A P300-based Brain-Computer Interface to Control a 3D LabVIEW Simulation using GTEC Unicorn P300 Speller Aimed at Cognitive Training

Oana Andreea Rușanu
Transilvania University of Brașov, Romania
Product Design, Mechatronics and Environment Department
Str. B-dul Eroilor No. 29
oana.rusanu@unitbv.ro

ABSTRACT

The Brain-Computer Interface (BCI) is an innovative, multidisciplinary research field that offers cutting-edge technologies in medical engineering. BCIs assist individuals with neuromotor disabilities in controlling assistive devices or enable mental communication through the P300 Speller interface. Additionally, BCIs provide opportunities for cognitive training for individuals suffering from cerebral strokes or spinal cord injuries by controlling interactive virtual simulations. This paper presents a novel approach for integrating the LabVIEW graphical environment with the GTEC P300 Unicorn Speller to control a 3D scooter guided by a humanoid robot across various movement directions. The proposed brain-computer interface utilizes the Unicorn headset equipped with 8 EEG sensors. Three subjects participated in experiments involving 16 movement commands across three difficulty levels.

Author Keywords

Brain-Computer Interface; P300 Evoked Biopotential; LabVIEW Instrument; Unicorn EEG headset.

ACM Classification Keywords

K.6.3 Software Engineering; D.1.E Programming Techniques; H.5 Information Interfaces and Presentation.

General Terms

Programming Environments; Visual Programming; Multimedia Information Systems; User Interfaces.

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INTRODUCTION

The brain-computer interface (BCI) is a medical engineering-based system designed to assist, train, and rehabilitate the cognitive and motor abilities of individuals who have suffered from stroke or spinal cord injuries or are diagnosed with conditions such as amyotrophic lateral sclerosis or locked-in syndrome. These individuals are unable to move their limbs and require alternative means to bridge the normal communication pathways between the motor cortex and muscles or peripheral nerves. As a multidisciplinary research area, BCI applications range from controlling mechatronic devices [1] to neurofeedback- based rehabilitation techniques, cognitive training [2], and video game control through mental commands [3].

Over recent decades, advancements in software and hardware technology have laid the foundation for innovations in brain-computer interfaces, virtual reality, artificial intelligence, and remote laboratories [4]. These developments have resulted in the creation of portable, state-of-the-art devices that enhance human-computer interactions, such as portable headsets with multiple electroencephalographic sensors—NeuroSky Mindwave Mobile, Emotiv Insight, Muse, or GTEC Unicorn. These devices make it feasible to use BCIs in home environments, providing valuable opportunities for people with neuromotor disabilities.

While invasive techniques, such as implanting intra-cortical sensors during brain surgery, have shown the most impressive results in BCI research, the development and testing of portable BCI systems [5] remain underexplored. Innovative approaches can focus on developing high- performance, creative solutions featuring compact designs and advanced functionalities that integrate various hardware platforms (e.g., Arduino and Raspberry Pi) and software environments (e.g., LabVIEW and Matlab).

Although most research in this field focuses on the physical rehabilitation of disabled individuals, their mental wellness and need for entertainment should also be considered. By designing and testing BCI applications in an interactive learning environment, such as games, additional benefits can be achieved for people with neuromotor disabilities. These benefits include cognitive training by focusing on safe virtual simulations, neurofeedback stimulation [6] to enhance mental focus, and providing an enjoyable experience through natural human-computer interaction.

This paper discusses the implementation and testing of an original P300-based BCI instrument that animates a virtual simulation in the LabVIEW graphical programming environment. The simulation involves guiding a 3D scooter steered by a humanoid robot through various movement directions using P300 mental commands. The novelty of this research lies in the development of a gaming paradigm for interactive learning, the original programming block diagram for integrating the LabVIEW environment with the GTEC Unicorn P300 Speller, and the description of the experimental stages.

This paper is organized into the following sections: Introduction; Software and Hardware for the Monitoring and Processing of the EEG signals; LabVIEW brain- computer interface for controlling a 3D scooter game; Results and experiments; Conclusions.

SOFTWARE AND HARDWARE FOR MONITORING AND PROCESSING EEG SIGNALS

The Unicorn headset, introduced in 2019 by the GTEC Medical Engineering Company in Austria, is equipped with 8 hybrid sensors to acquire electroencephalographic (EEG) signals at a sampling frequency of 250 Hz and a resolution of 24 bits, ensuring high accuracy in detecting neuronal biopotentials that are later used as commands in a BCI system. The Unicorn headset kit includes both free and paid licenses for official software tools. The Unicorn Recorder is used to acquire and record raw EEG signals from all 8 sensors, while the Unicorn Bandpower monitors EEG rhythms (delta, theta, alpha, beta, and gamma) during mental tasks.

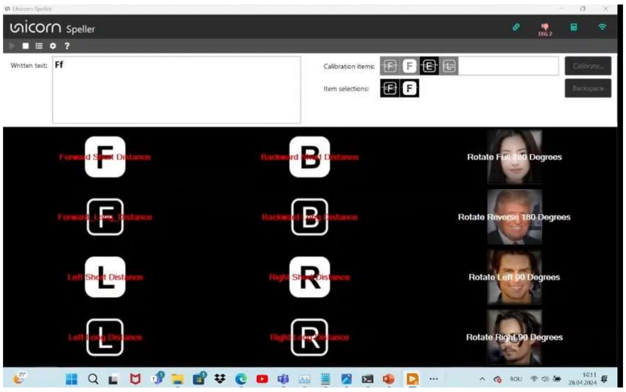

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Figure 1 The customized P300 Speller Palette for controlling the 3D scooter guided by a humanoid robot in LabVIEW.

The Unicorn P300 Speller provides a graphical user interface with standard and customized palettes, including dark and randomly flashing items that trigger P300 commands after the user mentally counts the number of flashes on the desired symbol. In the current research, the customized palette is shown in Figure 1. Each image must be edited if its size exceeds the number of bytes supported by the UDP Read LabVIEW Function; otherwise, delays or errors may occur during operation.

LABVIEW BRAIN-COMPUTER INTERFACE FOR CONTROLLING A 3D SCOOTER GAME

An original LabVIEW application was developed to integrate P300 evoked biopotential commands with the control of a 3D scooter game.

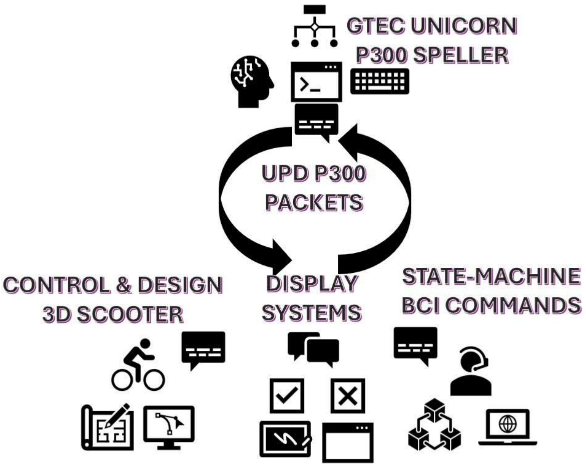

Figure 2. The complete workflow for the brain-computer interface to control a 3D scooter using P300 signals.

The LabVIEW instrument's block diagram includes programming sections (Figure 2) for acquiring and analyzing UDP packets containing P300 commands, designing and controlling the 3D segments of the scooter and humanoid robot, generating movement commands using a state-machine, calculating performance scores, and displaying results on the LCD TEXT 2x16 display system.

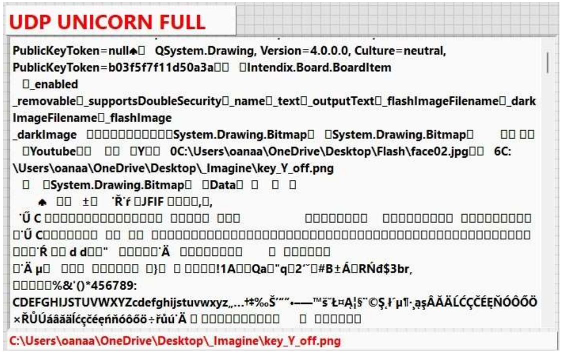

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Figure 3 LabVIEW received UDP packet for P300 evoked biopotentials transmitted from the GTEC Unicorn Speller.

The UDP-based integration between LabVIEW and the Unicorn P300 Speller was previously detailed by the same author [7]. Critical conditions include setting the same UDP port in both the LabVIEW application and the P300 Speller, and configuring the IP address to the local network (127.0.0.0) if both applications run on the same computer. The UDP packets consist of string data that embed the P300 response. By analyzing the UDP packet (Figure 3) with LabVIEW String functions to extract the image name corresponding to the P300 flashing symbol, a specific command is generated for controlling the scooter in various directions.

LabVIEW offers the 3D Picture Control palette with functions to create, edit, and control each segment of the scooter and humanoid robot structure.

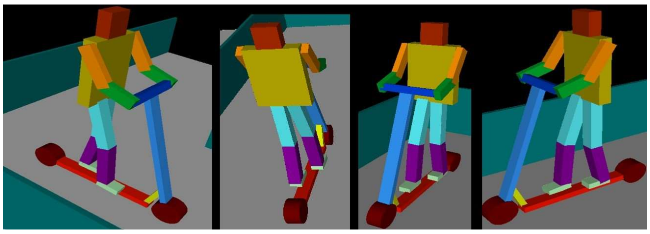


Figure 4 LabVIEW 3D scooter guided by a humanoid robot.

The 3D segments of the virtual character (Figure 4) were constructed and linked using LabVIEW functions and nodes—Create Box, Create Cylinder, Create 3D Axis, Color Change, Create Object, Invoke Node – Set Drawable, and Invoke Node – Add Object. Movement directions (Forward, Backward, Turn Left, Turn Right) were implemented by translating the 3D scooter along the X and Y axes or rotating it across each axis using functions from the Transformations section: Translate Object, Rotate Object, and Scale Object.

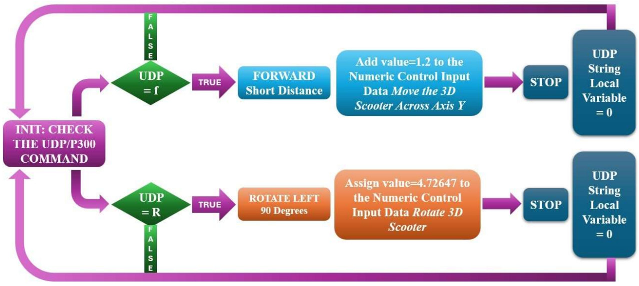
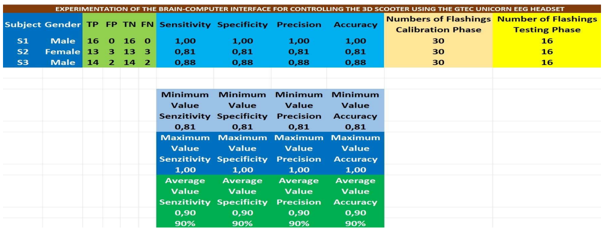


Figure 5 Examples from the LabVIEW Transition State-Machine to switch between scooter movement commands.

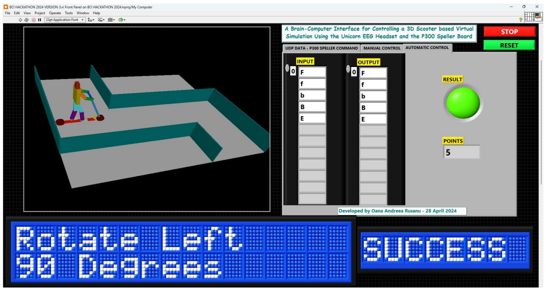
The LabVIEW state-machine for switching between movement commands of the 3D scooter includes sequences related to Initialization, Forward and Backward by short or long distances, Right and Left by short or long distances, Rotate Left – 90 Degrees, Rotate Right – 90 Degrees, Rotate Full – 180 Degrees, Rotate Reverse – 180 Degrees, and Reset. Based on the conditions UDP = f or UDP = R, two examples of state transitions are shown in Figure 5: Init – UDP=f (True) – Forward Short Distance – Stop – Init – UDP=R (True) – Rotate Left 90 Degrees – Stop – Init. Similar algorithms were implemented for other movement commands based on the P300 command conditions.

The proposed LabVIEW application (Figure 6) uses additional state-machine programming paradigms to compute results based on comparing expected commands (stored in an output string array) with actual commands recorded by the user after detecting P300 evoked potentials. If the user's command is correctly deciphered (e.g., the first input value matches the first output data), one point is added to the score, and "Success" is displayed on the small LCD TEXT 2x16. The executed movement command is shown on the large LCD. Otherwise, one point is deducted, and "Failure" is displayed on the virtual screen.



EXPERIMENTATION OF THE BRAIN-COMPUTER INTERFACE FOR CONTROLLING THE 3D SCOOTER USING THE GTEC UNICORN EEG HEADSET											
Subject	Gender	TP	FP	TN	FN	Sensitivity	Specificity	Precision	Accuracy	Numbers of Flashings Calibration Phase	Number of Flashings Testing Phase
S1	Male	16	0	16	0	1,00	1,00	1,00	1,00	30	16
S2	Female	13	3	13	3	0,81	0,81	0,81	0,81	30	16
S3	Male	14	2	14	2	0,88	0,88	0,88	0,88	30	16

Minimum Value Senzitivity	Minimum Value Specificity	Minimum Value Precision	Minimum Value Accuracy
0,81	0,81	0,81	0,81
Maximum Value Senzitivity	Maximum Value Specificity	Maximum Value Precision	Maximum Value Accuracy
1,00	1,00	1,00	1,00
Average Value Senzitivity	Average Value Specificity	Average Value Precision	Average Value Accuracy
0,90	0,90	0,90	0,90
90%	90%	90%	90%



BCI HACKATHON 2024 VERSION 3.vi Front Panel on BCI HACKATHON 2024.lvproj/My Computer

A Brain-Computer Interface for Controlling a 3D Scooter based Virtual Simulation Using the Unicorn EEG Headset and the P300 Speller Board

Developed by Oana Andreea Rusanu - 28 April 2024

Figure 6 The Front-Panel of the LabVIEW Brain-Computer Interface application for controlling the scooter.

EXPERIMENTAL RESULTS AND DISCUSSIONS

The experimental session (Figure 7) of the proposed BCI application was documented in a YouTube video [8]. It involved three participants: one Doctoral candidate (32 years) and two Bachelor students (23 years).

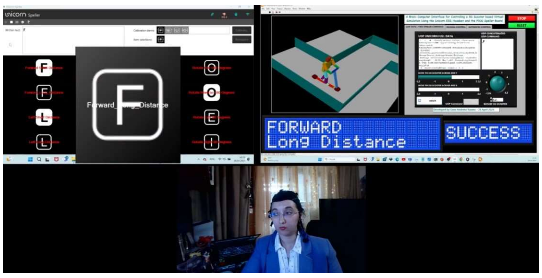
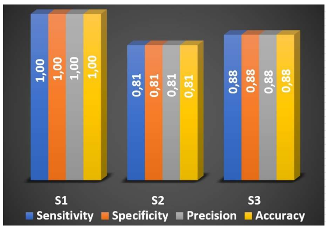


Figure 7 The subject (Doctoral Candidate) during the experimentation of the proposed Brain-Computer Interface.

The first experimental phase assessed EEG signal accuracy using the GTEC Unicorn Recorder application. The second phase involved calibrating the P300 Speller Palette by applying 30 flashes to each of the 4 P300 items. The third phase tested the proposed BCI LabVIEW instrument by requiring users to execute 16 movement commands based on P300 potentials at three difficulty levels: beginner (2 commands), intermediate (6 commands), and advanced (8 commands).

By correctly setting the P300 commands associated with the detected symbols, users could send sequences of multiple commands to control the virtual 3D scooter guided by a humanoid robot. During approximately 10 seconds, after randomly displaying all 16 flashes, users were required to focus their attention and mentally count the flashes to trigger the correct P300-based command transmitted to LabVIEW via UDP. If the user's intent (as determined by the proposed command) was correctly generated by the Unicorn P300 Speller, both TP (true-positive) and TN (true-negative) cases were incremented. TP cases consisted of correctly detected target P300 items, while TN cases corresponded to the accurate detection of non-target P300 symbols, with no alternative erroneous symbol being selected. The GTEC Unicorn P300 Speller does not allow simultaneous selection of multiple symbols, resulting in the increment of TN cases for non-target P300 items.

Figure 8 Results obtained by the three subjects after experimenting with the proposed BCI application for controlling the 3D scooter in the LabVIEW simulation.



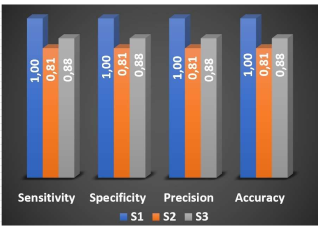


Figure 9 The graphical visualization of the Minimum, Average, and Maximum Values for Sensitivity, Specificity, Precision, and Accuracy obtained from the BCI experiments.

If the user's intent was incorrectly generated by the Unicorn P300 Speller, both FP (false-positive) and FN (false-negative) cases were incremented. An erroneously selected alternative P300 symbol is considered a false-positive result, as it does not reflect the user's intention, while a target-symbol erroneously not selected is a false-negative. In such cases, TP and TN were not incremented.

According to the experimental results (Figures 8 and 9), the average values obtained by the students were 90% for Sensitivity, Specificity, Precision, and Accuracy. The minimum value was 81% for all four measurements, calculated based on the TP, TN, FP, and FN cases. The first male subject achieved a maximum value of 100% for all four measurements.

The users completed a feedback questionnaire following the BCI application experiment. They confirmed that the instructions were clearly understood and acknowledged the high performance of executing the P300-based commands without difficulty. The participants reported feeling relaxed and engaged in the experimental activities, emphasizing that EEG signal accuracy was optimal at the beginning. All three subjects reached the Advanced level by successfully executing at least 70% of the proposed commands.

The quality of the EEG data was significantly improved by applying gel to all 8 EEG sensors and utilizing the GTEC Unicorn's electronic technology, which features a 250 Hz sampling frequency and 24-bit resolution, along with advanced filters and amplifiers.

CONCLUSIONS

This paper presented an interactive brain-computer interface implemented in the LabVIEW development environment to control a 3D scooter guided by a humanoid robot through various movement directions. Challenges addressed included achieving advanced functionality and maximum accuracy in integrating all programming stages: acquisition and analysis of UDP data packets encapsulating P300 responses, the state-machine for switching between movement commands and calculating the final score, and the state-machine for displaying messages (failure or success) on the LCD TEXT 2x16. The proposed BCI solution was successfully tested by three subjects who executed 16 movement commands across three levels: beginner, intermediate, and advanced.

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