CortexType: P300 Speller

Introduction

The P300 Speller, utilizing advanced brain-computer interface (BCI) technology, introduces a groundbreaking method of communication, particularly beneficial for individuals with severe physical disabilities. This innovative system taps into the P300 brainwave, a distinct electrical response the brain emits roughly 300 milliseconds after recognizing a stimulus. By identifying these signals, the P300 Speller can pinpoint the character you are focusing on, enabling communication without the need for physical movement. This interface not only eases interaction with computers but also significantly improves your ability to connect with the surrounding environment.

Event Markers and Synchronization with LSL

A vital component of the P300 Speller's functionality is the implementation of event markers. These markers denote the occurrence of stimuli, such as the flashing of grid rows or columns, within the Unity Paradigm. These markers are synchronized with EEG data from the g.tec Unicorn Hybrid Black EEG device through the Lab Streaming Layer (LSL), a network designed for real-time data exchange in research environments. This synchronization ensures precise timing between stimulus events and EEG data capture, critical for accurately decoding P300 signals and enhancing the system's reliability.

EEG Epochs

An EEG epoch is a specific segment of EEG data captured over a defined period, typically surrounding an event of interest. In the context of the P300 Speller system, an EEG epoch refers to the brainwave data recorded immediately before, during, and after the flashing of a row or column on the character matrix. These epochs are crucial for identifying the P300 signal, as they contain the electrical activity generated by your brain in response to the stimulus. By analyzing these epochs, the system can detect the distinctive P300 waveforms that occur approximately 300 milliseconds after you focus on the target character. This detection is vital for deciphering which character you are concentrating on, enabling the system to translate your attention into specific character selections. Essentially, EEG epochs serve as the fundamental units of data analysis in BCI systems, providing a window into your brain's response to stimuli and facilitating communication through the P300 Speller interface.

System Overview

The system utilizes Unity and PhysioLabXR for real-time EEG signal processing from the g.tec Unity Hybrid Black headset. Within Unity, you can access PhysioLabXR Scripting Interface functions, such as train() and predict(), using Remote Procedure Calls (RPC). For example, you'll invoke the train() function after each trial during the training phase and the predict() function after each trial in the testing phase.

Character Matrix

The interface features a 6x6 character matrix, which creates a grid of 36 characters divided into six rows and columns. As these segments flash randomly, your focus on a target character triggers distinct EEG signals, enabling the system to select characters based on your input. Within the Unity Editor, you can configure the characters you wish to train as targets, determine the number of times rows and columns flash in each trial, and set the flashing duration for each segment.

Training Phase

During the training phase, the target character (e.g., 'B') in your predefined training sequence will be highlighted for 3 seconds to indicate the target character in that trial. As the system flashes rows and columns randomly, it sends event markers to LSL, detailing the row and column information, whether it's a target or non-target, and their index. This meticulous process ensures EEG data are precisely correlated with each stimulus event, laying the groundwork for classifier training based on the P300 responses to target character flashes.

Testing Phase

In the testing phase, the classifier evaluates the most likely target row and column from EEG epochs. By averaging the probabilities for each row and column over multiple flashing repetitions, you can enhance overall accuracy. The convergence of these predicted rows and columns uncovers your intended character, demonstrating the system's capability to accurately interpret user intent through EEG signal analysis.

Run Starter Code

Hardware prerequisite:

1. Meta Quest 2
2. G.tec Unicorn Hybrid Black Headset

Software prerequisite

1. PhysioLabXR (run from source with PyCharm)
2. Unity 2022.3.10f1

Unity

In this task, Unity is employed as the Stimulus Presentation Software, allowing for the visualization of the character board and facilitating the transmission of event markers to PhysioLabXR. This setup aims to construct a close-loop brain-computer interface.

Character Matrix

The P300 Speller utilizes a 6x6 character matrix, comprising 36 characters, encompassing letters A-Z and numbers 0-9. This matrix is structured into six rows and six columns, with each row and column representing a distinct class. Character selection is achieved through the random flashing of rows and columns, a process that is repeated several times within a single trial.

During the training phase, a specific target character (e.g., 'B') is designated. Its position within the matrix is identified based on its row and column location (for instance, first row, second column). As the system randomly flashes rows and columns, event markers are dispatched to the Lab Streaming Layer (LSL). These markers specify the flash type (row or column) and its index, ensuring synchronization with the EEG signal for precise identification of EEG data corresponding to each flash event.

The ***GameManager.cs*** file, accessible at Neureality-Hackathon-Typing-2024, provides the capability to modify the frequency of random flashes across all columns and rows. It also allows for the adjustment of flash duration and interval for both the training and testing phases, offering flexibility in the experiment's setup.

Event Markers

The system includes an event marker stream transmitted through LSL, named **CortexTypeP300SpellerEventMarkerLSL**. This stream consists of five channels, indexed from 0 to 4:

- FlashingTrailMarker: Signals the start and end of a training or test trail.
- FlashingMarker: A value of 1 indicates a single column or row is flashing.
- FlashingRowOrColumnMarker: A value of 1 signifies a row, whereas 2 signifies a column.
- FlashingRowOrColumnIndexMarker: Identifies the index of the flashing row or column.
- FlashingTargetMarker: Indicates whether the target is flashing.

For additional details, please refer to Preset.cs.

Remote Procedure Calls (RPC)

Within the BoardController.cs, three RPC functions are defined: ***get_train_trail_epochs***, ***train_epochs***, and ***predict***. For detailed information on these functions, refer to CortexType.py.

PhysioLabXR

PhysioLabXR serves as the primary platform for developing a customized signal processing pipeline and classification model. For comprehensive information on how to utilize this tool, please refer to the PhysioLabXR pre-hackathon workshop and the PhysioLabXR documentation.

Evaluation Criteria for the P300 Speller Competition

To accurately assess your achievements in the P300 Speller competition, we employ a detailed evaluation methodology that encompasses both Character Recognition Accuracy (CRA) and Information Transfer Rate (ITR). These metrics are pivotal in determining the effectiveness and efficiency of the P300 Speller systems you develop.

Character Recognition Accuracy (CRA)

Definition: CRA evaluates the system's precision in identifying the characters you intend to communicate. It reflects the percentage of trials in which the system correctly recognizes the character you are focusing on, offering insight into the system's ability to accurately capture your intentions.

Formula:

$$CRA = (\text{Number of Correct Trials} / \text{Total Number of Trials}) * 100$$

Information Transfer Rate (ITR)

Definition: ITR measures the system's communication efficiency, taking into account both the accuracy of character recognition and the speed at which selections are made. It represents the rate at which information is correctly communicated through the system.

Formula:

$$ITR = CRA * (\text{Number of Correct Trails} / \text{Minutes}) * 100$$

Overall Score

The overall score is calculated using the following formula:

$$Score = 0.6 * CRA + 0.4 * ITR$$

References

1. Medina-Juliá, M. Teresa, Álvaro Fernández-Rodríguez, Francisco Velasco-Álvarez, and Ricardo Ron-Angevin. "P300-based brain-computer interface speller: usability evaluation of three speller sizes by severely motor-disabled patients." *Frontiers in Human Neuroscience* 14 (2020): 583358.
2. Krusienski, Dean J., Eric W. Sellers, François Cabestaing, Sabri Bayoudh, Dennis J. McFarland, Theresa M. Vaughan, and Jonathan R. Wolpaw. "A comparison of classification techniques for the P300 Speller." *Journal of neural engineering* 3, no. 4 (2006): 299.