Cognitive Efficiency in Robot Control by Emotiv EPOC

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Abstract— **Brain Computer Interface (BCI) has opened a new era in the field of neuroscience. It has the potentiality to improve the quality of life of severely disabled patients. It allows them to regain the power of moving things by their affective, cognitive and expressive brain activities. Emotiv EPOC head set is a safe and comfortable BCI system which contains a number of advanced electrode sensors. It can detect and process the user's thoughts, feelings and expressions in real time. A prototype of two wheeler robot is implemented and experimented which was controlled by the thought of human being. In average 72.65% accuracy is observed in the experiment for different aged people from 14 to 30 years old where the accuracy for the physically challenged people is 82% in average. Firstly the prototype software has to be trained by a specific user then it controls a wireless robot by the person's thought for driving the robot in forward, backward, left and right directions. This robot can be stopped by a specific facial expression which does not need any training. The article also investigated the shortcomings and reviews on the reliability of the cognitive output efficiency of Emotiv EPOC EEG device, based on user comments and related researches.**

Keywords- BCI, EEG, EMG, EOG, Sequential sampling. Efficiency

I.   INTRODUCTION

Electroencephalography (EEG) is well known term in BCI research community. Researches show that brain-computer interfaces (BCIs) have allowed some interesting advances in the area of medically disabled patients and it allows prosthetic limb and device movement [1], [2]. In the medical research area, BCI have been implemented to allow people with disabilities to guide wheelchairs [3]. Vehicle guidance have got a new arena as mind controlled vehicle allows for the prediction of voluntary human movement more than one-half second before it occurs [4], [5], [6]. The intention of moving something is generally known as cognitive thought in BCI. It becomes useful for severely paralyzed people to move things around them by the help of BCI. This technology is used to detect driver fatigue [7], [8], [9] and driver sleepiness [10], [11], [12]. Some other researches are also observed on mind controlled car [13], [14]. Efficiency of cognitive control is still a big challenge for controlling devices and even vehicles.

Brain computer interfacing has opened a new era to the world of technology. Brain-computer interfaces (BCIs) allow the user to interact with a system through mental actions alone unlike traditional control procedures such as physical manipulation or verbal commands [15]. There are basically two techniques that are used to monitor the user's brain activity and they include invasive (cortically-implanted electrodes) and non-invasive (EEG type) techniques. Invasive techniques usually provide more precise and accurate measurements. Neural activity from cerebral cortex is extracted and used to control prosthetic limb [7], [16]. To state specifically, in the invasive technique the subject on whom the experiment is to be done has to undergo an operation which includes implantation of electrodes or chemical substances in the brain [9]. Our society is still not ready to accept this kind of system. Even when we went with external Emotiv headset, we faced number of protests from patients and physically challenged group even though it did not include cortical implantation of electrodes. Emotiv EPOC uses a noninvasive type brainwave monitoring system where EEG is recording the data of electric activity in an interval of 20-40 minutes or even less from the scalp of the brain [17]. Noninvasive technique comes with an advantage of relieving the subject from the difficulties of operation as the subject can easily measure the neural activity through simple wearable items. EEG actually monitors the voltage fluctuations resulting from ionic current flows within the neurons of the brain and it occurs 1.5s before the movement takes place [4]. Diagnostic applications mainly focus on the neural oscillation provided with the EEG signals. After the recording of the stream of data usually the data are processed by detailed algorithm to decode the subjects' intention. The simple Event Related Potentials (ERP) makes this algorithm powerful and generalizes across users. The ERP component that emerges in the process of decision making is called the P300 (P3) wave [18]. It has been found that an event related potential across the parietal-central area of the skull is 300 ms and is lager after the target stimulus [18], [19]. To cut short, the process is all about combining the target items of low-probability with the high-probability non-target items which are detected by EEG and Electromyography (EMG). BCIs have been implemented on the patients with diseases that included problems regarding central nervous system. So, BCI has always been the only medium to interact with the world [20], [21]. With the vast advancement of sensor and related technology along with the improvement of algorithm type, BCIs have shown its potential not only to the clinical context but also to the general people.

In our research a robot is built which can follow brain commands efficiently. The intention was to experiment Emotiv EPOC on different type of users of different age and physical attributes to find the accuracy so that we can use it in robotic and autonomous applications. Users move the robot in specific directions according to our call. Our users were from the age range 14 to 30 years old including physically fit and physically challenged groups. Several differences were noticed on the pattern of thinking while training that provides the user thought pattern to Emotiv headset. For example some user were seemed to think about pushing a big box while some other thought about blowing something for training the PUSH command. After literature review and motivation, the paper is decorated with the architecture, implementation of software and hardware, communication and interfacing with robot. Experiment and result analysis is present before conclusion. The simple block diagram of prototype system is in figure 1 where "PriSha" indicates the name of interfacing software.
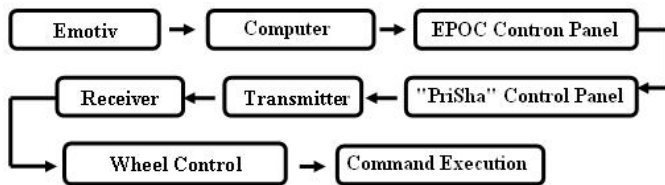

Figure 1. Simple block diagram

II. MOTIVATION

The patients who are not able to move any of the body parts and even speak; BCIs have been the only means for them to move things and even conversion of their thoughts in written form. Thus, the disabled or paralyzed patients can feel the essence of overcoming their inabilities to some extent as BCI is creating the path for them to communicate with other human. This is the reason that patients nowadays are adopting BCIs overlooking the shortcomings of it. With the vast advancement of sensor and related technology along with the improvement of algorithm type BCIs have shown its potential not only to the clinical context but also to the general people. Paralyzed or partially paralyzed people are very dependent on an assistant. BCI has opened a solution for them to reduce their dependency on others. Moreover, Emotiv Company provides a cheap consumer headset which is within the reach of common people.

The main motivation of the paper is to find the user efficiency in controlling devices with the cognitive thought which is extracted by this device. We prepared a robot and let the user control it with their thoughts and finally calculated the efficiency. This efficiency measurement led us to some significant conclusion about the user effectiveness of the device.

III. ARCHITECTURE

The architecture and control flow and communication is shown in figure 2. Firstly, the user has to wear the emotiv headset around his scalp as instructed in the Emotiv EPOC manual [22]. Then the thought is extracted by the headset and is sent to the control panel software. The control panel decodes the thought and responds by moving a virtual cube in specific directions according to the cognitive thought output. Then the thought is triggered with a key mechanism which ultimately presses the keys of our software. Our software sends the signal to the microcontroller with a transmitter. The microcontroller with the transmitter part sends the data which it gets from the "PriSha" software to the wireless receiver .The receiver microcontroller is burned with a particular code that sends specific commands to robot .This microcontroller is connected with a DC motor shield and a Radio Frequency (RF)-433MHz wireless receiver. Now after the receiver part receives the signals, the microcontroller on that part is programmed to manipulate the received signal and move the robot wheel in any specific direction.

IV. IMPLEMENTATION

A. Emotiv Configuration

Emotiv EPOC is a 14 channels neuroheadset. It has CMS and DRL references. These are used to achieve optimal positioning for accurate spatial resolution. The channel names are: AF3, AF4, F3, F4, F7, F8, FC5, FC6, P3 (CMS), P4 (DRL), P7, P8, T7, T8, 01, 02 of these channels AF3, AF4, F3, F4, F7and F8 are used for taking frontal EEG data from the part of the brain which is involved in planning, organizing, problem solving, selective attention and personality [14]. FC5 and FC6 are used for taking EEG from the part of the brain which works on the processes that are engaged in preparing a response of front-central EEG [23], [24].
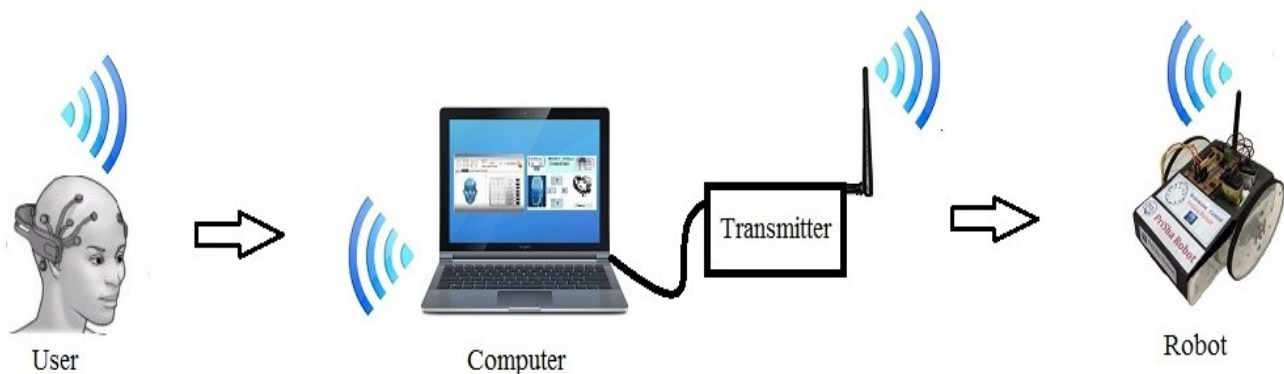

Figure 2. Overall System Diagram

To take EEG from the region in the back of the brain which processes visual information and which is mainly responsible for visual processing O1 and O2 channels are used. In case for partial area which controls sensation FC5 and FC6 are used. There are two temporal lobes, one on each side of the brain located at about the level of the ears. These lobes allow a person to differentiate one smell from another and one sound from another. They also help in sorting new information. T7, T8 are used for taking data from temporal sites. Figure 3 shows different connections of the sensors around the scalp and Table I is showing the Emotiv Headset configuration
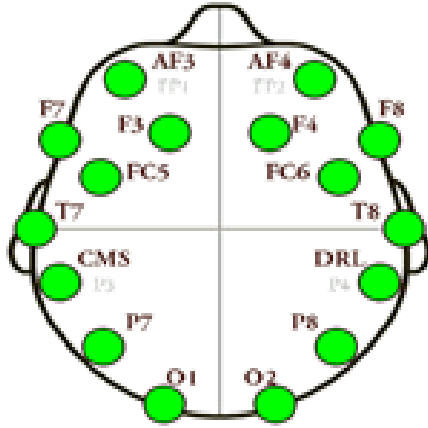

Figure 3. Sensors around the scalp

TABLE I. EMOTV HEADSET CONFIGURATION

Sl.no.	Emotiv Neuroheadset	
	Specification key	*Specifications*
1	Number of channels	14 channels with CMS/DRL references)
2	Sampling method	Sequential sampling, Single ADC
3	Channel names	AF3, AF4, F3, F4, F7, F8, FC5, FC6, P3 (CMS), P4 (DRL), P7, P8, T7, T8, O1, O2
4	Sampling rate	~128Hz but internally it is 2048Hz
5	Resolution	16 bits (14 bits effective) 1 LSB = 0.51µV
6	Dynamic range (input referred)	256mVpp
7	Bandwidth	0.2 - 45Hz and digital notch filters at 50Hz and 60Hz
8	Coupling mode	AC coupled
9	Connectivity	Proprietary wireless, 2.4GHz band
10	Impedance measurement	Contact quality using patented system
11	Battery Life	12 hours
12	Battery Type	Li-Poly

Sequential sampling and Single Analog to digital converter (ADC) sequential sampling is used internally in the Emotiv device. Sequential sampling is a non-probability sampling technique where one has to take single or a group of data in a

given time interval and analyze the results then again taking another group of data if needed and so on [25], [26]. ADC is a device that converts a continuous voltage to a digital number as the quantity's amplitude. The conversion involves quantization of the input [27].

Fixed sampling rate of 128Hz is used. Internally it is oversampled at 2048 Hz per channel but this bandwidth is used to remove very high harmonic electric frequency. If this harmonics are not removed then it mixes with the brain waves. The signal is filtered to reduce the frequency to 128Hz for wireless transmission. The main reason other systems offer higher sampling rates is to allow enough bandwidth to remove these signals. EPOC has an upper bandwidth limit of around 43Hz to avoid 50Hz and 60Hz interference in order to avoid very first evoked potentials [28], [29], [30]. Dynamic range is 256Vpp for Emotiv EPOC and EPOC is built in digital 5th order Sinc filter. It is an "ideal" low-pass filter. Coupling mode of Emotiv EPOC is AC. Proprietary wireless networks is used for Emotiv headset as it makes one of its' own protocols to get a reliable communication link in the 2.4 GHz band. The headset has a 3.7 volt and 600 milliamp rechargeable Lithium Battery inside it which provides users to use 12 hours continuously [31].

B. Emotiv Interfacing Software

The Emotiv headset collects sequentially sampled data and supplies the data to an application called EPOC Control Panel. It processes the data and provides three built- in outputs and they are- Affective, Cognitive, Expressive suits [32]. Expressive suit detects facial movements and detects different states such as smile, raise brow, left wink, right wink etc. Affective suit measures positive mental states such as concentration, meditation and excitement. Cognitive part stores user's neutral or relaxed mental state at first. Then system trained by the user's specific thoughts. Control panel has a C++ API which allows other applications to communicate with the control panel software [33]. Our "PriSha" software connected with the control panel using this application.

Proper wearing of headset shows a visual image of sensors in the screen like figure 3. Green represents the best quality contact, while a led turns black that means there is no signal, red for very poor signal, orange for poor signal and yellow for fair signal. A graphical representation of incoming EEG signals is shown in the control panel which is used for training and recognition of thought. Emobot is a virtual robot in the control panel that copies different facial and head movements of user. It copies different expressive states such as left wink, right wink, raise brow, smile, and blink and clinch teeth. Actually EMG portion of EEG data records the electric activity that is produced from the muscle movements [5], [6]. When The EEG data is recorded then muscle movements provide some extra data and are counted as noise which is usually filtered. Brain wave frequencies have been categorized into bands of different frequencies and they are delta (0.1-3.5Hz), theta (4-7.5Hz), alpha (8-13Hz), and gamma (greater than 30Hz). Different activities of our brain create different frequencies. For example imaginary motor control which relates to our motor control creates alpha band frequency. The system understands different

intention of the user through examining these frequencies [33], [34].

Electrooculography (EOG) is used to monitor the movements of eyes. The Emobot follows the user eyes if it is left or right [35], [3]. EMG and EOG are approximately same among different users so user does not need to train their data for getting facial output groups. These states can be used as commands by setting different keywords, mouse control and even audio files can be triggered with different states. For example a facial expression such as "Clinch Teeth' can be aligned with a "☺" or any emoticons, key words, audio files.

Cognitive part recognizes several directions of a floating virtual cube of control panel based on the several user thoughts. Thirteen intentional thoughts can be recognized and they are: UP, DOWN, RIGHT, LEFT, ROTATE RIGHT, ROTATE LEFT, LIFT, PUSH, PULL, DROP and INVISIBLE. The user need to train their data for each thought before using it. The user first has to provide neutral data by completely relaxing for eight second training period. Then for any specific thoughts out of the thirteen, the user has to train for eight seconds. The system stores the data using ERP which is taken during the training period and matches the data with the user thought to detect users' specific thoughts. A user can set only four thoughts at a time with the keywords or mouse control and even audio files. In our application we used PUSH, DROP, RIGHT, LEFT for forward, backward, right and left operation

C. Prototype Robot

Simple acrylic robot prototype is constructed which consists of two wheels that can move forward, backward, right and left, receiving command from the computer. The robot wheels are prepared by two 60RPM 12 volt DC motors. DC motor shield is also prepared to control the robot with the microcontroller. Figure4 is showing the robot that we prepared as a prototype for our system. Control software, control circuit, communication protocol and power are needed to control this piece of hardware.

Figure 4.   PriSha Robot

D. Interfacing software "PriSha" with the control panel

A graphical user interface (GUI) named "BRAU PriSha Control Panel" is developed to receive signal from the EPOC control panel. Our GUI and backend software is built on C#. On GUI it has four buttons that can listen for keyboard input. The buttons are usually blue. With each consecutive press of the buttons W, A, D and Z the buttons becomes red which indicates which particular key has been pressed. Figure 5 represents the software.

Figure 5.   BRACU PriSha Control Pannel

E. Sending output data from PriSha to the microcontroller

PriSha has a "connect" button on it as in figure 5. The software is designed in such a way that whenever the connect button is pressed the software directly connects with the microcontroller that is attached with an RF-433MHz transmitter. Before pressing the connect button the microcontroller has to be burned with particular code. Then while we press the connect button the microcontroller with transmitter part directly reads data from our software. Then the data is sent to another microcontroller. This microcontroller is attached with a motor shield. We built the motor shield for flexible operation of the microcontroller.

F. Motor Shield

We have used a DC motor shield as it allows controlling the wheel of the robot smoothly. It also solves speed and heat regarding problems. We made this motor shield as in figure 5 using the following circuit diagram.
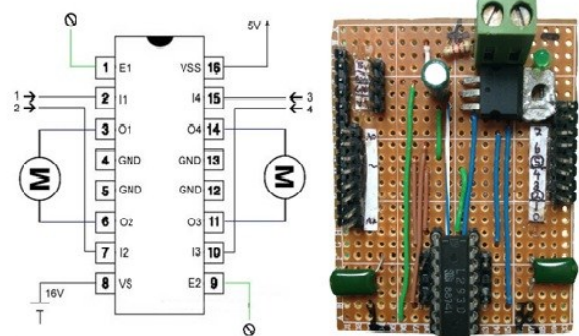

Figure 6.   Motor Shield

We used the above figure which represents the internal wiring of 88741 to build our motor shield .In our motor shield circuit we used 88741 microcontroller .Four input pins are I1, I2, I3, I4 and enable Pins are E1, E2. Outputs pins are O1, O2, O3, and O4 for two DC motors. Pin numbers 4,5,13 and 12 is grounded. Pin no. 8 requires 16 volt and pin no. 16 requires 5 volt voltage. Voltage sources are connected with the according pins with a simple circuitry connection. A maximum of 2 to 4 ampere current can be tolerated by the channels. To control the robot we programmed the microcontroller and we set the baud rate at 9600 and it is similar to the "PriSha" control panel software baud rate.

G.   Robot moves from brain commands

Firstly, W, A, D and Z commands are set with the specific thoughts. For example, W can be set for Push command, A for Left, D for Right and Z for Drop command. Whenever the user thinks about pushing anything the control panel triggers W and the forward button in the "BRACU PriSha Control Panel" software is pressed. Then through transmitting over the transmitter part ultimately the receiver part at the robot end gets the signal and manipulates the signal to command the robot to go forward. Same thing happens for the other three outputs. We have used Expressive suite to command the robot to stop as Cognitive suit only lets the user to train four thoughts at a time. We have set the button X for "Smile" command. Whenever the user smiles X button is pressed and all the four buttons becomes white ultimately sending stop command to the microcontroller at the robot end.

V.   EXPERIMENT AND RESULT ANALYSIS

We have experimented on ten users with different physical attributes to calculate the efficiency and the user friendliness of the Emotiv EPOC device. The challenging part was to train the disabled users for the experiment who later could smoothly control the robot. Each of the users had to provide their data regarding Age, Height, Weight, Physical Ability and Gender in the datasheet that had been provided to them before the experiment began. Then the author gave instructions to each of the users about training the neutral state and specific thoughts. The users were given to move the robot in four directions i.e. Forward, Backward, Left and Right. For moving the robot forward, Backward, Left and Right we used PUSH, DROP, LEFT and RIGHT thoughts respectively. Each user was given to move the robot in each direction for five times. For example a user had to think of pushing five times to move the robot forward for five times.

We calculated the efficiency of each thought commands for every user by calculating the successful thought output. For example if a user could successfully think (Pushing the cube inward) Push command for the all five times then he/she got 100% on that particular command. While trying to Push if the cube (which represents the specific thought output in the control panel) went in the other directions rather than the expected direction that that try was marked as zero. Thus in total two hundred and fifty data were taken from the entire users for Push, Left, Right and Drop commands. We have used Tally method to calculate efficiency of age range 14 to 20 and 21 to 30 in percentage. Then from the percentages of the four

commands we have found the average output percentage. There was no significant variation based on weight, height and gender.
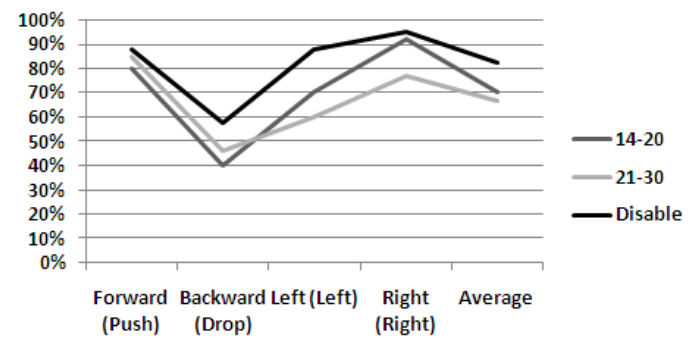

Figure 7.   Motor Shield

While experimenting, we noticed that the disabled user had more mental strength and their average success rate was 82% where for the age range 21-30 it was 70.5 and 67% was for the age range 14-20. Besides that, figure 7 shows that the users, age ranging from 21 to 30 years somehow had strong potential in Push command and the average rate is 85% and worst potential in Drop command and the average success rate is 46%. In every cases Right command was dominating over the Left command and it was most acute for the user aged 14 to 20 years. In every cases Right command was dominating over the Left command and it was most acute for the user aged 14 to 20 years. From figure 7 we see that normal users aging from 14-20 years had greater success rate in Left command compared to the users of age 21-30 years and worst in Drop command. Right and Left command had nearly same rate. Push command was dominating. There was no notable difference on the output based on gender. Thought pattern had an important role. The Emotiv device may have some internal algorithm with some common thought patterns for every thought. It can catch a certain pattern of thoughts and works best when those particular thoughts have been imagined under that defined pattern.

VI.   CONCLUSION

Emotiv EPOC is a user friendly device. Even a novice user can use it after training for two to five times. This device has shortcomings too. The experimented users have commented as follows: 5% user felt that the device works well when they move their hands. 2% felt that the device works better just after a command has been trained. 4% felt that the device cannot work simultaneously. They reported that they think in one particular direction and the cube moves in other directions. 75% user felt that it works better when they imagined any command rather than thinking about the cube to push inside. For example, when they thought about pushing a big thing the command worked correctly and frequently. Rest 14% was seemed using both imagination and hand movements. They could not reach to any conclusion. Summarizing the user feelings we get that experience with the Emotiv device vary user to user. Through experimenting various time it has been found that the device has no advantages over hand movements. Rather hand movement effects the EEG data signal acquisition.

During the eight second training period the user has to repeatedly imagine about specific thoughts to get better response. Some user directly tries to move the cube through visualizing and thinking to move it to a particular direction. This also works good but best recommended for the noisy environment. User with long hair had to face hardship to use this device. They had to wet their head to acquire the sensor contact quality. Though Emotiv has remarkable shortcomings still this cheap consumer headset has opened up a new era for the disabled person to get their ability back by dint of an acceptable cost. The Cognitive suit efficiency may be a lagging factor but the combination of Expressive suit along with Cognitive suit makes the device not only reliable but also worthy of controlling robots, prosthetic hands, wheelchair etc. smoothly.

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