Event Synchronization in the Construction of an EEG Motor Execution Database

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Summary

Electroencephalography (EEG) based brain-computer interfaces rely on well-labeled datasets to train and validate algorithms. However, available EEG datasets forego explaining the synchronizing methodology, lowering reproducibility and compromising label accuracy. This work describes a photodiode-based synchronization strategy, combined with a vertical-synchronization stimulus presentation to accurately timestamp motor execution events during data collection.

Introduction

Electroencephalography is a non-invasive neuroimaging technique that records the electrical activity of the brain through electrodes placed on the scalp. Due to its relative low cost and portability, EEG is widely adopted in BCI research [1]. Among the various BCI paradigms, motor execution (ME) addresses the analysis of brain signals generated during voluntary limb movements. ME-based BCIs have found applications in neuroprosthetics, motor rehabilitation after stroke, and human-machine interaction [2].

The development of robust ME-BCI algorithms requires large, high-quality, and well-labelled EEG datasets. Several public datasets have been released, such as the Physionet Motor Movement/Imagery dataset [3] and others presented in the context of BCI competitions. Nevertheless, many of these datasets share common limitations: a small number of subjects, a reduced number of recording sessions, limited task diversity, or insufficient detail regarding the data collection procedure. Among these limitations, one that is frequently overlooked is the accuracy of event timestamps, that is, the precise temporal alignment between the onset of a motor event and the corresponding label in the EEG recording.

The need for accurate event synchronization arises from the fact that the computer and the EEG acquisition device are typically independent systems with separate internal clocks. Even if both clocks are set to the same time reference, drifts arise at different rates due to differences in hardware and operating conditions. Over a recording session of several minutes, this drift can accumulate to tens of milliseconds, which is significant given that motor-related EEG features occur within a window of a few hundred milliseconds around the event onset [4].

The situation is worsened when an additional device is coupled to the setup. If, for example, a motion capture system or a force sensor is connected to the computer to record a correlate of the movement, this device has yet another independent internal clock. Aligning three or more data streams requires a common, hardware-level synchronization reference that establishes a common ground between devices.

Synchronization Strategy

The experimental method suggested in this work employs a slide-based stimulus presentation to instruct subjects to perform specific motor execution tasks. Each slide contains the task instruction and a small square region in one corner of the screen that alternates between black and white at each slide transition. This process is shown in Figure 1 (top).

A photodiode is attached directly to the screen surface, over the position of the square region. The photodiode is connected to a digital input channel of the EEG acquisition device, so that its output is sampled and timestamped under the same clock as the EEG signal. When the square transitions from black to white, the photodiode output produces a rising edge and when it transitions back to black, a falling edge. These transitions are detected in the recorded photodiode channel by applying a threshold to the signal. In this manner, every stimulus onset is represented by a hardware timestamp that is directly embedded in the EEG data stream, removing any dependence on the computer clock.

The slide-based stimulus presentation is implemented in Python using pygame with vertical synchronization (VSync) enabled. VSync locks frame appearance to the monitor’s refresh rate, ensuring that each new frame is presented at the start of a vertical blanking interval. For synchronisation purposes the computer timestamp is recorded at this flip event. Any stimulus delay introduced in the presentation labels is deterministic and established by integer multiples of the refresh period ($n \times 1/f_r$) due to the Vsync restriction, resulting in the formation of bands that can be easily adjusted to represent the real time flip.

To establish a common temporal reference between the computer and the EEG acquisition clocks, the timestamps of the photodiode transitions detected in the EEG stream are paired with the corresponding VSync-recorded computer timestamps. A linear fit applied to these paired timestamps yields an estimate of both the fixed offset and the slow drift between the two independent clocks, providing the transformation required to map all computer-side event times into the EEG clock domain. Band creation due to Vsync is corrected and a final offset is calculated. Figure 1 (right) shows how the synchronization between the stimulus computer and the EEG acquisition device is achieved, showing the progression from noisy, banded raw data to a clean and close distribution that maps computer timestamps into the EEG clock domain.

Conclusions

This work presents a synchronization approach for EEG motor execution data collection that addresses the inter-clock drift problem inherent to multi-device recording setups. By combining a pygame stimulus presentation with VSync enabled and a photodiode connected to the EEG acquisition device, hardware-level event timestamps are embedded directly into the EEG data stream. Sub-sample temporal accuracy is achieved through linear interpolation of the photodiode signal. The proposed method is low-cost, easy to implement, and applicable to any EEG acquisition system that provides at least one digital or analog input channel.

References

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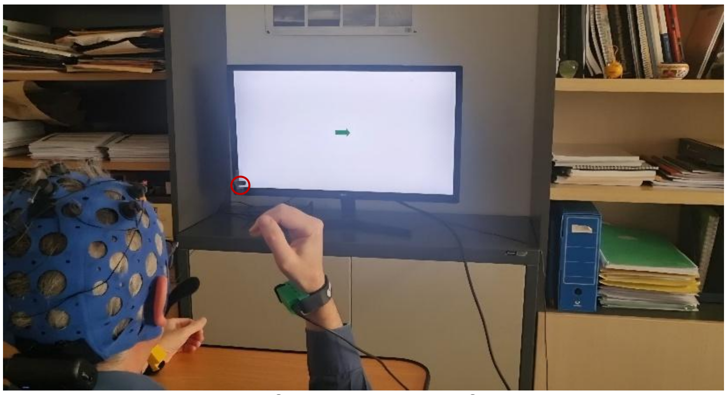

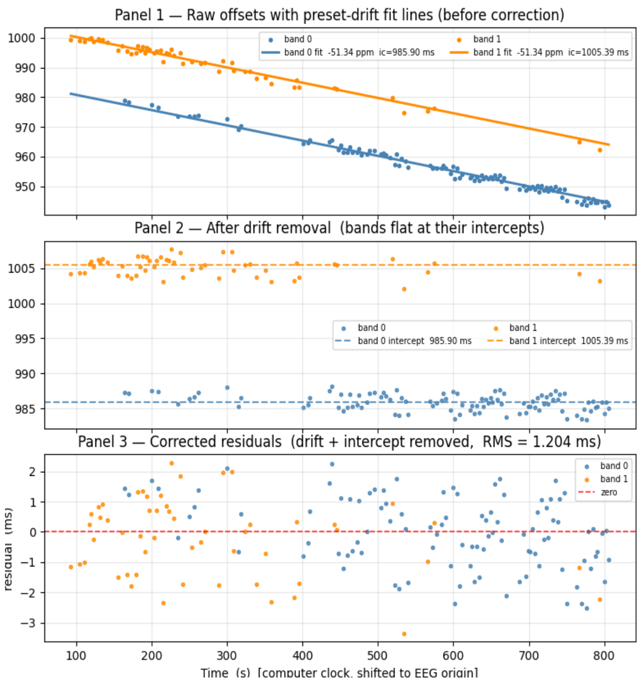

Figure 1. (Top) Example of a complete setup for synchronizing EEG measurements for MS. The patient receives visual cues to guide him through the movement he should perform. Accelerometers on his wrists enable real-time movement measurements and include timestamps linked to the computer's internal clock. The synchronization LED, circled in red, is located in the lower left corner of the display. (Right) Step-by-step process for aligning the computer's event timestamps with the EEG device's clock, from the raw, matched timestamps (which appear as diagonal bands due to VSync), through band correction and final linear adjustment that compensates for both the offset and drift between the two independent clocks.