IMPROVING THE ACCESSIBILITY AT HOME: IMPLEMENTATION OF A DOMOTIC APPLICATION USING A P300-BASED BRAIN COMPUTER INTERFACE SYSTEM

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Abstract: The aim of this study was to develop a Brain Computer Interface (BCI) application to control domotic devices usually present at home. Previous studies have shown that people with severe disabilities, both physical and cognitive ones, do not achieve high accuracy results using motor imagery-based BCIs. To overcome this limitation, we propose the implementation of a BCI application using P300 evoked potentials, because neither extensive training nor extremely high concentration level are required for this kind of BCIs. The implemented BCI application allows to control several devices as TV, DVD player, mini Hi-Fi system, multimedia hard drive, telephone, heater, fan and lights. Our aim is that potential users, i.e. people with severe disabilities, are able to achieve high accuracy. Therefore, this domotic BCI application is useful to increase their personal autonomy and independence, improving their quality of life.

Keywords: disability; brain-computer interface; domotics.

Introduction

A Brain-Computer Interface (BCI) is a communication system that monitors the brain activity and translates specific signal features that reflect the user's intent into commands that operate a device [1]. The method most commonly used for monitoring the brain activity in BCI systems is the electroencephalography (EEG). The EEG is a non-invasive method that requires relatively simple and inexpensive equipment and it is easier to use than other methods [2], such us magnetoencephalography (MEG) or positron emission tomography (PET).

BCI systems can be classified into two groups according to the nature of the input signals. Endogenous BCIs depend on the user's control of endogenic electrophysiological activity, such as amplitude in a specific frequency band of EEG recorded over a specific cortical area [2]. BCIs based on sensorimotor rhythms or slow cortical potentials (SCP) are endogenous systems and often require extensive training. Other systems depend on exogenous electrophysiological activity evoked by specific stimuli and they do not require extensive training [2]. BCIs based on P300 potentials or visual evoked potentials (VEP) are exogenous systems.

This preliminary study proposes the implementation of a BCI application to allow disabled people to interact with the devices present at their usual environment. Thus, the application will increase their autonomy and independence at home. The proposed BCI application uses the P300 evoked potentials as control signal. In previous studies [3, 4] a domotic application was implemented using a motor imagery-based BCI system. Potential users of this kind of systems evaluated the application. People with severe disabilities, both physical and cognitive ones, from a disability and dependence reference center located in León (Spain) participated in the study. Our results showed that subjects had severe difficulties to achieve high accuracy moving the cursor to the desired targets. Probably, it was due to their cognitive problems. Motor imagery-based BCI systems require an extensive training period and subjects need a very high level of concentration. Users have to pay complete attention to the motor imagery mental tasks necessaries to move the cursor. To overcome this limitation,

the present preliminary study proposes the implementation of a domotic control application using a P300-based BCI system. These systems do not require extensive training. Thus, the domotic application probably is easier to control for people with severe disabilities. In a BCI system based on P300 evoked potentials, a visual stimulus evokes characteristic electrophysiological activity. It is also called the 'oddball' paradigm [2]. Many visual stimuli are presented to the subject but only one is related to the option he wants to select. Thus, this specific stimulus evokes a potential peak, approximately 300 ms after the stimulus, called P300 evoked potential. Analyzing for what stimulus appeared the P300 potential it is possible to know what is the desired option.

Recently, several studies have analyzed the performance of P300-based BCIs with disabled people. Nijboer et al. reported a mean accuracy of 79% working with four subjects disabled by amyotrophic lateral sclerosis (ALS) [5]. In the study of Hoffman et al., five disabled subjects with different pathologies (cerebral palsy, multiple sclerosis, ALS, traumatic brain and spinal-cord injury, and post-anoxic encephalopathy) participated [6]. Four of them were able to achieve 100% accuracy after 12 blocks of stimuli presentations. However, the other disabled subject could not obtain classification accuracies above chance level [6].

P300-based BCI systems were initially used to select letters and allow subjects to communicate with other people. Recently, other applications using P300 potentials have been proposed: browsing the Internet [7], publishing messages in the Twitter social network, controlling the movement of a wheelchair [8] or teleoperating a robot [9].

Our domotic application allows the user to control several devices usually present at home: a TV set, a DVD player, a mini Hi-Fi system, a multimedia hard drive, a telephone, the lights of a room and the heating and ventilating devices. Thus, the users can interact more easily with their common environment, increasing their independence, personal autonomy and accessibility.

This communication is organized as follows: Section 2 introduces the P300 response bases. In Section 3, EEG recording details are presented. Section 4 describes the domotic BCI application design and in Section 5, the resultant application is shown. Finally, Section 6 contains a discussion of the preliminary results. It also includes the main conclusions and the proposed future work.

The 'Oddball' Paradigm and the P300-based BCI systems

A P300-based BCI has an apparent advantage. It requires no initial user training: P300 is a typical, or naive, response to a desired choice [2]. At the same time, P300 and related potentials change in response to conditioning protocols, and it is also likely they change over time and with the subjects' age [2, 10, 11].

Infrequent or particularly significant auditory, visual or somatosensory stimuli, when interspersed with frequent or routine stimuli, typically evoke in the EEG over parietal cortex a positive peak at about 300 ms [2, 12]. Thus, BCIs based on P300 evoked potentials are exogenous systems since they depend on exogenic electrophysiological activity evoked by specific stimuli. This P300 or oddball response has been used in BCI systems [2, 7, 8, 9, 13, 14].

The user faces a 6 x 6 matrix of letters, numbers and/or other characters [13]. Every 125 ms, a single row or column flashes. The rows and the columns are intensified in a random sequence in such a manner that all 6 rows and 6 columns were intensified before any was repeated [13]. Thus, in a complete trial of 12 (6 rows + 6 columns) flashes, each character flashes twice. The user makes a selection by counting how many times the row or column containing the desired choice flashes [2, 13]. Usually, EEG over parietal and occipital cortex is recorded, the average response to each row and column is computed and P300 amplitude for each possible choice is obtained. The P300 potential is prominent only in the responses elicited by the desired choice, and the BCI uses this effect to determine the user's intent [2].

In online experiments and offline simulations, a variety of different algorithms for recognizing the desired choice have been evaluated, and the relationship between the number of trials per selection and BCI accuracy has been described [2, 13]. These analyses suggest that the current P300-based BCI could yield a communication rate of one word (i.e. 5 letters) per minute and also suggest that considerable further improvement in speed should be possible. In people with visual impairments, auditory or tactile stimuli might be used [10].

EEG Recordings

A g.USBamp biosignal amplifier (g.tec, Austria) of 16 monopolar channels is used to record the subjects' EEG activity. The EEG channels are recorded monopolarly with the left ear serving as reference and the right ear as ground. Signals are sampled at 256 Hz, bandpass-filtered between 0.1 and 60 Hz and Notch-filtered at 50 Hz. Impedances are kept below 5 kΩ. Eight EEG channels are recorded: Fz, Cz, CP3, CP4, Pz, PO3, PO4 and Oz, according to the modified international 10-20 system [15]. This group of channels is selected because it is able to detect the proper P300 response around Cz and also other evoked potentials elicited by visual stimuli over the visual cortex [16]. A Common Average Reference (CAR) spatial filter is used to maximize the Signal to Noise ratio (SNR) [17].

The users start performing a calibration session. They have to select a fixed sequence of buttons from the matrix shown on the screen. The EEG activity related to the calibration session is then analyzed offline to detect the specific instants and channels where the P300 response and the other visual evoked potentials are more explicit and, therefore, easier to detect. To that purpose, we use the 'P300 Classifier' tool included in the BCI2000 general-purpose system [18]. This tool uses a Stepwise Linear Discriminant Analysis (SWLDA) [13, 14, 18] to select the best features for each subject. An LDA classifier is developed using these features. Once the classifier is defined, the domotic application can be used to control the environment.

Domotic Application Design

Digital homes are considered as accessibility tools, improving personal autonomy and quality of life by making easier the access to devices present at home. However, people with severe motor disabilities need a special interface to access these devices. BCI systems could be really useful for these people to control the devices present at their usual environment.

Our application will take into account the more common needs of disabled people: comfort (control of temperature, lights, etc.), communication (telephone) and entertainment (TV, DVD player, multimedia devices, etc.). Making easier the access to this kind of devices, disabled people will be able to perform by themselves common daily activities.

To implement the domotic application the BCI2000 general-purpose system will be used [18]. A friendly interface will be programmed in C++ language to show the different control options to the users. Thus, they will be able to navigate through different menus and access to most of the devices' functionalities. As the proposed devices are controlled by infrared (IR) signals, an IR emitter device will be used to send the commands to the TV, the DVD player, the telephone, etc.

After the calibration session, in the following sessions the users have to select a sequence of buttons previously proposed. For each button, if the BCI system selects the correct one, i.e. the proposed button, this trial counts as a hit, otherwise as a miss. Thus, it is possible to assess the accuracy as the percentage of hits to the sum of hits and misses. The SWLDA classifier indentifies the suitable discriminant function by adding spatiotemporal features (i.e., the amplitude valued at a particular channel location and time sample) to a linear equation based on the features that demonstrate the greatest unique variance [5]. In the initial experiments at our laboratory, a healthy person is able to achieve 90% accuracy after 15 blocks of stimuli presentations.

Results

Our application has been designed taking into account the needs of its potential users: people with severe disabilities. Our aim is that disabled people test and evaluate the BCI application. Users from the National Reference Center (CRE) of Disability and Dependence located in San Andrés del Rabanedo (León, Spain) will test the application.

The application is based on the P300 response to infrequent stimuli. It allows to control several devices related to domestic, comfort, communication and entertainment needs. Our application controls the following devices and their main functionalities:

- *TV*: switching on/off; volume control: turning up/down or muting; channel selection: up/down or selection from 0 to 9; menu configuration: accessing/exiting the menu, enter, right, left, up and down; accessing the teletext; and coming back to the main menu.

- *DVD player*: switching on/off; playing, pausing, stopping, going to the next or previous films or photos; exploring the DVD's contains: menu, list, up, down and enter options; muting the volume; and coming back to the main menu.

- *Hi-Fi* system: switching on/off; volume control: turning up/down or muting; radio or CD function selection; reproduction options: play/pause and stop; next or previous track or radio station selection; and coming back to the main menu.

- *Multimedia hard drive*: switching on/off; exploring the hard drive's contains: menu, up, down, right, left and enter; playing, pausing, stopping, going to the next or previous films, audio files, photos, etc; showing/hiding the subtitles; and coming back to the main menu.

- *Phone*: picking up and putting down the phone; dialing a phone number: selecting from 0-9; making a phone call; accessing the contacts list; dialing a memorized phone number; and coming back to the main menu.

- *Lights*: switching on/off; changing the light color: white, red, blue, green, orange or purple; turning up/down the intensity; flashing mode; and coming back to the main menu.

- *Heating*: switching on/off; turning up/down the intensity; programming the sleep function, from 30 min to 4h; activating/deactivating the swing mode; and coming back to the main menu.

- *Ventilating*: switching on/off; increasing or decreasing the speed; programming the sleep function; activating/deactivating the swing mode; activating/deactivating the desired ventilators; and coming back to the main menu.

The domotic application shows the user the main menu on the screen. The main menu consists on a 3 x 4 matrix of images that depict a specific action or device. It includes the devices previously specified and some control commands as stop, pause or resume the running application. The rows and the columns of the main menu will be randomly flashed while the user stares the desired image and counts how many times the row or column containing it flashes. Thus, as it is more likely any other image flashes than the desired one, when the desired image flashes a P300 potential is elicited, approximately 300 ms after the stimulus. Analyzing the user's EEG activity is possible to find out what row and column elicited a P300 potential. From this information it is possible to know what element of the matrix is the desired one: the intersection between the row and column that present a P300 response. Once the application knows the desired option it performs the command (pause, stop, resume) or accesses to the corresponding submenu (DVD, lights, telephone, multimedia hard drive, etc.). Every submenu shows the user a matrix of images related to different functions and options: switch on/off the device, turn up/down the volume, making a phone call, coming back to the main menu, etc. Likewise in the main menu, the rows and columns of the submenu are randomly flashed. Meanwhile, the user counts how many times the desired option flashes. Once the system identifies the desired action, it performs the corresponding command. For instance, if the user selects 'switch off the TV' the domotic application performs this command by means of an IR emitter device connected to the

PC. Thus, users can navigate through the application menus and control the domotic and electronic devices.

Figure 1 shows the main menu of the domotic BCI application. The users can select the desired device or stop, pause or resume the running application. Figure 2 also shows the main menu. In this specific frame one row of the matrix, the first one, is flashed.

Figure 3 and 4 show the DVD and heating submenus, respectively. They consist on two 3 x 4 matrices of images depicting the basic options of these devices. In the frame shown in Figure 4, one of the columns of the matrix, the third one, is being highlighted.

Figure 1. Main Menu of the domotic BCI application. The user can choose between different devices usually present at home: TV, DVD, telephone, heater, lights, etc.

Figure 2. Main Menu of the domotic BCI application while running. In this frame the first row is highlighted.

Figure 3. DVD Submenu of the domotic BCI application. The user can perform different commands over the DVD player: on/off, play, pause, forward, list, etc. It also allows the user coming back to the main menu.

Figure 4. Heating Submenu of the domotic BCI application while running. The user can select different commands of the heater: on/off, timer, increase/decrease power, activate/deactivate the swing option, etc. In this frame the third column is highlight

Discussion and Conclusion

The aim of this preliminary study was to implement a domotic application to increase the accessibility at home of people with severe disabilities. The usefulness of the implemented application will be tested and evaluated by users from the CRE of Disability and Dependence in the upcoming months.

A group of ten users from the CRE of Disability and Dependence has been formed to test the usefulness and performance of the domotic BCI application. Four users are the same that took part in our past studies [3, 4] with a motor imagery-based BCI application. Thus, we could compare the

results achieved with both kinds of BCI systems. We found that motor imagery-based BCIs had an important limitation: users with severe cognitive disabilities could not control the system suitably. As P300-based BCIs are easier to use and they do not require an extensive training period [2], probably results using this new application could improve previous results. We also include six new subjects in the study to assess more suitably the performance of the domotic application. Comments and suggestions from these users will be taken into account to improve the application and make it as much as functional and usable as possible.

Our results will be compared with other studies [5, 6] working with disabled people. We hope to achieve similar accuracy results. Nevertheless, this study also proposes a domotic application to increase the accessibility at home, allowing the subjects to control usual devices: TV, DVD player, mini Hi-Fi system, lights, fan, heater, telephone and a multimedia hard drive.

Our application could also be expanded to control any domotic device placed at a digital or intelligent home. It would be possible to add new output interfaces to the application: Bluetooth, Ethernet, Wireless LAN, etc. Therefore, disabled people could access any device placed in their usual environment decreasing their dependence on caregivers, nurses, relatives, etc.

The present work is a preliminary study and it presents some limitations. Although the domotic application is already implemented, it has only been tested by healthy users from our laboratory. In the upcoming months we will carry out experiments with potential users of BCI systems, from the CRE of Disability and Dependence.

In summary, the present preliminary study proposes a BCI application based on P300 potentials to allow disabled people to control effectively the devices present at home. Potential users of these systems will test and evaluate the application performance. Accuracy will be compared with other domotic application using a motor imagery-based BCI. Our experience with healthy users suggests that the results could be higher using P300-based BCIs, as they do not require a long and extensive training period.

References

[1]   J.R. Wolpaw, N. Birbaumer, W.J. Heetderks, D.J. McFarland, P.H. Peckham, G. Schalk, E. Donchin, L.A. Quatrano, C.J. Robinson, and T.M. Vaughan, "Brain-Computer Interface Technology: A Review of the First International Meeting", *IEEE Transactions on Rehabilitation Engineering*, 2000, vol. 8, pp. 164–173.

[2]   J.R. Wolpaw, N. Birbaumer, D.J. McFarland, G. Pfurtscheller, and T.M. Vaughan, "Brain–Computer Interfaces for Communication and Control", *Clinical Neurophysiology*, 2002, vol. 113, pp. 767–791.

[3]   R. Corralejo, D. Álvarez, and R. Hornero, "Brain Computer Interface Aplicado al Control de una Aplicación Domótica", *Actas del Simposio CEA de Bioingeniería*, 2010, pp. 28–36.

[4]   R. Corralejo, R. Hornero, and D. Álvarez, "A Domotic Control System Using Brain-Computer Interface", *International Work Conference on Artificial Neural Networks (IWANN)*, 2011, Accepted.

[5]   F. Nijboer, E.W. Sellers, J. Mellinger, M.A. Jordan, T. Matuz, A. Furdea, S. Halder, U. Mochty, D.J. Krusienski, T.M. Vaughan, J.R. Wolpaw, N. Birbaumer, and A. Kübler, "A P300-based Brain–Computer Interface for People with Amyotrophic Lateral Sclerosis", *Clinical Neurophysiology*, 2008, vol. 119, pp. 1909–1916.

[6]   U. Hoffmann, J.M. Vesin, T. Ebrahimi, and K. Diserens, "An Efficient P300-based Brain–Computer Interface for Disabled Subjects", *Journal of Neuroscience Methods*, 2008, vol. 167, pp. 115–125.

[7]   E.M. Mugler, C.A. Ruf, S. Halder, M. Bensch, and A. Kübler, "Design and Implementation of a P300-based Brain-Computer Interface for Controlling an Internet Browser", *IEEE Transactions on Neural Systems and Rehabilitation Engineer*, 2010, vol. 18, no. 6, pp. 599–609.

[8]   I. Iturrate, J.M. Antelis, A. Kübler, and J. Mínguez, "A Noninvasive Brain-Actuated Wheelchair Based on a P300 Neurophysiological Protocol and Automated Navigation", *IEEE Transactions on Robotics*, 2009, vol. 25, pp. 614–627.

[9]   C. Escolano, J. Antelis, and J. Mínguez, "Human Brain-Teleoperated Robot between Remote Places", *Proceedings of the IEEE International Conference on Robotics and Automation*, 2009, pp. 4430–4437.

[10] B. Roder, F. Rosler, E. Hennighausen, and F. Nacker, "Event-related Potentials during Auditory and Somatosensory Discrimination in Sighted and Blind Human Subjects", *Cognitive Brain Research*, 1996, vol. 4, pp. 77–93.

[11] N.S. Dias, P.M. Mendes, and J.H. Correia, "Subject Age in BCI2000", *Proceedings of the 2nd International IEEE EMBS Conference on Neural Engineering*, 2005, pp. 579–582.

[12] E. Donchin, and D.B. Smith, "The Contingent Negative Variation and the Late Positive Wave of the Average Evoked Potential", *Electroencephalography and Clinical Neurophysiology*, 1970, vol. 29, pp. 201–203.

[13] E. Donchin, K.M. Spencer, and R. Wijesinghe, "The Mental Prosthesis: Assessing the Speed of a P300-based Brain–Computer Interface", *IEEE Transactions on Rehabilitation Engineering*, 2000, vol. 8, pp. 174–179.

[14] L.A. Farwell, and E. Donchin, "Talking Off the Top of Your Head: Toward a Mental Prothesis Utilizing Event-related Brain Potentials", *Electroencephalography and Clinical Neurophysiology*, 1988, vol. 70, pp. 510–523.

[15] H.H. Jasper, "The Ten Twenty Electrode System of the International Federation", *Electroencephalography and Clinical Neurophysiology*, 1958, vol. 10, pp. 371–375.

[16] G. Schalk, and J. Melliger, "BCI2000 Bulletin Board: Channels for P300 Experiments", available in:

http://www.bci2000.org/phpbb/viewtopic.php?f=2&t=918&p=3263, 2011.

[17] D.J. McFarland, L.M. McCane, S.V. David, and J.R. Wolpaw, "Spatial Filter Selection for EEG-based Communication", *Electroencephalography and Clinical Neurophysiology*, 1997, vol. 103, pp. 386–394.

[18] Schalk, G., and J. Mellinger, *A Practical Guide to Brain-Computer Interfacing with BCI2000*, Springer-Verlag London, 2010.

Acknowledgements