Electroencephalogram-based Brain Controlled Robotic Wheelchair

B. Jenita Amali Rani[1*] and A. Umamakeswari[2]

[1]Embedded Systems, School of Computing, SASTRA University, Thanjavur - 613401, Tamil Nadu, India;
amaliraj29@gmail.com
[2]School of Computing, SASTRA University, Thanjavur - 613401, Tamil Nadu, India; aum@cse.sastra.edu

Abstract

A Brain Computer Interface (BCI) is at its early stage in their development, but the new significant improvement needs to be taken to help bring back the quality of moving freely in a person with a disability. The BCI is a captivating application which could be used in various fields like Gaming, Education, Industrial and Medical areas. In this paper, EEG-based Brain controlled Wheelchair has been developed using BCI with the help of Neuro sky technology. The Event-Related Potential (ERP) offered the Neurosignal information with the help of P300 component. BCI system consists of a Biosensor to capture the EEG/EMG signals. The signals will be processed by the ThinkGear module in MATLAB. The Level Analyzer Technique is performed on all the training signals and Alpha and Beta waves are extracted for controlling the wheelchair. The command signals are transmitted to the Microprocessor via RF medium. The robotic module designed consists of ARM 7 Microprocessor coupled with DC motor to perform the command. The Eye blinking strength and attention level were used to control the direction of the wheelchair. The wireless BCI system could allow the paralyzed people to control their wheelchair without any complexity, provided it is more enhanced, portable and wearable.

Keywords: Brain Computer Interface, ElectroEncephaloGram, ElectroMyoGram, Level Analyzer Technique, Robotic Wheelchair

1. Introduction

Robots have not only been extensively used in industrial areas, but progressively introduced in human day today life. For disabled people, assertive robots are widely used to do their work without human interaction. Particularly, in wheelchair applications, the wheelchair can operate with the conventional input tools like joystick, mouse, voice and keyboard, but these input methods can be efficiently used by healthy people only[1]. However, these input methods are not easy to operate because of the joystick quick turn may leads to more complexity to control the wheelchair for elderly and disabled people[2].

To address this problem, Brain-Computer Interface (BCI) system has been developed as shown in Figure 1. It eliminates the conventional types of communication and provides a direct connection between the human brain and external devices[3]. The Brain-Computer Interface (BCIs) started with Hans Berger, German neurologist who discovered the activities of electrical patterns of the human brain and recorded it with the help of EEG (Electroencephalography). BCI is also called as Mind-Machine interface, which provides a direct contact path between the human brain and the computer or external devices. The activities of electrical signals can be obtained by firing millions of neurons in the brain. When we think, millions of neurons are fired together and each cerebral state generates different patterns of activity. These electrical activities can be measured and recorded from the scalp by using EEG. Normally, BCIs are classified into three methods. They are 1. Invasive BCIs 2. Partially Invasive BCIs and 3. Non-Invasive BCIs.
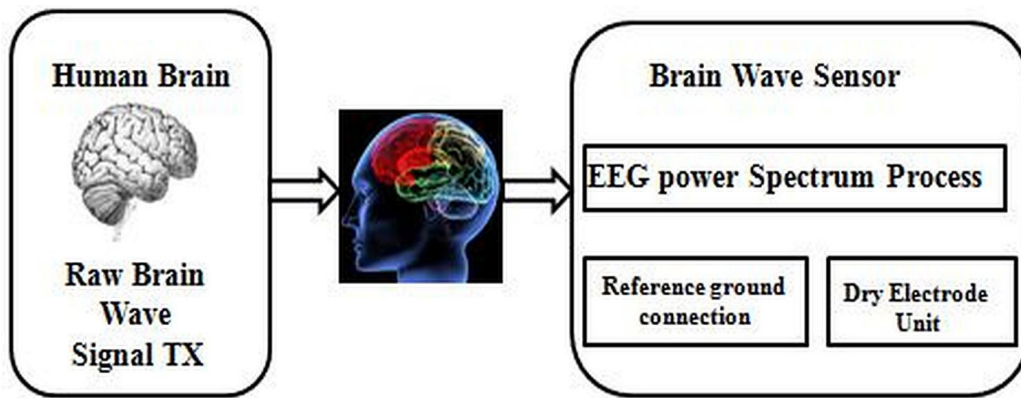
Figure 1. BCI System.

The electrical activities of the brain signals are recorded by using Invasive, Partially Invasive or Non-invasive BCIs. In invasive BCIs method, the electrodes are directly fixed in or on the grey matter using neurosurgery, but in Non-invasive method, small metal electrodes are placed on the surface of the scalp[4].

The human brain can be classified into four structures: Cerebral cortex, cerebellum, brain stem, and hypothalamus. The Cerebral cortex is one of the most concerning and relevant BCIs and it can be divided into two hemispheres. Each hemisphere is again divided into four lobes that are Frontal, Parietal, occipital and temporal lobe. The frontal lobe area is mostly used for obtaining the electrical activities EEG and EMG signal[5]. To capture the neural signals, single channel, dry, bio-sensor located at the FP1 frontal lobe is used. The various parts of consciousness will be captured by using ERP (Event-Related Potentials) or EP (Evoked Potential) with P300 component.

In this paper, EEG and EMG signals are focused to obtain the attention and eye blink in order to move the wheelchair. Mainly EEG signal focused on captured signals from the brain and EMG[6] (electromyogram) which is more focused to pick up the electrical activity given by our muscles. Depending on the type of connections, BCIs[7] are classified into two types, Wired BCIs and Wireless BCIs. The main advantage of the Wireless BCIs system is that it is free from wires and could allow the paralyzed people to control their wheelchair without any complexity, provided it is more enhanced, portable and wearable.

The paper is ordered as follows. Section II, details the related works. Section III, explains proposed methodology. Section IV, describes the EEG analysis and Section V, and explains the design flow. In section VI and VII,

detail the hardware methodology and experimental results. Finally, Section VIII, concludes the paper. The main objective of this paper is to develop a mobility assistive device for physically disabled and elderly people to do their work without others interacting in their life.

2. Related Works

The Brain-Computer Interface (BCIs) system assists the disabled people. In this section, we discuss the various brain-computer system and wheelchair that has been developed with different time span and a brief description of the work[8]. For the past two decades, EEG-based brain-controlled robotic research and its development has achieved a great deal of attention because, it brings back mobility to disabled people with motor disability and neuromuscular disorder. The advantage is that it improves the quality of the disabled people to be self-independent in their life.

Millan et al, proposed the first Noninvasive EEG-based brain-controlled robots. To manage the operation, asynchronous protocol and machines learning techniques were used. The relevant signals were captured by 8 scalp sensors, which are located at the standard fronto centro parietal positions F3, F4, C3, CZ, C4, P3, P2, and P4. The raw EEG signals were first transformed with the help of surface Laplacian and computed by using 2nd order spherical spline. Movement and control over the robot states can be done by mapping the 8 infrared sensory values into six robot's states for the help of Multilayer Perceptron (MLP)[8].

Morten Enemark Lund et al, proposed the concept of wheelchair controlled by the inductive tongue. In order

to follow the standard joystick, 8 sensors with fuzzy logic based control of the multi-directional wheelchair were designed. It has 18 intra oral sensors, which were operated by tongue piercing and the entire setups were placed upon the oral cavity system. The output values of the sensors were transmitted through wireless to the external micro-controller which processed the information in order to control the wheelchair using an analog joystick[9].

Vaibhav Gandhi et al, proposed Adaptive User Interface (iAUI) to control the robot based on an adaptive mechanism of shared control. The acquired EEG signal's noises were removed by using recurrent quantum neural network technique. The major advantage is that it improves the information transfer rate by using multiple motion command options like left, right, backward and start/stop[10].

Pires et al., described a design of Robchairs for overcoming the problem of locomotion and localization. To control the wheelchair, an analog joystick was incorporated on the wheelchair. Gathering the related sensor information, controlling and communicating with the user workstation such a performance can be done by using an RTOS. Obstacle avoidance algorithm was used to avoid the collision[11].

Mandel et al. discussed the Steady-State Visually Evoked Potential (SSVEP) BCI with a shared control system to navigate a wheelchair. The target locations were reached by using the nearness diagram navigation method with a safety layer, which ensured the collision-free movement[12].

3. Proposed Methodology

3.1 System Overview

The proposed EEG-Based Brain Controlled Robotic Wheelchair consists of three modules:

3.1.1 BCI System Module

Bio-sensing technologies play a vital role in health care. The Wireless EEG headset consists of a single-channel, dry, bio-sensor which is used to capture the EEG and EMG signals (Attention and Eye blink) located on the

FP1 frontal lobe. Table 1 gives the information about the specification of wireless EEG headset.

The signal processing can be done in data processing module with the help of MATLAB tool. The captured signals are preprocessed by ThinkGear and sent to the PC.
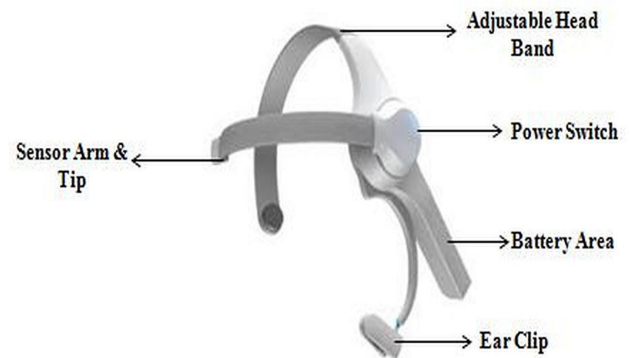
Figure 2. NeuroSky Wireless EEG headset.

The Figure 2 shows the NeuroSky wireless EEG headset for capture the Neuro signals.

3.1.2 Data Processing Module

The artifacts and noise produced in the system can be removed by performing FFT analysis. The Attention[13] and blinking signal levels are differentiated by using the Level analyzer technique. The output signals are transmitted to the wheelchair.

### 3.1.3 Robotic Wheelchair Module

It consists of an ARM 7 Microprocessor to control the movement of the wheelchair by capturing the command received. The prototype model of the wheelchair with above specifications is designed for evaluating the working model.

4. EEG Analysis

4.1 Electroencephalogram (EEG) Acquisition

A wireless Single-channel EEG bio-sensor is used to capt-

Table 1. NeuroSky wireless EEG headset Specification

Dry EEG system	Sensor type	Bandwidth	Resolution	Channels	Sampling rate	Transfer	Weight	Battery life
NeuroSky	Dry	3-100 Hz	12 bits	1	512 Hz	Wireless	90g	8 Hours

ure the electrical signals in the brain, which is located on the frontal lobe (FP1). The other ground and reference electrodes are placed on the earlobe. Figure 3 shows the location of an EEG sensor for recording the Neuro signal.
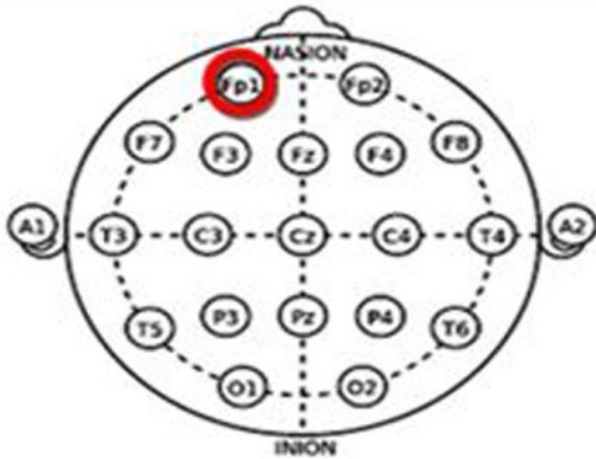
Figure 3. Biosensor placed in the position of FP1 on frontal lobe for EEG recordings.

An event-related potential offered a sensory information about the brain response at a specific latency time and P300 is evoked at every 300ms after the specific event occurs. P300 is widely used in the BCI world for the performance of detecting the target. In this paper, EEG and EMG were used for acquired signals. EEG focused on obtaining the brain electrical activities and EMG more concentrated on capturing the muscle activities like Eye blink. Generally, EEG signals are characterized by rhythmic activity. Each band has a different level of rhythmic

activities. Table 2 gives the information about the different frequency bands and their rhythmic activities.

The level analyzer values have been determined by using the ThinkGear technology meter-values of attention and eye blink strength. The attention or concentration can be managed visually focusing on a particular point. During the focusing or concentration of the particular user, level range from 1-100[14]. The strength of observed blink value range from 0-255, (for small blink-0 and large blink-255) the attention range between 40-60 at any given moment is considered as "neutral or baseline". The range between 60-80 is "slightly elevated" and above 80 is considered as "elevated[15]".

The EEG raw signal which is collected can be analyzed by using offline processing method. The computation of the signals is done with the help of MATLAB process. However, in MATLAB, C programming has been written to remove the artifact and noise from the EEG electrical signals and only the range of Alpha (8-12 Hz) and Beta (13-30 Hz) can be taken out for further processing. The Level analyzer technique applies to both signals for signal classification.

Steps to be followed for signal Classification:
1. Assign port num1 to the appropriate COM port.
2. Initialize the EEG headset.
3. Get the Neuro signals from Wireless EEG headset Via RF module.
4. Checks, If (Blinking Strength > 40 && blink level == 3), Interrupt has been sent to start the wheelchair.
5. Then, Check If (Focusing level > 50), for moving forward.

Table 2. EEG rhythmic activity frequency bands

| Band	Frequency	Applications
Delta	1-3 Hz	Found during continuous attention tasks
Theta	4-7 Hz	Drowsiness in adults
Alpha 1 Alpha 2	8-9 Hz 10-12 Hz	Relaxed Closing the eyes
Beta 1 Beta 2	13- 17 Hz 18-30 Hz	Active thinking, Hi alert Focus
Gamma 1 Gamma 2	31- 40 Hz 41- 50 Hz	Shown in short-term memory matching and in cross modal sensory

6. Check, If (blink strength > 90), send an interrupt for moving right side.
7. Else.
8. Check, If (blink strength < 60), send an interrupt for moving the left side.
9. Go back to Step 6.

Using MATLAB programming, Interrupt threshold levels are assigned to each condition in MATLAB tool, by obtaining the correct interrupt function for Blink and Attention. These values are transmitted via RF module to the Microprocessor for wheelchair maneuvers. This paper describes various Interrupts for different types of action to control the wheelchair, depending on user desire, they can change their mode to operate and control. The interrupts names and their corresponding actions are listed in Table 3.

Table 3. Interrupt names and their corresponding actions

Interrupt	Corresponding actions
W	To move forward
S	To move backward
D	To turn right
A	To turn left
E	Rotate Clockwise
Q	Rotate Anticlockwise
O	Rotate 90 Degrees
P	Rotate 180 Degrees
Z	Forward Continuously
X	Stop

After analyzing the resulting values, the recorded EEG data of Attention and Eye Blink over the specified period of time has been plotted. The black line shows the blinking strength, and the red line shows the attention level of the particular user as shown in this Figure 4.
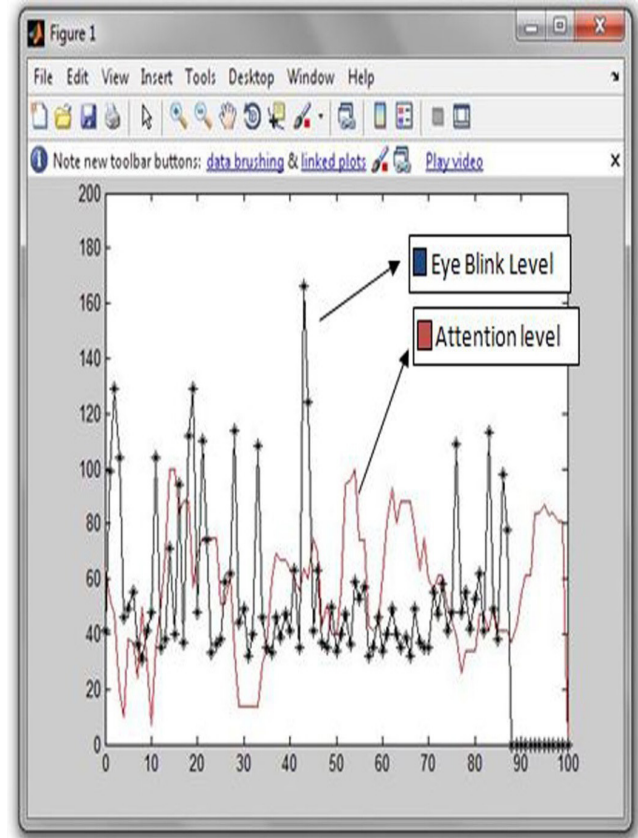
Figure 4. Black lines indicate blinking strength and Red lines indicate Attention Level of the user.

5. Design Flow

The workflow gives the step by step process about the brain-controlled wheelchair. The Figure 5 shows the design flow of brain controlled wheelchair. Initially, the NeuroSky headset16 is turned on, which is capable of gathering the neuro signals. The EEG, dry, Biosensor captures the signal and sends to thinkGear technology for preprocessing the raw EEG data. After analyzing, digital signals are sent to the MATLAB computing environment for extracting the alpha and beta wave signals for further classification. The Level analyzer technique is used to process the signal. The Eye blink and focusing level will be taken for analyzing the process. According to the level of the eye blink and focusing level, the corresponding interrupt will be sent to the processor via RF module. The two DC motors coupled with the processor controls the movement of the wheelchair. Each interrupt has a corresponding control operation like (Forward, Turn right. Turn left and stop... etc.)
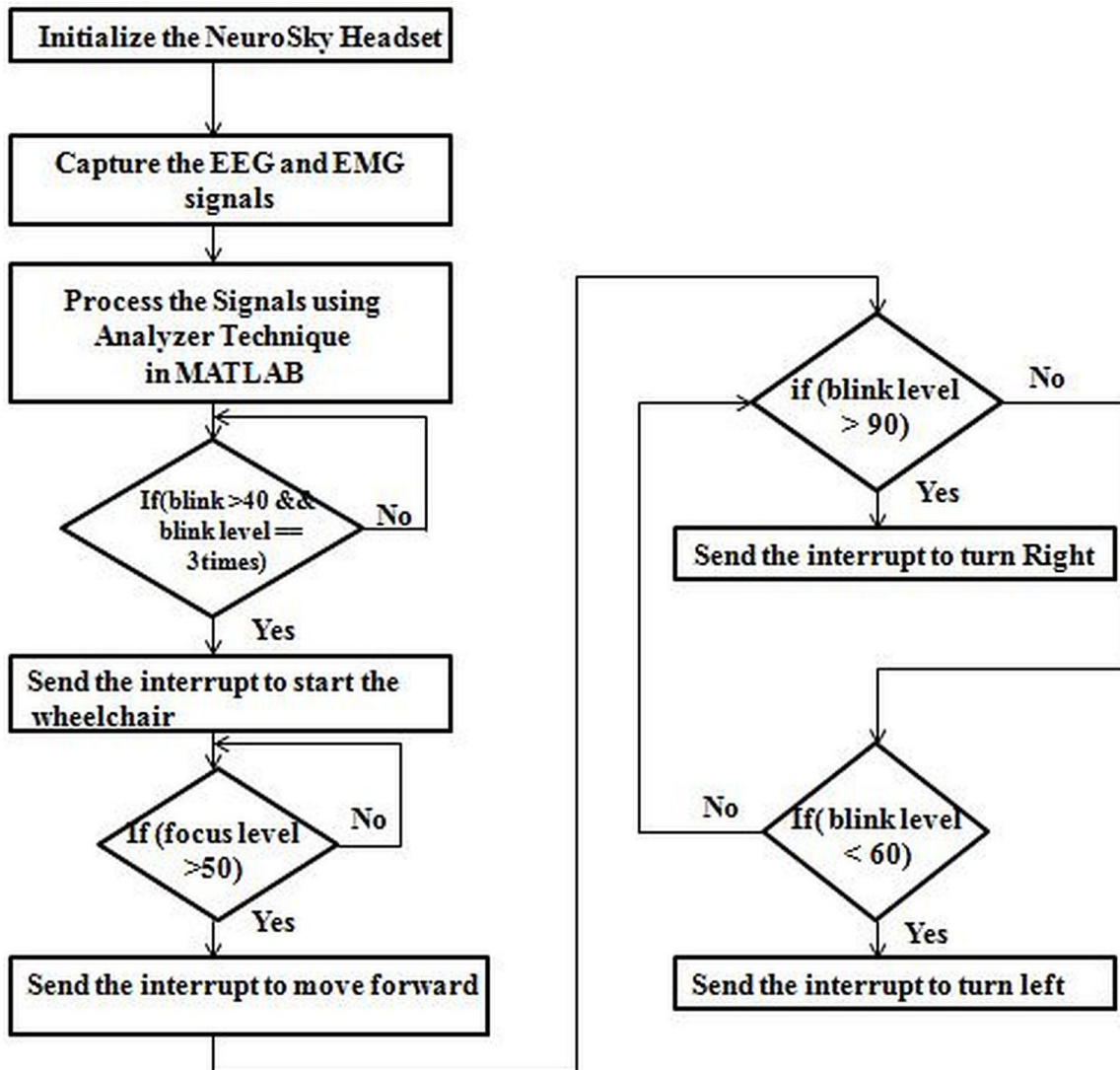
Figure 5. Design flow of brain controlled wheelchair.

6. System Hardware

6.1 ARM Processor

ARM 7 (LPC2148) processor based on 32 bit operation, with RISC (Reduced Instruction Set Computer) Principle. It is based on Von Neumann Architecture, which shares the data and instruction both in the same bus. The ARM 7 processors have 16 data registers and two processor status register. It uses Pipeline Mechanism to execute the instruction. The main features of ARM 7 are low power and high performance. In this hardware setup, ARM Processor is used for receiving the signals from RF module and process it. After processing the signals, it sends the control to the DC motor circuit in order to direct the

movement of the wheelchair accordingly (forward, left, right and backward)[17].

6.2 RF Module

RF module is a device which transmits and/or receives the signals from one device to another device through radio frequency communication. For wireless communication, XBee[18,19] and XBee-PRO OEM RF Modules were engineered to IEEE 802.15.4 standards. It has low power and low-cost wireless sensor networks. It provides reliable delivery of data and operates within ISM 2.4GHz frequency band. An RF Transmitter module[20] is connected to PC via Serial data Converter. The Processed values are sent via RS 232 to the Xbee receiver. The XBee receiver

collects the information and forwards it to the Processor via UART[21].

6.3 Software Description

The KEIL μversion3 is used to compile and debug the program. Embedded C is used to feed instruction to the processor. The program was downloaded into the hardware and the simulation results were obtained. Figure 6 shows the simulation result of interrupt command to the DC motor using KEIL software.

7. Experimental Result

ARM 7 Processor act as a controlling core and XBee communication act as a transmission medium for data transfer. The Personal computer is working as a signal-processing center by using MATLAB computing environment. Neurosky technology is used, to capture the neuro signals patterns from the user, where the single channel, dry, and biosensor located at the FP1 frontal lobe with minimal hair area. It delivers the raw EEG signals with some noise and artifact's values. To communicate

Figure 6. Simulation result.

with PC, first Neurosky software needs to install on PC. After completing the installation, they ensure the connection and communicate with PC via Bluetooth.

The function of Thinkgear technology allows the headset to measure the EEG signals and pre-process the signals. It removes the unwanted noise and artifacts from the packets of data, which obtain from the sensor. The sample training signals are to be taken from the buffer and preprocessed for extracting the Alpha and Beta (focusing and Eye Blink) signal. They applied, the Level Analyzer Technique for each of these patterns and categorize the signal according to the described condition level for eye blink and focusing or attention. The entire process is done on MATLAB. Figure 7 shows the overview the system.

The output is sent in the form of interrupt from MATLAB to Microprocessor via RF modules like Xbee or XBee-PRO module. The output is sent from PC to Xbee through the serial data converter. The Robotic platform consists of ARM 7 Microprocessor coupled with two DC motors for wheelchair movement. The receiver side Xbee connects with Processor by UART for sending the collected output to the processor. The direction of the wheelchair will be controlled by the reception of the interrupt value. Each interrupt has its own control function and depending on the arrival of interrupt value the operation will be changed. The impaired people can control their wheelchair by EEG based technology without any complexity. It gives the quality of life to the disabled
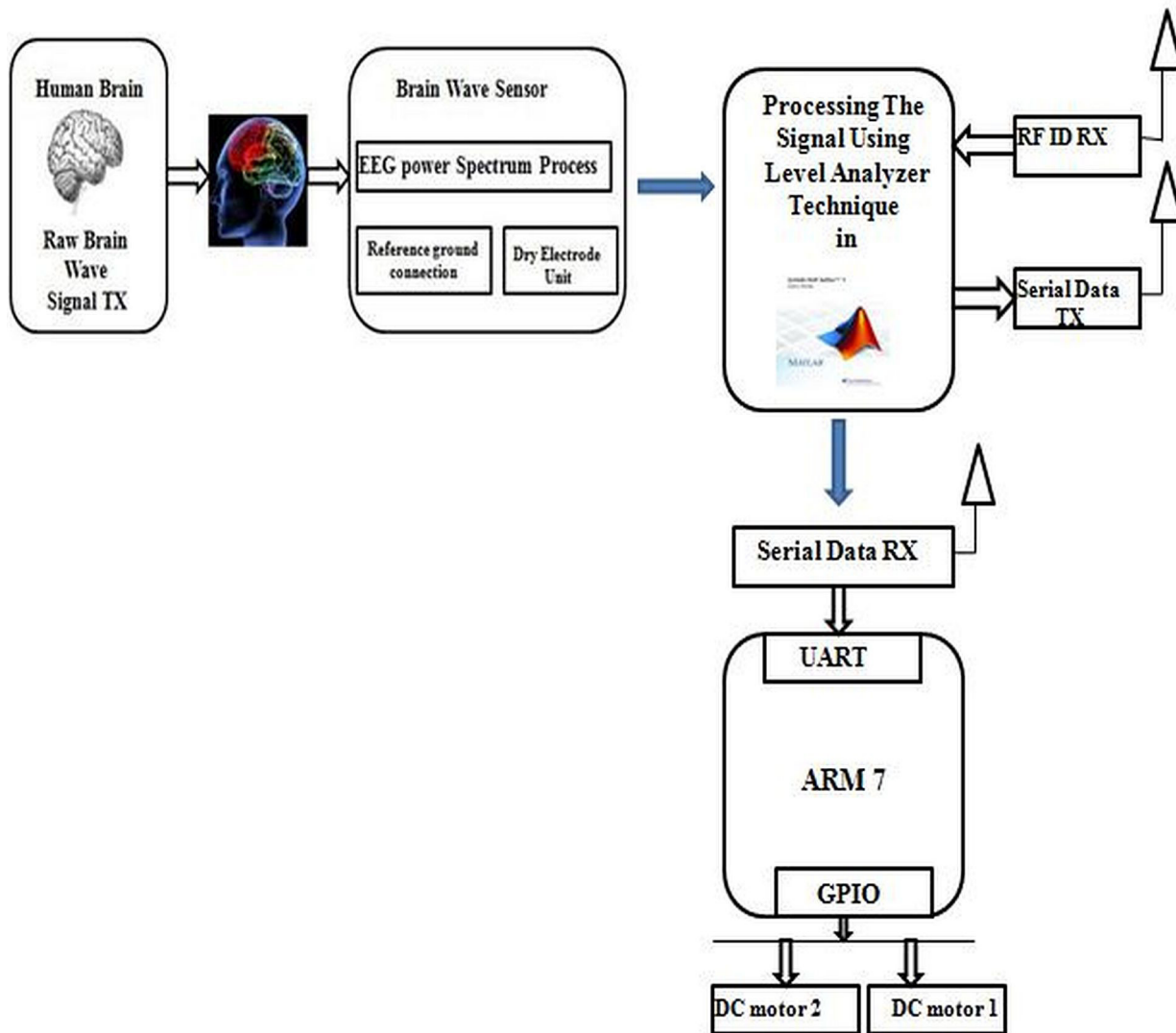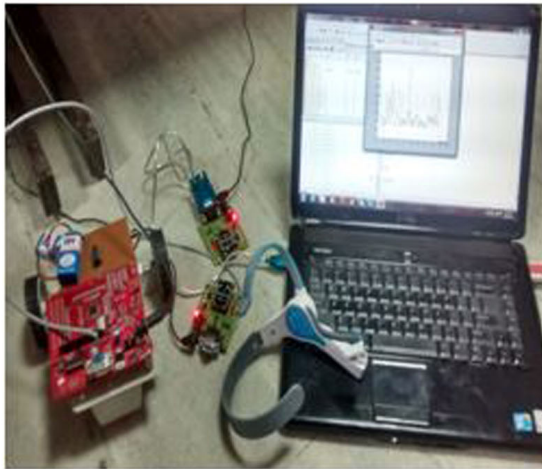

Figure 7. The overview of the system.

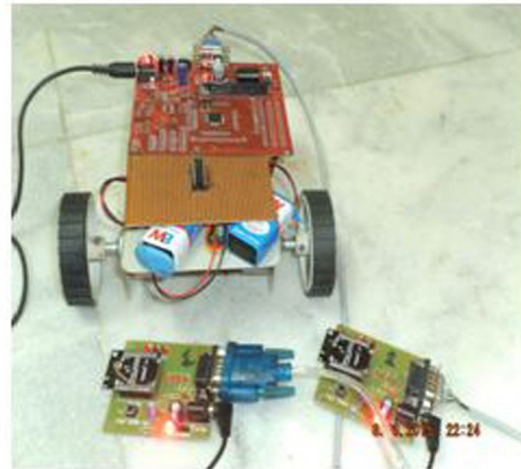**Figure 8.**   Find Cut Dimension – Pseudo Code.

people with independent of wires and provides enhanced portability, free motion, wearable with low power consumption. Figure 8 shows the experimental setup.

8. Conclusion and Future work

An EEG-based Brain-controlled wheelchair was developed for elderly and disabled people to lead their daily life without any difficulties. Two methods were proposed. The attention signal was used for making a forward movement of the prototype and Eye blink strength was used for controlling the start/stop operations. The performance based on various metrics was analyzed. The prototype model of EEG-based wheelchair has been developed with the help of Neuro sky technology. The level analyzer technique was implemented in signal processing and the wheelchair was controlled by ARM 7 Microprocessor. It can assist the people do their work without human interaction and enrich their standard of life. Though the BCI system field is at its early development, but it requires improvement on the wheelchair to be more user-friendly. The wheelchair shall be further enhanced by removing artifacts and noise level precisely in signal processing and focus on additional improvement of the detection of irregular eye blink so that, the wheelchair can be controlled accurately without any collision.

9. References

1. Kanniga E, Selvaramarathnam K, Sundararajan M. Embedded control using mems sensor with voice command and CCTV camera. Indian Journal of Science and Technology. 2013; 6(6):4794–6.
2. Perrin X, Colas F, Pradalier C, Siegwart R, Chavarriaga R, del RMJ. Learning user habits for semi-autonomous navigation using low throughput interfaces. 2011 IEEE International Conference on Systems, Man, and Cybernetics (SMC); IEEE; 2011.
3. Lee S, Shin Y, Woo S, Kim K, Lee H, Fazel-Rezai R. Review of wireless brain-computer interface systems. In: Fazel-Rezai R, editor. Brain-Computer Interface Systems - Recent Progress and Future Prospects. 2013.
4. Brain Computer Interface.
5. Fischl B, Salat DH, Busa E, Albert M, Dieterich M, Haselgrove C, et al. Whole brain segmentation: automated labeling of neuroanatomical structures in the human brain. Neuron. 2002; 33(3):341–55.
6. Mahendran R. EMG signal based control of an intelligent wheelchair. IEEE International Conference on Communications and Signal Processing (ICCSP); 2014. p. 1267–72.
7. Kaur M, Ahmed P, Rafiq MQ. Technology development for unblessed people using BCI: A Survey. International Journal of Computer Applications. 2012; 40(1):18–24.
8. Bi L, Fan X-A, Liu Y. EEG-based brain-controlled mobile robots: a survey. IEEE Transactions on Human-Machine Systems. 2013; 43(2):161–76.
9. Lund ME, Christiensen HV, Caltenco HA, Lontis ER, Bentsen B, Struijk J. Inductive tongue control of powered wheelchairs. 2010 Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC); IEEE; 2010. p. 3361–4.
10. Gandhi V, Prasad G, Coyle D, Behera L, McGinnity TM. EEG-based mobile robot control through an adaptive

brain-robot interface. IEEE Transactions on Systems, Man, and Cybernetics: Systems. 2014; 44(9):1278–85.

11. Pires G, Honorio N, Lopes C, Nunes U, Almeida A. Autonomous wheelchair for disabled people. Proceedings of the IEEE International Symposium on Industrial Electronics (ISIE); 1997.

12. Mandel C, Luth T, Laue T, Rofer T, Graser A, Krieg-Bruckner B. Navigating a smart wheelchair with a brain-computer interface interpreting steady-state visual evoked potentials. 2009 IROS 2009 IEEE/RSJ International Conference on Intelligent Robots and Systems; IEEE; 2009.

13. Rebolledo-Mendez G, Dunwell I, Martinez-Miron EA, Vargas-Cerdan MD, De Freitas S, Liarokapis F, et al. Assessing neurosky's usability to detect attention levels in an assessment exercise. Human-Computer Interaction New Trends. 2009; 5610:149–58.

14. NeuroSky Mindset Instruction Manual. Available from: http://developer.neurosky.com/docs/doku.php?id=hinkgear.net_sdk_dev_guide_and_api_reference.

15. NeuroSky Mindset Instruction Manual. NeuroSky, Inc; 2009 June 19.

16. NeuroSky BrainWave Signal (EEG) of NeuroSky, Inc. Available from: http://frontiernerds.com/files/neurosky-vs-medical-eeg.pdf

17. Carlson T, Demiris Y. Human-wheelchair collaboration through prediction of intention and adaptive assistance. IEEE International Conference on Robotics and Automation (IEEE-ICRA 2008); 2008.

18. Piyare R, Lee S-R. Performance analysis of XBee ZB module based wireless sensor networks. International Journal of Scientific and Engineering Research. 2013; 4(4):1615–21.

19. XBee manual. Available from: https://www.sparkfun.com/datasheets/Wireless/Zigbee/XBee-Manual.pdf

20. Kumar KA, Thamizharasi K. Gesture controlled robot using MEMS accelerometer for eradication of weeds. Indian Journal of Science and Technology. 2015; 8(5):460–5.

21. XBee manual. Available from: https://www.sparkfun.com/datasheets/Wireless/Zigbee/XBee-Manual.p