Analysis of Brain Activity while Performing Cognitive Actions to Control a Car

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Abstract— **In this paper we will present a real time brain computer interface system that operates a LEGO Mindstorms NXT car using the EEG signals produced by the electrical activity of brain. The brain signals are acquired using an EEG device and are translated into signals that can be understood by the NXT car. The NXT car moves according to the instructions provided. The experimental prototype uses an Emotiv EPOC headset that acquires data from 14 sensors to fully control the movement of a NXT Car. We have used the Cognitive states (intent of physical actions) and Expressive states (facial expressions) to control the NXT car. The system achieves more than 90 percent accuracy by using facial expressions however the accuracy of the system using cognitive actions is slightly above 80 percent. This technology is very useful for the disabled and elderly people as well as for those who work in dangerous environments.**

Keywords— **Brain activity, EEG, Cognitive actions, Expressive actions.**

I. Introduction

In the past ten years, research of brain computer interface (BCI), especially non-invasive electroencephalogram (EEG) based BCI has increased tremendously. The applications of BCI systems on assistive technologies include the restoration of movements, communication and environmental control etc [1]-[3]. Recent research efforts show the possibility of brain computer interface (BCI) being used for motion disabled people. BCI is very hard to use in application domains due the error percentage of 10 to 20 %. This is one of the important problems of using virtual reality based BCI systems.

However the capabilities of BCI systems are improving continuously so as the cost, power and processing capabilities of embedded processors and digital signal processors. Thus feature extraction and classification algorithms for BCIs can be used on low cost embedded systems such as the Emotiv EPOC and NeuroSky headset [2]-[4] which can detect the brain signals for media and entertainment applications. These systems can be used as the interface between the brain and different output devices, like robots for spying, to handle dangerous tasks, for guiding disabled and elderly, for navigating wheel chairs, and so on.

Electroencephalogram (EEG) signal is an input for the BCI systems. EEG can be obtained by recording the electrical activity of neurons in the brain by placing the electrodes over a subject's scalp [4]. During the electroencephalography measurement, sometimes we get signals that are not required; these are called EEG artifacts [6]-[7]. The EEG artifacts are considered a disturbance in a measured brain signal. Some type of artifacts can be identified and extracted from the recorded signals. There are two different types of artifacts; which are the external artifacts and the internal artifacts. External artifacts are caused by outer actions such as instrumental (electronic equipment) and environmental noise; and internal artifacts are caused by the subject himself, e.g. muscle artifacts caused by the movement of the users, eye blink artifact caused by blinking of eyes; and also an eye movement artifact caused by the movement of eyes.

In this paper, we focus on the electroencephalography signals produced by the brain electrical activity to control a NXT car. We use the Emotiv EPOC headset [8] to capture EEG signals. The EEG signals are transmitted via Bluetooth to the interface computer. These signals are then read by the software and are analysed and interpreted for further action. Based on the interpretation, a message is sent to the NXT car via Bluetooth to perform the specified action.

II. System overview

A. Electroencephalography (EEG)

The Emotiv EPOC is a neuro-signal acquisition and processing wireless headset that consists of 14 wet electrodes. EPOC uses three built-in suites to determine the signal inputs: Expressiv, Affectiv, and Cognitiv. The user's facial expressions are analysed by the Expressiv suite, the user's emotional state is interpreted by the Affectiv suite while the Cognitiv suite analyses user's intent to control a movement.

Emotiv software development kit (SDK) comes with a library and applications that allows the users to interpret the EEG signals and write an application to interface it with external devices. In this work, Cognitiv suite is used to evaluate the user's brain activity, when the user intends to perform a distinct physical action or many actions on a virtual (training) and a real object (testing/application). In

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addition Expressive Suite is used to control the movement of the real object, when the user makes some upper and lower facial expressions like smirk, left wink or right wink.

Emotiv's headset is equipped with 14 saline sensors: AF3, AF4, F3, F4, F7, F8, FC5, FC6, P7, P8, T7, T8, O1, O2 and two additional sensors that serve as CMS/DRL reference channels as shown in Fig. 1. To maximize the detection, all the felt pads on top of the sensors have to be moisturized with a saline solution.

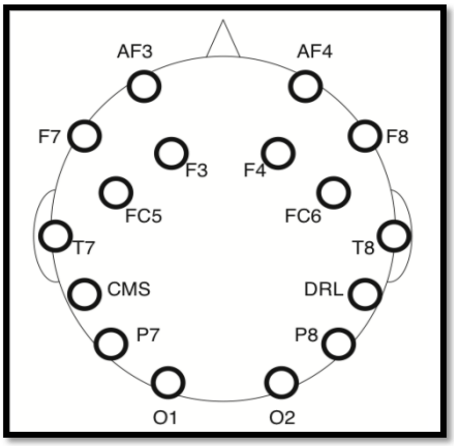

Fig. 1. Positioning of Emotiv EPOC electrodes

B. NXT Car Navigation Control

The Mindstorms NXT car is a programmable robotic kit from Lego which can be assembled into many kinds of models, like a robotic car; that sends the commands to the NXT Intelligent Brick via Bluetooth connection. This NXT car receives a series of instructions from a PC via bluetooth to perform an operation.

C. Interface of EEG Headset and NXT Robotic Car

The interface between the Emotiv EPOC API (application program interface) and Mindstorms NXT car is developed by writing a program in C++. The program receives an instruction from Emotiv API whenever the user thinks of any specific cognitive and expressive action. The instruction received is processed and the output command is sent to the NXT robot via the Bluetooth serial connection. The robot will then perform the action commanded. A unique user profile for each user is required to be trained to map the user's brain-patterns. It is also possible to directly acquire the real-time signals from the headset, via the Emotiv EmoEngine. The EmoEngine translates the brain activity from each electrode into a manageable data structure called EmoState [8].

III. Experimental setup for data acquisition

The main goal of this research is to design, develop and implement a BCI system to control the NXT car using the Emotiv EPOC headset. When the user thinks of a certain action (such as PUSH an object), then the Emotiv EPOC headset will receive the EEG signal and send it through the Emotiv EmoEngine to interpret and compare the data (with the user's training data).

This EmoEngine receives pre-processed EEG data and performs feature extraction and classification. The Emotiv detection system compares the trained EEG data with the data from EmoEngine and translates it into EmoState. EmoNXT (interface software) receives input from EmoState and determines which action to apply. On the basis of which, a series of output commands/instructions are sent to NXT bricks via Bluetooth COM Port. This brick converts the input instruction from Bluetooth and controls the motor and sensors to perform the specific instructions such as move forward backward etc. Hence the whole process may be divided into two steps; the training session and the testing/applying session.

A. EEG Signal Acquisition

The first step is to record the EEG signals from the brain. Emotiv headset is used to collect the EEG signals using the 14 electrodes. Each user has to make his user profile for EEG acquisition.

B. Training the Cognitiv Suite

The Cognitiv Suite is used to acquire the user conscious thoughts and intents to control the NXT car. In this project we have used Push and Pull cognitive states for training the cognitive activity to move the car forward and backwards.

C. Acquiring Expressiv States

The Expressiv suite is used to acquire user's facial expressions to control the NXT car. In this research we have used left and right smirk to control the left and right motion of the car. To control the speed of the car we have used left and right wink. To speed up the car use right wink and to decrease the speed use left wink.

D. Analysis of Cognitive Actions

The EEG study to analyze cognitive actions is conducted with 16 subjects (14 males, 2 females; mean age 22.39±1.02 years). Four types of activities have been tested. These are Push, Pull, Left and Right. The subjects were asked to train two activities (Push and Pull) 3 times, then rest for 2 minutes and then test each trained activity for 5 minutes. Then repeat the same procedure for Left and Right movement. EEG recordings were made while testing the different activities. At the end of the session, subjects filled in the questionnaire that included information about their CGPA (Cumulative Grade Point Average), weekly physical activity and difficulty level of training testing sessions.

IV. EXPERIMENTAL RESULTS

Based on the user's intent and thoughts, the NXT car is able to perform a specific task such as move forward or backwards. A human thought such as push or pull will move the car forwards or backwards respectively. The NXT car had been programmed successfully to perform four moves which are the forward, backward, right and left. The speed control consists of four different speeds; that can be used successfully.

In addition, some experiments had been done to analyse the effectiveness of the two parts of the system; which are the Emotiv headset and the LEGO Mindstorms NXT car. The tests have been done by 5 subjects and each activity is repeated 20 times to calculate the sensitivity of the command. By correct command with correct action it means that "what user had thought, the same result was seen on the car". Whereas by correct command with wrong action means that "the user had some other intent but that action was not translated to the car."

The task is categorized as difficult if the accuracy is less than 10 out of 20, while a value between, 10 to 15 is considered as a task of moderate difficulty, whereas a value larger than 15 out of 20 is considered as an easy task.
Testing consists of four parts:

1. Testing PUSH state without the existence of the PULL state: Fig. 2 and Table 1 shows the results.
2. Testing PULL state without the existence of the PUSH state: Fig. 3 and Table 2, shows the results.
3. Testing PUSH state with the existence of both PUSH and PULL states: The third part and fourth part are the most important part in this testing because this is the requirement for the navigation of the NXT car. Here, the PUSH and PULL states will be tested with the existence of both states. There are three types of cognitive states; that are the NEUTRAL, PUSH and PULL. Fig. 4 shows the experimental results.
4. Testing PULL state with the existence of both PUSH and PULL states: Table 3, shows the results.
5. Testing LEFT WINK States: In addition to cognitive state, we have also used the facial expressions. The results are shown in Table 4.

The subjects that belong to high physical activity group (>= 4 hours/week) have right parietal (P_R) and frontal delta and theta activity for Push, Frontal (F) and parietal for all the rhythms for Left. On the other hand low physical activity group has Parietal (P), Frontal, Temporal and Occipital, delta, theta and alpha activity for all movements, with especially high absolute power for Pull delta and theta activity and Right theta activity.

Subjects with high CGPA (>= 3), shows high delta, theta, alpha activity in F, P, O, T lobes for right movement. High delta activity in also noted in F, P, O, T region for Push, Pull and Left, high theta activity is noted in P, F, O, whereas high alpha activity is found in F, P for Push, Pull, Left movement. Very high delta is observed in frontal lobe for Right. High delta activity for push in right P, for Pull in F, P_R and left high theta activity in P,F.

Table 1 Test results on a single Push State

Subject	Correct command with correct action	Correct command with wrong action	Sensitivity
1	15/20	5/20	0.75
2	18/20	2/20	0.90
3	17/20	3/20	0.85
4	19/20	1/20	0.95
5	17/20	3/20	0.85

Table 2 Test results on a single Pull State

Subject	Correct command with correct action	Correct command with wrong action	Sensitivity
1	15/20	5/20	0.75
2	16/20	4/20	0.80
3	14/20	6/20	0.70
4	18/20	2/20	0.90
5	16/20	4/20	0.80

Table 3 Test results on a Pull State with the existence of Push and Pull States

Subject	Correct command with correct action	Correct command with wrong action	Sensitivity
1	8/20	12/20	0.40
2	10/20	10/20	0.50
3	9/20	11/20	0.45
4	16/20	4/20	0.80
5	13/20	7/20	0.65

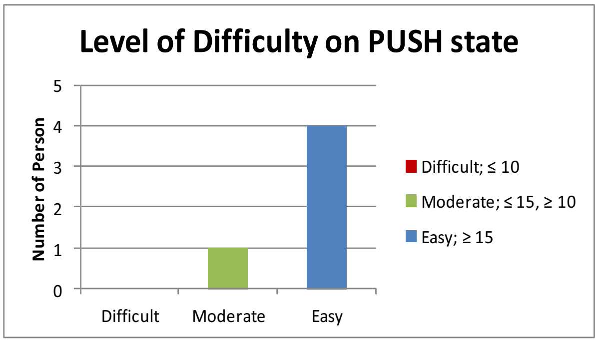

Fig. 2. Bar chart of the level of difficulty on a single PUSH state

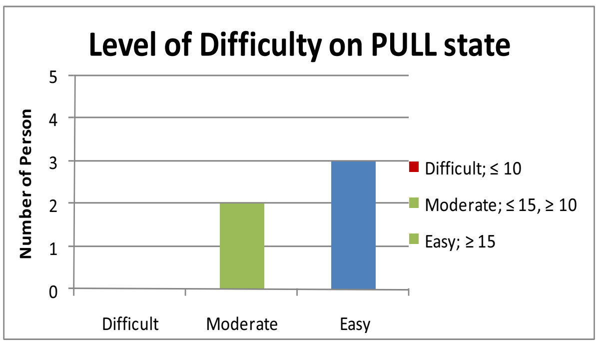

Fig. 3. Bar chart of the level of difficulty on a single PULL state

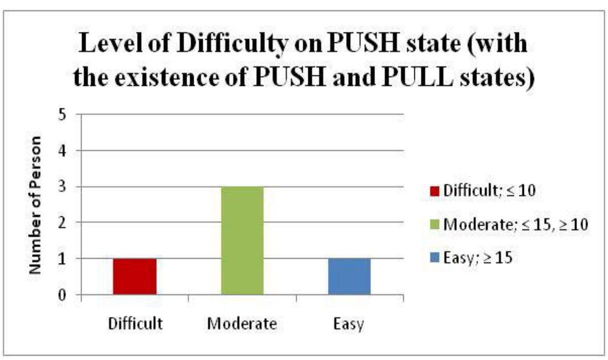

Fig. 4. Bar chart of the level of difficulty on a PUSH state with the existence of PUSH and PULL states

Table 4 Test results on a Left Wink State

Subject	Correct command with correct action	Correct command with wrong action	Sensitivity
1	18/20	2/20	0.90
2	18/20	2/20	0.90
3	18/20	2/20	0.90
4	19/20	1/20	0.95
5	18/20	2/20	0.90

V. Conclusion

This paper presents a non invasive and cheap, real time brain computer interface system. In this system, the brain EEG signals are acquired by a 14 sensor headset, which are then fed to the NXT robotic car via a computer interface. Six actions have been intended i.e. Push, Pull, Left and Right wink and Left and Right smirk on the basis of which the car moves forward, backwards, turns left or turns right. The speed control which has four kinds of speed can be used successfully It has been observed that the system developed was successfully able to control the movements of the car in real time.

From the results of EEG analysis, we conclude that training the brain to perform virtual physical activity results in high brain activation for subjects with less weekly physical activity. It is also seen that subjects with high CGPA have more brain activation while performing virtual physical activity.

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