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EEG-Based Brain-Computer Interface for a Tetraplegic Individual Using Motor Imagery for Cybathlon 2024

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Introduction: Brain-computer interfaces (BCIs) have shown significant promise over the past decades but often fail to meet the requirements for robustness, portability, and usability in real-world scenarios [1]. Motivated by the Cybathlon 2024 competition, we worked towards addressing these challenges by developing a modular, online EEG-based BCI system to increase accessibility for individuals with severe mobility impairments, such as tetraplegia.

Material, Methods, and Results: Our system uses three mental and motor imagery (MI) tasks for up to five control signals. The data is collected using a 24-channel mobile EEG with a custom electrode layout. The pipeline consists of four modules: data acquisition, preprocessing, classification, and the transfer function to map classification output to control dimensions. These modules run in parallel to optimize the online delay. The preprocessing includes FIR bandpass filtering between 4 and 40 Hz, artifact removal (ASR and auto-rejection), and epoching with a sliding time window of 1.5 seconds. The feature extraction was done with Morlet and Common Spatial Pattern. As our deep learning classifier we use three S4D-layers [2] trained on augmented offline data achieving an accuracy of up to 82% for three classes.

We developed a data collection tool in the form of a T-Rex Dinosaur game, where the mental tasks control the game during quick-time events. This resulted in a better user experience, improving the collected data quality and quantity. We also implemented a mobile feedback application that can be used by any device with an internet connection. The components were designed with a human-centered approach in collaboration with the tetraplegic user to ensure optimal usability.

Our pilot completed one task during the Cybathlon competition but faced performance challenges under high-stress conditions in the arena, reducing accuracy. These observations suggest that stress negatively impacts MI performance, affecting BCI reliability. Despite these setbacks, our low budget set up (ca. 3000 € all costs included) and the pipeline demonstrated feasibility for real-world applications and laid the groundwork for further optimization.

Conclusion: We provide insights into developing a framework for portable BCIs, bridging the gap between the laboratory and daily life. Specifically, our framework integrates modular design, real-time data processing, user-centered feedback, and low-cost hardware to deliver an accessible and adaptable BCI solution, addressing critical gaps in current BCI applications. Future work will focus on increasing the robustness of our system by for example quantifying the effects of stress on MI and BCI performance, and improving system adaptability with increased data reusability through meta-learning.

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