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Towards P300 based brain computer interface for Computer Aided Design

C. Postelnicu[1], M. Duguleana[1], F. Garbacia[1] and D. Talaba[1]

[1]University Transilvania of Brasov, Department of Robotics and Virtual Reality

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Abstract

The paper evaluate the row-column P300-based spelling interface for geometric modeling tasks in the engineering design process. In the first part of the paper is presented a BCI-CAD interface that can be used for geometric modeling applications. The proposed solution for BCI-CAD integration tries to preserve all advantages of using the existing legacy CAD software and add on top of it a BCI interface as an alternative to the existing classical WIMP paradigm. In the second part, we present a evaluation study of the BCI-CAD system by trials with subjects carrying out a standard CAD modeling session. The results are discussed in the last part of the paper.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [Information Systems]: User Interfaces—

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1. Introduction

Today, tens of millions of people are living with paralysis. Among these, around 1% suffer from tetraplegia (also known as quadriplegia), a form of paralysis that causes partial or total loss of use of limbs and torso. Once destined to live an isolated and distressful life, these people are now able to have a normal existence, thanks to some breakthrough advances in rehabilitation and medicine, based on which the research community can take the next steps. There are areas that can be significantly improved, and one of them is related to the social integration, specifically the working activities. Tetraplegics need first of all to overcome the sense of inutility, one of the most vicious effects of their condition. It is necessary to inspire these people a sense of integration, of accomplishment. This challenge requires a continuous commitment to developing new human-machine interaction technologies and conducting research regarding the usage of new input signals within adaptive multi-modal interfaces.

One of these is the Brain-Computer Interface (BCI). BCI's technology research is still at its infancy but has an almost limitless and unexplored potential to become a key element within natural Human-Computer Interaction (HCI). BCI is a key technology that can be used within a multimodal user interface (UI) especially designed for people affected by tetraplegia. Others may include data collected from speech, touch and gaze.

One of the most beneficial BCI-mediated activities for disabled people could be the use of Computer Aided tools (CAx) with the purpose of designing parts, assemblies and products in general as if their disability did not exist. This would greatly enhance their quality of life and dramatically increase their social and even professional interaction capacity. Computer Aided Design (CAD) and Computer Aided Engineering (CAE) systems are unique tools that allow and facilitate the human innovation activity. Modern CAD/E software relies heavily on the conventional Windows, Icons, Menus, Pointer (WIMP) UIs. Not only WIMP UIs restrict the degree of natural interaction between the user and such applications, but also make it almost impossible for such applications to be used by tetraplegics or other people with disabilities.

In theory, if developed to its full potential, brain-computer interaction could be used to create entire CAD assemblies by just thinking. By using a hybrid multi-level fusion approach, BCIs can be augmented with other information channels in order to fully cover the field of CAD/CAE. This technology could have a great impact not only for the lives of tetraplegics, but for the entire 3D modelling community.

2. State of the art

There are approximately 40 million persons with disabilities living in EU, and of these, approximately 50% are of

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working age. The European Disability Strategy 2010-2020 tries to gain more substance and to concentrate the large degree of national subsidiarity into an integrated approach that addresses both "soft policy" instruments (e.g. indicators, benchmarks, targets, best practice guidelines and recommendations) and "hard law measures" (e.g. primary legislation, directives or regulations).

Social measures are however not enough. Progress towards higher or complete social integration needs to be addressed technologically. This can be taken for a fact, considering the integration variety across EU. In developed countries for example, more than 50% of disabled people are actively working, whereas in developing countries, the ratio is of around 15% [ANE12]. One of the main recommendations of Academic Network of European Disability (ANED) is the use of European funding to support the development of initiatives to foster social integration, such as H2020-ICT-2014-1 programme.

This section summarizes the current state of the art for this article.

2.1. CAD/E

All CAD software relies heavily on WIMP interface. Thus, the introduction of multimodal UIs for performing CAD operations is not a simple task. There are many issues that affect CAD operations and need to be investigated. When engaging in a CAD scenario, there are 2 main types of tasks that are used: selection tasks and dimensioning tasks. Aside these, in order to operate a CAD system, the user must also interact with application GUI, by file system operations (i.e. New, Save, and Open commands), editing operations (i.e. Erase, Undo, Move, Copy) and display control operations (i.e. Zoom, Pan, View, Redraw/Regenerate) [Ter14].

Selection tasks. Many operations in CAD involve the selection of a particular entity (a point, an edge, a face or an entire object). In the case of a point selection, multimodal UIs may emulate mouse movements, as the mouse pointer metaphor eliminates completely issues such as occlusion. However, the multi-selection problem is another issue that needs to be dealt with, as by selecting a point the user also selects at least an edge or a plane. In many CAD operations, users need to work with intersection points, and in some cases, selecting a line or a plane by their centre rather than at the intersection would not be a viable option [GBT12, Tal08]. Hence such cases must be tackled by intelligent and adaptive algorithms, i.e. by persistent labelling each entity and using its unique name in operations. For the case of BCI usage, labels could be spelled by P300 signals.

Dimensioning tasks. Every CAD model, every designed piece has specific dimensions required by specific tasks. During the execution of specific operations (such as scale, fillet, extrusion, protrusion and so on) users may have to input dimensions one or multiple times, depending on the operation. This is usually achieved via a standard keyboard. However, within multimodal UIs, numbers can be inserted i.e. by voice input or drawing pens [RPC97, Ovi97]. For the case of BCI usage, dimensioning tasks may be covered by using P300 signals.

2.2. Brain-Computer interfaces

A BCI device is known today as a direct communication pathway between human brain and computer. Based on the signal acquisition component, BCI can be divided into two categories: non-invasive and invasive. Among the most used non-invasive technologies one can mention EEG. EEG produced in the recent years some of the most spectacular results, mainly due to its fine temporal resolution, high degree of usability/portability and low equipment costs. All the main drawbacks of this technology - which include high susceptibility to noise, extensive training time before usage, low spatial resolution and complicated fusion algorithms used in multimodal interaction - are addressed at the moment by public and private research [MC12, CF12].

Among all the types of EEG signals that have been observed and used by scientists, two categories distinguish themselves: evoked signals/potentials and spontaneous signals. Evoked potentials (EPs) are generated unconsciously by the user when he perceives an external stimulus, while spontaneous signals do not depend on external stimulus being generated voluntarily by the subject. In the category of EPs, the main signals are the Steady State Evoked Potentials (SSEP) and the P300.

The EPs category has a great advantage achieving higher information transfer rates and also, very good classification accuracies during selection-based applications. Thus, we aim to integrate EPs, specifically the P300 potentials, in CAD applications which are mainly based on selecting different commands, coordinates, surfaces, and so on. The P300 is a positive peak in the EEG signals appearing approximately 300ms after the user visually perceives a relevant stimulus. It is typically generated within a paradigm that randomly generates stimulus of target and non-target types. If a target stimulus is perceived by the user then it will trigger a P300 in the user's EEG [FD88]. P300 was used in the beginning for spelling applications, but their appliance evolved for control in smart-homes, computers and even robotic wheelchairs. The classic P300-based spelling paradigm organizes the letters and digits in a matrix - "a virtual keyboard" - the user being able to select one of them by gazing at the desired item and mentally counting each time the item is highlighted. The first paradigm assumed that items were organized in rows and columns (RC paradigm) being flashed each 125ms in a random order [FD88]. Each time the user perceived the chosen item (the row or column it belongs is highlighted) a P300 potential is triggered in the EEG's. The presence or the absence of the P300 within EEG's associated with the order the rows and

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columns that were highlighted makes possible the identification of the chosen item. Since then, various paradigms were proposed: single character paradigm [CG09], the checkerboard paradigm [GT10], the half-checkerboard paradigm [PT13], lateral single-character [SB12], binomial coefficients based flashing methods [JJ11] or gaze independent ones [PA11].

2.3. Brain-Computer Interfaces in CAD applications

CAD/CAE is a field where the traditional WIMPs dominate due to the complexity of the interaction metaphors. In recent years however, the emergence of new technologies such as pen-based systems, haptic devices and the evolution speech recognition software is providing a viable alternative to the classical means of interaction. The main goal behind the usage of such equipment is to develop a more natural way of interaction and to reduce the number of steps needed to activate CAD commands. BCIs take a step further and, based on new developments, make now possible for users to engage in CAD/CAE activities.

The idea of using BCI in CAx activities is relatively new. Several studies have already showed that BCI can be used i.e. in virtual environments to manipulate virtual objects or navigate inside the scenes [AL08, RK07, PA06] . From that point, it is just a straight line to the investigation of different applications of brain computer interfaces in CAD environments.

3. BCI-CAD interface

The main principle of the BCI-CAD tool used was to maintain the usual CAD functions as known and used by the professionals and just add a BCI user interface that works in parallel with the conventional one. Thus, we worked with a legacy CAD software to which we just developed functions based on BCI, replacing the conventional input devices like mouse and keyboard.

3.1. BCI-CAD software interface

The software configuration is designed as a modular distributed network based on the strict separation of its management into layers: a module for the model database management and a module to drive the interaction and virtual environment (BCIModeller).

The BCIModeller module handles all the aspects of user interaction such as reading and interpreting the data received from the BCI device, sends entity generation commands to the SolidWorks, reading model information from the legacy software, generate VR files and transmits them to the visualisation display. The proposed architecture provides methods by which objects in virtual environment can be manipulated, added, or removed. Microsoft Windows is the operation system used for VR and CAD system. The VR 3D database and model communication is made in VRML2.0 (Virtual Reality Modeling Language) and BS Contact Stereo is used as a viewer for the 3D models. SolidWorks offers an API (Application Programming Interface), which provides the means for creation and access to the CAD model data. The modules added to the legacy software are implemented in C++ language.

In order to create a closed loop between CAD system and BCIModeller that allows users to create and modify 3D objects interactively using BCI, a module allowing the transfer of CAD models information from the SolidWorks system that was created. The geometry and topology of Solidworks CAD models are encapsulated in a VRML file that includes all parts, surfaces and tessellations as well as their relationships. Each VRML tessellation is linked to one surface and each surface corresponds to only one part. The VR model entities are treated as individual objects with unique identifiers that correspond with the names from the CAD database. The resulting parts' geometry files preserve the part name, and they are referenced by their names from the VRML scene file. The tool is completely automated and was developed using SolidWorks API.

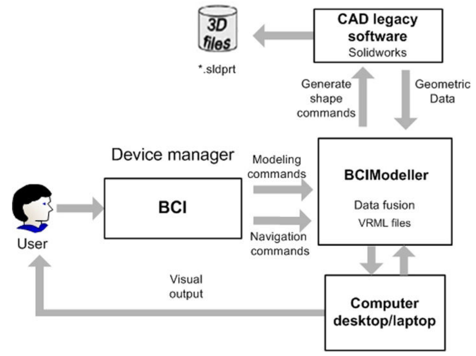

Figure 1: *Software architecture of the BCI-CAD system.*

3.2. BCI-P300 interface

The command selection interface is based on the use of P300 potentials. The interface assumes grouping of CAD commands in the form of a 6x6 matrix, organized on rows and columns (see Figure 2). The row-column (RC) P300 paradigm assumes flashing of elements contained by a row or a column at a time. In this experiment the RC paradigm highlights each row/column for 100 ms (flash time). Between the flashes is a short time while all items are grey for 60 ms (dark time). After each column/row is highlighted for 12 times the classifier, based on the linear discriminant analysis (LDA), applied on the EEG recorded signals decides which item the user did select. Selection of a command lasts 23.04 s (6 rows x 160 ms x 12 flashes + 6 columns x 60 ms x 12 flashes = 23.04s), while between each selection is a pause

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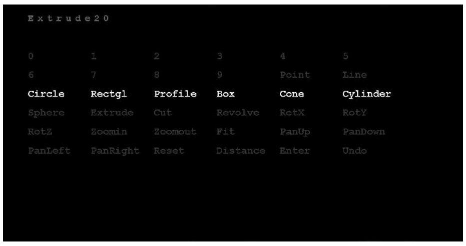
of 5 s. Initially the users are asked to follow a simple training test with the P300-based command selection interface, being instructed to select 8 commands (items) in the following sequence: Rectangle 30 Enter Extrude 20 Enter. During this training test the BCI does not give feedback to the user. The calibration data are then processed using the LDA to compute the EEG weighting parameters. The LDA is based on the use of 800 ms epochs of the EEG signals beginning at the onset of the highlighted stimulus. All epochs are entered the LDA and based on the weighting coefficients computed after the calibration phase the classifier will decide which is the item the user selected.



Extrude20

0	1	2	3	4	5
6	7	8	9	Point	Line
Circle	Rectgl	Profile	Box	Cone	Cylinder
Sphere	Extrude	Cut	Revolve	RotX	RotY
RotZ	Zoomin	Zoomout	Fit	PanUp	PanDown
PanLeft	PanRight	Reset	Distance	Enter	Undo

Figure 2: *P300 interface.*

3.3. BCI setup

THE BCI-P300 based interface assumes the recording of EEG signals from the user's scalp by mean of electrodes. During this experiment is was used the g.USBamp (g.tec Medical Engineering GmbH, Austria) device in order to record the EEG signals. Eight electrodes, placed at Fz, Cz, P3, Pz, P4, PO7, Oz and PO8 locations according to the 10/20 extended International System [Soc91], were used for recording the EEG signals. All channels were referenced to the user's right earlobe and grounded to the user's forehead. Electrodes are connected to the g.USBamp through the g.SAHARAbox, the used gold alloy electrodes being dried - no conductive required. All EEG signals were acquired at a sampling rate of 256 Hz and filtered by a 50 Hz notch filter. Further, EEG signals are band-pass filtered between 0.5 - 30 Hz.

Figure 3: *Participant using the BCI-CAD system.*

4. BCI-CAD experiment

The aim of the evaluation study presented in this section is to assess the way BCI-CAD interface can be used to design products.

4.1. Experiment set-up

The experiment consisted in modeling the CAD part presented in figure 4 composed from two rectangle features, a cylinder and a blind pocket. For the modeling process was used a 2D engineering drawing where are ilustrated the axonometric views of the 3D part. Modelling of the test CAD part consists of the following tasks: (i) select the rectangle command and create a 15 cm x 10 cm grid rectangle; (ii) select the extrude command and create a 3D feature with the height of 6 cm; iii) select the rectangle command and create a 3 cm x 10 cm rectangle on the top of the first rectangular feature; (iv) select the extrude command and create a 3D feature with the height of 3 cm; v) select the circle command and create a circle with the radius of 5 cm on the top of the first rectangular feature; vi) select the extrude command and create a cylinder feature with the height of 3 cm; vii) select the circle command and create a circle with the radius of 3 cm on the top of the cylinder feature; viii) select the cut command and create a blind pocket feature on the cylinder feature;

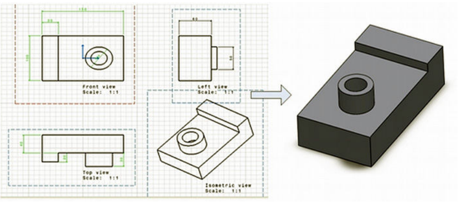
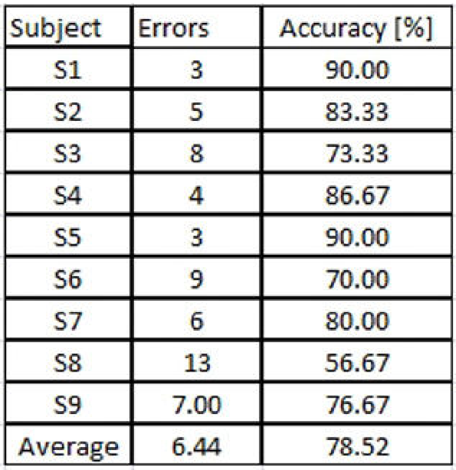


Figure 4: *The 3D CAD part used in the evaluation study: the 2D drawing and the 3D CAD model.*

4.2. Results

Nine healthy subjects (7 male, 2 female, aged 20-31) participated in the experiments and all of them gave their written informed consent. Three of them had previous experience with BCI systems (S1-S3). They were asked to first perform a calibration phase and a test for designing a CAD model (see Section 4.1). For the online test they were asked to design a CAD model which assumed the selection of 30 commands/items from the P300 matrix. For each participant the online accuracy was computed (considering number of errors during test). The total time computed for selecting all the commands/items from the menu (excluding pauses between selections) was of 11.52 min (160 ms x 12 rows/columns x 12 flashes x 30 commands = 691.2 s), while including pauses results a total of 14.42 min (691.2 s + 29 commands x 6 seconds). Results obtained for each user are listed in Table 1. An average accuracy of 78.52% was obtained, while the average number of errors was of 6.44.



Subject	Errors	Accuracy [%]
S1	3	90.00
S2	5	83.33
S3	8	73.33
S4	4	86.67
S5	3	90.00
S6	9	70.00
S7	6	80.00
S8	13	56.67
S9	7.00	76.67
Average	6.44	78.52

Figure 5: *Results obtained for each user.*

5. Conclusions

This study intended to evaluate the row-column P300-based spelling interface for CAD modelling. It represents initial tests regarding a robust interface between BCI and CAD. The proposed interface does evaluate only the selection of commands required for CAD modelling, but further developments based on current results should lead to a complete modelling interface. For the present study the average accuracy obtained was of 78.52% which is over the minimum accuracy level of 70% required for a BCI system. We cannot compare directly the obtained accuracies with other studies since most of other studies consider only very short words when evaluating accuracy rates [CG09, GT10]. Still, a direct comparison between RC-based speller applications and the present interface shown similar accuracy rates: 78.52% for the present study, 77.34% in Townsend [GT10] or 85.3% in [CG09]. Extensive studies must be performed in order to see exactly how are accuracy rates influenced by a long-term use of such an application since CAD modelling requires the use of many commands selections.

6. Acknowledgements

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