Brain-controlled NXT Robot: Tele-operating a robot through brain electrical activity

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Abstract— This paper focuses on the research of human-robot interaction through tele-operation with the help of brain-computer interfaces (BCIs). To accomplish that, a working system has been created based on off-the-shelf components. The experimental prototype uses the basic movement operations and obstacle detection of a Lego Mindstorms NXT Robot. There are two versions of this prototype, taking readings from the users' brain electrical activity in real-time performance. The first version is made by using a Neurosky Mindset, and is based on the attention levels of the user as the robot accelerates or decelerates. The second version is using an Emotiv Epoc headset taking readings from 14 sensors, being able to control fully the robot.

Keywords – serious games, brain-computer interfaces, human-robot interaction, tele-operation.

I. INTRODUCTION

Robotics is an increasingly developed field with elements from different scientific principles including electronics, mechatronics, software engineering, physiology, human-machine interaction and psychology. On the other hand, Brain-Computer Interface (BCI) technology is a rapidly growing field of research with various applications in modern computer games [1], prosthetics and control systems [2] through to medical diagnostics. Although research on BCI started during the 1970’s only the last few years we have been able to introduce brain-computer interfacing to simple users mostly through serious games with commercial products.

In the past, a number of research groups have investigated various ways in controlling robotic platforms mainly electrical wheelchairs or robotic arms for people suffering from a diverse range of impairments. A very good example that combines both platforms is the 9-degree-of-freedom (DoF) Wheelchar-Mounted Robotic Arm System from the University of South Florida, Tampa [3]. This kind of research had a profound impact on the person’s independence; social-activity; and self esteem [4]. This technology launched for commercial use with headsets that use simplified version of an electroencephalograph. Examples include the mind-controlled electric carts using NeuroSky’s technology with the drivers wearing MindSet headsets [5] demonstrated on Courtesy of “The Doctors” show on CBS [6]. Another relevant project originated from the BCI research group of The University of Essex and demonstrated the NXT robot as the main control object on Channel 4 TV in 2007 [7]. Another example of a non-medical EEG for controlling a remote device is the Emotiv Epoc headset moving a robotic arm [8]. Using a series of 16 electrodes, the EPOC can measure levels of attention and facial expressions [9]. Emotiv Epoc was launched in the same period as the Neurosky’s Headset.

The aim of this research is to introduce the field of human-robot interaction using BCIs to tele-operate a robotic unit. In particular this research focuses on how a robotic unit operated through brainwaves can overcome the kinetic constraints of the user. The prototypes use the basic movement operations and obstacle detection of a Lego Mindstorms NXT Robot [10]. The robot is controlled through a Neurosky Mindset for the first prototype and Emotiv Epoc for the second taking readings from the users’ brain electrical activity in real-time performance. This activity produced by firing neurons of the brain is recorded through electroencephalography (EEG) [11] and it can be used as the basis for the development of serious applications ranging from computer games to computer simulations.

II. SYSTEM ARCHITECTURE

For the development of the experimental prototype, a Desktop PC running Windows XP was used as the main development system and a Netbook PC running Windows 7 for demonstration purposes. The basic hardware components are a Lego Mindstorms NXT robot, the Neurosky Headset and the Emotiv Epoc headset as illustrated in Figure 1.

Figure 1 System Architecture
The Neurosky headset was used to get raw brainwave signals from the users. The raw EEG has usually been described in terms of frequency bands: GAMMA greater than 30 (Hz), BETA (13-30 Hz), ALPHA (8-12 Hz), THETA (4-8 Hz), and DELTA (less than 4 Hz) [12]. The headset is calculating through a chip the Raw EEG to produce the eSense Meters (Attention and Meditation) and output it to the PC [5]. On the other hand, the Emotiv EPOC Headset is a neuro-signal acquisition and processing wireless neuroheadset with 14 saline sensors being able not only to detect brain signals but also users facial expressions. As for the robot, the Lego Mindstorms NXT kit has been used being a cross-platform programmable robotics unit released by Lego in 2006. The version that was used includes a 32-bit AT91SAM7S256 (ARM7TDMI) main microprocessor at 48 MHz (256 KB flash memory, 64 KB RAM). It includes 4 different types of sensors such as: servo motors, touch, light, sound and ultrasonic.

Three identical servo motors that have built-in reduction gear assemblies with internal optical rotary encoders that sense their rotations within one degree of accuracy. The touch sensor detects whether it is currently pressed, has been bumped, or released. This has been implemented in the prototype to allow for collision detection. The light sensor detects the light level in one direction, and also includes an LED for illuminating an object. The light sensor can sense reflected light values (using the built-in red LED), or ambient light on a scale of ‘0’ to ‘100’, ‘100’ being very bright and ‘0’ being dark. If calibrated, the sensor can also be used as a distance sensor. The light sensor is used as a height detector on this model [10].

As far as the software components are concerned, the programming language that was used is JAVA with the use of Eclipse IDE. LeJOS was installed to the NXT robot as the main OS so it can be programmed in JAVA. LeJOS is a tiny Java Virtual Machine ported to the NXT brick in 2006. The main advantage of LeJOS NXJ is that it provides the extensibility and adaptability of JAVA [13]. Furthermore, the pcomm and bluecove libraries were used for the Bluetooth communication between the computer and the robot. Finally, for the computer-headset communication in the Neurosky set the thinkgear library has been used from the Mindset development tools and for the Emotiv Epoc headset the Emotiv Development Kit.

III. FIRST PROTOTYPE (NEUROSKY SYSTEM)

To initialise the application, the steps that need to be followed are briefly described here. Initially, the new firmware (LeJOS) must to be installed to the NXT robot with the drivers as well as the MindSet Development Tools. This will allow to send raw data through sockets from the PC to the robot and vice versa in order to establish a two way communication. As a result, ‘attention’ and ‘meditation’ readings from the mindset can be recorded in real-time performance. There is no need for user training as it is very simple for the user to control. After the connection is established between the main program and the robot, the values from the headset will be parsed to the robot through the dedicated computer. The user interacts directly with the robot and there is no need calibrating or using the computer, only to be concentrated to the robot. Both the raw brainwaves and the eSense Meters (Attention and Meditation) are calculated on the ThinkGear chip. The calculated values are output by the ThinkGear chip, through the headset, to the dedicated PC [5].

The software application that was created establishes a bluetooth connection with the robot and the mindset. Readings from the mindset are processed continuously passing instructions to the robot. If the user’s ‘attention’ level reaches a threshold level, the program instructs the robot to move forwards (Figure 2).

![Figure 2 Operation of the system on a navigation test surface](image)

On the other hand, when the users attention drops from that threshold level, the program will instruct the robot again to stop. Also based on the attention level, the robot will accelerate or descelerate. If the robot hits an obstacle with the bumper sensor the robot will send a notification to the PC and both programs (on the computer and the robot) will be terminated. An overview of this is illustrated in Figure 3.

Moreover, to monitor the attention levels real time, the LiveGraph real-time plotter application and API were used by reading a CSV file that is exported by the main application (class) in which the values were recorded from the mindset. The advantage of using LiveGraph is that it is an open-source tool that can automatically update graphs of real-time data while it is still being computed by the application. It also allows the comparison of data series even in applications that output over 1000 series simultaneously [14].
To decide on the threshold level (which level we must set the limit for the robot to move) readings were recorded from the mindset on different stages of concentration. For this system there is no need for any kind of user training and the threshold level is the same for all potential users based on the sample that was gathered from 5 users.

Table 1 Descriptive statistics of attention level taken from 5 users

<table>
<thead>
<tr>
<th>State</th>
<th>Max</th>
<th>Min</th>
<th>Median</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calm</td>
<td>44</td>
<td>20</td>
<td>27</td>
<td>30</td>
</tr>
<tr>
<td>Normal</td>
<td>59</td>
<td>34</td>
<td>44</td>
<td>45.7</td>
</tr>
<tr>
<td>Concentrated</td>
<td>67</td>
<td>43</td>
<td>57</td>
<td>56.6</td>
</tr>
</tbody>
</table>

Table 1 illustrates the gathered statistic information we collected from 5 users of different backgrounds to decide the threshold level of the system in different stages of concentration. The range of age is between 19-32, three males and 2 females with only one of them to have familiarity with robotics.

The first set of recordings examined the attention level for three different states: calm, normal and concentrated. The results were plotted in a graph ranging between 0-100% and are illustrated in Figure 4.

Next, the second set of recordings measured the same states (calm, normal and concentrated) but this time in terms of the meditation levels. Results are illustrated in Figure 5.

Based on those measurements it was decided the values that were used as a threshold value for the movement of the robot. Finally, one of the main characteristics of the system is its use of operation as well as the adaptability. This adaptability refers to the need of the device to be trained for new users. In this case it can be worn by different users producing different outputs [1].

IV. SECOND PROTOTYPE (THE EMOTIV SYSTEM)

A more advanced version is under development with the robot performing basic maneuvering (moving forwards, backwards, turn left and turn right) with the help of Emotiv Epoc headset. The system is currently operational [15] and user testing will be the next step of the project. The Emotiv EPOC Headset is a neuro-signal acquisition and processing wireless neuroheadset with 14 saline sensors being able not only to detect brain signals but also user’s facial expressions [9].
Figure 6 illustrates the Emotiv Epoc system in operation. With this it is possible to obtain and analyse more accurate user data to produce a more sufficient and robust software system to control the robot. For this research the Emotiv Development Kit was used connecting the headset to the Emotiv control panel to create and train a new user profile. By using the Emotiv Emokey tool (that emulates keyboard keystrokes) it is possible to parse inputs into the robot through a Java application. Finally, a basic graphics user interface (GUI) is made for the user to interact sufficiently with the system.

V. CONCLUSIONS AND FUTURE WORK

This project presented an affordable human-robot interaction system based on tele-operation with the help of brain-computer interfaces. The experimental prototype allows a robot to be controlled successfully through users’ brain electrical activity in real-time performance, allowing for the generation of serious applications. The aim of this research focuses in the ways that a robotic platform is controlled for future applications and studies the way the human brain works (in terms of attention and mediation levels). This kind of research can transform the way we live today enhancing human potential.

Future work will include the combination of different readings with the use of more sophisticated device equipped with more electrodes. Moreover, a large sample of users will be tested to qualitatively measure the effectiveness of the system. Furthermore, a third prototype will be developed with the robot performing more functionality with the help of custom BCI devices [16]. Finally, other physiological data will be extracted including body posture and facial expressions so that it will be possible to determine user’s visual attention.

ACKNOWLEDGEMENTS

The authors would like to thank the Interactive Worlds Applied Research Group (iWARG) members for their support and inspiration. Two videos that illustrate the operation of the system can be found at: http://www.youtube.com/watch?v=zxRxHVQ9Wds and http://www.youtube.com/watch?v=D9-2xQbkii14.

REFERENCES