Generic Brain-computer Interface for Social and Human-computer Interaction

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***Abstract*—After suffering a more severe disease like spinal cord injury or stroke patients are often not able to interact or even communicate with their environment anymore, especially at the beginning of rehabilitation. Brain-Computer Interfaces (BCIs) can substitute this temporarily lost communication channels and might support rehabilitation by providing an alternative way for controlling a computer only by thoughts without any muscle activity. This enables the patient to communicate by writing letters on the screen, to stay socially in contact with friends or people outside the rehabilitation facility by participating in games like Second Life, where they may appear as healthy persons. Another application isto control items in their room connected to the BCI system like the lights which can be turned off and on as it can be done in a virtual smart home without leaving the bed. In this paper, the technology of such BCIs and the mentioned applications are described utilizing the P300 approach. A generic BCI interface is presented, which allows controlling them and concurrently and transparently switching among them. The results of a recent study show that a BCI can be used by patients suffering from cervical spinal cord injury almost as well as by healthy people which encourages us to think it may assist rehabilitation regarding the social aspect. A variety of BCI can be implemented with the aim of provide them a more active and accessible lives.**

Keywords-Brain-Computer Interface; BCI; P300; Visual Evoked Potentials; speller; Second Life; Virtual Smart Home

I. INTRODUCTION

Many disorders can affect or even completely damage the usual communication channels a person needs to communicate and interact with his or her environment. Spinal cord injury, stroke and Amyotrophic Lateral Sclerosis (ALS), for example, can result in partial or complete loss of voluntary muscle activities including speech. In such severe cases, a Brain-Computer Interface (BCI) might be the only remaining possibility to communicate [1]. BCI based on Electroencephalography (EEG) provides a new non-invasive communication channel between the human brain and a computer without using any muscle activity. It measures and analyzes the electrical brain activity during predefined mental tasks and translates them into the corresponding action intended by the user. But, even for less severe levels of affection, a BCI can improve quality of life of partially paralyzed patients during rehabilitation by enabling them to control a computer and specially prepared electronic devices, or to stay in contact with friends through social networks and games, for example.

BCIs based on P300, positive-going waves with a peak typically at typical latency of 300-1000 ms from stimulus onset, provide goal-oriented control and are mainly used for spelling devices. Farwell and Donchin were one of the first pioneers who used the P300 for communication [2]. Furthermore, this approach can also be used for game control [3] or navigation (e.g., moving a computer mouse [4]). The P300 evoked potential is elicited when a unlikely event occurs randomly between events with high probability. It manifests itself in a positive deflection in the amplitude of the EEG signal around 300ms after a visual stimulus onset. Different classification techniques have been evaluated for P300 spellers whereby both the Fisher's linear discriminant analysis and the stepwise linear discriminant analysis yielded very robust performances [5]. These classification methods need to be trained on each individual subject to adapt them to the particular brain activity behavior of a person. However, training of such a BCI system can be accomplished within several minutes [6]. Guger et al. demonstrated that more than 70% of a sample population is able to use such a spelling setup with an accuracy of 100% [9].

This paper presents a generic User Datagram Protocol (UDP), Extensible Markup Language **(**XML) based BCI command interface (according to the recently introduced international BCI interface standard, see www.gtec.at) and its application to implement control interfaces enabling social interactions like spelling, interacting virtually with other participants in Second Life, operating Twitter and controlling a virtual smart home. All of these applications are based on the P300 speller principle. Results of a spelling application study done with 100 healthy people will be compared to a recent study also including spinal cord injury patients showing that this type of a BCI would be suited for rehabilitation assistance.

This paper presents different applications (Twitter Interface, Virtual Smart Home Control and a Generic Control Interface) tested with healthy people. The outcomes from them are shown in different tables in Section III.

II. MATERIAL AND METHODS

For a P300 spelling device, a 6x6 matrix of different characters and symbols is commonly presented on a computer screen [7]. In single-character mode all characters are flashed in a random order but only one character after each. In row-column mode, a whole row or a whole column flashes at a time. The subject has to concentrate on a specific letter he or she wants to write. The flashing of exactly this character or the corresponding row or column is a relative unlikely event which induces a P300 component in the EEG signal reaching its maximum amplitude around 300 ms after the onset of the flash.

For all other characters, rows or columns no such P300 component is elicited because they are not relevant to the subject currently.

To measure the P300 component acquisition of EEG, signals from 8 electrode positioned mostly over occipital and parietal regions is sufficient [8]. To train the BCI system, an arbitrary word like LUCAS is announced to the system to be aware of which characters the subject is supposed to concentrate on (targets) and which not (non-targets). Each of these letters respectively, each row and column flashes several times e.g., for 100 ms per flash. The subject focuses on each of these letters, one after the other, and increments a mentally running count whenever the letter flashes the subject is currently concentrating on. EEG data of a specific time interval around each flash is then sent to a Linear Discriminant Analysis (LDA) classifier to learn to distinguish the typical EEG signal form of the target characters from the typical signal form of all other non-targets.

The applications described in the following were solely tested with healthy people. All of the following applications are based on the same principle and setup. They basically differ in the content of the matrix where letters may be replaced by symbols or phrases to control the associated applications.

A. *P300 Twitter Interface*

Through the social network Twitter (Twitter Inc.), users can exchange messages. These messages can be sent over the Twitter website, by smart phones or by SMS (Short Message Service). They are displayed on the author’s profile page and are limited to 140 characters per message. Interfacing possibilities can be extended through the application programming interface provided by Twitter.

The control mask of the classical speller application was extended to add the necessary Twitter control commands in the first two lines (Fig. 1). The remaining characters are used for spelling resulting in a total of 54 possible symbols. Fig. 3 shows the Unified Modeling Language (UML) diagram of required actions for using the Twitter service.

The system was initially trained with 10 target symbols for the BCI user. Then, another user was asking questions through Twitter and the BCI user had to answer each question every other day. A total of 9 questions were asked which means that the BCI user had to use the P300 interface on 9 different days whereas they selected between 6 and 36 characters each day.

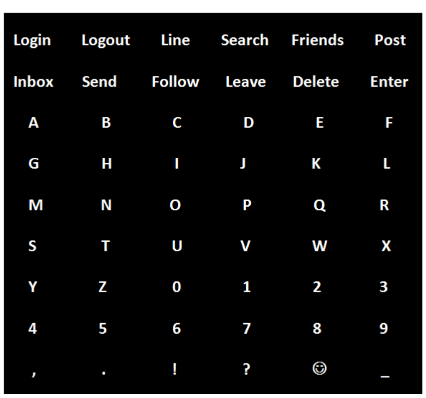

Fig. 1 The extended P300 interface control mask for Twitter.

B. *Virtual Smart Home Control*

A virtual 3D representation of a smart home was designed based on the XVR environment (eXtreme Virtual Reality, University of Pisa) [10] [11]. Seven different control masks were developed for the P300 BCI in order to control the virtual smart home environment.

Fig. 2 Two views of the virtual smart home and the corresponding control masks.

Fig. 2 shows two example views of the virtual apartment with their corresponding control masks. The pictures on the top show a 3D view of the living room (Fig. 2a) and the corresponding main control mask (Fig. 2b) enabling the user to control some of the devices in the living room like the TV set, the room light or the telephone. Fig. 2c shows a bird’s-eye view of the virtual apartment. The living room, for example, can be found in its top left corner and the bathroom is located in the bottom right corner together with the entrance door. Using the related “GoTo” P300 BCI control mask (Fig. 2d), the user can beam himself to 21 different locations in the apartment. Using the seven control masks, it should be possible for users to switch the lighton and off, to open and close the doors and windows, to control the TV set, to use the phone, to play music, to operate the video camera at the entrance, to walk around in the house and to move their selvesto a specific place in the apartment.

The subjects were instructed to avoid unnecessary movements and to accomplish some specific tasks like opening the front door, moving to specific places in the apartment or manipulating the light source or the room temperature. Further details on the setup and results can be found in [10].

C. *Generic Control Interface*

The interface was designed with the intention to control multiple applications and devices simultaneously and to provide a common way of sharing BCI control in a consistent manner among them. The various applications, like the Twitter (Section II.A), differ in the content of the P300 BCI matrix where letters may be replaced by symbols or phrases to control the associated applications.

In a first step, the possible control states and the commands available in each state to move on to the next state are identified using Unified Modeling Language (UML) diagrams, which yield a simple and clear overview of all required elements. Based on the diagrams, the detailed descriptions of the states and the actions to be taken along with the transition

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to the next state, an XML file describing the required masks, the position of the different symbols within the mask and the commands to call is generated for each application. Upon startup, the initial interface descriptions of the different applications are merged and symbols are added for switching among them. Fig. 3 shows the UML diagram for the Twitter application. Fig. 1 shows the P300 mask resulting thereof. Whenever a control symbol or character is selected by the user, the BCI emits the command or character string associated with the symbol or executes the related action.

Alternatively, the interface allows for online updating the control mask of the application in reaction to its current internal state or the state of its environment in real-time. Thereby, it sends the adopted description of the control mask to the interface unit through the UDP network socket. At the beginning of the next flash cycle, the BCI interface will load this updated mask and present it to the user for the selection of the appropriate commands.

III. RESULTS

The interface was implemented for and tested with the two applications, Twitter and Second Life presented above. For the 2 systems, the control states were identified using UML state diagrams. Based on these the control mask, descriptions were generated, merged and the symbols for switching between the applications were added. In the following sections, some the results achieved for each of the applications are discussed.

The EEG data were recorded for all above applications including the interface test applications with a g.MOBIlab+ Biosignal Amplification Unit (g.tec medical engineering GmbH, Austria) at 256 Hz sample rate and transferred to the computer wirelessly via Bluetooth®. A MATLAB/Simulink model controls the interface masks, processes the received data via a specific device driver and dispatches the targeted commands via the described UDP XML message passing interface. A notch filter (50 Hz or 60 Hz) and a band pass filter were applied to the signals in order to eliminate possible artifacts before they were down-sampled to 64 Hz. Data from 100 ms before each flash onset to 700ms afterwards were filtered and down-sampled again to get 12 feature values (i.e. samples) per channel and flash. These data chunks were sent to the LDA to determine if a target character flashed or not. The subjects were sitting or standing, dependent on the application, in front of a computer screen and were instructed to relax as much as possible.

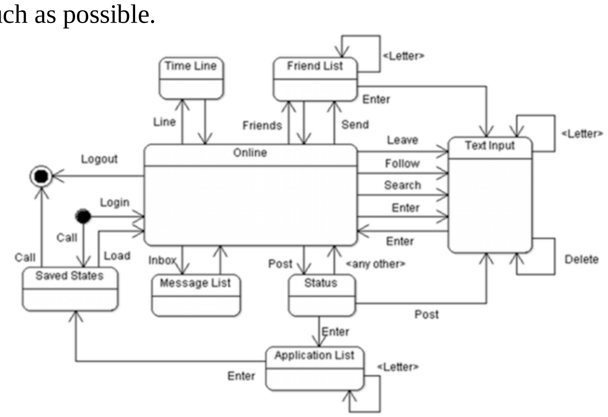

Fig. 3 UML diagram of the actions required to use the Twitter service

A. P300 Twitter Interface

TABLE I. QUESTIONS AND TEXT INPUT WITH THE P300 TWITTER INTERFACE

Tweets	Number of characters	Duration [hh:mm:ss]	Errors	Errors %	Number of flashes	Time per character [s]
Friend: Which kind of Brain-Computer Interface do you use?						
BCI: P300 GTEC BCI	**13**	**00:11:09**	**3**	**23,08**	**8**	**51**
*FRIEND: Are you using the g.GAMMAsys**?***						
BCI: Exactly!	**7**	**00:06:18**	**1**	**14,29**	**8**	**54**
FRIEND: Active or passive electrodes? For explanation: the active system avoids or reduces artefacts and signal noise.						
BCI: Active electrodes	**17**	**00:06:10**	**0**	**0,00**	**5**	**22**
FRIEND: The mounting of the active system is very comfortable. You do not need to prepare the skin first, do you?						
BCI: you are absolutely right	**24**	**00:08:55**	**1**	**4,17**	**5**	**22**
FRIEND: How many electrodes are needed to run the BCI?						
BCI: For P300 we usually use 8 electrodes	**36**	**00:14:21**	**2**	**5,56**	**5**	**24**
*FRIEND: What amplifier are you using for the Brain-Computer Interface**?***						
BCI: g.MOBIlab+	**10**	**00:04:42**	**1**	**10,00**	**5**	**28**
FRIEND: h, g.MOBIlab+ - this is the g.tec's portable biosignal acquisition and analysis system!						
FRIEND: How long does it take to code the software for the BCI for TWITTER?						
BCI: 3 Weeks	**7**	**00:03:13**	**1**	**14,29**	**4**	**28**
FRIEND: How many characters are you able to write within a minute?						
BCI: 3 TO 4	**6**	**00:03:15**	**0**	**0,00**	**5**	**33**
FRIEND: You are using the BCI device for one month? Did you get faster in writing during this period?						
BCI: Yes, from 2 to 4 characters	**27**	**00:06:38**	**1**	**3,70**	**3**	**15**
FRIEND: Great, thank you for answering the questions!						

Table I shows the results of the answers from the BCI user (bold sentences) to the 9 questions (italic sentences). The improvement of the user's performance from the first session to the last one is interesting.

For the first session, it took the user 11:09 min to spell 13 characters with 3 mistakes. The user was instructed to correct any mistake yielding an average of 51 seconds selection time for each character. In contrast to this, the last session was accomplished in a time of 6:38 min for 27 characters with only 1 mistake resulting in an average selection time of 15 seconds per character. The number of flashes per character decreased from 8 to only 3 flashes as well.

B. Virtual Smart Home Control

A total of 12 healthy subjects participated in the case study. The system was trained on 42 selected target symbols for each subject. In contrast to the previous applications, the subjects were standing in front of a 3D power wall for projection of the virtual smart home while using this BCI.

In the virtual smart home study, the subjects needed between 3 and 10 flashes per character (mean 5.2 flashes per character) to achieve an accuracy of 95% in single-character mode [10]. Table II lists the accuracy of all subjects for each of the 7 control masks among other parameters. The more symbols a mask contains, the lower is the probability of occurrence of one symbol. This results in an increase of the amplitude of the P300 component in the EEG signal. Also the time needed to select a single character increases because it takes the system more time to flash all the characters.

Interestingly, the subjects achieved only 26.39% accuracy for the “Go to” mask, which is quite bad compared to the other control masks. We think this is due to its different layout. While all the other control masks were arranged in a matrix layout, the “Go to” mask was the only one where the symbols were placed at apparently random positions related to the appearance of the virtual apartment. More detailed results of the virtual smart home study can be found in [10].

TABLE II ACCURACY, NUMBER OF SYMBOLS, OCCURRENCE PROBABILITY PER SYMBOL, NUMBER OF FLASHES PER SYMBOL AND MASK (E.G., 25 X 15 = 375) AND SELECTION TIME PER SYMBOL FOR EACH MASK

Mask	Accu-racy	No. Sym-bols	Proba-bility	No. Flashes	Time per character
Light	65.28%	25	4%	375	33.75 s
Music	76.11%	50	2%	750	67.50 s
Phone	63.89%	30	3.3%	450	40.50 s
Temper-ature	76.39%	38	2.6%	570	51.30 s
TV	65.74%	40	2.5%	600	54.00 s
Move	75.93%	13	7.7%	195	17.55 s
Go to	26.39%	22	4.5%	330	29.70 s

IV. DISCUSSION

Extending the standard P300 speller by icons and symbols enables the user to control more complex scenarios. In [10], it is shownthat a proper design of interface masks allows control of domotic devices in avirtual smart home study with comparable reliability as it has been reached for the spelling application. This paper discusses the usage of the BCI interfaceto control smart homes or operating social interaction applications like sending or answering Twitter messages.The generic BCI interface which uses XML based description files simplifies the definition of the control masks. By merging the control masks of several applications like Twitter and environments like a virtual smart home, it is possible to use the different systems concurrently. To switch to another application, it is sufficient to select the symbol or sequences of symbols used to load its control mask. If not running, the application will be started and initialized to receive the control commands from the BCI.

In a recent study, Guger et al. evaluated a P300 speller (6x6character matrix) in row-column mode with 100 healthy subjects (32 female and 68 male at the age of 27.9 ± 10.9) using a similar setup as described in this study [9]. Using a subset of 81 subjects, 88.9% of them were able to use the speller with an accuracy level of 80-100% whereas 72.8% reached an accuracy of 100%. The average accuracy level was 91.1% with a spelling time of 28.8 seconds for a single character. Since this speller is based on the same P300 principle, the results indicate that the previously described applications might also perform better using row-column mode instead of single-character mode.

The results of the study show that a P300 brain-computer interface can also be used by patients suffering from more severe diseases. This encourages us to think that a BCI may be helpful during rehabilitation. Especially when people are bound to bed or rehabilitation facilities, it is important to keep them socially engaged. The applications described here help people to keep in touch with friends and other people all around the world through popular social networks and platforms, like Twitter. Another important fact is that patients may appear as healthy people, for example,in Second Life,which may be a benefit regarding psychological aspects to let the disability fade from people’s minds. Furthermore, a BCI can also be used for wheelchair control, which many authors identify as their target application. However, there are still some minimum requirements to operate a BCI. In fact, there is a certain percentage of the population (including healthy people as well) that is not able to operate a specific type of BCI at all, which may have various reasons [13].

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