# BRAIN COMPUTER MUSIC INTERFACE FOR PROSTHETIC HAND

**A PROJECT REPORT / THESIS**

*Submitted in partial fulfillment for the award of the degree of*

**B. Tech**

in

**Mechanical Engineering**

*by*

**NAGARJUN VINUKONDA – 15BME0458, 10649110**

**School of Mechanical Engineering**

UNIVERSITY OF PLYMOUTH

VIT
Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

**May & 2019**

# DECLARATION BY THE CANDIDATE

I hereby declare that the project report entitled "**BRAIN COMPUTER MUSIC INTERFACE FOR PROSTHETIC HAND"** submitted by me to Vellore Institute of Technology, Vellore in partial fulfillment of the requirement for the award of the degree of **B-Tech** in **Mechanical Engineering** is a record of bonafide project work carried out by me under the supervision of **R. Ramakrishnan.** I declare that this report represents my concepts written in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I further declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed. Further I affirm that the contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma and the same is certified.

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Date: 20-05-2019                                        Nagarjun Vinukonda

Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

## School of Mechanical Engineering

## BONAFIDE CERTIFICATE

This is to certify that the project report entitled "**BRAIN COMPUTER MUSIC INTERFACE FOR PROSTHETIC HAND"** submitted by **NAGARJUN VINUKONDA (15BME0458)** to Vellore Institute of Technology, Vellore, in partial fulfillment of the requirement for the award of the degree of **B-Tech** in **Mechanical Engineering** is a record of bona fide work carried out by him/her under my guidance. The project fulfills the requirements as per the regulations of this institute and in my opinion meets the necessary standards for submission. The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma and the same is certified.

**Project Supervisor Coordinator**
Ramakrishnan R

**Head of the Department** **External Examiner**

# University of Plymouth

Date: 20-05-19

## CERTIFICATE BY THE EXTERNAL SUPERVISOR

This is to certify that the project report entitled "**BRAIN COMPUTER MUSIC INTERFACE FOR PROSTHETIC HAND"** submitted by **NAGARJUN.V (15BME0458)** to Vellore Institute of Technology, Vellore in partial fulfillment of the requirement for the award of the degree of B.Tech in Mechanical Engineering is a record of bona fide work carried out by him/her under my guidance. The project fulfills the requirements as per the regulations of this institute and in my opinion meets the necessary standards for submission. The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university. During the project internship, the attitude and the conduct of student is ______________________________.

Eduardo Reck Miranda
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Moreover, I would extend my thanks to the sources through which we gathered information about my project using Internet and would like to seek apology for any mistake done during working of this project.

I would also like to thank the authors of all the articles I have referred to for the requirement of carrying out this project. I would finally like to thank VIT University and University of Plymouth for giving me such a platform to gain experience and greater comprehension of the subject.

Place : Vellore

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**(Nagarjun Vinukonda)**

Date : 20-05-19

# TABLE OF CONTENTS

# ABSTRACT

The Interdisciplinary Centre for Computer Music Research is a world-leader in the field of Brain-Computer Music Interfacing (BCMI). A BCMI systems uses electrical activity of the brain, referred to as EEG (short for electroencephalogram) to control musical systems, such as generative music software and digital sound synthesisers. The EEG is detected by means of electrodes placed on the scalp of a person. The main aim of my research is to enable people with severe motor impairment (e.g. paralysis of the limbs) to make music. This project is to develop a BCMI system to control a prosthetic hand to play a musical instrument such as a drum or a keyboard. This project uses SSVEP (Steady state Visually Evoked Potential) Method to read EEG data and MATLAB and Openvibe softwares for signal processing and control of Open bionics Brunel hand.

Keywords: SSVEP, BCI, nodes, flickering channels, frequency, CCA.

# LIST OF FIGURES

## LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| FR | Flickering Region |
| CCA | Canonical Correlation Analysis |
| EEG | Electro-Encephalography |
| SSVEP | Steady-State Visual Evoked Potentials |
| BCI | Brain Computer Interface |
| FFT | Fast Fourier Transformation |
| ITR | Information Transformation Rate |
| LDA | Linear Discriminant Analysis |
| CSP | Common Spatial Pattern |
| LSL | Lab Streaming Layer |
| SNR | Signal to noise ratio |

# CHAPTER 1

# INTRODUCTION AND LITERATURE REVIEW

## 1.1 INTRODUCTION

A (BCI)Brain Computer Interface system is a communication system that reads brain activity and converts it into commands for a computer or other devices. The major aim of this technology is for muscular or motor-neuron disabled users.

There are different ways for acquiring brain signals, these are classified into invasive and non-invasive techniques. While the invasive techniques are cortical (implanting electrodes near surface of the brain) and intracortical (implanting electrodes deep inside the brain) provides much better brain signals than non-invasive, they are also very dangerous as anything related to brain surgery is risky even in this era and the electrodes implanted may get rusted. The non-invasive techniques like Magnetoencephalography (MEG) and Functional magnetic resonance imaging (fMRI) may have merits better brain signals, but they also have demerits like equipment cost and non-portable devices. Among the non-invasive techniques, the EEG (Electro-Encephalography) is the current trending method for ease of use, low equipment cost and portable availability to acquire brain waves.

Human-Computer interfaces can use different signals from the body in order to control external devices. The other techniques for detecting electrical activity are EOG-Electrooculogram which is based on eye movement, EMG-Electromyogram based on muscle movements and EEG-Electroencephalogram based on neural activity detected on scalp can be used as input signal. EEG-based brain-computer interface (BCI) systems are used with following methods: (i) slow cortical potentials, (ii) the P300 response, (iii) steady-state visual evoked potentials (SSVEP) or (iv) motor imagery. [1]

Actually different types of classifications can be established for BCI technology, from the physiologic point of view BCI devices can be classified in exogenous and endogenous. The exogenous devices provide some kind of stimuli to the user and they analyse the user's responds to them, examples of this class are devices based on visual evoked potential or P300.

On the contrary, the endogenous devices do not depend on the user's respond to external stimuli, they base their operation in detecting and recognising brain-wave patterns controlled autonomously by the user, example of this class is motor imaginary.

SSVEP-based BCIs uses flashing regions on screen called stimuli also called as flickering regions. Each of these flickering regions are flashed with different frequency constantly as shown in fig 1.1. When a person gazes at one of these flickering regions, that sources specific frequency component will increase in the EEG being measured and gives better SNR over the occipital lobe. Hence, while gazing at different flashing regions where each of them represents a predefined command, after the signal processing and statistical analysis the person gives this command by gazing onto the screen to actuate prosthetic hand. The analysis is either done by FFT-based spectrum comparison, preferably including also the harmonics, or via the canonical correlation analysis (CCA).

CCA is a multivariable statistical method used when there are two sets of data, which may have some underlying correlation. First, CCA finds a pair of linear combinations, called canonical variables, for two sets (each set consist of each electrode data), such that the correlation between the two canonical variables is maximized. Then it finds a second pair, which is uncorrelated with the first pair of canonical variables but has a next highest correlation. This constructing of canonical variables takes place up to the maximum value is provided as output. The coefficients describe the correlation relation of the two sets and largest coefficient of multiple correlation coefficients is considered. [2]

Why SSVEP? Because of its advantages such as little user training, ease of use, and high information transfer rate (ITR) [3, 4].

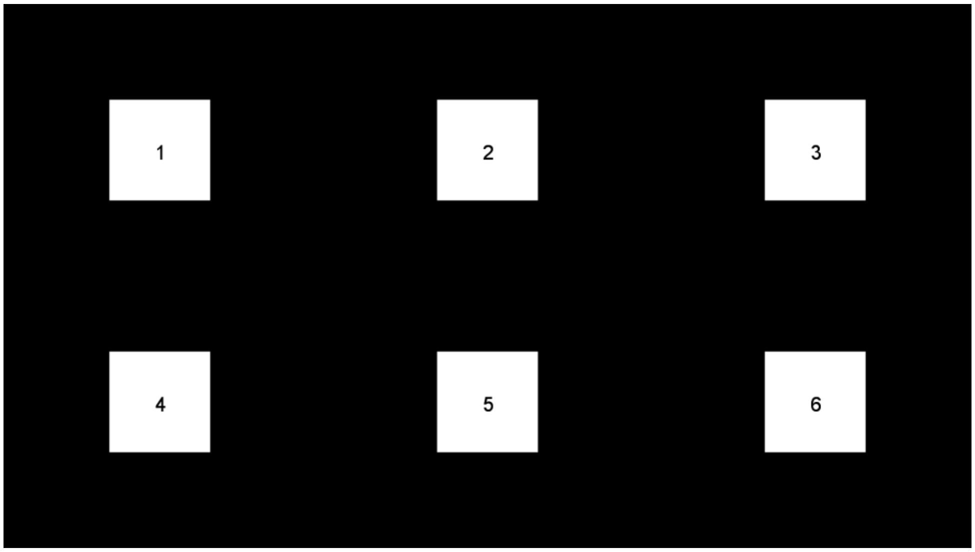


**Fig. 1.1** Different FR's on-screen flickering frequencies.

## 1.2 LITERATURE

Yijun Wang et al (2008), In his article, it presents methodology of SSVEP and advantages of SSVEP system that are: little user training, and a high information transfer rate; Convenient and Comfortable to Use; Stable and Reliable System Performance; Low-Cost Hardware based on the experiment analysis. [3]

Guangyu Bin et al, (2009) this article described the three stimulus modulation approaches used in current VEP based BCIs: time modulation (t-VEP), frequency modulation (f-VEP), and pseudorandom code modulation (c-VEP). In t-VEP, the FC's are independent of each other. They won't be in same phase and the time at which region flickers is different. In f-VEP the channels or regions are in different frequencies and they might be inn same phase. In c-VEP each region has its own pseudo pattern, they flash at different patterns. Through the experiment conducted on four subjects in this article, it has been concluded that f-VEP and c-VEP are better used for online based system. For my research in order to use FFT we need to use f-VEP, which has high ITR according to the reference article. [4]

Ming Cheng et al (2002)., In this article 13 subjects are used for experimental analysis of BCI system with 12 FC's, in order to dial a telephone number. Through this experiment on frequency-coded SSVEP, approaches to improve the performance of the system are discussed, where training is required to get accurate results, followed by sophisticated signal processing. The transfer rate of a BCI system depends on three factors: number of selections, accuracy and speed. [5]

Gernot R M¨ uller-Putz et al, (2005), In this article 5 subjects are used for SSVEP based BCI system, where three SSVEP harmonics yielded a significantly higher classification accuracy than was the case for one or two harmonics. This classification is based on ofline bci system and LED based system. For this experiment each segment 12 non-overlapping frequency components (LED) between 6 and 39 Hz (four separate stimulation frequencies, each with three harmonics) with a bandwidth of 0.5 Hz were used. The classification based on combined harmonics led to a significant increase of the accuracy.[6]

Xiaogang Chen et al, this study compared two hybrid target-coding strategies: (1) mixed frequency and phase coding, and (2) joint frequency and phase coding on a simulated online BCI experiment using a 40-target BCI speller on 6 subjects. The results of this experiment suggested that the hybrid frequency and phase coding methods are highly efficient for multi-target coding in SSVEP BCIs with a large number of classes to get a high-speed BCI speller. For each frequency, the number of phases is equal to the number of frames per cycle. For both coding methods, the classification accuracy decreased as stimulation frequency increased. [7]

Yijun Wang eta l, (2006), An experiment SSVEP based is conducted on certain subjects. These results were consistent to the finding that SSVEPs in higher frequency band show lower amplitude response and SNR. [8].

Vojkan Mihajlovi et al, (2013), In this paper SSVEP based BCI experiment is carried on 6 different subjects for dry, wet and gel electrodes. Based on experiment, classification accuracy and average information transfer rate is higher for gel followed by water and then dry based electrodes. [9]

Harun ÇĠĞ (2017), This paper evaluates SSVEP based BCI experiment in offline mode using Openvibe as software. It also describes different steps on configuration, training acquisition, Common Spatial Pattern filters (CSP) training, classifier training used in Openvibe which are further used as reference for my experiment. [10]

Peng Yuan et al, (2015), This paper aims to create new training-free SSVEP based BCI system using joint frequency phase coding, where its idea is to transfer SSVEP templates from the existing subjects to a new subject to enhance the detection of SSVEPs. In this framework the experiment uses transfer template based canonical correlation analysis (tt-CCA) which attains higher accuracy than standard CCA [11].

## 1.3 SCOPE OF THE WORK

Based on the literature review and the equipment available for the experiment, I aim to create simple f-SSVEP based BCI system working offline without training using Openvibe software. And apply CCA for better accuracy. And further, create transformation algorithm for interface between output and prosthetic hand.

## 1.4 OBJECTIVES OF THE WORK

This project aims to develop BCMI system to read EEG (Electroencephalogram) of the brain and control the Open Bionics Brunel hand by use of SSVEP (Steady State Visually

Evoked Potential) method, which enables people with severe motor impairment play musical instrument such as a Keyboard.

# CHAPTER 2

# PROPOSED SOLUTION / METHODOLOGY

## 2.1 EUIPMENT

For my research, I use g.tec GAMMAsys cap as shown in fig.2.1 for connecting electrodes to head, g.SaharaBox for determining change in potential and g.Mobilab+ for amplifying EEG signals.

**Fig. 2.1 g.tec GAMMAsys cap**

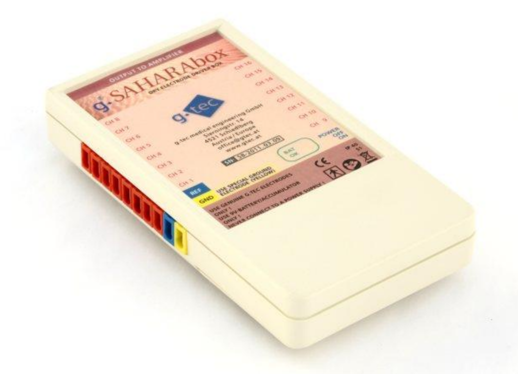


**Fig. 2.2 g.SaharaBox**

**Fig. 2.3 g.Mobilab+**

The electrodes are positioned on EEG cap and when the headset is wearing on scalp, the electrodes detect voltage spike this detects the EEG waves and the Sahara box is designed for implementing change in potential to get better signal reducing noise. Later the signals are sent into g.GAMMA cap for amplification and further into system.

The prosthetic hand I am using is Openbionics Brunel hand, a 3d-printed hand, which has four motors to move five fingers. Except for all other fingers, pinkie and ring fingers move together as they are connected to single motor. The prosthetic hand is Arduino based hardware, i.e it uses chestnut PCB.

**Fig. 2.4 Openbionics brunel hand**

## 2.2 METHODOLOGY

The EEG-data is derived with seven gold electrodes placed mostly over visual cortex on positions POz, PO3, PO4, O1 and O2. The reference electrode is placed at the Cz and the ground electrode at position FPz. This project can be done through any of method FFT or CCA. I have worked on both methods, but I am only going to describe CCA method.

Standard steps for executing CCA method:

- The EEG signals are recoded through a platform called Openvibe software.
- The readings from EEG is taken for the particular band range is sent from Openvibe to MATLAB using Lab streaming Layer. The signal processing is done both in Openvibe and MATLAB. In Openvibe, band pass butterworth filter is applied for filter order 15 and band range from 4 to 34.
- After acquiring data in MATLAB, a filter is applied. First butterworth filter, a high band pass filter from 4Hz is applied of filter order 6. Later, a low band pass filter up to 34Hz is applied of filter order 24.
- In Matlab, a code is written for CCA for matching the input frequency data for the list of target frequency as output.
- Later after statistical analysis, the obtained output of target frequency is sent to Arduino of hand through serial communication for actuating the fingers of the hand.

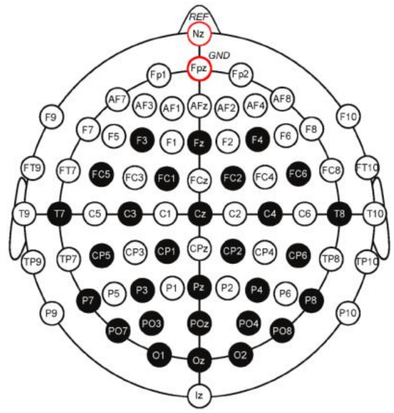


**Fig. 2.5** Electrode positions

EEG data are recorded with a sampling rate of 256 Hz with the g.SaharaBox and amplified using g.Mobilab+ devices.

# CHAPTER 3

# RESULTS AND DISCUSSION

## 3.1 ANALYSIS OF THE DATA

For the experiment I am using all stimuli from 8 to 13Hz as shown in Fig. 1.1, where flashing region 1 is 8Hz; 2 is 9Hz, 3 is 10Hz; 4 is 11Hz, 5 is 12Hz and 6 is 13Hz.

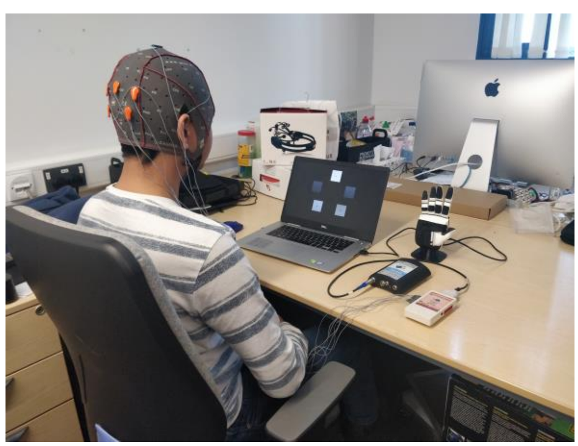

**Fig. 3.1** experiment

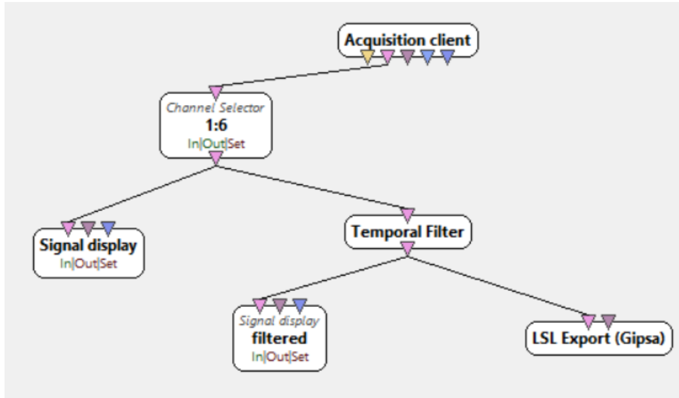


**Fig. 3.2** Openvibe data acquisition and exportiation of data to MATLAB

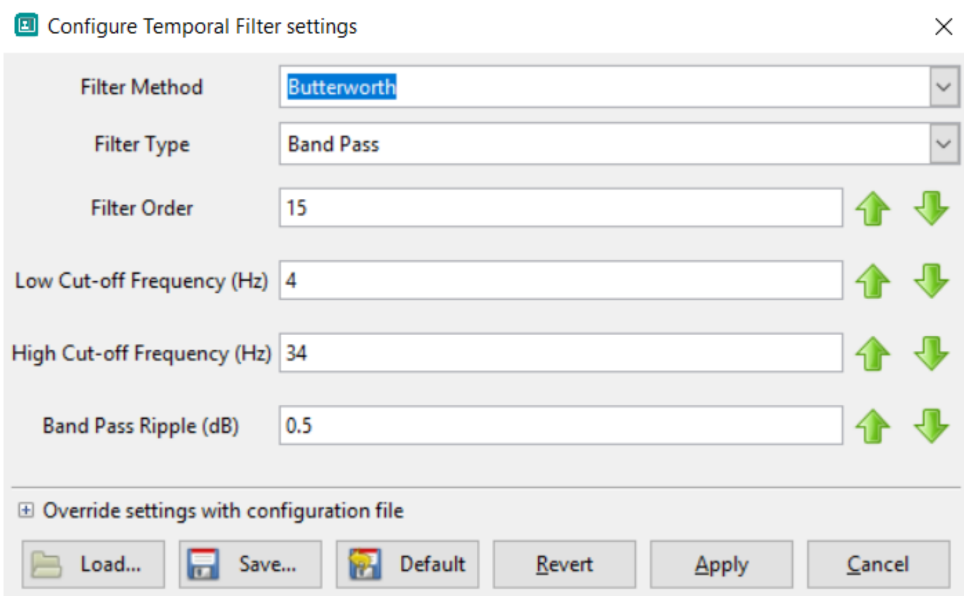


**Fig. 3.3** Openvibe applied filter

## 3.2 RESULTS and DISCUSSION

When I am looking at 1 as shown in fig. 1.1, the stimuli flashing at 8Hz, the thumb will actuate; looking at 2 index finger actuates; looking at 3 middle finger actuates; looking at 4 pinkie and ring finger together actuates; looking at 5 index and middle fingers will open and all other fingers get closed;  looking at 6 index and thumb fingers will  open and all others get closed.

The sent data from Openvibe is received by LSL and processed in MATLAB as follows:

```
%% instantiate the library
```

```
disp('Loading the library...');
lib = lsl_loadlib();
% resolve a stream...
disp('Resolving an EEG stream...');
result = {};
while isempty(result)
    result = lsl_resolve_byprop(lib,'type','EEG'); end
% create a new inlet
disp('Opening an inlet...');
inlet = lsl_inlet(result{1});
disp('Now receiving data...');
while true
 tic;
 data3 = zeros(2048,6);
 syms i;
 i = 0;
 while (true) && (i<2048)
    % get data from the inlet
   [k,ts] = inlet.pull_sample();

   k(:,7)=[];       %delete unnecessary column
   i=i+1;
   data3(i,:) = k;  %display data in data3 matrix
 end
data3 = bcmiFilter(data3);
targetFreq = [8.0 9.0 10.0 11.0 12.0 13.0];
referenceSignals = zeros(6, 2048 , 4);

Fs = 256;
T = 1/Fs;
L = 2048;
t = (0:L-1);
    %=======Calculation of reference signals (harmonics)========
for i = 1:6
   for j= 1:2
        referenceSignals(i,:,2*j-1) = sin(2*pi*targetFreq(i)*j*t/ Fs)';
        referenceSignals(i,:,2*j) = cos(2*pi*targetFreq(i)*j*t/ Fs)';
   end
end
dataLength = 2048;
    %======================================
    %================Calculation of correlation values=======

data4 = data3(1:dataLength,:); %The matrix of data recorded from the headset...
Each column is for one electrode.
ccaValues = zeros(1,6);
  for data3 = 1:6
     tempReferenceSignals=squeeze(referenceSignals(data3,1:dataLength,:));
     [A,B,r] = canoncorr(data4, tempReferenceSignals);
     ccaValues(data3) = r(1);
  end
[val,ind] = max(ccaValues);
fprintf('%f\n',ind);

%==============Serial Communication=======================%
if ~isempty(instrfind)
      fclose(instrfind);
      delete(instrfind);
end
  if ind==1
```

```
    a = serial('COM8','BaudRate',115200,'TimeOut',5,'Terminator', 'CR');
    fopen(a);
    sendData=1;
    fprintf(a,'%i',sendData);
    fclose(a);
elseif ind==2
    a = serial('COM8','BaudRate',115200,'TimeOut',5,'Terminator', 'CR');
    fopen(a);
    sendData=2;
    fprintf(a,'%i',sendData);
    fclose(a);
elseif ind==3
    a = serial('COM8','BaudRate',115200,'TimeOut',5,'Terminator', 'CR');
    fopen(a);
    sendData=3;
    fprintf(a,'%i',sendData);
    fclose(a);
elseif ind==4
    a = serial('COM8','BaudRate',115200,'TimeOut',5,'Terminator', 'CR');
    fopen(a);
    sendData=4;
    fprintf(a,'%i',sendData);
    fclose(a);
elseif ind==5
    a = serial('COM8','BaudRate',115200,'TimeOut',5,'Terminator', 'CR');
    fopen(a);
    sendData=5;
    fprintf(a,'%i',sendData);
    fclose(a);
elseif ind==6
    a = serial('COM8','BaudRate',115200,'TimeOut',5,'Terminator', 'CR');
    fopen(a);
    sendData=6;
    fprintf(a,'%i',sendData);
    fclose(a);

  end
end
```

When we run this code in MATLAB while looking at flickering region ‘2’ of stimuli the MATLAB result is as follows:

**MATLAB Result.**

>> ReceiveData

Loading the library...

Resolving an EEG stream...

Opening an inlet...

Now receiving data...

2.000000

The ‘2’ is the output in MATLAB as given above, which is the number of target frequency given on the screen.

Now this data is sent to Arduino in hand for actuating the fingers. The code in Arduino is as follows:

```
#include <FingerLib.h>
// uncomment one of the following to select the board
//#define ALMOND_BOARD
#define CHESTNUT_BOARD
// number of controllable fingers (number of motors)
#if defined(ALMOND_BOARD)
#define NUM_FINGERS 5
#define MYSERIAL Serial
#elif defined(CHESTNUT_BOARD)
#define NUM_FINGERS 4
#define MYSERIAL SerialUSB
#else
#error 'No board selected'
#endif
// uncomment one of the following to select which hand is used
//int handFlag = LEFT;
int handFlag = RIGHT;
// initialise Finger class to array
Finger finger[NUM_FINGERS];
byte x;
int j = 0;
void setup()
{
  // configure all of the finger pins
  pinAssignment();
//  MYSERIAL.println("Pins configured");
  delay(2000);
}
void loop()
{
 if(SerialUSB.available() > 0)
  {
   x = Serial.read();
   j++;
  }
  if(j>0)
  {
   if((char(x)=='1'))
   {
    delay(1750);
    finger[0].close();
    delay(1750);
    finger[0].open();

   }
   else if((char(x)=='2'))
   {
    delay(1750);
    finger[1].close();
    delay(1750);
    finger[1].open();
   }
   else if((char(x)=='3'))
   {
    delay(1750);
```

```
    finger[2].close();
    delay(1750);
    finger[2].open();
   }
   else if((char(x)=='4'))
   {
    delay(1750);
    finger[3].close();
    delay(1750);
    finger[3].open();
   }
   else if((char(x)=='5'))
   {
    delay(1750);
    finger[3].close();
    finger[0].close();
    delay(1750);
    finger[3].open();
    finger[0].open();
   }
   else if((char(x)=='6'))
   {
    delay(1750);
    finger[3].close();
    finger[2].close();
    delay(1750);
    finger[3].open();
    finger[2].open();
   }

  }
}
```

This code will read number 2 sent from Matlab as binary data in Arduino and responds to actuate the finger. When the number '2' in bytes is converted into character and recognised in Arduino as finger 1 (index finger). The result is opening and closing of index finger.

Hence, when the hand kept on keyboard as shown in fig 3.4, it will play keys of keyboard making music.

**Fig. 3.4: Brunel hand on keyboard playing music**

# CHAPTER 4

# CONCLUSIONS

The results are accurate when increasing the data length. The current data length I am using is for 8 sec. The accuracy can also be increased by increasing the number of harmonics, where I am using two harmonics for detecting in my project.

The aim of this study is to create an interface between prosthetic hand and data obtained from the brain. I am able to achieve this through coding in MATLAB and Arduino. My aim is to work this project with exp2: CCA, but I also work exp:1 (FFT) for verification of accuracy.

## 4.1 Drawbacks

Furthermore, the results obtained in the experiment is not accurate, this depends upon the subject's concentration on FC, surrounding problems around subject, light falling on screen, signal processing method, etc. Hence, these parameters are required to be followed strictly in order to gain better results.

One of the challenges is the no. of flickering regions on the screen. If we increase more flickering regions on screen it will increase different options for operating prosthetic hand, but this will also decrease the space between each flickering regions, as a result there will be a possibility of decrease in SNR. While gazing at one flickering region the noise from nearby flickering region with different frequency will also be recorded, leading the EEG data collected having the noise.

The current challenge in my system is: as the stimuli are designed in MATLAB and needs to run in it and also the signal processing, data acquiring script is written in another MATLAB script, which needs to run along with stimuli program, there is a time gap between running these two scripts, which is leading to generate noise. The solution for this may be use of multi-threading for run the two scripts simultaneously.

### 4.2 Future work

1) Building feedback system.

Increasing more stimuli on screen increases different options for prosthetics hand to work, but this will also increase noise as stated above in the challenges. So, on implementing feedback system that is able to flash the flickering region at the relax time for identifying the gazed flashing region and also designing the flashing region for shifting to new screen of different stimuli. We can able to increase no. of options for operating the prosthetic hand.

2) EEG headset

The EEG headset I am currently using is uncomfortable due to requirement of acquiring better signal by squeezing the electrodes on the scalp. In future, I was hoping if headset is designed sophisticatedly and in comfortable manner with gaining better result.

3) optimising signal processing

I am applying twice butterworth filter for getting bettering signal quality for my experiment. If signal processing techniques are improved with better filters, the reduction of noise will increase the accuracy of the data.

4) using Machine learning

The SSVEP is not required much user training. But if training is done the results will be much better than non-training. By use of Machine learning the data acquired can be trained to get better result.

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