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**INSTITUTE OF ENGINEERING**

**THAPATHALI CAMPUS**

**A Major Project Proposal**

**On**

**Human**-**Computer Interaction using Neuromuscular Signals**

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# ABSTRACT

This project is about designing a Brain Computer Interface (BCI) that reads Electromyographic signals from different parts of Peripheral Nervous System (PNS). The signal is perceived from different muscles of articulatory system that is associated with internal articulation of voice commands delivered by the brain. The signal in the range of microvolt is amplified to volts and error occurred due to movements of other muscles than muscles involved in internal articulation is filtered using instrumentation amplifiers in two steps combined with high pass and low pass filters. Amplifiers and filters are embedded in a printed circuit board along with Arduino and Bluetooth module for remote communication. Signals are converted to digital using ramp type analog to digital conversion (ADC) which is inbuilt in Arduino. The signal sent to remote computer is received at receiving side using a Bluetooth module and Arduino. At receiving side the signal is sent to a computer using Universal Asynchronous Receiver/Transmitter (UART) protocol. Then the computer decodes the signal using AI running in Python programming language. Trained models in python uses artificial intelligence (AI) to predict what the user want to speak and finally the information of the signal i.e. English alphabet, is displayed on the computer screen.

*Keywords: Electromyography, Internal Articulation, Peripheral Nervous System*

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# List of Abbreviations

ADC Analog to Digital Converter

ALS Amyotrophic Lateral Sclerosis

BCI Brain Computer Interaction

CMRR Common Mode Rejection Ratio

DFT Discrete Fourier Transform

ECG Electrocardiography

EEG Electroencephalography

EMG Electromyography

EMS Electrical Muscle Stimulation

FFT Fast Fourier Transform

IDE Integrated Development Environment

NEMS Neuromuscular electrical stimulation

PNS Peripheral Nervous System

RCA Radio Corporation of America

UART Universal Asynchronous Receiver/Transmitter

# 1. INTRODUCTION

## 1.1 Background

Electrophysiology is the science and technique of studying the electrical phenomena that play a role in the life of plants and animals. These phenomena include the membrane potential, being ubiquitous among living cells, and its changes, which constitute signals playing an important part in the physiology of any organism. These signals may be slow changes caused by the changing concentration of some chemical substance, or the fast transient peaks called “action potentials” or “spikes”, which arise by the fast opening of molecular “gates” in the membrane of neurons and similar types of electrically active cells.

Movement of body parts of living being is fully coordinated and controlled by their brains. Both voluntary and involuntary movements are controlled by brain. When brain wants to move a muscle of a body part, it informs ‘motor cortex’. Motor cortex calculates the amount of contraction and relaxation needed for a muscle to move and it sends the signal to spinal cord. The spinal cord then sends the signal to axiom, which is connected to a particular muscle and muscle is moved in the coordinated direction. All these signals from the brain to the muscles are in the form of electric signals. The feeble electric signals cannot be felt by the humans themselves but it can be detected after proper amplification. There exists devices such as an electroencephalograph to do so. Perceiving such electrical signals, henceforth termed impulses, provides insight on both the physical and mental health.

Similarly, during production of speech from vocal cord there involved complex series of finite and coordinated neuromuscular communication. For the complete generation of sound more than 100 muscles are involved. When a person articulates a word internally without acoustic vocalization and no significant movements in facial muscle and tongue, more than 15 muscles which are parts of speech system, are neurologically activated. These particular muscles receive feeble electrical signals from the PNS. The electrical impulse perceived in the form of potential difference can be used to decode the actual word that the person is articulating. [1]

Using human computer interaction through neurological signals is a relatively new way of human-machine interaction. In practice, inputs are being given through significant movement of body parts whether the system is manually controlled, touch control or gesture control. In this project, inputs for machines are generated from neuromuscular signals that arises as action potential on muscles as voluntary muscular operation during internal articulation of speech.

## 1.2 Motivation

Motivation is one of the factors, which encourages a person to the commitment of any action and play a crucial role as psychological determinant. There are research and project which have motivated us for this project. The following of the sources are motivations:

Backyard Brain is a team of engineers, scientists and researchers that have been constantly researching on inner working of nervous system. And have designed some interface and hardware with cheap electronics that can help students in providing insight into the working of the nervous system. The equipment for conducting such experiments costs much but they aim to provide students below graduation to do experiments on nervous system maintaining ethics regarding experimentation on living beings. [2]

AlterEgo is a personalized wearable silent speech interface that allows its users to silently converse with a computing device without any voice or any discernible movements - thereby enabling the user to communicate with devices, AI assistants, applications or other people in a silent, concealed and seamless manner. A user's intention to speak and internal speech is characterized by neuromuscular signals in internal speech articulators that are captured by the AlterEgo system to reconstruct this speech. This interface is used to facilitate a natural language user interface, where users can silently communicate in natural language and receive aural output (e.g.: - bone conduction headphones), thereby enabling a discreet, bi-directional interface with a computing device, and providing a seamless form of intelligence augmentation. [1]

This project is selected as it has interfacing of brain signals with computer. Brain computer interface (BCI) is new field for research and product development. In this context, this project provides platforms for research on this field. It is also intended to help on one of the evolving field of science and technology i.e. bio-technology.

## 1.3 Objectives

The main objectives of our projects are:

* To develop a system to extract neural signals from articulatory system.
* To transmit the signal wirelessly to a remote computer.
* To display the decoded text from the signal.

## 1.4 Project Applications

This project is applicable in many research oriented bio-electronic product development for medical and research purpose. As this project provides a new way of human and computer interaction, it can be used to develop a system on that basis. Following are some of the applications of this project.

### 1.4.1 Human computer interfacing system using neuromuscular signals

Brain Computer interface (BCI) is a method of interfacing brain signals with a computer. The signals generated from motor neurons during speech production can be used as commands for performing specific tasks like moving mouse cursers, typing a letter, clicking an icon etc. This method could be a faster approach for human computer interaction.

### 1.4.2 Communication medium for ALS patient

Using brain computer interface (BCI) system, ALS (Amyotrophic Lateral Sclerosis) patient can give instruction to computer. Patients suffering from ALS has lost ability to move voluntary body parts due to malfunctioning of nerves cells in brain and spinal cords. The gradual paralysis of body parts makes person unable to do any voluntary controls over body parts. Those patients can use this project as a method of input for computer. The signals from articulatory muscles of patients can be taken as commands for various tasks like pronouncing the words, changing speed and direction of wheelchair, giving commands for other IOT devices etc.

### 1.4.3 Communication in places where audio is not possible

In some places where audio signals cannot be used for communication is suitable applicajtion fields of this project. In space, due to absence of air medium, audible sound cannot be used. In practice, electrical devices are used which captures sound within the helmet and communicated via wireless medium. In this approach, Human-Computer Interaction using neuromuscular signals can be applied for communication.

Similarly, for other situations like communication under water by marine troops, Sea Explorer, extremely crowded areas during emergencies and peoples in low air pressure areas like mountaineers in high mountains can also communicate using same technique.

### 1.4.4 Multilingual device

Extending this project by implementing soundless hearing using bone conduction method can be developed as a multilingual device. The device can translate one language into another and send it to user through bone conduction. This enables the communication between peoples who don’t understand each other’s language.The device works as a separate mechanism in brain that converts one language into another.

## 1.5 Scope of Project

The scope of this project includes the extraction of impulses form different muscles of our articulatory system that are activated during internal articulation of speech. The extraction process includes detecting electrical impulses in the muscle and decoding those signals in order to find what person is vocalizing. Several trained neural networks are used to extract the sound. Once the sound is identified it is then transmitted to another device wirelessly and displayed in the screen.

This project does not include the decoding of signals produced during articulation of sentences and special characters. It is not compatible for languages other than English. The BCI is unidirectional and offline.

# 2. LITERATURE REVIEW

There has been a number of attempts in electrophysiology for analysis of neural activities. “AlterEgo: A Personalized Wearable Silent Speech Interface”, a research accomplished by Arnav Kapur, Shreyas Kapur and Pattie Maes which was published by MIT Media Lab in 2018, presents a natural extension of the user's own cognition by enabling a silent, discreet and seamless conversation with machines and people. It presents a wearable silent speech interface that allows users to provide arbitrary text input to a computing device or other people using natural language, without discernible muscle movements and without any voice command i.e. without explicitly saying anything. The nerve impulses were sourced as seven channels from laryngeal region, hyoid region, levator anguli oris, orbicularis oris, platysma, anterior belly of the digastric mentum using electrodes on the outer skin. [3]

According to neuroprosthetics experiment, ”Control Machines with your Brain” done from 2009-2017 by Backyardbrains, a team of researchers and engineers, the EMG signals were extracted from Muscle SpikerShield which was interfaced with microcontroller and the data obtained was visualized in Spike Recorder App developed by the team. The research was further extended as Human-Machine Interfaces, which included control of robotic arm, video games and voiceless communication. [4]

A research paper by Michael Wand and Tanja Schultz named “SESSION-INDEPENDENT EMG-BASED SPEECH RECOGNITION” describes the method of speech recognition by surface EMG signals. By recording the electric active potentials of human articulatory muscles. Speech recognition using EMG signals dates back to 1980s. 93% accuracy was observed on 10 word vocabulary. It suggests that good result can be obtained even for the signals taken when words are spoken silently. [5]

“Electrical Stimulated as a Modality to Improve Performance of the Neuromuscular System”, a research paper by Vanderthommen Marc and Duchateaus Jacques in October 2007 transcutaneous neuromuscular electrical stimulation (NEMS) can modify the order of motor unit recruitment and has a profound influence on the metabolic demand associated with producing a given muscular force. Tetanic contractions elicited by pulses of high intensity and short duration induce a high metabolic stress in the muscle, contribute to the reversal of motor unit recruitment, and improve the maximal capability of the neuromuscular system primarily not only through increased force-generating capacity of the muscle but also through intensified voluntary activation. [6]

# 3. METHODOLOGY

## 3.1 Theoretical Conditions

In articulatory system during the production of audible sound, brain controls all the functions related to contraction and expansion of different muscles to produce a particular sound. Different nerves are used as signal transmission media through different nerves to control the muscles related to the activity.

There are three different mechanisms of acoustic speech namely, speech respiration, phonation and articulation. Respiration provides pressure and vibration on muscles necessary for the production of speech. Phonation is the process of sound production by passing air through larynx (voice box) tissue. Articulation is soft movement of articulatory organs to imitate speech without production of audible sound.

Different types of nerves involved in articulatory system and respective muscles movement are tabulated below

Table 3‑1: Nerves and Muscle movements in Articulatory System

|  |  |  |  |
| --- | --- | --- | --- |
| **S.N.** | Nerve | Movements | Sensory Functions |
| 1 | Trigeminal Nerve (CN V) | Biting and chewing | Sensory data from palate, teeth and anterior tongue |
| 2 | Facial Nerve (CN VII) | Facial muscle | Sensation to external ear |
| 3 | Glossopharyngeal Nerve (CN IX) | Elevation of Pharynx and larynx | Sensation to posterior tongue and upper pharynx |
| 4 | Vagus Nerve (CN X ) | Elevation of palate phonation | Sensory data from external ear, tongue and larynx |
| 5 | Hypoglossal Nerve (CN XI) | Movement of tongue | Sensory data from tongue |

Plasma membranes of neurons like all other cells, have an unequal distribution of ions and electrical charges between the two sides of the membrane. Normally, cell has positive charge (Na+) outside the plasma membrane and negative charge (K-) inside the membrane. The difference resulting from their potential is known as resting potential which is in the order of millivolts. Exchange of ions occurs in the plasma membrane of cell for maintaining unequal concentration of the charges which is known as sodium-potassium pump. When a neuron sends information down an axon, away from the cell body of a neuron, temporary reversal of electrical potential occurs along the membrane for few milliseconds which is defined as action potential. Action potential begins at one spot and spreads to adjacent area of the membrane, propagating message along the length of cell membrane. Sodium and potassium ions passes through protein channel gates that can be opened or closed. After the generation of action potential, there is a brief refractory period during which membrane can’t be stimulated, this prevents the message from being transmitted backward.

Triggering muscle movement begins in the motor cortex, where series of action potentials occur, signals the spinal cord and the information related to the movements conveyed to the relevant muscles via motor neurons. This begins with upper motor neurons that carry signals to the lower motor neurons. The lower neurons are the actual instigators of muscle movement as they innervate the muscle directly at the neuromuscular junction. The innervation causes the release of calcium ions within the muscles ultimately creating a mechanical change in the tension of the muscles which involves depolarization. Thus generated fluctuations in the electrochemical gradient resulting from muscle response during nerve stimulation of muscles are measured using Electromyography (EMG). [7]

For the analysis of superimposed motor unit action potentials (MUPAs) generated from several motor units, the EMG signals can be decomposed into their constituents MUPAs distinguished by their characteristic shapes. The shape and size depends on where the electrode is located with respect to the fibers and are different if electrode position is altered slightly. [8]

## 3.2 Mathematical Modeling

The signal (voltage) generated deep within oral musculature is attenuated when conducted through bone and tissue. So electrode is placed where the skin surface is nearer to that muscle. The thus generated is inversely proportional to the distance between electrode and the muscle.

|  |  |
| --- | --- |
|  | 3.2.1 |

Where V is the voltage sensed and d is the distance between electrode and muscle.

Let V1, V2,…,VN be the potential differences recorded by n electrodes and Vc be the threshold voltage of internal articulation. The rms voltage is calculated as:

|  |  |
| --- | --- |
|  | 3.2.2 |

If Vrms > Vc, the signal detected is due to the muscle movement.

If Vrms < Vc, the signal detected is due to muscle response during internal articulation so it is further analyzed.

If Vrms = Vc, the signal is rejected.

Fast Fourier Transform (FFT) is an algorithm that computes the discrete Fourier transform (DFT) of the sequence and its inverse transform as well by conversion of a signal from its original domain (time or space) to its frequency domain or vice-versa. The sequence of signals of different frequencies are decomposed into its components of different frequencies by factorizing the DFT matrix into a product of sparse (mostly zero) factors.

Let x0, x1, x2,....,xN be a vector space in complex domain. The DFT is defined by the formula

|  |  |
| --- | --- |
|  | 3.2.3 |

Where, k ranges from 0 to N-1

Where, is a primitive Nth root of 1.

Evaluating this definition directly requires **O (N2)**   operations: there are **N** outputs *Xk*, and each output requires a sum of **N** terms. An FFT is any method to compute the same results in **O (NlogN)** operations.

## 3.3 Proposed System Block Diagram

Figure 3‑1: System block diagram

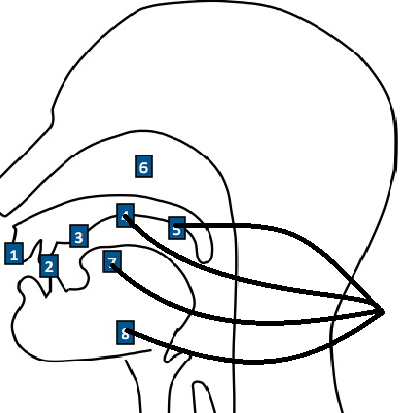
Bluetooth transmitter

(2.4 GHz)

Signals from articulatory muscles using electrodes

RCA cable

Computer



Wireless medium

Bluetooth

Receiver

UART

Display Unit

Data processing using AI

1st stage Amplifier

2nd stage Amplifier

Instrumentation Amplifier

Band pass filter

ADC

Circuit Board

## 3.4 Elaboration of Working Principle

The system has EMG adhesive type electrodes attached to facial areas to extract the signals generated from different muscles that are responded during internal articulation of a sound. Electrodes detect potential difference of muscles during the process and is fed to instrumentation amplifier using RCA cable, which amplifies the impulse with very high gain and the signal is filtered using band pass filter. Band pass filter cuts higher and lower frequency signal and suitable signal is extracted. Then it is converted to digital signal and transmitted to PC using Bluetooth communication.

## 3.5 Description of Instrumentation / Tools

### 3.5.1 Hardware

#### 3.5.1.1 Electrodes

An electrode is a solid electric conductor (need not be a metal) that carries electric current into non-metallic solids, liquids, gases, plasmas or vacuum. Gold plated Silver EMG cup electrodes of 10 mm diameter and 2mm hole for application of electrode cream or gel is suitable for signal extraction as Gold plating provides better conductivity and immunity to noises. The electrode is adhesive to skin and paste provides good conductivity. There are two main types of EMG electrodes: surface (or skin electrodes) and inserted electrodes. Surface electrodes are used for extraction of signals from muscles. The electrode is connected to amplifier using RCA cable.



Figure 3‑2: Gold plated EEG EMG electrodes

#### 3.5.1.2 Amplifier and Filter

Instrumentation amplifier amplifies the weak signal from the muscles and make it detectable for the microcontroller which extract the data and send it for further processing. The voltage signal is of magnitude range of 10 microvolts, which is very small for filtering and feeding to ADC. The instrumentation amplifier is a type of differential amplifier that eliminates the use of input impedance matching also rejects superimposed noise and interference noise. It provides very low DC offset voltage, low noise, very high open-loop gain, very high common mode rejection ratio (CMRR) and very high input impedance.

High pass and low pass filters are used along with amplifier for better signal amplification and filtering. High pass filter is used to avoid aliasing of signals below 1.5 Hz and low pass filter cutoffs the unwanted high frequency signals resulting from movement of other muscles of facial region during internal articulation. Signals above 10 Hz frequency is eliminated by low pass filter.

AD620 and OP37AJ amplifier ICs are used along with resistors and capacitors for signal amplifying and filtering. AD620 has bandwidth of 120 KHz with gain range of 1 to 1000, settling time of 15 µs and 100 dB min Common-Mode Rejection Ratio (CMRR). The signal is first pre-amplified with AD620 instrumentation amplifier and low frequency noise is eliminated. Using filter after 1st stage amplification blocks low noises on further amplification. Amplifier OP37AJ amplifies the signal to higher strengths and then low pass filter is introduced to reject high frequency noises. Finally another OP37AJ amplifier amplifies the signal to produce output in the level of volts. Gain of amplifiers and frequency of filters can be set using resistors and capacitors, which provides flexibility for similar kind of varying signals. [9]

Instrumentation Amplifier AD620

2nd order high pass filter

Amplifier OP37AJ

Amplifier OP37AJ

2nd order low pass filter

Vin(µV)

Vout (V)

Figure 3‑3: Block representation of Amplifiers and Filters

#### 3.5.1.4 Arduino

The signal obtained is in analog form. Now this signal is converted to digital signal using ATMega8 microcontroller of Arduino. It is used for both signal conversion and transmission through Bluetooth media. Arduino is also used as serial input device for computer. 6 pins out of 14 can be used for Pulse Width Modulation (PWM) output.

Arduino Uno is a microcontroller board based on ATMega8.It has 6 analog input pins, 14 input/output digital ports which are used to connect external electronic circuits and different modules. Arduino Uno provides 6 pins for ADC having resolution of 10 bit. It maps input voltage between 0 to 5 volts into integer values between 0 and 1023.

#### 3.5.1.5 Bluetooth Modules

HC-05 is a Bluetooth module used for wireless communication. It can be used as both master and slave and hence using two modules enables two way communication. Signal that is converted to digital by Arduino is transferred to another Bluetooth device within the specified range.

### 3.5.2 Software Requirements

#### 3.5.2.1 Arduino IDE

The Arduino IDE is a cross-platform application that is written in functions from C and C++. It is used to write and upload programs to Arduino compatible boards but also, with the help of third party codes, other vendor development boards. The source code for IDE is released under the GNU (General Public License).

#### 3.5.2.2 Python

Python is an interpreted, object-oriented, high-level programming language with dynamic semantics. Its high-level built in data structures, combined with dynamic typing and dynamic binding, make it very attractive for Rapid Application Development, as well as for use as a scripting or glue language to connect existing components together.

Python is used for data processing. Python has provided libraries like pyEEG, pySpACE, bioSPPy for pre-processing of signals. These libraries can be used for signal classification. Further processing of signal is done by using Neural Network in python. The voltage signal in the digital form is analyzed to predict the possibility of letter that the person is articulating.

#### 3.5.2.3 KiCad

#### KiCad is a free software suite for electronic design automation (EDA). It facilitates design of schematics for electronic circuits, converting them to printed circuit board (PCB) designs along with circuit simulation. It has built-in footprints of different electronic components. Footprint of new components can also be designed manually.

# 5. EXPECTED OUTPUT

The final output of this project is expected as a wearable set of electrodes connected to amplifier circuit. Person using the device articulates English alphabets internally as an input for the system. Signal is then sent to a computer using Bluetooth communication. Finally, computer decodes the message i.e. English alphabet that the person is articulating and alphabet is displayed in the screen. Overall process is summarized in the following steps:

* Articulation of Alphabets
* Amplification and filtering of EMG signals
* Transmission to remote computer via Bluetooth
* Signal processing using AI
* Displaying on Screen

Figure 5‑1: Expected output

Internal Articulation

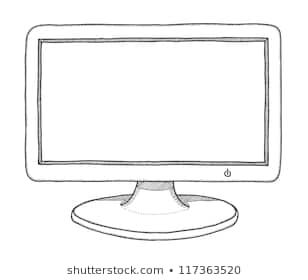
Electrodes

* Amplification
* Filtering
* Transmission

Impulse signals

(Wireless media)

Processing



A B C



Display

# 7. EXPECTED PROJECT BUDGET

Table 7‑1: Expected project budget

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **S.N.** | **Title** | | **Model** | **Quantity**  **(pcs.)** | **Rate (NRs.)** | **Price (NRs.)** |
| **1** | Arduino | | Uno | 2 | 950 | 1900 |
| **2** | Bluetooth Module | | HC-05 | 2 | 790 | 1580 |
| **3** | Gold plated Silver Electrodes | | EEG EMG | 20 | 230 | 4600 |
| **4** | Instrumentation amplifier | | AD620 | 5 | 114 | 570 |
| **5** | Op-amp | | OP37AJ | 10 | 114 | 1140 |
| **6** | Passive electronic components | * Resistors * Capacitors * Header pins * Diodes | - | - | - | 2000 |
| **7** | Conductive Paste | | polyoxyethylene(20)cetyl ether | 200gm | 200 | 200 |
| **8** | PCB board | | - | 2 | 250 | 500 |
| **9** | Miscellaneous | | - | - | - | 5000 |
|  | **Total** | |  |  |  | 17490 |

# 8. PROJECT SCHEDULE

Table 8‑1: Gantt chart

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Title | 1st month | 2nd month | 3rd month | 4th month | 5th month | 5th month | 7th month | 8th month | 9th month |
| Project Selection |  |  |  |  |  |  |  |  |  |
| Research | y | y | y | y | y | y | y |  |  |
| Model Development |  |  | y | y |  |  |  |  |  |
| Testing and Debugging |  |  |  |  | y | y | y |  |  |
| Data Collection |  |  |  |  |  |  |  |  |  |
| Documentation |  |  | y | y | y | y | y | y | y |
| Report Submission |  |  |  |  |  |  |  |  |  |

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