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Optimizing P300 Speller Performance through Uncertainty Quantification

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Introduction: Brain-computer interfaces (BCI) provide individuals with impaired motor movements the ability to control communication devices. One prominent application is the P300 speller, which leverages the P300 event-related potential (ERP) captured through electroencephalography (EEG) to enable communication [1]. However, challenges such as slow speed and low accuracy hinder the effectiveness of current P300 speller systems. In this study, we propose an adaptive threshold method that incorporates uncertainty quantification (UQ) to improve the P300 speller [2].

Material, Methods and Results: We implemented two strategies: early stopping, which terminates the classification process once sufficient confidence is reached, and trial rejection, which prevents making predictions with high uncertainty. The Riemannian Minimum Distance Metric (MDM) with Bayesian Accumulation (BA) classifier was used to evaluate the model [3, 4, 5]. For our experiment, we rejected samples where the predictive confidence did not meet a set threshold. Testing on a dataset from 8 patients with amyotrophic lateral sclerosis (ALS) [6] demonstrated that the integration of UQ significantly outperformed existing methods. Specifically, early stopping with UQ reduced the number of flashes by 12%. Trial rejection, on the other hand, improved accuracy to 94.1% (Fig.1) with coverage of 75.3%, representing a 14.1% accuracy increase over the state-of-the-art classifier by rejecting 24.7% of the data.

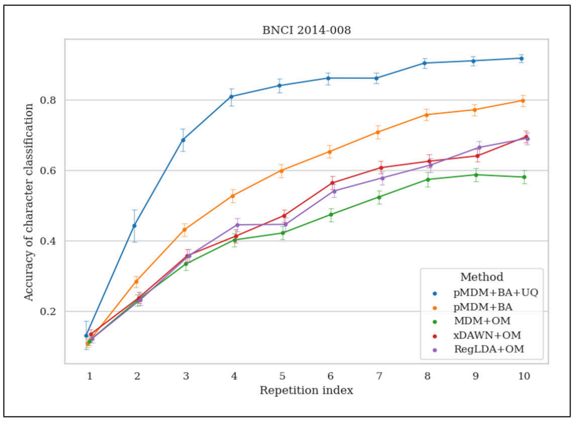

Figure 1: *Average accuracy versus repetition index across all the participants. The plot demonstrates that our model with UQ matches the state-of-the-art accuracy at the 4th repetition and achieves the highest overall accuracy.*

Conclusion: These results demonstrate the potential of UQ to enhance both the speed and accuracy of the P300 speller, offering a more efficient and robust solution. Our method could be further improved by combining early stopping and trial rejection techniques, as both utilize similar approach based on the highest probability outputs. Moreover, adopting a data-driven approach to optimize these parameters could minimize manual intervention.

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