

NEURO-SYNC: A Real-Time Framework for Affective State Decoding and Spectral Telemetry Using Machine Learning

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Abstract

Emotions are complex **psychological and physiological** state that impacts **human activity, decision-making process and social response**. Recognizing and examining emotions is an essential part of human-computer interaction, the field of mental health tracking, and one of the primary premises for adaptive intelligent systems. **Automatic emotional analysis** is a technique in which emotions are detected based on **facial expressions, speech signals and body gestures**. This automatic approach sometimes provides unreliable results since external signs can be intentionally controlled by an individual or even vary due to environmental conditions. To address these constraints, physiological signals, like **Electroencephalogram (EEG)**, are commonly utilized to assess brain electrical activity via sensors located on the **scalp**. We presented **NEURO-SYNC**, a **unified hardware agnostic platform** to label human affective states from the EEG signal as part of this research. The system analyzes emotional responses using the publicly available **DREAMER dataset** that includes multi-channel EEG recordings. In order to reduce noise, **filtering, normalization and downsampling** are performed on the signals. The analysis used partitioned data along with window and overlapping techniques to reduce spectral leakage, where the signals power incorrectly spreads out to other frequencies, based on **Welch's method**. **Power Spectral Density (PSD)** features are computed in this case across **Alpha, Beta Theta and Gamma** frequency bands as they represent key characteristics of biological brainwave patterns. To categorize emotional states, a supervised machine learning pipeline built on the Random Forest classifier is used. Calm, Happy, Sad, and Stressed are the four emotional quadrants into which the system divides EEG patterns. Additionally, a **Cognitive Vitality Index** is presented that uses frequency-ratio based heuristics to estimate levels of focus, stress, and relaxation. A **real-time dashboard** is created to visualize anticipated emotional states, brain activity patterns, and past EEG trends in order to improve usability. In addition to showcasing the potential of EEG-based emotion recognition for advanced brain-computer interface applications, adaptive healthcare systems, and mental health monitoring, the proposed system effectively classifies emotions.

Keywords

Affective Computing, Brain Computer Interface, DREAMER Dataset, EEG-based Emotion Recognition, Machine Learning, Random Forest Classification.