International Journal of Basic and Applied Biology
Print ISSN: 2394-5820, Online ISSN: 2349-2539, Volume 2, Number 6; July-September, 2015, pp. 352-358

http://www.krishisanskriti.org/ijbab.html

A Mind Controlled Mouse for Elderly People with Multiple Disabilities using Discrete Wavelet Transforms and Independent Component Analysis

K. Padma Vasavi[1], S. Radhika[2] and G. Durga. K. Prasad[3]

[1]SVECW
[2,3]JRF, SVECW
E-mail: [1]padmavasaviece@svecw.edu.in, [2]radhika.surampudi@gmail.cpm, [3]prasadgudavalli@gmail.com

Abstract—*According to a statistical survey made by World Health Organization (WHO) India suffers from highest number of road accidents and out of which more than ten percent of them are prone to head injuries. This scenario leads to patient's death or make the victim to become comatose. Also, many different disorders can disrupt the neuromuscular channels through which the brain communicates with and controls its external environment. Brainstem stroke or spinal cord injury, cerebral palsy, muscular dystrophies, multiple sclerosis and numerous other diseases impair the neural pathways leading to communication and control which make the victims intellectually or physically disabled. Most often, the communication for paralyzed people is established by using a Brain Control Interface (BCI). Most of the existing systems had experimented Brain Computer Interface either with animals or healthy human beings. But, this paper focuses on movements of the mouse cursor controlled by a person with multiple disabilities. The mouse cursor movement would further be used by the disabled person to have a communication with his caretaker by means of the software developed by us. The proposed system uses discrete wavelet transforms for de-noising the muscular and cardiac signals. An independent component analysis is performed in order to extract the beta rhythms from the EEG signal. The mouse control is achieved by interfacing the mouse with a microcontroller which receives the operating voltages from the Data Acquisition System (DAS) which acquires and conditions the EEG signals coming from the user brain. The proposed system is tested on several young and elderly persons and is found to be working with more than 95% accuracy*

1. INTRODUCTION

A Brain–Computer Interface (BCI) activates electronic or mechanical devices with brain activity alone. BCIs and BMIs allow direct brain communication in completely paralyzed patients and restoration of movement in paralyzed limbs through the transmission of brain signals to the muscles or to external prosthetic devices. We differentiate invasive from noninvasive BCIs: Invasive BCIs use activity recorded by brain implanted micro- or macro electrodes, whereas noninvasive BCIs use brain signals recorded with sensors outside the body boundaries. Advances in cognitive neuroscience and brain imaging technologies have started to provide us with the ability to interface directly with the human brain. This ability is made possible through the use of sensors that can monitor some of the physical processes that occur within the brain that correspond with certain forms of thought. Researchers have used these technologies to build brain-computer interfaces (BCIs), communication systems that do not depend on the brain's normal output pathways of peripheral nerves and muscles. In these systems, users explicitly manipulate their brain activity instead of using motor movements to produce signals that can be used to control computers or communication devices.

The BCI systems are classified into dependent and independent systems based on the usage of brain activity. A dependent system uses the activity in the brain's normal output path ways. An independent BCI system does not use brain's normal output path ways. Based on the placement of electrodes, the BCI systems are classified into Invasive and Non-Invasive systems.

The invasive systems involve attaching the electrodes directly to the brain tissue. The patient's brain gradually adapts its signals to be sent through the electrodes. The non-invasive systems involve placing the electrodes on the scalp of the patient and taking readings. The non-invasive methods take Electroencephalogram (EEG) readings of the brain. An electroencephalogram is a measure of the brain's voltage fluctuations as detected from scalp electrodes. It is an approximation of the cumulative electrical activity of neurons.

In 1950, Jase Delgado made the first wet brain implant on a living animal. In 1976, DARPA initiated the super BCI research. In the same year, Jacques J. Vidal has coined the term "BCI" and has proved that it can be used for communication. Researchers at Case Western University used

64 electrode EEG skull cap to return limited hand movements to quadriplegic people. In the year 2002, implanted monkeys were trained to move a cursor on a computer screen by researchers at Brown University. Brain gate, a brain implant system was developed by cyber kinetics along with Neuroscience department of Brown University in 2003. A high accuracy BCI controlled wheel chair was developed in Japan in 2005 [7].The work by Lisazyga in 2009 explained the details of the system that can urn brain waves into FM radio signals and decode them into sound [8]. Again in 2009, Dr. Chris James experiment had one person using BCI to transmit thoughts translated as series of binary digits, over the internet to another person whose computer receives the digits and transmits them to the second user's brain through flashing an LED. In 2010, a team from Singapore has developed an EEG based BCI training program that combines the advantages of traditional computerized programs and the "Neuro Feedback Training (NFT)" [9]. In 2011, the first thought controlled social media network is utilized by the Neurosky. The University of Technology, Sydney, has developed a "Thought controlled wheel chair" [10]. In 2011, Haier electronics developed the world's first BCI technology Smart TV [11]. In their paper "A New Gaze BCI Driven Control of Upper Limb Exo-skeleton for Rehabilitation in Real World Tasks" published in 2012, Antonio Frisoli et. Al., proposed a new multi-modal architecture for gaze independent BCI driven control of upper limb exo-skeleton for stroke rehabilitation to provide assistance in the execution of reaching tasks in a real world scenario [13]. A hybrid BCI to control the direction and speed of simulated or real world wheel chair was developed by Jinyi Long et.al in 2012 [14]. Nethu Robinson et.al from Nanyang University Singapore, used a signal processing technique to extract features from non-invasive EEG recordings for classifying voluntary hand movements in 2013[15].

In 2003, researchers at Duke University taught rhesus monkeys to consciously control the movement of a real time robotic arm using only feedback from a video screen and their thoughts. All the systems discussed above had experimented Brain Computer Interface either with animals or healthy human beings. But, this paper focuses on movements of the mouse cursor controlled by a person with multiple disabilities. The rest of the paper is organized as follows: Section 2 gives the overview of proposed methodology, section 3 discusses the experiments made and results obtained and finally section 4 concludes the paper.

2. PROPOSED METHODOLOGY

The functional diagram of proposed methodology for mouse cursor control using Brain Computer Interface (BCI) is shown in Fig. 1. The brain signals are acquired using EEG electrodes. The signals from the brain are very weak and are in the order of micro volts. Therefore, an instrumentation amplifier is used to amplify these signals to be in the order of hundreds of milli volts. The amplified signals from 22 positions on the brain are then acquired by a 22 channel Data Acquisition System. Then the analog brain signals are sampled and quantized to make them digital signals. The signal thus acquired suffers from three different noises: one coming from the recording instrument, second from the Electro Cardio Gram signals of the heart and the third from the electrical impulses from the muscles. So, Discrete Wavelet Transforms are used for de-noising the unwanted signals and extracting only the signals pertaining to brain. The EEG signal consists of alpha, beta, theta, delta, mu and gama rhythms which vary from 5Hz to 50 Hz. Since we are interested only in the beta rhythms of the EEG signals an Independent Component Analysis is applied on the EEG signals to separate all these rhythms into individual components. After extracting the beta rhythms threshold levels are set one each for right click of the mouse, left click of the mouse and movement of cursor position. These threshold voltage levels activate a microcontroller interfaced with the Data Acquisition System which in turn controls the mouse movement.

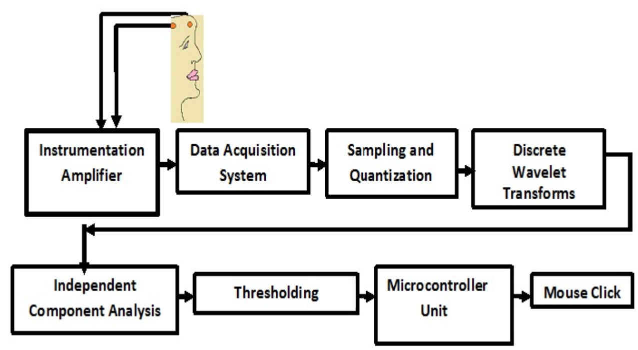


Fig. 1: Functional Diagram of Proposed Methodology

The detailed description of each of the sub systems used in the proposed method is given below:

3. ELECTRODES

The EEG electrodes are chosen for mouse control by brain. The electrodes are placed at different positions according to 10-20system rule and the layout is shown in Fig. 2.

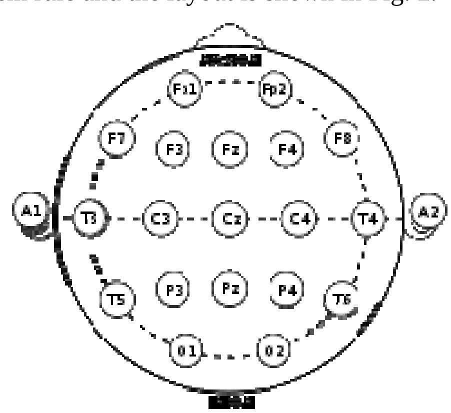


Fig. 2: 10-20 EEG system

The 10–20 system or International 10–20 system is an internationally recognized method to describe and apply the location of scalp electrodes in the context of an EEG test or experiment. Each site has a letter to identify the lobe and a number to identify the hemisphere location.

The letters F, T, C, P and O stand for frontal, temporal, central, parietal, and occipital lobes, respectively.

4. INSTRUMENTATION AMPLIFIER

The INA122 is a precision instrumentation amplifier for accurate, low noise differential signal acquisition. Its two-op-amp design provides excellent performance with very low quiescent current, and is ideal for portable instrumentation and data acquisition systems. The INA122 can be operated with single power supplies from 2.2V to 36V and quiescent current is a mere 60mA. It can also be operated from dual supplies. By utilizing an input level-shift network, input common mode range extends to 0.1V below negative rail (single supply ground). The schematic diagram for connecting a single electrode to the Instrumentation Amplifier is shown in Fig. 3.

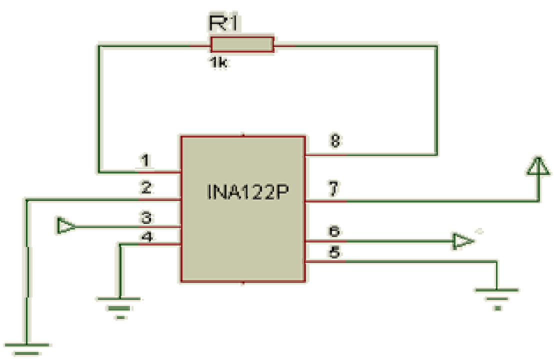
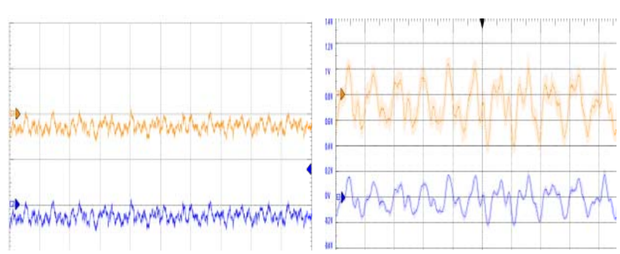


Fig. 3: Schematic diagram for connecting a single electrode to Instrumentation Amplifier

The pins of INA122p are connected as follows. Pin 1 and pin 8 are connected to 1K resistor. Pin2 is connected to v- whereas pin3 is the Input pin which is given to NIA sensor head band, pin 4 is connected to ground. Pin5 is the reference pin which is connected to ground. Pin 6 is the output pin and pin7 is connected to power supply 5V. The main purpose of using the instrumentation amplifier is a differential amplifier optimized for high input impedance and high CMRR.



(a) (b)

Fig. 4: Brain Signals in (a) Relaxation State and (b) Excitation State

An instrumentation amplifier is typically used in applications in which a small differential voltage and a large common mode voltage are the inputs. And also to it amplifies from micro volts to volts. The results are observed by using Analog Discovery Kit and the results are shown in Fig. 4 (a) and Fig. 4 (b).

5. DATA ACQUISITION SYSTEM (DAS)

Data Acquisition System (DAS) is the process of measuring an electrical or physical phenomenon such as voltage, current, temperature, pressure, or sound with a computer. The DAS used in the proposed method is shown in Fig. 5.

Fig. 5: Data Acquisition System

The DAS used in the proposed method is NI PCI 6289, which is high accuracy multi function data acquisition (DAq) device which is optimized for 18 bit analog input accuracy. The resolution is equivalent to 5.5digits for DC measurements. To ensure accuracy the amplifier technology is optimized for low noise and fast setting to 18 bits. The onboard low pass filter rejects high frequency noise and prevents aliasing. These devices are ideal for applications like test control and design.

6. DISCRETE WAVELET TRANSFORMS

As mentioned earlier, the Discrete Wavelet Transforms (DWT) is used for de-noising the EEG signal from muscular, ocular and cardiac artefacts. The DWT decomposes the EEG signal into low frequency approximate coefficients and high frequency detailed coefficients. As a result, the signal with high energy is concentrated in certain wavelet coefficients. On the contrary, noise energy distribution does not change which means that its energy is not retained by large coefficients. So, partial reconstruction of EEG signal is done by applying inverse wavelet transform only on the coefficients in which the concentration of energy is very high. Thus, the EEG signal is de-noised using DWT.

7. INDEPENDENT COMPONENT ANALYSIS

Independent Component Analysis (ICA) is a method for solving the blind source separation problem. It is a way to find a linear transformation of the measured sensor signals such that the resulting source signals are as statistically independent from each other as possible. ICA not only de-correlates the signals (2nd order statistics) but also reduces higher – order statistical dependencies. The separation of alpha, beta, theta and delta waves using ICA for the EEG signal shown in Fig. 4(b) is shown in Fig. 6.

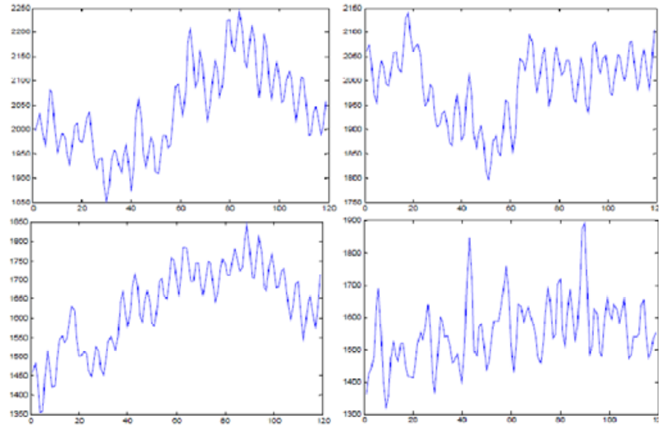


Fig. 6: Separated Alpha, Beta Theta and Delta Waves from Top Left Corner to Bottom Right Corner

After separating the beta rhythms suitable thresholds are set for three excited states of the human subject. The thresholds are used for operating a mouse connected to personal computer.

The details of the methodology are discussed in this section and the experiments made and results obtained in operating a mouse controlled by EEG signals are discussed in the next section.

8. EXPERIMENTS AND RESULTS

The experimental setup for the proposed methodology is shown in Fig. 7. Experiments were conducted on ten healthy volunteers in the age group varying from 18 years to 45 years to identify the required beta rhythms and the possible range of thresholds for distinguishing between state of excitement and state of relaxation. Later, the same experiments were repeated on elderly people in the age group of 65-70 years. Three specific experiments are conducted on each subject at different times in a day: once in the early morning when the subject is in a peaceful mood and the second during the peak working time where the subject is in highly stress mood and the third during evening time when the subject is completely exhausted and is physically weak compared to his morning's strength.

Fig. 7: Experimental Set-up

The following experiments are conducted on the human subjects in order to determine the thresholds for active state and relaxed state:

1. Eye Open and Close
2. Colouring a single circle with single colour
3. Colouring multiple circles with multiple colours

The following are some of the observations which are made from the experiments made on volunteers for the research.

Eye Open and Close: In this experiment, the subject is made to open and close their eyes repetitively to understand the agitation level of the brain for doing this simple action. Bio signal acquisition which acquires EEG signal at a sample rate of 128Hz and the real time data is continuously acquired for one minute duration for each subject.

The results that are obtained at each location for the close and open eye feature are described below. The EEG signals at FZ, FPZ and CZ Positions of Subject1 are shown in Fig. 8.

The EEG signals at FZ, FPZ and CZ Positions of Subject2 and Subject3 are shown in Fig. 9 and Fig. 10 respectively

The red colour region in the graphs shown in Fig. 8, Fig. 9 and Fig. 10 corresponds to delta waves, green region corresponds to theta rhythms, blue region is that of the alpha waves and yellow region corresponds to beta waves

Subject1. Gender: Male; Age: 27

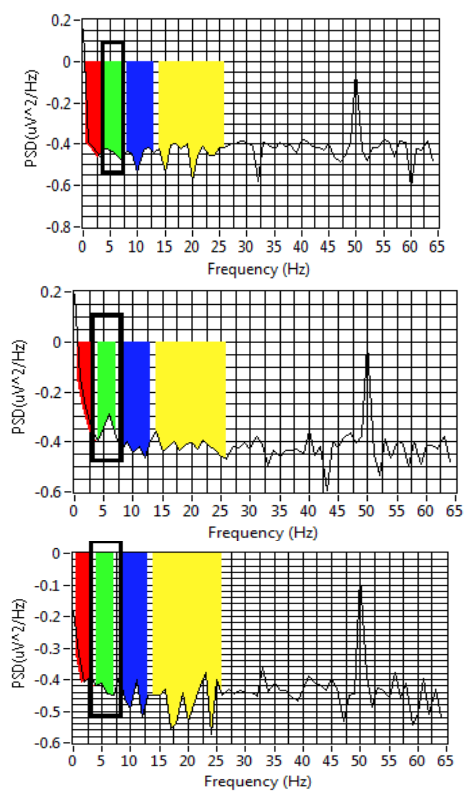


Fig. 8: EEG signals at FZ, FPZ and CZ Positions of Subject1

Subject2: Gender: Female; Age: 60

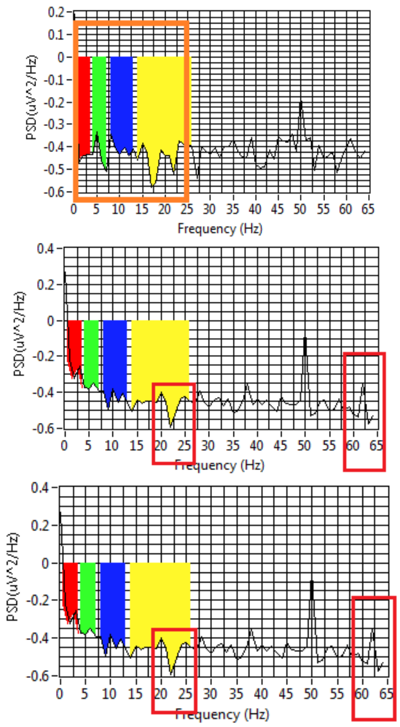


Fig. 9: EEG signals at FZ, FPZ and CZ Positions of Subject2

Subject3: Gender: Male; Age: 65Y

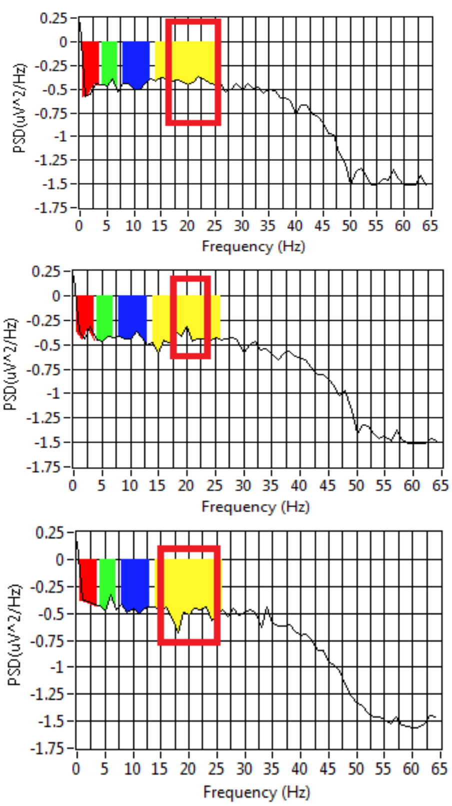


Fig. 10: EEG signals at FZ, FPZ and CZ Positions of Subject3

For young and healthy subjects this task is equivalent to doing nothing so theta regions are predominant when compared to other regions. On the other hand, this task has given some cognitive load on the elderly person, and their excitement is clearly indicated by the variations in the beta regions of the EEG signals.

The next experiment made is to colour a single circle with a single colour. In this experiment also the volunteer's age is varying from 25 years to 65 years

The results are taken by placing electrodes at different positions like FPZ, FZ, CZ, and PZ. The results are as follows:

Subject1. Gender: Male; Age: 27

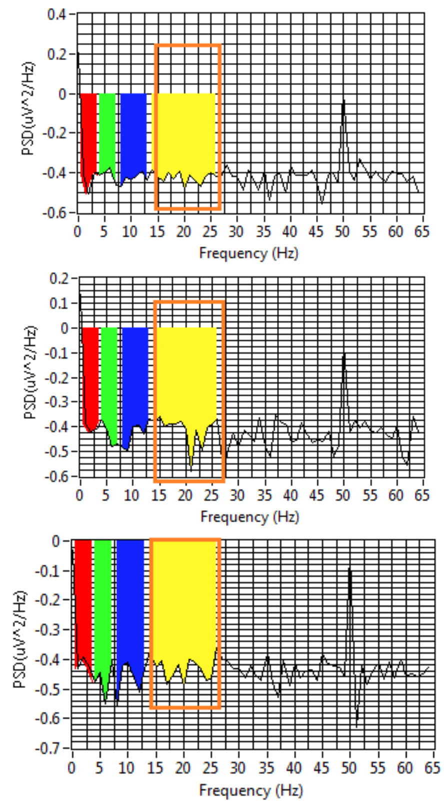


Fig. 11: EEG signals at FZ, FPZ and CZ Positions of Subject1 colouring Single Circle

Subject2: Gender: Female; Age: 60

As illustrated in the above Fig. s, the power spectral density of the beta waves is minimum amongst the other rhythms which indicate that the subject is in relaxed state.

The next experiment is to colour three different circles with three different colours. The three circles are coloured as per the instructions given by the trainer at random intervals.

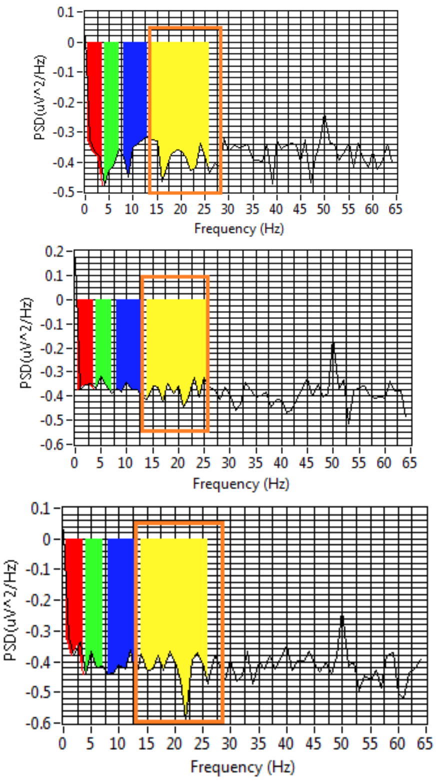


Fig. 12: EEG signals at FZ, FPZ and CZ Positions of Subject1 colouring Single Circle

The red colour region in the graphs shown in Fig. 13 corresponds to delta waves, green region corresponds to theta rhythms, blue region is that of the alpha waves and yellow region corresponds to beta waves

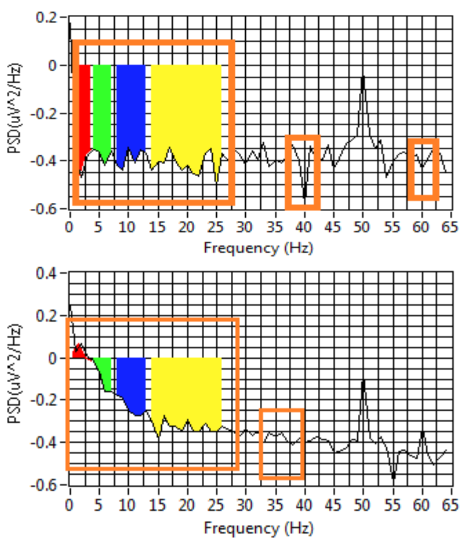


Fig. 13: EEG Waves for Colouring Three Different Circles

As shown in the Fig. , the signals in all the regions are changing according to the instructions given by the trainer. If there is good time between two instructions the persons brain is in the relaxed state. As the time between two instructions is less the excitement is predominantly observed in the beta region.

The variations in Power Spectral Density of these rhythms for each of the experiment are given in Table I.

Table I: PSD for various Features for Subject1

Parameters	Delta(%)	Theta(%)	Alpha (%)	Beta (%)
Eye Open and Close	11	14	21	52
Single Circle Colouring	13	15	21	49
Multi Circle Coloring	14	15	20	50
Left Eye Normal Blink	13	14	21	50

A graph is plotted for the power spectral distribution percentage of each of the rhythms of the EEG signal and is shown in Fig. 14

Then, three threshold levels are chosen for mouse right click, left click and movement of cursor position.

The circuit diagram for interfacing the DAQ to microcontroller is shown in Fig. 15.

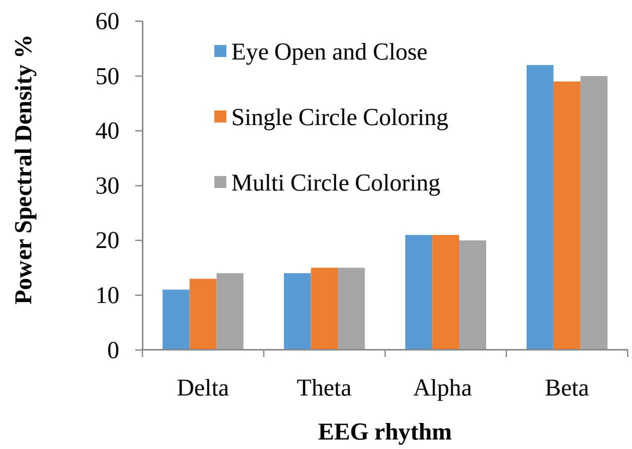


Fig. 14: Power Spectral Density of EEG Rhythms

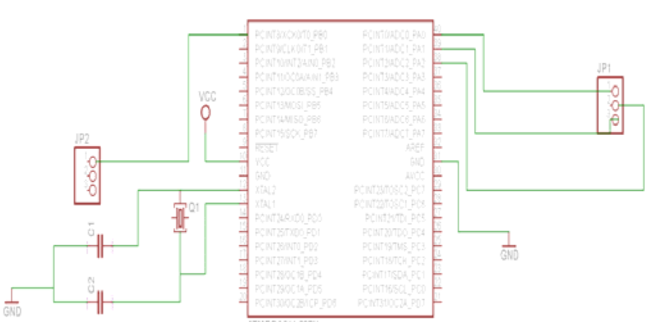


Fig. 15: Schematic for DAQ-Microcontroller Interface

Finally, all the subjects were able to control the mouse by doing all the operations.

9. CONCLUSION

A Brain controlled mouse to operate a personal computer is developed. This mouse can be controlled by elderly people with multiple disabilities. The developed mouse control uses brain signals de-noised by wavelet filters and the blind source separation of beta rhythms is performed using an Independent Component Analysis. Its performance is tested on several human volunteers in the age group of 25 years to 65 years and is found to be working well with almost 100% efficiency

10. ACKNOWLEDGEMENTS

This work is a part of the research project being carried out at Shri Vishnu Engineering College, Bhimavaram with a financial support from Department of Science and Technology (DST). The authors would like to express their sincere thanks to DST for sponsoring the project. The authors wish to express their profound sense of gratitude to Sri. K. V. Vishnu Raju garu Chairman, SVES, for his encouragement towards innovation and research. She also would like to express her sincere thanks to Sri Ravichandran Rajagopal, Vice-Chairman, SVES, for supporting at all times of need. They also would like to thank Dr. G. Srinivasa Rao garu, Principal, SVECW for facilitating with a good research environment. Finally, the first author would like to offer her tributes to (Late) Sri. K. Venkat Rao garu, who had been a source of inspiration to pursue the research in BCI

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