  
     |     |        | - Uses EEG quite sometimes |
| 2  | 23  | Male   | - IT Background, Worker  
     |     |        | - First time using EEG |
| 3  | 22  | Male   | - Engineering Background, Final Year Student  
     |     |        | - First time using EEG |
| 4  | 23  | Male   | - Engineering Background, Final Year Student  
     |     |        | - First time using EEG |
| 5  | 23  | Male   | - Engineering Background, Final Year Student  
     |     |        | - First time using EEG |
| 6  | 23  | Female | - Accounting Background, Worker  
     |     |        | - First time using EEG |
| 7  | 23  | Male   | - Actuarial Science Background, Worker  
     |     |        | - First time using EEG |
| 8  | 20  | Male   | - Engineering Background, Student  
     |     |        | - First time using EEG |
| 9  | 23  | Female | - Accounting Background, Student  
     |     |        | - First time using EEG |
| 10 | 23  | Male   | - Accounting Background, Student  
     |     |        | - First time using EEG |

Table 2. Subject’s description

Table 5.1 shows the description of the subjects participated in the training and testing for the project. As notice in the table, most of the subjects are first time using EEG devices. Hence, the brain wave control for focus and concentration might varies. 3 out of 10 of the subjects is workers, 4 out of 10 of the subjects is final year students, different stress level could be appeared during the data recording session which could lead to low accuracy output. Table 3 shows the list of the testing that will be performed for the project and the numbers of the subjects involved in the testing.
Table 3. Testing List

| Test No. | Test Name                                      | Subjects Involved |
|---------|-----------------------------------------------|-------------------|
| 1       | Classification and Modal Types Testing        | 1                 |
| 2       | Individual Offline Analysis                   | 1,2,3,4,5,6,7,8,9,10 |
| 3       | Individual Control Accuracy (Virtual)         | 1,2,3,4,5,6,7,8,9,10 |
| 4       | Individual Control Accuracy (Reality)         | 1,2,3,4,5,6,7,8,9,10 |
| 5       | Individual Learning Curve                     | 1                 |

Classification and Modal Types Testing Definition

This testing is used to identification the relationship between the Classifier Learner accuracy and prediction function output accuracy towards the recorded trail data prediction.

Setup

i. 5 modals of the subject will be inserted into the classification learner and identified the trained classifier of LDA, ESD, SVM and QDA accuracy as shown in Figure 8.

![Data Browser](image)

**Fig. 8.** Classifier Learning Accuracy

ii. All individual classifier will then bring into Offline analysis UI for prediction test for accuracy output.

iii. Classifier accuracy and prediction accuracy will be recorded and perform analysis of deciding the final modal type and classifiers used.

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III. Results and Discussion

Individual Control Accuracy (Virtual)

![Subject's Virtual Score Point](image)

**Fig. 9.** Virtual Score Point results

Trained subject requires to perform virtual control before proceeding to the reality control. Figure 9 shows the variation of different subject on virtual control score point achievement. Subject 1 has the higher score point by following the random finger queue done by Simon Said gaming since subject 1 is the one has the longest training period among of the subjects. Subject 6 and 7 have intermediate score point, because they have long hair that might affects the recording results. Subject 4 has issues in concentrating the event cue therefore the score point is lowest among all.

Individual Control Accuracy (Reality)

![Move Control Accuracy](image)
Figure 10 shows the event control accuracy of 10 subjects. The subjects require to hold the finger for the event control for total of 10 second and each prediction results will be recorded. Both classifier agreement holds the actual movement executed and one classifier agreement holds one of the classifier does not agree on the movement is executed. Shows in figure 7, the accuracy of the both classifier agreement for all the subject are almost the same for both events, where subject 1 holds the highest control accuracy of 50% for both event. For subject 1, when performing move event control 80% of the time one of the classifier is agreed to move and rest event control is 60%.

**Individual Learning Curve**

![Figure 10. Event Control Accuracy](image)

Table 4. Learning Curve

| Day | Manual | Auto | Time | Virtual |
|-----|--------|------|------|---------|
|     | Both   | One  | Both | One     |
| 1   | 50.00% | 80.00%| 20.00%| 26.00%  |
| 2   | 52.00% | 88.00%| 28.00%| 34.00%  |
| 3   | 58.00% | 82.00%| 26.00%| 44.00%  |
| 4   | 56.00% | 84.00%| 28.00%| 40.00%  |
| 5   | 52.00% | 84.00%| 28.00%| 46.00%  |

Table 4 shows the learning curve over 5 days continues control and training for subject 1. In day 1, subject shows 50% and 20% accuracy for controlling on manual and auto mode, where the timing to fully grasp the hand is 56 seconds. Virtual gaming score point is 60. In day 5, subjects show improvement of 52% and 28% accuracy for controlling and 53 seconds takes to fully grasp the hand. Virtual score point is 80. This shows the subject with sufficient training and continuous control for the BCI system, subject’s brain wave able to modulate to follow the brain that has been trained easier than day 1.
IV. Conclusion

In conclusion, this paper discussed the real-time control on the BCI system that perform actuations on the rehab hand for rehabilitation is achieved with system and circuit design. The accuracy of the event controlling is around 45% to 60%. With sufficient continuous training and controlling, human’s brains able to modulate the brain signal to suit the pre-recorded signal trained classifier in the system to control the actuator unit. The limitation of the device is slight delay of the processing on the brain signal and actuators control of 1 second. The features require up to 1 second of data to perform prediction and electroencephalogram used has limitation and restriction on direct raw data acquisition to the system to perform fast real-time control. Therefore, in recommendation the electroencephalogram used could be open source to reduce the difficulties of the system to acquire raw data and determine alternative features group for the system to reduce process time.

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