Neural X

Final Year Project

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4th year student

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Project Detail

Type (Nature of project)	[ ] **D**evelopment [ ] **R**esearch [ ] **R&D**
Area of specialization	

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*The candidates confirm that the work submitted is their own and appropriate credit has been given where reference has been made to work of others

Plagiarism Free Certificate

This is to certify that, I am Muhammad Ali Malik S/D/o Sarfraz Nawaz Malik, group leader of FYP under registration no CIIT/FA16-BCS-117/LHR at Computer Science Department, COMSATS Institute of Information Technology, Lahore. I declare that my FYP report is checked by my supervisor and the similarity index is ________% that is less than 20%, an acceptable limit by HEC. The Report is attached herewith as Appendix A.

Date: _____________ Name of Group Leader: Muhammad Ali Malik Signature: ______________

Name of Supervisor: Mr. Imran Raza
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Designation: Dean
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HoD: ________________________
Signature: ________________________

Abstract:

Neural X is a system based on Brain Computer Interface (BCI) for handicapped people. As there are millions of people in Pakistan who are physically impaired which include disorders such as cerebral palsy, spinal injury, etc. This limits a person's ability to move or perform any physical task. To carry out even simple tasks in daily life, these people face difficulties. Neural X, our system based on BCI, helps to fill this void. Neural X provides the intelligent use of Electroencephalography (EEG) signals to control a wheelchair. The interface provides direct communication between the brain and the wheelchair. Using Emotiv Epoc headset brain EEG signals will be read and transmitted as input into the system. After the pre-processing and classification, the output will be sent to the wheelchair controller. Then it, will perform the desired function. Moreover, machine learning and data mining techniques will be used to increase the effectiveness of the system.

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1: Introduction

1.1 Project Overview

Brain computer interface (BCI) is a technology that lets its users interact with electrical devices by only using brain activity. BCI uses brain activities and translates them into active commands to operate electrical devices. Systems based on BCI enable communication and control systems for patients suffering from physical diseases. These interfaces allow interaction between the brain, eyes, and body. This encourages us to develop bioengineering control devices to help these physically impaired people [1].

BCI uses these three following methods to obtain signals from the brain [2]:

- Non-invasive
  In this method, a headset/cap is placed on the scalp of the users. The sensors/electrodes then measure the frequency of neurons or in other words potentials (electroencephalogram).
- Semi invasive
  In this method, the electrodes are placed on the exposed surface of the user's brain (Electrocorticography).
- Invasive
  The micro electrodes are played inside the brain of an individual when measure the single activity of a single neuron.

Hence, BCI measures brain activity from the central nervous system (CNS) then obtains these signals from the user, improves/enhances these signals then changes it in a way that it interacts with the external and internal environment.

According to World Health Organization (WHO) there are at least 30 million disabled people in Pakistan [3] and tens of millions of people are injured or disabled every year due to road accidents [4]. BCI based systems enable people suffering from motor neuron disease, brain stem stroke, or many other disorders to communicate and perform activities in society. In the growing independent world, BCI would significantly help individuals with severe disorders. Therefore, there is a worldwide research currently going on about the BCI.

Research on BCI started in the 1970s in the University of California, its main objective and focus was to help the disabled people by developing neuro prosthetics applications. BCI can't read the mind with 100% accuracy but it can calculate the small changes of energy radiation that occurs in our brain [5].

The four main steps of the BCI are as follows:

- Collecting Brain Signals
- Interpreting Brain Signals
- Classification of unseen example
- Outputting commands to wheelchair controller.

Neural X is a system based on BCI. This system will lead to physically impaired peoples to control the movements of the wheelchair independently. Its main function is to take Electroencephalography (EEG) signals from the user via headset, process them, classify, and then map action command to the wheelchair controller for execution. EEG is the method in which the brain activity of a living thing is calculated by using or placing the electrodes on the scalp surface. In this, the server will do the pre-processing of signals and is paired with the controller of the wheelchair which controls the movement of the wheelchair. The wheelchair can perform five activities for the user i.e. start, stop, move in forward, left, right and backward direction.

1.2 Objectives:

- Information processing by using brain signals or EEG signals
- To provide an alternative way to control actuators directly from the brain.
- To be used for rehabilitation and restoration for disabilities and brain strokes.
- To help disabled people to perform tasks.
- To reduce the effort of the user and provide reliability.

1.3 Problem Statement:

Around 15% of the world population experience some form of disability, and its percentage is higher in developing countries. In Pakistan 20 million people have disabilities, this makes up to 10% of the nation-state's population. Physically disabled patients form a large number of minority groups all over the world. They are ignored by society, have less access to services, mostly live in isolation and have an inferiority complex. They often lack access to employment opportunities and remain dependent on others to perform daily life activities. They basically fall in the category of untapped potential in our society. This vacuum is prevalent in our communities. Therefore, these individuals require such systems that address these issues and help bridge this gap which will enable them to restore some of their functions or give them the ability to perform simple day to day tasks. Assistive devices enable them to actively participate in their daily lives, rather than being passive in their routines. This also increases their ratio of activities in the community and in extreme cases into the economy as well.

1.4 Assumptions and Constraints

1.4.1 Assumptions:

- The System is being developed for the physically impaired persons who are unable to move.
- This system can also be used by the elderly persons who are mentally healthy and can understand system constraints.
- This system is designed to deal with situations where response time is critical.
- The System is flexible to control and change the movement of the wheelchair.
- This system provides smooth speed and movement control.

1.4.2 Constraints:

The System is designed to move in six directions and is not able to handle other thoughts of the user. In this case system will not classify signals correctly.

- The Model is trained for a specific user and can only classify his thoughts properly.
- Peoples with mental disabilities can't use this system.
- Due to the problem of gear, higher weight cannot be supported.

1.5 Project Scope:

This project has a wide range of scope in the following areas:

- Physically challenged people:
  People suffering from physical disorder (handicapped or paralysed) can use this wheelchair
- Patients in the hospital:
  Peoples in hospitals suffering some temporary or permanent physical disorder can also use this wheelchair according to their requirements.
- Old Age Homes:

This wheelchair can also be used by peoples in old age homes by persons unable to perform any simple movement tasks.

2 Requirements Analysis

2.1 Related Work:

In 2017 a group of researchers in “University des Sciences et de la Technologie” developed a BCI based controller to control the movement of the wheelchair in a virtual environment. They used electroencephalographic and Electro-oculographic signals collectively and perform signal processing and feature extraction on these signals. Then they classified these signals using an artificial neural network (ANN) and obtained a classification accuracy rate of 93%. They finally used this classifier to control wheelchair [6].

In a research paper, an electric wheelchair was developed. In which researchers controlled the movement of wheelchair using intentional eye blinking time. Concentration of these EEG signals obtained by eye blinking is transmitted to STM32 and used to handle the wheelchair movement. They tested the wheelchair movement many times to keep the error rate at a lower level [7].

In Ming Chuan University, researchers developed a smart wheelchair that can be controlled using two functions. In real-time control function, they obtained left movement accuracy of 70% and for right about 60%. In automated guided function they tested whether the wheelchair is moving right on the guided path or not [8].

In Shenghong, a researcher, presented a new P300-based threshold-free brain switch. This switch contains four buttons, one is the target button where the user can focus to generate switch command and the other three are pseudo buttons. He used two support vector machine classifiers in the detection algorithm to obtain SVM scores of all four buttons. Based on scores, he mapped the movements of a wheelchair [9].

In a research paper authors presented the uses of Emotiv Epoc. They used three methods (Digital filters, wavelet transform and independent component analysis) to identify characteristics (like “closed eyes”,” opened eyes”) of some person’s status. Similarly, they created home appliances control models using EEG signals on a Labview software [10].

In 2016 K. Kim and H. Suk proposed a brain-controlled wheelchair where they used a steady-state somatosensory evoked potential (SSSEP) model to handle three commands (left, right, forward).

They performed obstacle avoidance and a driving task along a predefined path and checked the efficiency of a wheelchair and completed [11].

In a research paper authors proposed a motor imagery-based brain actuated vehicle. They control the direction and speed of a wheelchair using an imagery-based model instead of EEG signals and get results close to their expectations [12].

Alter ego is a peripheral neural interface developed by the Massachusetts Institute of Technology (MIT). This project aims to allow human beings to talk in natural language with machines, artificial intelligence assistants etc without physically saying a word. It is wearable and uses a non-invasive method to obtain neural signals from the user. Its model is trained to be activated when the user's internal speech articulators are activated e.g. when a user thinks of a word. This allows human computer interaction which is internal to the human user such as speaking to yourself [13].

A project was developed by Chittagong University of Engineering and Technology. This project aimed to move a wheelchair via brain signals. The brain EEG signals were taken from NeuroSky headset from the user. The different movements of the wheelchair were classified by using the level of attention of the user. The user was required to see at a graphical image in which different areas were mapped to change the level of attention of the user accordingly. Double blink was used to turn on or off the device by the user [14].

In a project, the developers used brain activity to move a wheel-chair. A non-invasive method that is headset was used to get EEG signals from the user. The movement of the wheelchair was controlled by motor imagery. Left-hand stationary was used for forward movement whereas right-hand stationary was used for backward movement. Left-hand short motor imagery was used for left-turning whereas for right-turning, short right-hand motor imagery was used. For stopping both left- and right-hand motor imagery was used [15].

In a project developed by the Massachusetts Institute of Technology (MIT). The project aimed to control male sperms via brain activity. This was done as a symbolic representation against gender oppression on females by males. The EEG signals were used to train a model that would control the movement of sperms that were placed in a circuit under a microscope. The user was required to think of moving the sperms on an x y plane. According to which the circuit voltages were mapped to control the movements of the sperms accordingly [16].

A project was developed in the areas of entertainment using BCI. There are various games developed in the project. Few of them are to play the simple game of checkers to move a player's piece in the software using EEG signals from the user. Another game developed was a Hot and

Cold game. In this a user needs to guide a robot using only two commands hot or cold. Hot tells the robot that it is moving in their right direction whereas the cold one indicates that the user is going in the wrong direction. As minimal command requires playing the game it is suitable for the early stages of BCI. The model was trained for these binary commands. The use of games to control objects makes the task more enjoyable for the user and opens limitless possibilities for in the future to be able to play more complex games [17].

A project was developed for controlling digital appliances using BCI. To increase accuracy, in this project they have used eye blink as a measure of selection for the user. The EEG signals are collected via the headset (NeuroSky.) In the training phase the user is given a grid of cells a which he must look at the cell and concentrate on that cell and blink. As the blink generated for the cell is unique the cell gets locked. This repeated for the other entire cell. The involuntary blinking is discarded by the user. The Brain – Drive aim is to be used for controlling of wheelchair or any other electronic/digital advice [18].

A project was developed to move an automated vehicle via BCI. The main difference between this and a normal driver is that controls the motion of the vehicle via arms and foot. However, in this project, the movement is controlled by Brain activity and motor. The project assumes that trajectory and the speed of the vehicle is known beforehand. This project includes a model to control speed and direction also a motor imagery model to control the angle of the steering [19].

In a paper, Band Power (BP) and Radical Basis Function (RBF) were used to design the four states for BCI. This was for neurodegenerative persons. When the average accuracy of this system was calculated it resulted in 92.50%. This large number shows that there is a fair chance to control the systems by commands generated by the brain. This study was conducted at the Renmin University of China located in Beijing [20].

In Taiwan, at the National Kaohsiung University of Applied Sciences, a group of students used the electrooculogram (EOG) signals which are produced as a result of an eye blink. They used these signals to turn on/off the motor. They used double and triple blinks for this function [21].

At the school of Mechanical Engineering, Beijing Institute of Technology, China – a group of students proposed a system in which a wheelchair system was described for handicapped people to control their movements. They used a convolution neural network (CNN) to extract features and improved forward floating search algorithm (ISFFS) for channel selection. This system executed commands more efficiently and accurately [22].

In a research paper, motor imagery and P300 potential were combined to form the brain-controlled wheelchair. Eleven functions could be performed i.e. move forward, move backward, move left, move right, move left45, move right45, accelerate, decelerate, turn left, turn right and stop. In this paper, left and right movements were controlled by translating brain signals when the user thought of executing left or right limb moto imagery. All the experiments conducted gave good results and thus, have the potential for applications for pace control [23].

For the physically disabled people, a student of MIT College of Engineering proposed an application technology. In this paper, it was explained that an eye blink would be used to process an action or command. The eye blinking pattern is then mapped to the physical activities that are to be performed by the wheelchair [24].

A group of six persons, from the University of Jinan in China made a system of Steady State Visual Evoked Potential (SSVEP) that controlled the wheelchair with four operations(forward, reverse, left, and right).In this, the acquired SSVEP signals , after being pre-processed were classified and then the wheelchair was moved in a certain direction based on that classification. The accuracy of the direction intended was 79.4% [25].

2.2 Stakeholders list

- Attendant
- User
- Project Supervisor
- Project Development Team

2.3 Requirements elicitation

2.3.1 Functional Requirements

FR01: Connectivity

Req. No.	**Functional Requirements**
FR01-01	The system shall enable the attendant to pair the headset and wheelchair.
FR01-02	The system shall allow the attendant to enter headset Id and device (headset) related information into the devices software.

FR01-03	Configurations should be added correctly for successful connection.
FR01-04	In case of successful connectivity, the system shall display successful connection.
FR01-05	In case of error in connection the system shall display error message.

FR02: Command Initialization

Req. No.	**Functional Requirements**
FR02-01	The User shall think of a command to control the wheelchair (forward, backward, left, right and stop).

FR03: Signal Processing

Req. No.	**Functional Requirements**
FR03-01	The system shall acquire the EEG signals from the headset.
FR03-02	The system shall pre-process the signals.
FR02-03	The system shall extract required features from the signals and discard the rest (Feature Extraction).

FR04: Model Training

Req. No.	**Functional Requirements**
FR04-01	The system shall use a learning algorithm to find patterns in the processed signals to create a model.

FR05: Real Time Classification

Req. No.	**Functional Requirements**
FR05-01	The system shall classify the new unseen example using the trained model.

FR05: Mapping of Action Command

Req. No.	**Functional Requirements**
FR05-01	The system shall transmit the classification of the command (unseen example) to the serial.
FR06-02	Arduino connected with the wheelchair's controller shall reads command from the serial

FR06: Command Execution

Req. No.	**Functional Requirements**
FR07-01	Input Command's strength shall meet the confidence level to get mapped onto the wheelchair's controller
FR06-02	The Wheelchair controller shall execute the operation according to the input action command (forward, backward, left, right and stop).

2.3.2 Non-Functional Requirements

NFR01: Performance

NFR01-01	Electrodes should be placed in accurate position.
NFR01-02	Average pairing time of headset and server should be less than 2 seconds.
NFR01-03	Average pairing time of server and wheelchair should be less than 2 seconds.
NFR01-04	Average configuration time of headset and server should be less than 2 seconds.
NFR01-05	Average configuration time of headset and wheelchair should be less than 2 seconds.
NFR01-06	Server must receive continuous signals according to requirement time.
NFR01-07	After pairing configuration process should start without any delay
NFR01-08	After signal acquisition signal processing should start automatically without any delay

NFR01-09	After signal acquisition signal processing should start automatically without any delay
NFR01-10	After signal processing model training should start automatically without any delay
NFR01-11	Unseen real time signals should be processed in parallel with model training.
NFR01-12	Classified command should be mapped within 1 second.
NFR01-13	Obstacle should be detected from distance of 5.6 meter and from range 240 degrees.

NFR02: Security

NFR02-02	Server should not be connected to any other system except headset and wheelchair.
NFR02-03	Headset and wheelchair should only be connected with one same server
NFR02-04	Trained model should be saved in server database for future needs.

NFR03: Defects-Maintenance

NFR03-01	Pairing and configuration problems should be properly resolved before signal acquisition

NFR04: User Documentation

NFR04-01	Help documentation must be complete in providing information about pairing and configuration to attendant.

NFR05: Usability

NFR06-01	The server shall perform all steps smoothly one after the other.

2.4 Use Case Design

Use case design diagram for the System is shown in the *Figure 1* below.

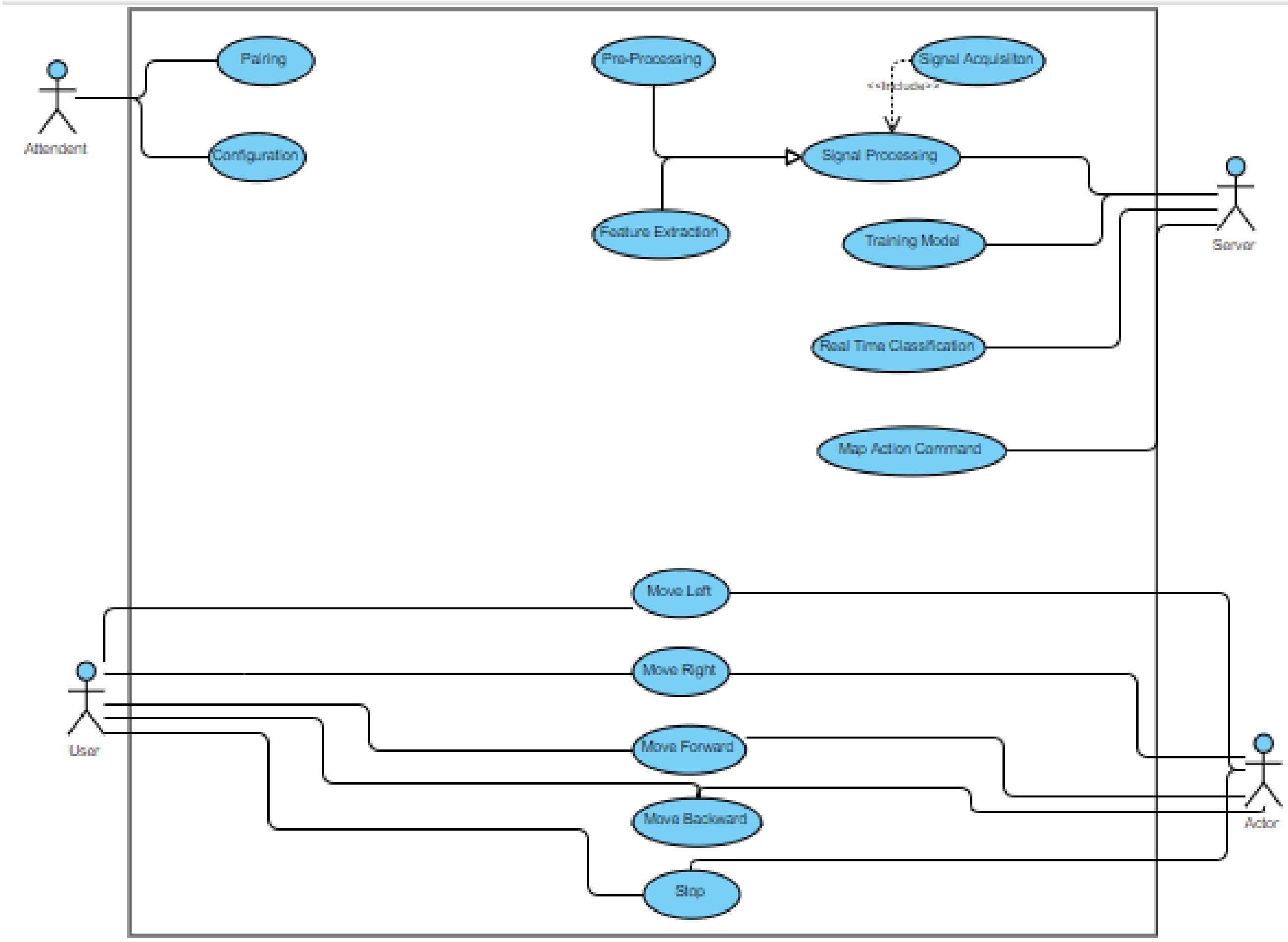

Figure 1: Use Case Diagram of System

2.5 Use Case Descriptions

2.5.1 UC01: Pairing

Use Case Name	Pairing
Abstract	No
Purpose	To establish connection between headset, server and wheelchair
Actors	Attendant

Importance	Primary	
Overview	This use case enables data transmission between the components	
Requirements	Emotive Epoc headset, Server, Wheelchair	
Status	Essential	
Uses	None	
Pre-conditions	None	
Post-conditions	If connection established configuration process will start	
	Actor Actions	**System response**
	Typical Course of Actions	
	1. Attendant turns on the headset	
		1a. Headset pairs with the server.
	2. Attendant turns on the wheelchair.	
		2a. Headset pairs with the server.
	Exceptional Course	
		1. Headset unable to pair with the server. 2. Wheelchair unable to pair with server.

2.5.2 UC02: Configuration

Use Case Name	Configuration	
Abstract	No	
Purpose	To adjust settings and specifications according to the headset's software	
Actors	Attendant	
Importance	Primary	
Overview	This use case completes the connectivity between headset, server and wheelchair	
Requirements	Server with headset's software	
Status	Essential	
Uses	n/a	
Pre-conditions	Pairing	
Post-conditions	Command transmission will start after this process.	
	Actor Actions	**System response**
	Typical Course of Actions	
	1. Attendant enters User ID and device (headset) related options.	
		1a. Server displays connectivity feedback.
	Alternative Course	
	1. Attendant enters invalid User ID	

		1a. Server displays error message.
	Exceptional Course	
		1a. No connection established between server and the headset
		2a. No connection established between server and the wheelchair.

2.5.3 UC03: Command Initialization

Use Case Name	Command Initialization	
Abstract	No	
Purpose	To command the wheelchair	
Actors	User	
Importance	Secondary	
Overview	This use case allows user to control the movements of wheelchair.	
Requirements	Emotive Epoc Headset	
Status	Non-essential	
Uses	n/a	
Pre-conditions	Pairing and Configuration	
Post-conditions	Server will acquire signals from the headset.	
	Actor Actions	**System response**
	Typical Course of Actions	
	User thinks of a command (forward, backward, left, right and stop) to control the wheelchair.	
	Exceptional Course	
		User does not think of controlling the wheelchair.

2.5.4 UC04: Signal Acquisition

Use Case Name	Signal Acquisition
Abstract	No
Purpose	Server acquires EEG signals from the headset.
Actors	Server
Importance	Primary
Overview	In this use case server acquires EEG signals from the headset for further processing
Requirements	Headset, Server
Status	Essential
Uses	n/a
Pre-conditions	Pairing and configuration
Post-conditions	Signal Processing

	Actor Actions	**System response**
	Typical Course of Actions	
	Server acquires signal.	
	Exceptional Course	
		Signal acquisition fails.

2.5.5 UC05: Signal Processing

Use Case Name	Signal Processing	
Abstract	No	
Purpose	Server pre-processes the acquired EEG signals and extracts the desired features	
Actors	Server	
Importance	Primary	
Overview	In this use case server outputs processed EEG signals.	
Requirements	None	
Status	Essential	
Uses	n/a	
Pre-conditions	Signal acquisition	
Post-conditions	Processed signals will be used for model training	
	Actor Actions	**System response**
	Typical Course of Actions	
	Server pre-processes the acquired signals.	
	Server extracts required features from the pre-processed signals.	

2.5.6 UC06: Model Training

Use Case Name	Model Training	
Abstract	No	
Purpose	The learning algorithm finds patterns in the processed data signals to create a model artifact.	
Actors	Server	
Importance	Primary	
Overview	This use case will create a model for further real time classification of processed signals.	
Requirements	n/a	
Status	Essential	
Uses	n/a	
Pre-conditions	Signal pre-processing and feature extraction.	
Post-conditions	Classification will be done after this use case.	
	Actor Actions	**System response**
	Typical Course of Actions	
	Model will be trained on the processed signals.	

2.5.7 UC07: Real-Time Classification

Use Case Name	Real-Time Classification	
Abstract	No	
Purpose	The new unseen real time processed signals will be classified using the trained model.	
Actors	Server	
Importance	Primary	
Overview	This use case will use the processed signals to classify a class(command).	
Requirements	n/a	
Status	Essential	
Uses	n/a	
Pre-conditions	Trained model and processed signals.	
Post-conditions	The classified command will be mapped on the controller of the wheelchair.	
	Actor Actions	**System response**
	Typical Course of Actions	
	Signals will be classified by the server.	

2.5.8 UC08: Map Action Command

<table>
<tr><td>Use Case Name</td><td colspan="3">Map Action Command</td></tr>
<tr><td>Abstract</td><td colspan="3">No</td></tr>
<tr><td>Purpose</td><td colspan="3">The classified command is transmitted to the wheelchair controller.</td></tr>
<tr><td>Actors</td><td colspan="3">Server</td></tr>
<tr><td>Importance</td><td colspan="3">Primary</td></tr>
<tr><td>Overview</td><td colspan="3">The result of the classification is mapped by the sever to the wheelchair controller for command execution.</td></tr>
<tr><td>Requirements</td><td colspan="3">n/a</td></tr>
<tr><td>Status</td><td colspan="3">Essential</td></tr>
<tr><td>Uses</td><td colspan="3">Authentication</td></tr>
<tr><td>Pre-conditions</td><td colspan="3">Classified command</td></tr>
<tr><td>Post-conditions</td><td colspan="3">Wheelchair executes command</td></tr>
<tr><td></td><td colspan="2">Actor Actions</td><td>System response</td></tr>
<tr><td></td><td colspan="2">Typical Course of Actions</td><td></td></tr>
<tr><td></td><td colspan="2">Classified command is mapped by the server</td><td></td></tr>
<tr><td></td><td colspan="2">Exceptional Course</td><td></td></tr>
<tr><td></td><td colspan="2"></td><td>Data transmission fails.</td></tr>
</table>

2.5.9 UC09: Command Execution

Use Case Name	Command Execution	
Abstract	No	
Purpose	To perform the command.	
Actors	Wheelchair	
Importance	Primary	
Overview	This use case enables the wheelchair to perform the movement according to the given input.	
Requirements	n/a	
Status	Essential	
Uses	n/a	
Pre-conditions	Command mapping to the wheelchair.	
Post-conditions	None	
	Actor Actions	**System response**
	Typical Course of Actions	
	Wheelchair performs action (forward, backward, stop, left, right)	

2.6 Software development life cycle model

For the design we are going to use a combination of the waterfall model and Rapid Prototyping.

2.6.1 Why Use Waterfall Model:

We used the waterfall model because our requirements are well known, and we are not required to go back to the previous stage and our next stage is dependent on the previous stage. We also use this because our technology is completely understood and there are no ambiguous requirements.

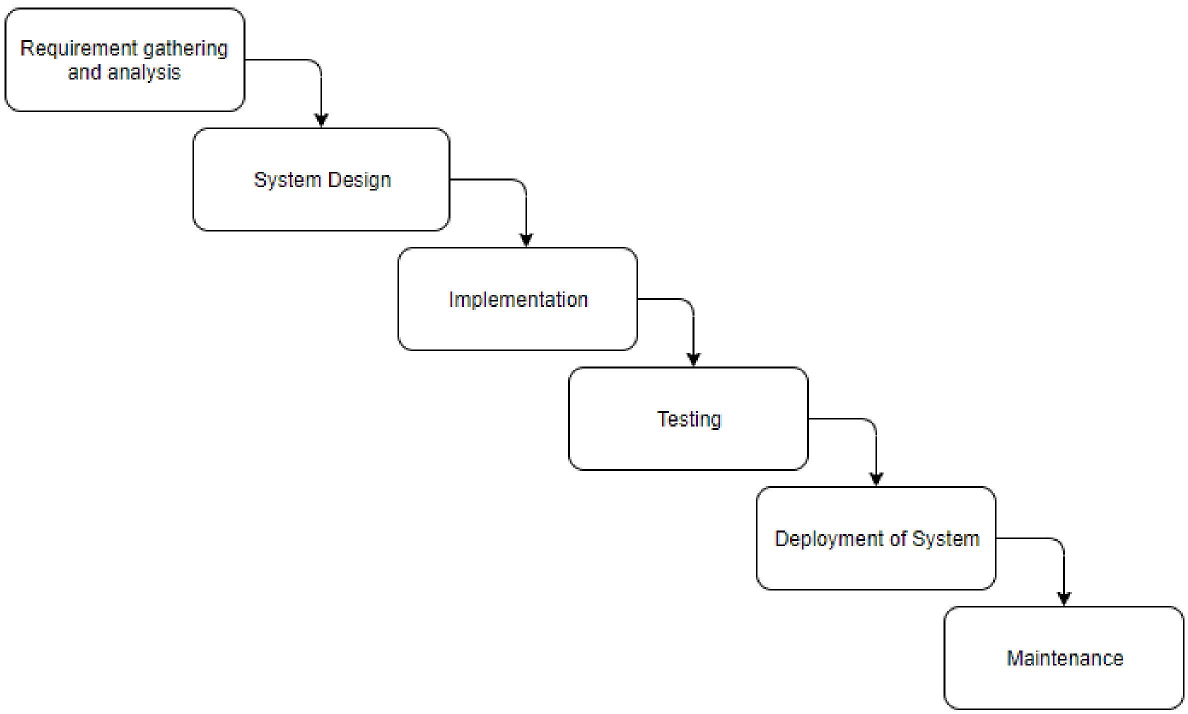

Figure 2: Waterfall Model Diagram

3 System Design

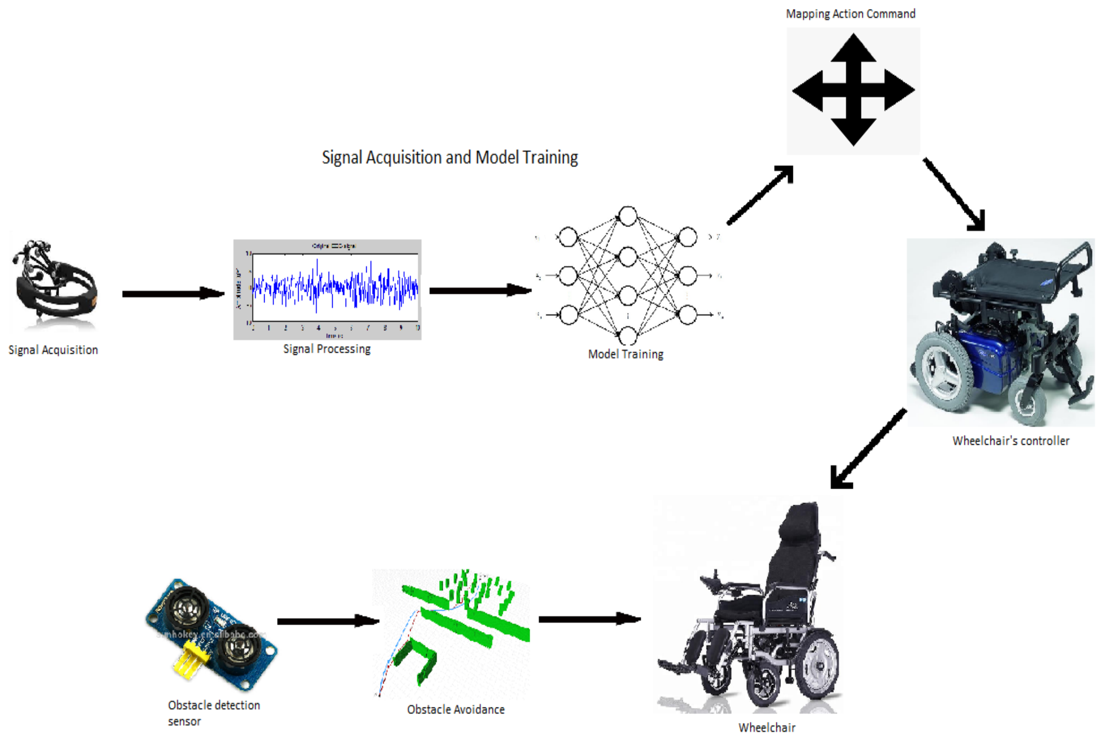

Figure 3 System Design

3.1 Activity Diagram

3.1.1 Pairing

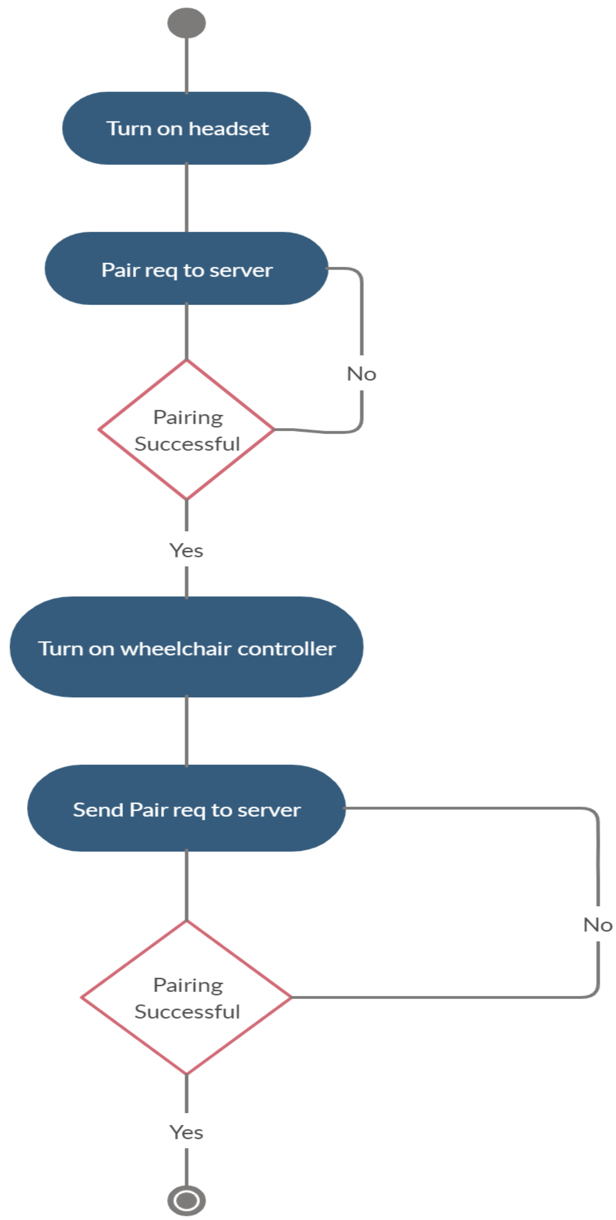

Figure 4: Activity Diagram for Pairing

3.1.2 Configuration

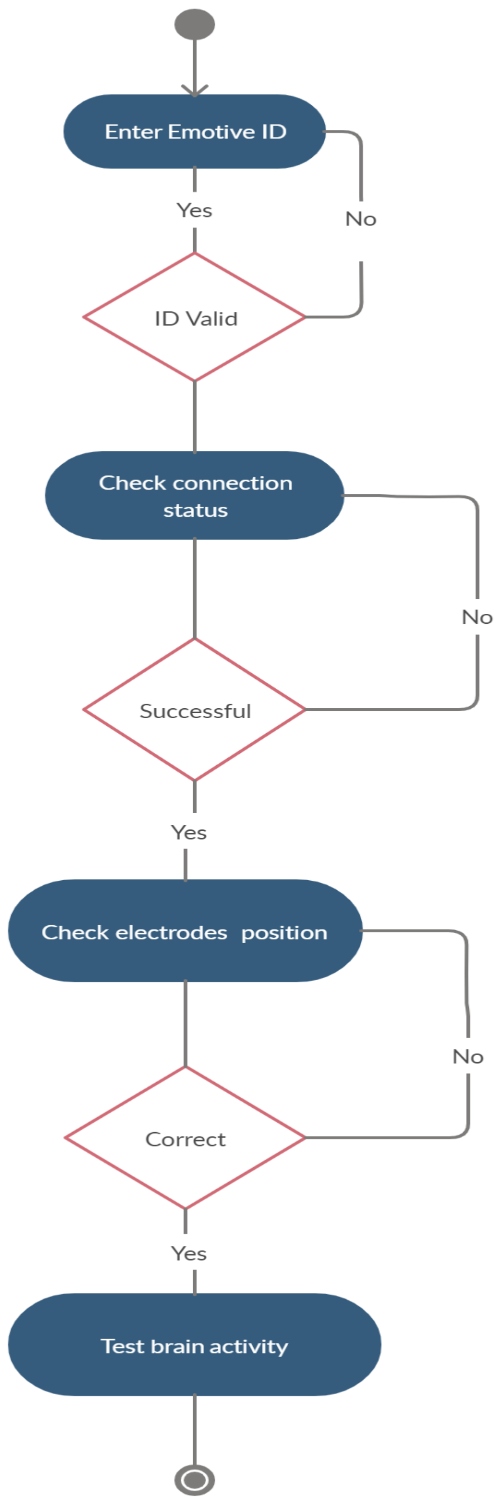

Figure 5: Activity Diagram for Configuration

3.1.3 Model Training

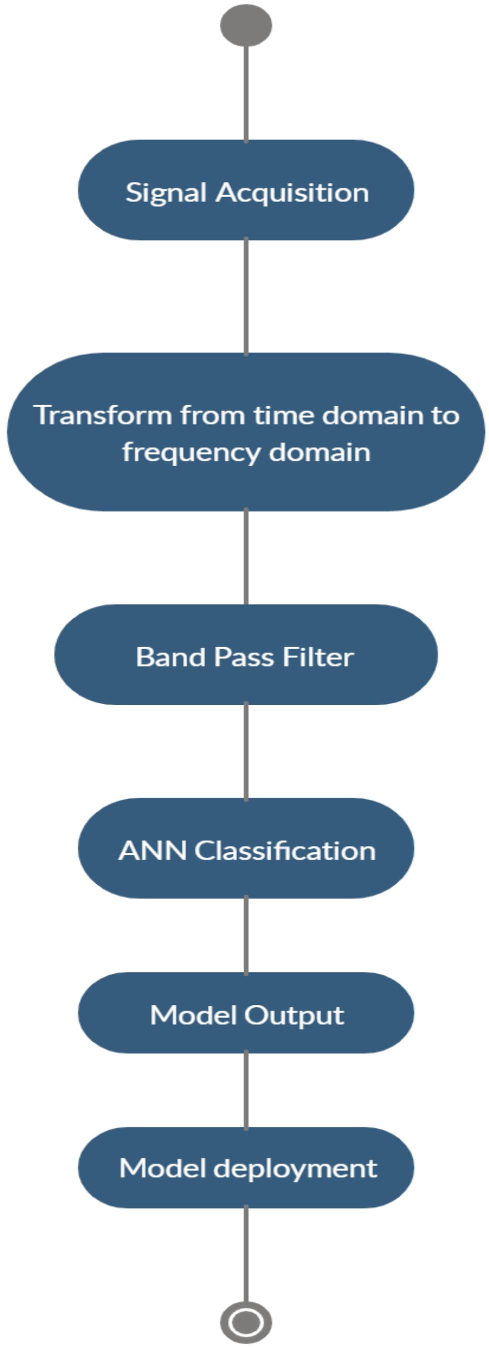

Figure 6: Activity Diagram for Model Training

3.1.4 Command Execution

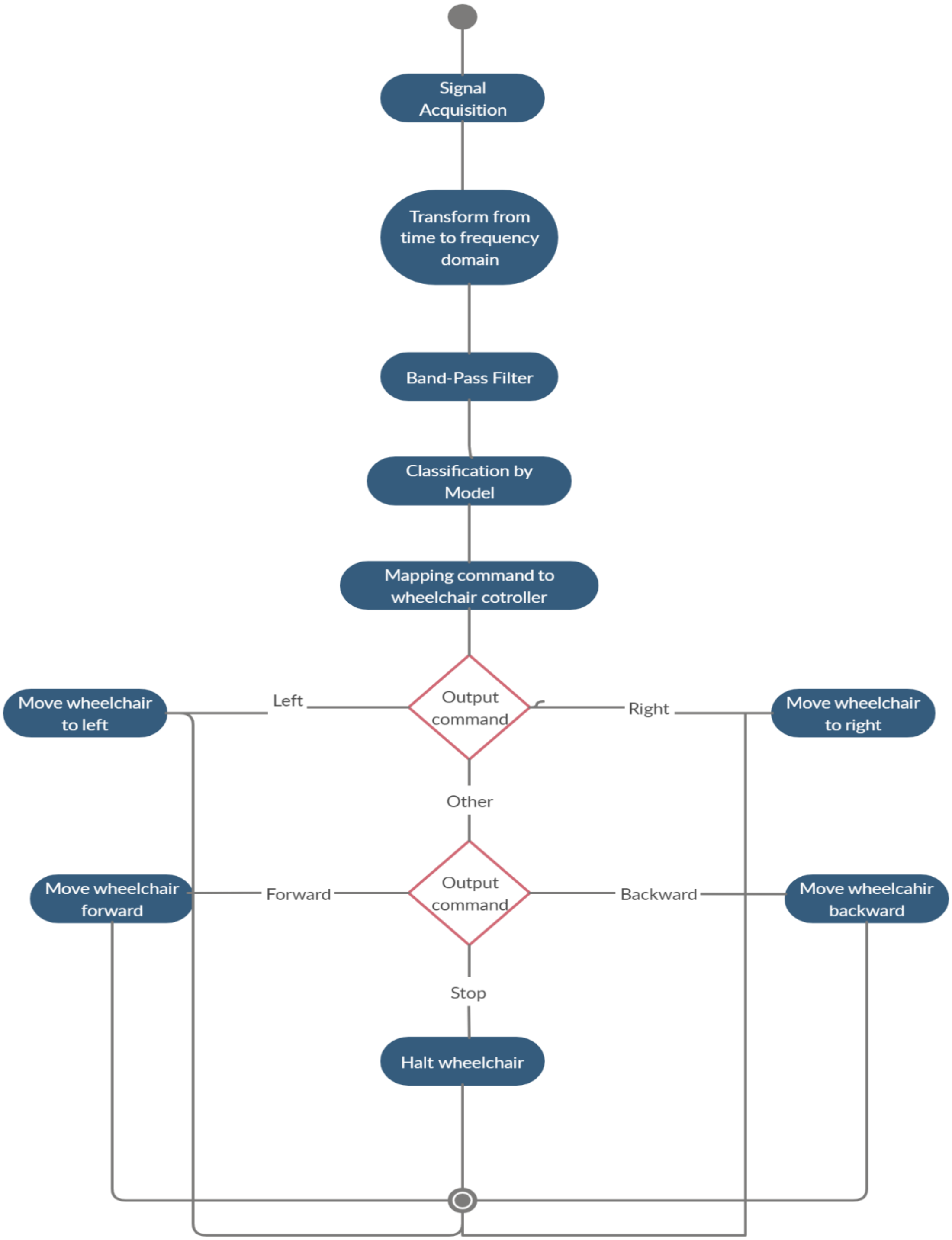

Figure 7: Activity Diagram for Command Execution

3.2 Sequence diagram

3.2.1 Pairing

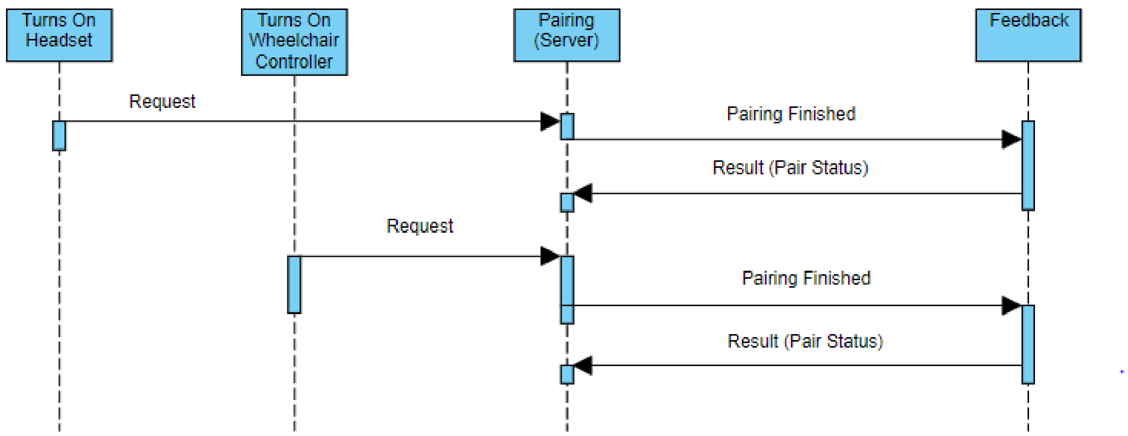

Figure 8: Sequence Diagram for Pairing

3.2.2 Configuration

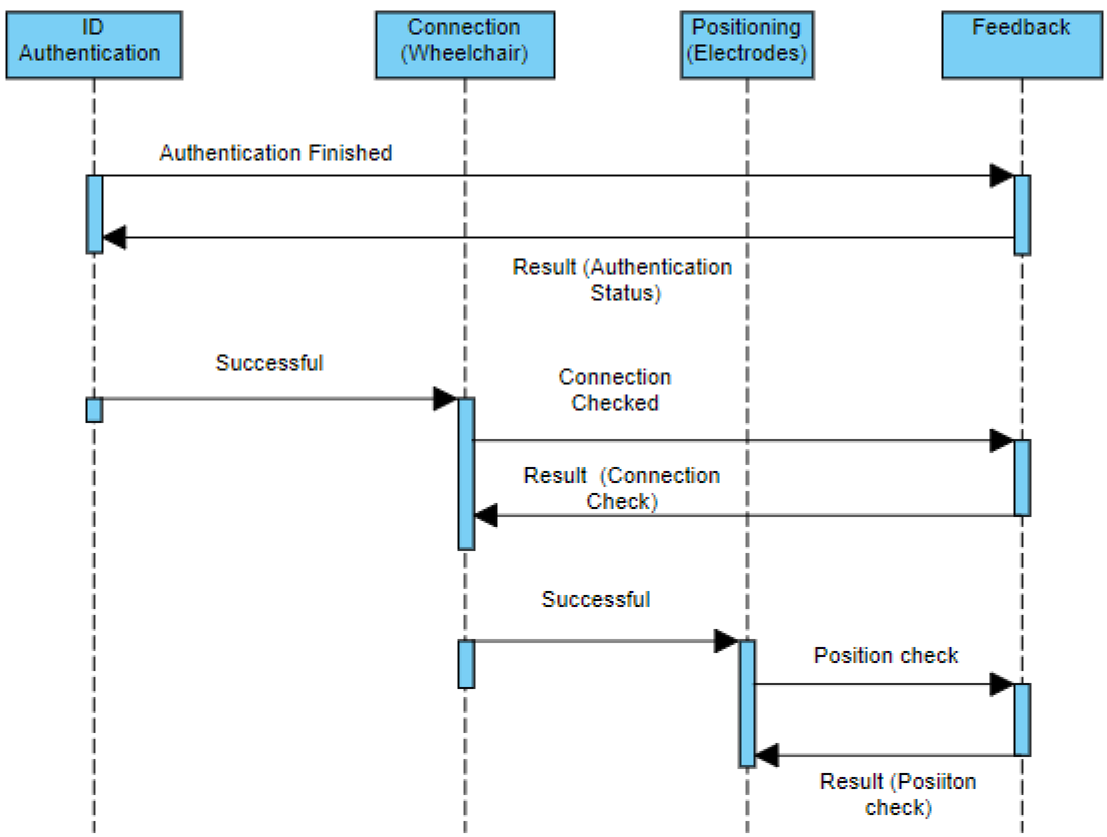

Figure 9: Sequence Diagram for Configuration

3.2.3 Training of Model

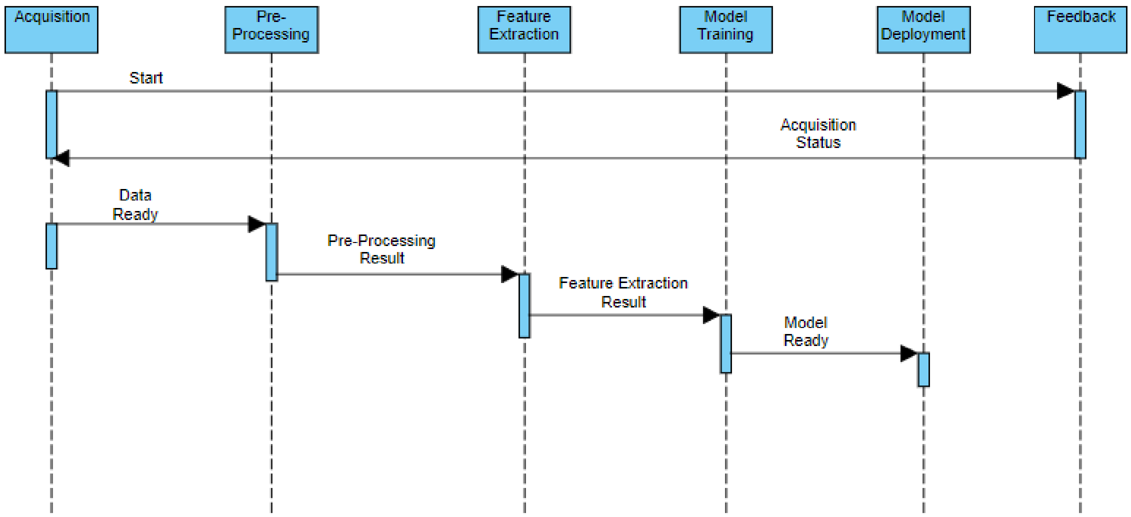

Figure 10: Sequence Diagram for Training of Model

3.2.4 Command Execution

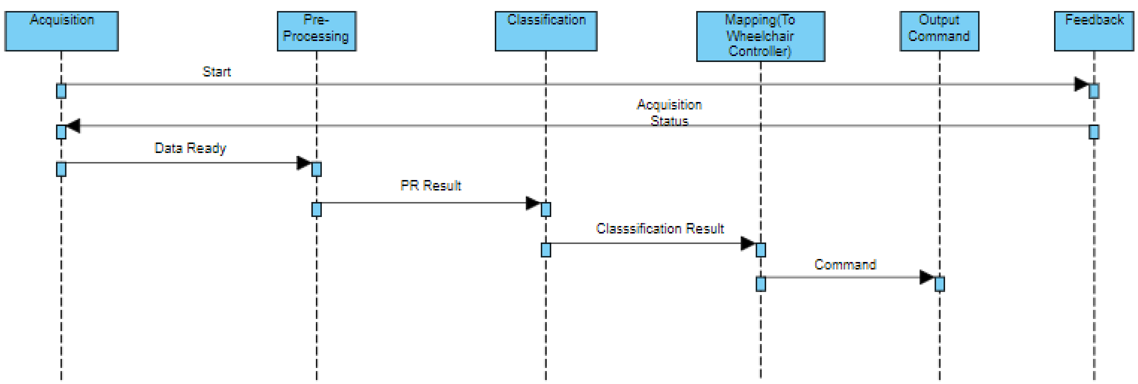

Figure 11: Sequence Diagram for Command Execution

3.3 Software architecture

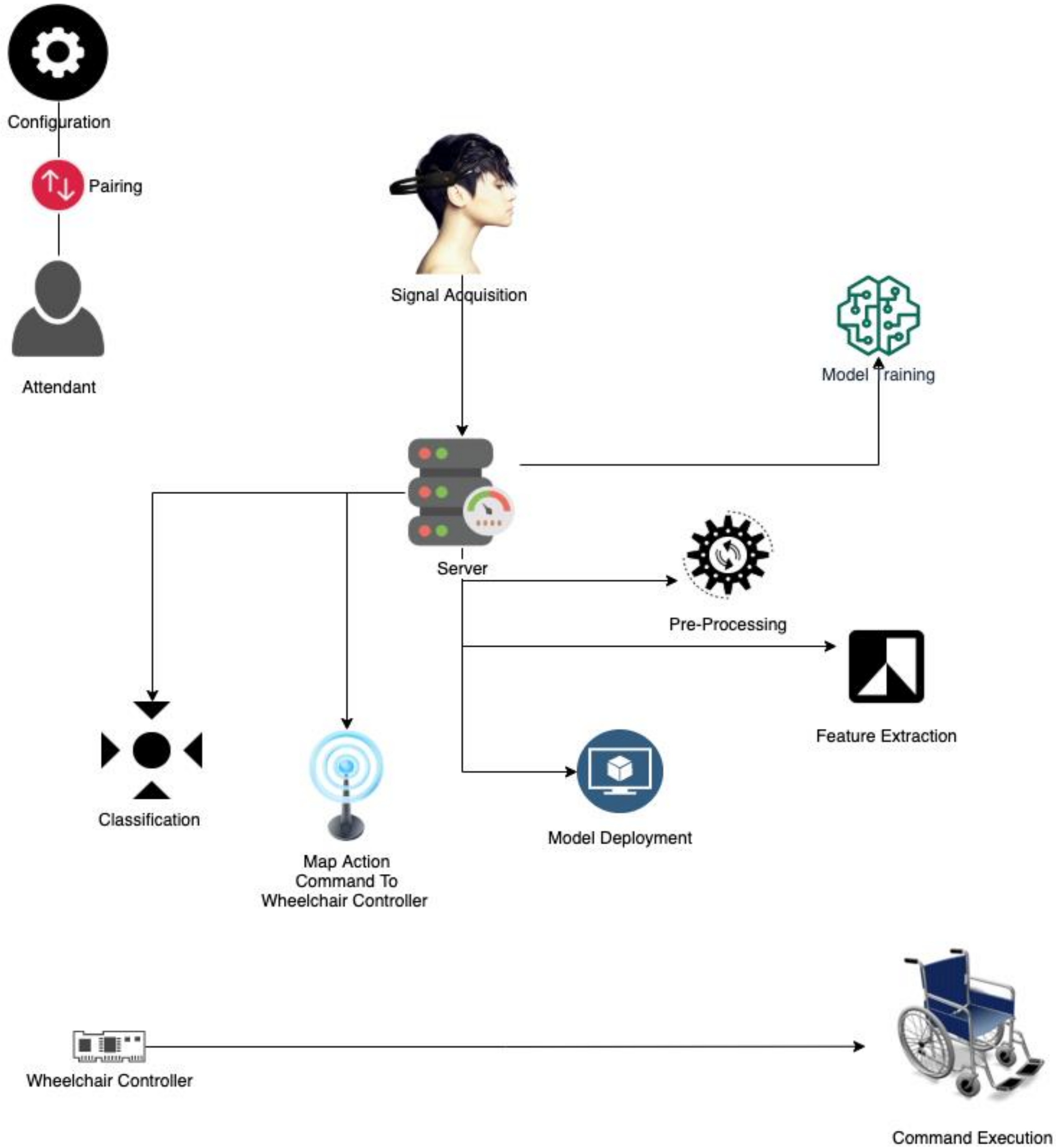

Figure 12: Software Architecture of the system

3.3.1 Pairing

As shown in Figure 12 the attendant will pair the headset with the server and configure accordingly. The individual (attendant) will turn on the Emotiv Epoc headset. The headset will then send a pairing request to the server. The server will accept/reject the request. The headset will in return send feedback to the individual via an LED indicator. The individual will afterwards turn on the wheelchair. The connection between server and the wheelchair is made by XBees connected with the Arduino board. The Figure 13 below shows the connection of the headet with the server via bluetooth.The headset is connected to the Emotive BCI App wirelessly. This enables the transmission of eeg signals into the system.

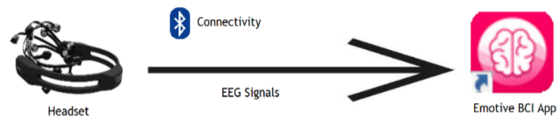

Figure 13: Pairing of headset with BCI App

3.3.2 Configuration

As shown above in Figure 12, during the configuration phase the individual (attendant) will open the headset's software on the server and then enter Emotiv ID, which uniquely identifies the headset. The individual will be required to create a unique profile of the user, this profile will store the data of the trained model on the server, and this enables the server to store different user's data separately. The software will check connection status and positioning of the electrodes. In case of connection failure or incorrect position of electrodes it will give feedback to the individual to fix that error accordingly. The software shows the connectivity level of each electrode to the user visually by showing different colours (Green as high contact connection, Red as low contact, Orange as average contact and Grey as no contact) on the interface. Finally, after the configuration process is complete the software will test brain activity.

3.3.3 Signal Acquisition

After the headset and the system have been configured, then as shown in Fig 12, the user will wear the headset and the signal acquisition process by the server will begin. The Brain signals will be extracted from the user using a non-invasive method from the Emotiv Epoc Insight headset. We followed the international standard for placing the five electrodes of the Insight headset on the scalp. As shown in the Figure 14 below, this standard enables us to obtain optimal signals. The signals acquired are in the form of electroencephalography (EEG). EEG measures brain activity which is caused by the flow of neurons. The advantage of using EEG signals is that it has the ability to check brain activity in real time (at the level of milliseconds). The user will wear a headset which will capture the brain signals. Then the signals are then sent to the server.

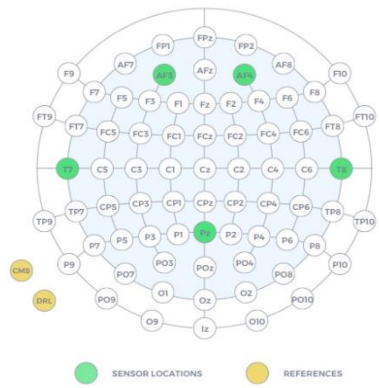

Figure 14: Placement of 5 electrodes of emotive insight on head

3.3.4 Pre-Processing

After the signal acquisition process, as shown in the above Figure 12, the server will pre-process these signals. The EEG signals attained from the headset must undergo pre-processing as the signals that are picked up from the scalp are not necessarily an accurate representation of the signals originating from the brain. As the method used is non-invasive, there is distortion due to factors such as noise. The data is transformed into understandable format. Real time data is often incomplete and lacks certain trends therefore data is pre-processed to get optimal signals. Pre-processing is done by filtering, applying Fourier transformation and Principal Component Analysis (PCA).

3.3.5 Feature extraction

As EEG signals are complex it becomes difficult to extract the feature so feature extraction process is applied which helps to discard the features with low contribution and noise. As shown in the above Fig 12, features are extracted, the amount of data is effectively reduced but the remaining dataset accurately describes the original data set. EEG signal differentiates on the basis of frequencies. There are five types of frequencies Delta, Theta, Alpha, Beta and Gamma. In this project we are concerned with Beta waves as these waves are associated with behaviour and actions. There are variety of feature extracting methods, some of them are: Band powers, Cross-correlation between EEG band powers frequency representation and time-frequency representation.

3.3.6 Model Training and Deployment

As every individual has unique brain frequencies, therefore, every user profile is required to train the model for the five commands (Neutral, Forward, Left, Right and Backward).Model training process shown in above Fig 12 starts after the pre-processing and feature extraction phase is completed. The training is done on extracted features of the EEG signal acquired. The recommended time to train a particular command is 8 hours. This ensures accuracy as well as efficiency while working in a real time environment. After the model is trained (for every unique user profile), the model is deployed for real time classification. Now real-time unseen data can used to predict the classification from this model.

3.3.7 Real Time Classification and Decision Making

In the light of above Fig 12, after the model has been trained and deployed, by the server, it can be used by the user in an environment for real time classification (in run time).The Emotiv Epoc headset will be used by the user to generate EEG signals for a desired command to move the wheelchair. The signals will be pre-processed and then will be used as input on the server. A decision making mechanism is set up to increase accuracy and avoid misclassified commands to be executed. This is done using confidence levels, a parameter is set up which decides whether the command should be executed or not on the basis of these confidence levels. If the user-generated signal's strength meets the confidence level, then the action command will be mapped unto the wheel chair controller otherwise it will be nullified.

3.3.8 Map Action Command and Command Execution

Referring to above Fig 12, Wireless communication needs to be set up for executing our desired result. The server will map the classified action command wirelessly to the wheelchair for command execution. After the signal has been classified it has to be mapped to the wheelchair controller. .This mapping will be done by the server wirelessly via microcontrollers (Arduino integrated with Xbee).One of the pair will be integrated with the server (sender) while the other one with the wheelchair controller (receiver).The wireless communication is done via XBees whereas processing is done on Arduinos. As the microcontroller receives the action, it will execute the action command (left, right, forward, back, and stop) respectively on the wheelchair.

3.3.9 Obstacle Avoidance

As shown in Fig 3, sensor is integrated into our project. As our project will be working in real-time environment there will be limitations such as distractions, distortions, noise etc. Hence, there is a chance of error i.e. misclassification. Therefore, in order to rule out these errors we have integrated a sensor into the system that measures the distance of objects from the sensor up to 5.6 meters. Its range is up to 240 degrees which helps us tackle this issue in a holistic manner. This sensor will help our system to avoid obstacles. This in turn makes the user more environment friendly. The respective command will only be executed when there is no hindrance in its path.

3.4 Network Diagram (Gantt chart)

Gantt chart for the Neural X System is shown below in Figure 14.

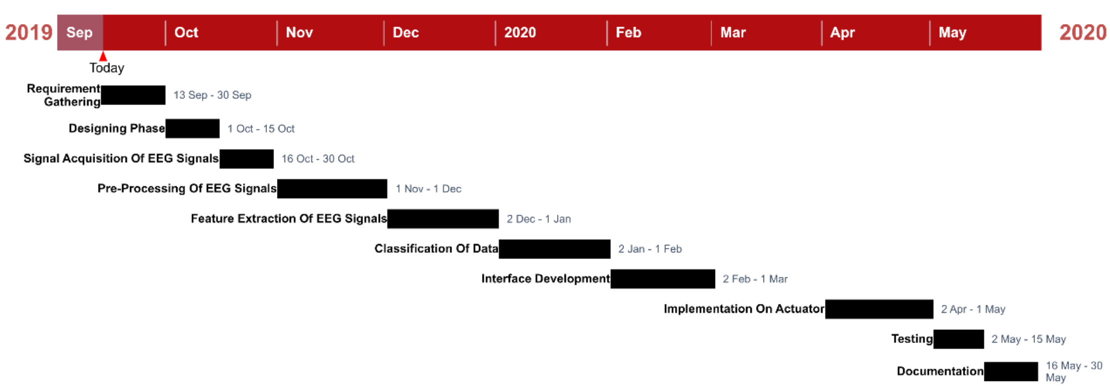

Figure 13: Neural X Gantt Chart

4 System testing

4.1 Test Cases

Following are test cases for Neural X

Test Case Id	TC 01
Project name:	Neural X
Use Case ID:	UC 01
Purpose	To establish connection between headset, server and wheelchair
Environment:	<Server><Headset><Wheelchair>
Pre-Requisite:	"none"
Strategy:	When the headset is turned on, it will be paired with server and t the server will be paired to the wheelchair
Expected Results:	Connection established
Observations:	The connection was successfully established between the headset, server and wheelchair
Result:	Passed

Description:

This test is taken to establish connection between headset and the server and then between server and the wheelchair.

Test Case Id	TC 01
Project name:	Neural X
Use Case ID:	UC 02

Purpose	To adjust settings and specifications according to the headset's software
Environment: Pre-Requisite:	<Server><Headset> Headset should be paired with the Server
Strategy:	The placement of electrodes of the headset will be done with 100% efficiency. The User ID and headset related required information will be filled
Expected Results:	The connection is completely established with correct configurations.
Observations:	The headset was configured with the server.
Result:	Passed

Description:

The above case is to check the setting of the headset and the correct placement of electrodes on user's head.

Test Case Id	TC 02
Project name:	Neural X
Use Case ID:	UC 01
Purpose	The user will think of a command to control the wheelchair.
Environment: Pre-Requisite:	<Server><Headset> Headset should be paired and configured with the Server
Strategy:	The user will have to concentrate on one of the trained commands.
Expected Results:	Generation of command.

Observations:	Command was generated
Result:	Passed

Description:

The above test is done to check if commands in the form of EEG signals are generated.

Test Case Id	TC 02
Project name:	Neural X
Use Case ID:	UC 02
Purpose	Server will acquire EEG signals from the headset.
Environment:	<Server><Headset>
Pre-Requisite:	Headset should be paired and configured properly with the Server
Strategy:	The EEG signals generated by the user will now be acquired by the server
Expected Results:	The signals are acquired successfully.
Observations:	Generated EEG signals were acquired by the server.
Result:	Passed

Description:

The above case is to check if the server has received the commands which are in the form of EEG signals. This test was a success.

Test Case Id	TC 03
Project name:	Neural X
Use Case ID:	UC 01

Purpose	Pre-processing and Feature extraction.
Environment: Pre-Requisite:	<Server> Successful acquisition of EEG signals
Strategy:	Server will pre-process the signals and then it will extract the required features.
Expected Results:	The signals are pre-processed successfully.
Observations:	The server pre-processed the signals .
Result:	Passed

Description:

The test was performed for the server to pre-process the acquired EEG-signals and then later extract the features to be used from them.

Test Case Id Project name: Use Case ID:	TC 03 Neural X UC 02
Purpose	Finding patterns and creating a model.
Environment: Pre-Requisite:	<Server> Successful pre-processing of signals and extraction of features.
Strategy:	Model will be trained on the processed signals.
Expected Results:	A model is created for further classification of processed signals.
Observations:	Model is created
Result:	Passed

Description:

The test is conducted after the SSG signals have been pre-processed .This was done to check whether patterns were found by the learning algorithm and the creation of model artifact.

Test Case Id	TC 04
Project name:	Neural X
Use Case ID:	UC 01
Purpose	Classification of new signals
Environment:	<Server>
Pre-Requisite:	Trained model and processed signals.
Strategy:	The new unseen real time processed signals will be classified using the trained model
Expected Results:	Signals will be classified.
Observations:	SIgnlas are classified
Result:	Passed

Description:

The test is conducted to check whether the sever has classified the unseen real time signals to a command or not and the results showed that this was successful.

Test Case Id	TC 06
Project name:	Neural X
Use Case ID:	UC 01
Purpose	Mapping of classified command .
Environment:	<Server><Wheelchair>
Pre-Requisite:	Processed and classified command.

Strategy:	The classified command is transmitted to the wheelchair controller by the server.
Expected Results:	Command is mapped.
Observations:	Command was transmitted to the controller.
Result:	Passed

Description:

This was done for the server to transmit the classified command to the wheelchair controller for conduction of further actions.

Test Case Id	TC 07
Project name:	Neural X
Use Case ID:	UC 01
Purpose	To move the wheelchair..
Environment:	<Server><Wheelchair>
Pre-Requisite:	Mapped command on the wheelchair controller.
Strategy:	After the command is transmitted to the controller of wheelchair, the Wheelchair will then perform an action (forward, backward, stop, left, right)
Expected Results:	Movement of wheelchair based on command
Observations:	Wheelchair was moved in the direction thought by the user
Result:	Passed

Description:

It was done to see if the wheelchair moves in the direction of classified command and it successfully did.

4.2 5.2 Unit / integration / acceptance testing

4.3 Pairing and configuration Unit Cases

<table>
<tr><td colspan="3">Test Case #: 01</td><td colspan="3">Test Priority (Low/Medium/High): High</td></tr>
<tr><td colspan="3">System: headset</td><td colspan="3">Test Case Name: Pairing</td></tr>
<tr><td colspan="3">Designed by: Fareeha Sohail</td><td colspan="3">Subsystem: server, wheelchair</td></tr>
<tr><td colspan="3">Executed by: Fareeha Sohail</td><td colspan="3">Design Date: 2-01-2020</td></tr>
<tr><td colspan="3">Short Description: The test is for checking the connection of headset with wheelchair and server</td><td colspan="3">Execution Date: 12-01-2020</td></tr>
<tr><td colspan="3">Pre-Condition:</td><td colspan="3">Wheelchair and system hardware integration must be done.</td></tr>
<tr><td>Step</td><td>Action</td><td colspan="2">Expected System Response</td><td>Pass/ Fail</td><td>Comment</td></tr>
<tr><td>1</td><td>Attendant will turn on the headset</td><td colspan="2">Lights should blink</td><td>Pass</td><td>Headset Lights blink which indicated headset is on.</td></tr>
<tr><td>2</td><td>Attendant will turn on the wheelchair.</td><td colspan="2">Wheelchair should raise an alert</td><td>Pass</td><td>Wheelchair raised a sound.</td></tr>
<tr><td>3</td><td>User will gear the headset</td><td colspan="2">Headset should start receiving signals from brain</td><td>Pass</td><td>Signals received by headset.</td></tr>
<tr><td colspan="6">Post-Condition: Headset successfully paired with the server.</td></tr>
</table>

Test Case #: 02			**Test Priority (Low/Medium/High):** High	
System: Headset			**Test Case Name:** Configuration	
Designed by: Fareeha Sohail			**Subsystem:** laptop, wheelchair	
Executed by: Fareeha Sohail			**Design Date:** 11-01-2020	
Short Description: This test is for checking connection of headset with system			**Execution Date:** 18-01-2020	
Pre-Condition:			Headset, wheelchair and server should be set properly.	
Step	Action	Expected System Response	Pass/ Fail	Comment
1	Attendant will enter User ID and other required information.	Server should display successful connection message	Pass	Server displays connection established message.
Post-Condition: This test is for checking whether headset connected with the system or not. Success message ensured successful connection.				

4.3.1 Signals Processing Unit Cases

Test Case #: 01	**Test Priority (Low/Medium/High):** High
System: Server	**Test Case Name:** Signals acquisition
Designed by : Ali Malik	**Subsystem:** Headset, wheelchair

<table>
<tr><td colspan="3">**Executed by:** Ali Malik</td><td colspan="3">**Design Date:** 18-01-2020</td></tr>
<tr><td colspan="3">**Short Description:** The test is for checking whether receiver and sender XBees are working properly or not.</td><td colspan="3">**Execution Date:** 25-01-2020</td></tr>
<tr><td colspan="3">**Pre-Condition:**</td><td colspan="3">Headset wheelchair and server configured.</td></tr>
<tr><td>Step</td><td>Action</td><td colspan="2">Expected System Response</td><td>Pass/ Fail</td><td>Comment</td></tr>
<tr><td>1</td><td>User will focus</td><td colspan="2">Serial should receive some values</td><td>Pass</td><td>Serial received values</td></tr>
<tr><td colspan="6">**Post-Condition:** Serial received values which ensures that headset is sending signals which is properly read transmit by respective XBees.</td></tr>
</table>

<table>
<tr><td colspan="3">**Test Case #:** 02</td><td colspan="3">**Test Priority (Low/Medium/High):** High</td></tr>
<tr><td colspan="3">**System:** Headset</td><td colspan="3">**Test Case Name:** Processing</td></tr>
<tr><td colspan="3">**Designed by:** Ali Malik</td><td colspan="3">**Subsystem:** laptop, wheelchair</td></tr>
<tr><td colspan="3">**Executed by:** Ali Malik</td><td colspan="3">**Design Date:** 26-01-2020</td></tr>
<tr><td colspan="3">**Short Description:** This test is for checking strength of signals generated by user and their processing.</td><td colspan="3">**Execution Date:** 29-01-2020</td></tr>
<tr><td colspan="3">**Pre-Condition:**</td><td colspan="3">Signals are received on serials.</td></tr>
<tr><td>Step</td><td>Action</td><td colspan="2">Expected System Response</td><td>Pass/ Fail</td><td>Comment</td></tr>
</table>

	User is asked to think of a specific action	User should focus for that action	pass	User focused according to his training
1	Open console of Arduino to observe signal’s values	Values on console should match with the expected values according to user’s thoughts	Pass	Expected values on console obtained
Post-Condition: This test is for testing processing of signals as they are sent from headset to server according to user’s thought.				

4.3.2 Classification and Command Execution Unit Cases

Test Case #: 01	**Test Priority (Low/Medium/High):** High
System: Server	**Test Case Name:** Classification
Designed by: Tayyaba Akram	**Subsystem:** Headset, wheelchair
Executed by: Tayyaba Akram	**Design Date:** 2-02-2020
Short Description: The test is for checking whether signals are classified according to user’s thought or not.	**Execution Date:** 12-02-2020
Pre-Condition:	Signals are processing properly

Step	Action	Expected System Response	Pass/ Fail	Comment
1	Attendant checks output via console	Signals should classify according to user’s thought	Pass	Console received required values

		and values should match expected result.		
Post-Condition: Signals are classified according to user's thought				

Test Case #: 02	**Test Priority (Low/Medium/High):** High
System: Wheelchair	**Test Case Name:** Command Execution
Designed by: Tayyaba Akram	**Subsystem:** Server, headset
Executed by: Tayyaba Akram	**Design Date:** 13-02-2020
Short Description: This test is to check mapping of classified signals	**Execution Date:** 22-02-2020
Pre-Condition:	Signals are classified

Step	Action	Expected System Response	Pass/ Fail	Comment
	Observation of wheelchair's movement	Wheelchair should move in expected direction	pass	Wheelchair moves in desired direction.
Post-Condition: This test is to test mapping of classified signals. Movement of wheelchair in desired direction ensures that signals are mapped properly.				

5 Conclusion

5.1 Project summary

In this report, a system based on BCI has been presented. The key features of this system are that it will receive commands in the form of signals from the Emotive-Epoch headset. The signals will be then acquired by the server and processed by it. The processed signals then will be sent to the trained model to classify the command and then for further mapping of commands. In this way, the final command transmitted to the wheelchair controller will be executed. The user will be able to move forward, stop, move backward, move left and move right the wheelchair.

5.2 Problems faced and lessons learned

During the process of this system, it was observed that training of several EEG commands is a very difficult task, therefore we had to stick to only the commands necessary. Whenever there is a new user, the model must be trained again based on his signals which is a complex challenge. It is very hard to understand the process of our brain sending activity commands to our muscles, and they sometimes don't need attention and effort. Our brain sometimes generates inconsistent and complex thought patterns depending upon the user's mental state, attention and awareness. Also, the battery must be charged, which will require the assistance of others.

5.3 Future work

- To achieve even in higher accuracy for the classification of command 14/64 -channeled device can be used.
- To control the wheelchair more efficiently, sensors that can detect obstacles can be used.
- Various patterns can be used to make the system more efficient.
- A global positioning system (GPS) can be installed in the future so that the wheelchair moves to a certain point if its battery is lower than a certain point for recharging.

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Appendix A:

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