World Applied Sciences Journal 26 (5): 566-572, 2013
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2013.26.05.1007

# P300-Based EEG Signal Interpretation System for Robot Navigation Control

[1]*Intan Helina Hasan,* [2]*Abd Rahman Ramli,* [3]*Siti Anom Ahmad and* [1]*Rosiah Osman*

[1]Functional Devices Laboratory, Institute of Advanced Technology,
Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[2]Department of Computer and Communication Systems Engineering,
Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[3]Department of Electrical and Electronic Engineering, Faculty of Engineering,
Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia

**Submitted:** Oct 11, 2013; **Accepted:** Nov 14, 2013; **Published:** Nov 23, 2013

**Abstract:** In recent years, Brain-Computer Interface (BCI) research has provoked an enormous interest among researchers from different fields. The most popular approach is a non-invasive method, using Electroencephalogram (EEG) analysis which acquires signals from the brain. The aim of this project is to develop a brain signal interpretation system that can convert one thought into multiple movements for mobile robot navigation. A signal interpretation system is designed and developed to receive the EEG signal via User Datagram Protocol (UDP) transmission, converts the signal to several robot commands that are pre-programmed according to the robot's programming software and send the commands to the robot through the operating computer. Using signals from four electrodes to evaluate the signal interpretation system, a success rate of 75-80% is received, while a total response time of only 61 seconds needed by the system from the start of the stimuli until the robot has finished all commands sent by the system, as compared to the conventional method of one-thought-one-movement which can take around 30 seconds per command. With this system, user can expect faster execution of the robot commands, less thinking therefore less exhausting, making BCI a pleasant experience for all users regardless of their health conditions.

**Key words:** Brain-computer interface(BCI) · Electroencephalography (EEG) · Event related potentials (ERPs) · P300

## INTRODUCTION

The idea of controlling a robot by a mere thought has evidently provoked an enormous interest in BCI among scientists from different fields; from neuroscientists to communication and electrical engineering researchers. Even though the idea has long existed in science fiction and fantasy, it was not until recently that researchers began to seriously consider BCI as an alternative to machine and robot control system application due to a few reasons [1].

In general, methods used to measure brain signals are divided to two groups: invasive and non-invasive. Non-invasive method refers to signals' extraction using electroencephalography (EEG), magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI). However MEG and fMRI are less popular than EEG due to its portability issue among others [2]. Although EEG is currently used in most BCI application, it has few setbacks such as limited bandwidth (10 to 40Hz), spatial resolution up to 20mm and recordings are susceptible to electromyography (EMG), electrooculography (EOG) and other mechanical artifacts [3]. Nevertheless, researchers prefer to pursue EEG-based BCI for its advantages of non-invasive, convenient and inexpensive. Invasive method is more aggressive, since it involves surgeries to implant electrodes used to extract brain signals into the grey matter of the brain. Invasive approaches are based on recordings from single or multiple neurons using Micro-Electrode (ME) or Micro-

**Corresponding Author:** Intan Helina Hasan, Functional Devices Laboratory, Institute of Advanced Technology, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia.
Tel: +603-89468464. Fax: +603-89467006.

Electrode Array (MEA) [2]. These approaches can provide better temporal resolution, but there are still risks in safety measurement due to the surgeries needed and there are long-term risks and stability issues that need to be solved before invasive methods can be fully adapted as measurement technique for BCI [3].

There are four types of EEG features that can be used to control BCI. Sensorimotor Rhythm (SMR) and Slow Cortical Potentials (SCP) are two types of EEG signals that require months of feedback training before the user can successfully control the BCI. Steady State Visual Evoked Potential or SSVEP is quite similar to Event Related Potentials or ERP, where the user only needs little training before can fully operate the BCI. However SSVEP also depends on the user's gaze shifting to process brain signals, therefore this type can be difficult to use with patients that have sight disabilities. ERPs, such as P300 brain signal, are evoked by external visual, auditory or tactile stimuli. The P300 brainwave occurs 300ms after each stimulus and has a robust and obvious waveform that makes it suitable for BCI system usage. Few research groups around the world have succeeded in BCI system application. Among them are the ASPICE project by Santa Lucia Foundation in Rome [4], a BCI operated wheelchair by University of Zaragoza, Spain [5] and BCI tele-operated museum guide by San Camillo Institute in Italy [6]. These projects use P300-based EEG brain signals recorded to move the wheelchair or the robots.

Currently the P300-based BCI application is to use a graphical interface by concentrating on the cursors displayed onscreen to move the robot. This application can be used in wheelchair navigation, or to control robot movements. However, one of the main reasons of the BCI research is to help people with neuromuscular disorders, physically disabled and elderly people with the daily tasks or chores. If this 'one-thought-one-movement' scenario is to be applied for their usage, it will be time consuming and an exhausting experience for users. Therefore, an improved interface needed to be developed to allow the BCI to become a more user-friendly interface for the targeted user groups. This project aims to investigate what are the best methods that can be used in order to improve current BCI application to suit the targeted groups, specifically on EEG measurement preparation (simple EEG device usage and minimum electrodes for recordings), stimulus presentation method and suitable translation algorithm for designated output devices such as robots, wheelchairs or computers.

EEG Signal Interpretation System (ESIS) is designed to function as the 'connector' between a general purpose system called BCI2000 [7] and external devices.

Table 1: Images and parameters used in BCI2000

| | Image | |
|---|---|---|
| Parameter |  |  |
| Stimulus Type | 1 (target stimulus) | 0 (non-target stimulus) |
| Selected Stimulus | 1 | 2 |

This system will act as a tool to receive data from BCI2000, computes the data and translates them to commands for mobile robot navigation. Even though BCI2000 is used to provide data to the system for translation, it can also be integrated with other available signal processing system, since the data is received via User Datagram Protocol (UDP) transmission protocol. The system will be installed on the computer controlling the robot, which is referred as the local computer, while the remote computer refers to the computer where BCI2000 is located and serves as the operator's machine for data acquisition, signal processing and analysis.

## Methodology

**EEG Signal Interpretation System Development:** First, a connection is established between local and remote computer using UDP port. The UDP port is bound to the IP (Internet Protocol) address of the computers which enables the system to be installed at any computer within the same network. When the connection is established, the program reads the data from the UDP port of the remote computer that stores data from BCI2000. All information from BCI2000 is sent including running time, stimulus time, stimulus type and selected stimulus. For this project, only two images are used for stimulus presentation for easy recognition. Table 1 shows the images and parameters that correspond with each image.

For the sample datasets, user is asked to choose the 'drink' image, thus setting the stimulus type to 1 as the target stimulus, while the other image is set to 0 which represents non-target. As a result, BCI2000 processed and analyzed the signals during the target and non-target stimulus and then sent the result to the signal interpretation system. The system then received the selected stimulus result, translated it to the desired image displayed during the session and then labeled it as a variable called 'input'. When the input is set, the next step is to call the strings of commands to be sent to robots. In order to make the system easy to use and more robust, robot commands are not being programmed in the system, instead the commands can be pre-programmed separately

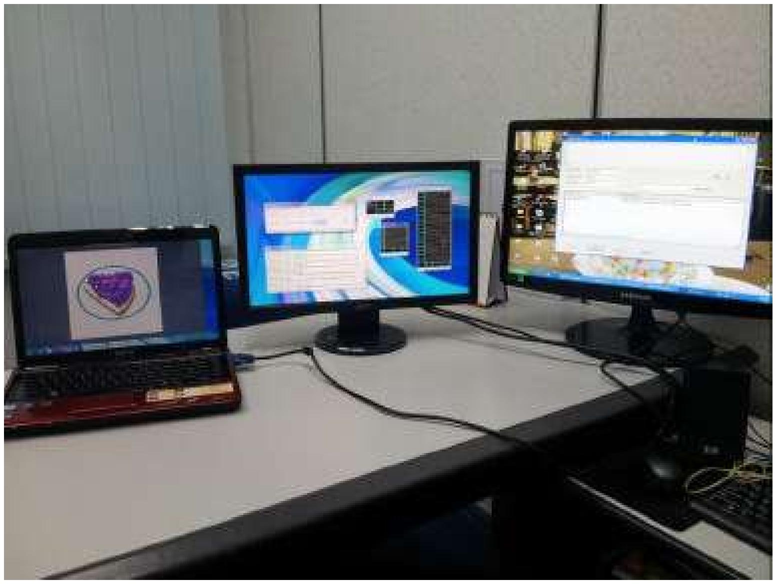

Fig. 1: System integration and evaluation with local and remote computers

using any programming language suitable for robots and then create the executable file. Once the executable file is created, the system then calls to the file to be executed.

The programming of the interpretation system is based on Visual Basic language programming, thus a GUI is created to allow system operator to easily change the configuration of the system. Using the GUI, the operator can change the remote computer's IP address and UDP port number, local computer's UDP port number, the number of commands to be read from the UDP port and the corresponding executable files.

**System Integration and Evaluation:** The final phase of this project is the integration of the whole system which includes BCI2000 and EEG Signal Interpretation System and the evaluation of the system with the Mobile Robot Simulator. Figure 1 shows the whole system setup. The system must have a local computer or machine for data acquisition and signal processing using BCI2000 and a remote computer for the EEG Signal Interpretation System setting and command execution of the mobile robot simulator.

For local computer, it is preferable to have two different monitors to separate the monitor for the user to see the displayed images and another monitor for the system operator to operate BCI2000 and monitor the signals coming from the user. This computer will be the main computer for data acquisition, signal processing and analysis. Meanwhile, the newly developed EEG Signal Interpretation System along with the mobile robot controller or simulator are installed in the remote machine. This system will communicate with the local machine via UDP port.

After all systems are configured and running, the whole system will be evaluated using the sample datasets which will be replayed as if the data is being 'recorded' at the time, using the File Playback module included in the BCI2000 system. The whole signal processing and analysis is then sent to the signal interpretation system which is on the remote computer to be filtered and then used the results to translate to related commands. Once the results are obtained, the system then matched the results to the corresponding executable files for mobile robot simulator and executed the files accordingly.

For mobile robot simulator, RobotBASIC is chosen since it is a multi-purpose programming language developed to serve as robot simulator, real robot control system and create simulated environments for games among others. The software was originally developed by Professor John Blankenship with help from Samuel Mishal [8]. It is available for free download from the internet with aims to helps teachers and students understand more about programming and robots thus create the excitement of learning. The robot simulator in RobotBASIC closely mimics any mobile robots in the market. Apart from the simple commands such as to move forward and turn, it also has sensors that can be programmed, such as ultrasonic, infrared and bumper sensors. For this project, two programs have been developed as simulation for real mobile robot navigation.

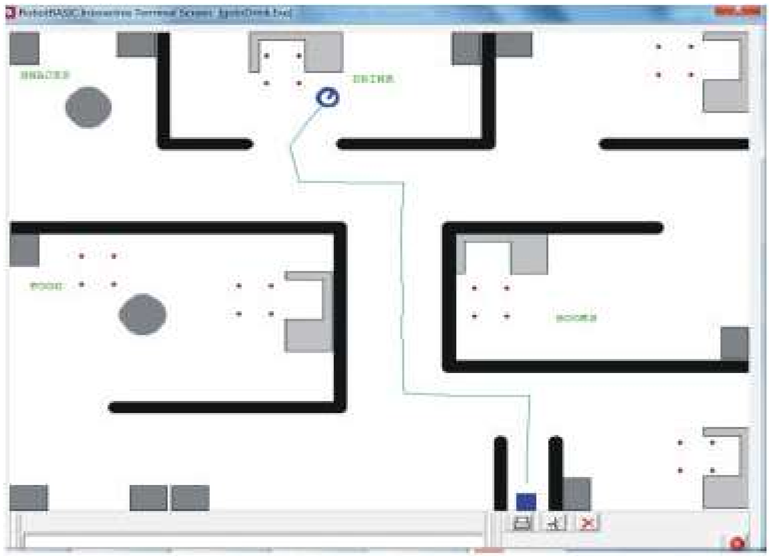


Fig. 2: Simulation program for robot navigation to ‘drink’

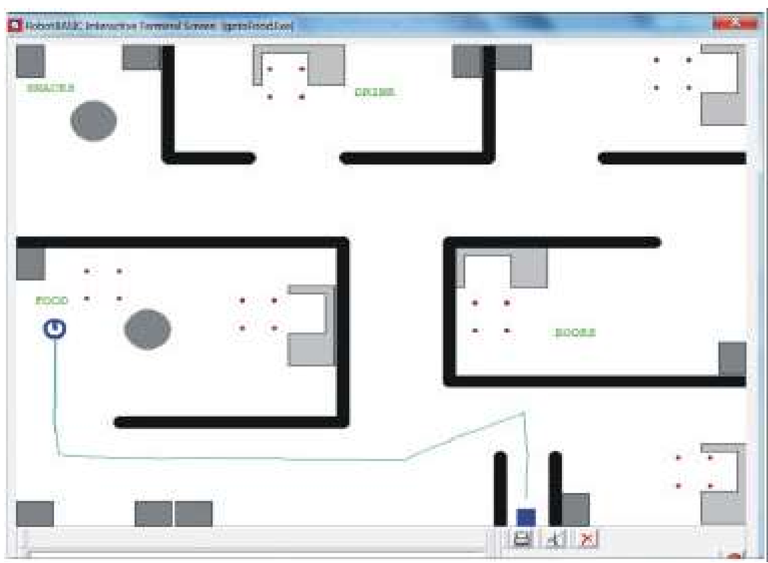


Fig. 3: Simulation program for robot navigation to ‘food’

Figure 2 shows the simulation of a robot navigating to where a drink is located, named ‘gotoDrink.exe’ and Figure 3 shows the simulation for navigation towards food named ‘gotoFood.exe’. These executable files are used later in the system evaluation.

To determine the success rate of this system, 30 trials were done for five different electrode configurations which are 64, 32, 16, eight and four-channel electrodes placement. The first set of electrodes used all 64 channels in the EEG datasets. The second set which consists of 32 electrodes is basically using half of the 64 channels by eliminating channels evenly throughout the scalp. Same approach is used for the third set of 16 electrodes. For the set of 8 electrodes, a combination of four midline electrodes and four parietal electrodes is used based on the previous publications [9,10] to study the effect on the success rates. The last set of four electrodes is chosen based on the analysis done in the previous section. Based on these configurations, 30 trials are done to calculate the overall success rate. This is to investigate whether the success rate is related with the number of electrodes used for the data acquisition. At the same time, the response time of the whole system is also being recorded according to different operating system configuration. This is for comparison with the conventional method of controlling BCI which has been published previously to show improvement of this system if implemented in BCI.

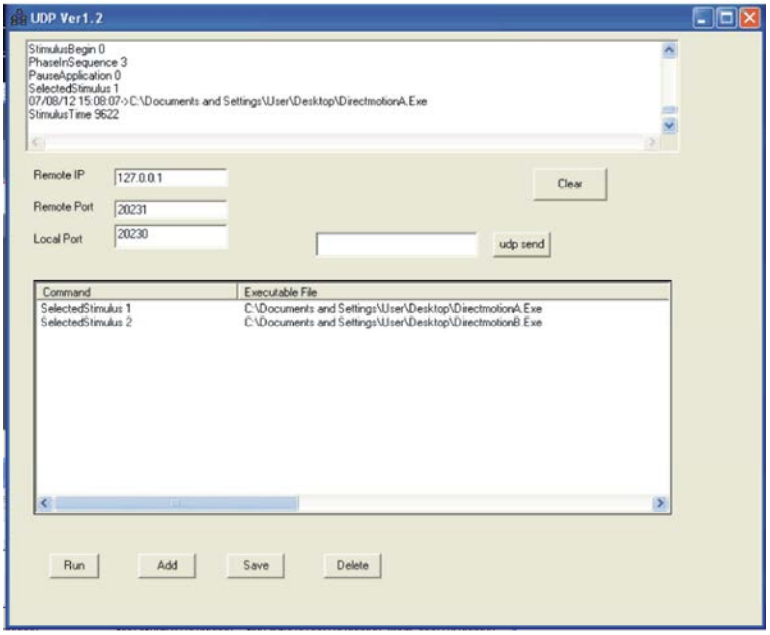


Fig. 4: GUI of the EEG Signal Interpretation System (ESIS)

## RESULTS AND DISCUSSION

**GUI of EEG Signal Interpretation System:** Figure 4 shows the completed GUI of the EEG Signal Interpretation System. The important part of the GUI is the command and executable files in the lower white box. This is where the command that the program should 'translate' from the UDP and the executable files related to the command is set. Executable files refer to the pre-programmed series of commands that are needed to be sent to a mobile robot, a simulator or any external device. The information can be edited using the buttons Add, Save and Delete, while the Run button is used to test the validity of the executable files. For this project, if the image 'Drink' which is the target image is translated as the chosen image, the command from the UDP port should be 'Selected Stimulus 1', while if the 'Food' image is chosen, then the command should be 'Selected Stimulus 2'. After the commands are set, the matching executable files are then being added to the list, such as gotoDrink.exe and gotoFood.exe.

The EEG Signal Interpretation System was developed with aim to give assistance to the user by allowing user to give only one instruction or evoke one thought and the system can then translate the instruction to series of commands. Therefore the GUI created is also a simple and straight-forward interface to make it user-friendly and easy to operate. Robot navigation programming is not programmed in the system, instead the programming can be done separately and later create either executable file in. exe format or maybe binary file to allow user to pre-program any external device to be used with this system. By doing this, the user can actually create a 'library' of executable files for different robots, since each robot sometimes uses different language. As for the machine-to-machine data transmission, UDP transmission is used instead of TCP/IP (Transmission Control Protocol / Internet Protocol) connection which is more common for data transmission. This is because UDP transmission is connection-less and there is no server or client protocol that needs to be addressed like the TCP/IP transmission. However, there are some disadvantages of using UDP transmission, such as there is no guarantee that the data sent is received by the other machine. Therefore BCI2000 system solved this problem by sending short and self-contained messages that are also readable by human.

**Success Rate:** To determine whether the system is working and achieved the objective of this project, success rate is measured as part of the system evaluation. For this project, the success rate is determined using the analyzed EEG datasets and selected electrode configurations. The system is considered successful when the executable file gotoDrink.exe is executed, indicating that the system has correctly translated the target image 'drink', while if the system interpreted the result incorrectly, the executable file 'gotoFood.exe' is executed instead. 30 trials are done to calculate the overall success rate and the results are shown in Table 2.

Table 2: Success Rate for EEG Signal Interpretation System

| Number of electrodes | Success rate | | | | | |
|---|---|---|---|---|---|---|
| | After 10 trials | Percentage (%) | After 20 trials | Percentage (%) | After 30 trials | Percentage (%) |
| 64 | 10 | 100 | 20 | 100 | 30 | 100 |
| 32 | 9 | 90 | 18 | 90 | 27 | 90 |
| 16 | 9 | 90 | 17 | 85 | 26 | 86.7 |
| 8 | 8 | 80 | 17 | 85 | 25 | 83.3 |
| 4 | 8 | 80 | 15 | 75 | 23 | 76.7 |

Table 3: Response time for different computer operating system configuration

| Computer Brand | Operating system | Processor | Random-access memory (RAM) | ESIS response time (second) |
|---|---|---|---|---|
| Acer | Windows XP Professional | Intel Core 2 Duo CPU E8400 @ 3.00GHz | 2.00GB | 59 |
| Lenovo | Windows 7 | Intel Core 2 Duo CPU E8500 @ 3.16GHz | 4.00GB | 59 |
| Toshiba | Windows 7 | Intel Core i5-2410M | | |
| CPU @ 2.30GHz | 4.00GB | 61 | | |

As can be seen from the table, the percentage of the success rate decreased almost consistently when the number of electrodes is decreased as well. However, the lowest success rate is 75% for four electrode configuration, which is fairly high considering the number of electrodes used. Based on Table 2, the success rate of this system relates to the number of electrodes used for signal processing and analysis. The reason is simply because when more electrodes are used, more data is collected and processed, therefore increasing the classification accuracy. Instead, fewer electrodes can make the system unavailable to seize all the features needed for classification and as the result can lower the success rate [9]. However, the success rate can be improved by adopting better and more intelligent classification method. BCI2000 uses linear classification method which is straight forward and easy to understand. There are other classification methods which have been studied and produced good results, such as Pearson's correlation method (PCM), Fisher's linear discriminant (FLD), stepwise linear discriminant analysis (SWLDA), linear support vector machine (LSVM) and Gaussian support vector machine (GSVM). Based on the comprehensive comparison done by Krusienski *et al*., FLD and SWLDA have showed advantages of good classification techniques for P300 signal [11].

**Response Time:** Another method to compare the system effectiveness with other systems developed by other groups is to see the response time of the whole system. The response time is calculated from the start of the stimulus presentation until the simulator has finished executed all commands.

As the result, the total time of the stimulus presentation is 21 seconds and after the result of the chosen image is displayed, the system then executed the corresponding file for robot navigation simulation which lasted around 38 to 40 seconds, which varied according to the file executed and the computer system configuration. Table 3 shows the total response time for different computer operating system configuration.

The response time obtained by this experiment is considered very well since only one command is needed from the user via the stimulus presentation and then the system executed the robot's overall movement; from the starting point to navigation to where the target is located and later return back to the start point. As can be seen from the table, different computer system configuration almost had no effect on the response time, thus it can be considered that the system is stable enough to be used on any system configuration. The response time however does depend on the travel distance of the robot from the start point to the goal and the navigation difficulty (e.g. many obstacles).

Although one may say that this type of navigation lacks of freedom since the navigation is already pre-programmed, the main idea behind this study is to help users with routine tasks; which means the path and the target are basically in a fix position, for example a hospital ward or one person's residential home where furniture are randomly moved, especially the refrigerator, couch, dining tables and others.

## CONCLUSION

This project applied a command translation concept that is different from other BCI application studies to date, where the system only needs one command from the user, translates the command to the specified target and elaborates the commands needed by the robot to navigate to the target and then return back to the user. By using this approach, the total response time is shorter and user can worry less about the exhaustion from using the system. It can also be concluded that with a minimum number of electrodes, this system can still achieve fairly high success rate which is also a good advantage since less electrodes used mean less preparation needed for electrode placement for EEG acquisition. In future work, several points will be considered to improve the BCI system, including a simple presentation method, careful timing of stimulus duration and easy-to-use EEG device setup implementation. There is also a possibility for future work to develop electrode sensors using the advanced nanotechnology which will aim to provide comfort to users due to their size, thus can make the sensors and the device user-friendly.It is hoped that by improving the system, a BCI application in our daily lives' tasks will be few steps closer to reality and can contribute to a better living for the targeted groups.

## ACKNOWLEDGEMENTS

This work was supported by grant 05-02-10-0930RU from the Research University Grant Scheme, Universiti Putra Malaysia. The EEG Signal Interpretation System is protected by copyright under Universiti Putra Malaysia.

## REFERENCES

1. Wolpaw, J.R., N. Birbaumer, D.J. McFarland, G. Pfurtscheller and T.M. Vaughan, 2002. Brain-computer interfaces for communication and control. Clinical Neurophysiology, 113: 767-791.
2. Gerven, M.V., J. Farquhar, R. Schaefer, R. Vlek, J. Geuze, A. Nijholt, N. Ramsey, P. Haselager, L. Vuurpijl, S. Gielen and P. Desain, 2009. The brain-computer interface cycle. Journal of Neural Engineering, 6(4).
3. Schalk, G., 2009. Sensor modalities for brain-computer interfacing. In J. Jacko (Ed.), Human-computer interaction. novel interaction methods and techniques, pp: 616-622.
4. Cherubini, A., G. Oriolo, F. MacRí, F. Aloise, F. Cincotti and D. Mattia, 2008. A multimode navigation system for an assistive robotics project. Autonomous Robots, 25: 383-404.
5. Iturrate, I., J.M. Antelis, A. Kubler and J. Minguez, 2009. A Noninvasive Brain-Actuated Wheelchair Based on a P300 Neurophysiological Protocol and Automated Navigation. IEEE Transactions on Robots, 25: 614-627.
6. Chella, A., E. Pagello, E. Menegatti, R. Sorbello, S.M. Anzalone, F. Cinquegrani, L. Tonin, F. Piccione, K. Prifitis, C. Blanda, E. Buttita and E. Tranchina, 2009. A BCI teleoperated museum robotic guide," In the Proceedings of the International Conference of Complex, Intelligent and Software Intensive Systems, CISIS, 2009: 783-788.
7. Schalk, G., D.J. McFarland, T. Hinterberger, N. Birbaumer and J.R. Wolpaw, 2004. BCI 2000: A general-purpose brain-computer interface (BCI) system. IEEE Transactions on Biomedical Engineering, 51(6): 1034-1043.
8. Blankenship, J. and S. Mishal, 2012. Robotbasic. Retrieved January, 2012, from http://www.robotbasic. org/index.html.
9. Hoffmann, U., J. Vesin, T. Ebrahimi and K. Diserens, 2008. An efficient P300-based brain–computer interface for disabled subjects. Journal of Neuroscience Methods, 167: 115-125.
10. Krusienski, D.J., E.W. Sellers, D.J. McFarland, T.M. Vaughan and J.R. Wolpaw, 2008. Toward enhanced P300 speller performance. Journal of Neuroscience Methods, 167(1): 15-21.
11. Krusienski, D.J., E.W. Sellers, F. Cabestaing, S. Bayoudh, D.J. McFarland, T.M. Vaughan and J.R. Wolpaw, 2006. A comparison of classification techniques for the P300 Speller. Journal of Neural Engineering, pp: 3.