EEG Epoch Classification Using Fourier Transform and LLM Transformer:

A Theoretical Approach

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Analyzing Electroencephalography (EEG) signals requires a robust mathematical framework to address challenges such as noise, artifacts, and event-related data variability. This study investigates the application of Fast Fourier Transform (FFT), Short-Time Fourier Transform (STFT), and Wavelet Transform to classify EEG epochs, focusing on the theoretical underpinnings of these techniques. Our hypothesis is that combining frequency-domain transformations with time-domain features can enhance event classification, particularly across varying epoch lengths of 1–3 seconds.

Preprocessing involves advanced artifact rejection methods, including Independent Component Analysis (ICA) and wavelet decomposition, to mitigate noise from muscle movements, eye blinks, and baseline drift. EEG signals are segmented into overlapping windows to improve the capture of event-related potentials (ERPs) and reduce information loss. FFT is used as the primary method for spectral feature extraction, while STFT and Wavelet Transform are explored to capture time-frequency dynamics. Additional time-domain features, such as mean and variance, are integrated to complement frequency-domain analysis. The labeled epochs from open-source EEG datasets (e.g., PhysioNet, BCI Competition) and those labeled using Fourier Transform methods are utilized to train a Transformer encoder-based supervised learning model. This model leverages pre-trained architectures and positional encodings to optimize its performance for time-series data. Rigorous evaluation through cross-subject and cross-event validation ensures generalizability. Metrics such as accuracy, precision, recall, and F1-score are employed to assess performance.

Initial results demonstrate FFT's computational efficiency in identifying dominant frequency components critical for event classification, while STFT and Wavelet Transform provide complementary insights into transient neural activities. This study establishes a theoretical foundation for combining signal processing and machine learning, offering a scalable approach to EEG analysis. Future research will refine these methods, extend their applicability to diverse neural datasets, and explore innovations in feature extraction and model optimization for neural data classification.

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