CortexType: P300 Speller

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1 Introduction

The P300 Speller, utilizing advanced brain-computer interface (BCI) technology, introduces a communication pathway directly from the brain to, 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.

1.1 Event Marker

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.

1.2 Real-time Digital Signal Processing

Real-time digital signal processing (DSP) and filtering are crucial in EEG signal processing, particularly for brain-computer interfaces like the P300 Speller. These techniques enhance the clarity and reliability of EEG data by reducing noise from external sources and isolating relevant brain signals, such as the P300 wave, essential for accurate system responses. By allowing for the immediate extraction of signal features and enabling adaptive filtering, real-time DSP ensures the BCI system is efficient, responsive, and tailored to individual users, significantly improving the user experience and system performance.

1.3 EEG Epoch

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.

2 Starter Code Overview

2.1 Prerequisite

2.1.1 Hardware:

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

2.1.2 Software:

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

2.2 Unity

In this task, you will use Unity as the Stimulus Presentation Software to visualize the character board and send the event markers to PhysioLabXR and build a close-loop brain computer interface.

2.2.1 Character Matrix

The P300 Speller operates on a 6x6 character matrix, which includes 36 characters from A-Z and 0-9. This matrix is organized into six rows and six columns, each representing a class. To select a character, the system randomly flashes rows and columns, repeating this process several times in a single trial.

During the training phase, a target character (for example, 'B') is identified. Its position in the matrix is determined by its row and column (in this case, first row, second column). As the system flashes rows and columns randomly, event markers are sent to the Lab Streaming Layer (LSL). These markers detail the type of flash (row or column) and its index, synchronizing with the EEG signal to precisely identify EEG data corresponding to each flash event.

The **GameManager.cs** file, located at Neureality-Hackathon-Typing-2024 allows you to adjust the number of times all the columns and rows flash randomly. Additionally, you can set the flash duration and interval for both the training and testing phases separately, providing flexibility in the experiment setup.

2.2.2 Event Markers:

There is one event marker stream will send through LSL which is called **CortexTypeP300SpellerEventMarkerLSL**. The stream consists five channels, indexing from 0 to 4:

- FlashingTrailMarkerIndex = 0, // Train 1, -1 Test 2, -2
- FlashingMarkerIndex = 1, // 1 means active
- FlashingRowOrColumnMarkerIndex = 2, // 1 means row, 2 means column
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- FlashingRowOrColumnIndexMarkerIndex = 3, // 0 - 5 which indicates the index of the row or column
- FlashingTargetMarkerIndex = 4, // 1 is target, 0 is non-target
- TrainMarkerIndex = 5, // send 1 to trigger start
- TestMarkerIndex = 6, // send 1 to trigger end
- InterruptMarkerIndex = 7, // interrupt the train or test function

For more detail, please refer to Preset.cs.

2.3 PhysioLabXR

PhysioLabXR will be the primary tool for you to build the customzied signal processing pipeline and classification model. Please refer to the PhysioLabXR pre-hackathon workshop and PhysioLabXR documentation for more detail about the tutorial.

The RenaScript is located at CortexType.py.

3 Evaluation Criteria

To accurately assess your achievements in the P300 Speller competition, we employ a detailed evaluation methodology that encompasses both Character Recognition Accuracy (CRA)

$$CRA = (NumberofCorrectTrials/TotalNumberofTrials) * 100 \tag{1}$$

and Information Transfer Rate (ITR).

$$ITR = CRA * (NumberofCorrectTrails/Time(s)) * 100 \tag{2}$$

These metrics are pivotal in determining the effectiveness and efficiency of the P300 Speller systems you develop.

The overall score is described as:

$$Score = 0.6 * CRA + 0.4 * ITR \tag{3}$$

We recognize that conducting a live demonstration can sometimes be challenging due to factors like battery level, hair condition, and headset condition. Therefore, you have the option to submit a recorded video along with your code and a description of your implementation at the competition's conclusion. Although a live demo is encouraged and offers an extra credit of 10 points, you are allowed up to three attempts. Your final score will be based on the highest score achieved among the live demos and the video recording, ensuring a fair assessment of your P300 Speller system's performance.