Towards Practical Emotion Recognition Using fNIRS-Derived Hemodynamic Signatures

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Synopsis

This study evaluates the effectiveness of a functional near-infrared spectroscopy (fNIRS) based brain computer interface for predicting and objectively identifying basic emotional states. Prefrontal hemodynamic responses were recorded during exposure to standardized affective stimuli, and time-domain features extracted from oxygenated hemoglobin signals were classified using supervised machine learning algorithms. High classification accuracies were achieved in both binary and three-class emotion recognition tasks, demonstrating that fNIRS-derived features provide reliable and computationally efficient biomarkers for emotion decoding. The findings support the feasibility of lightweight fNIRS-based BCIs for real-time emotion recognition in clinical and human computer interaction applications.

Background

Objective recognition of emotional states has attracted increasing attention across cognitive neuroscience, affective computing, and clinical research, as emotions play a fundamental role in perception, decision making, and behavior. Conventional emotion recognition approaches predominantly rely on behavioral cues such as facial expressions, speech prosody, or self-report instruments. While informative, these measures are inherently subjective and can be influenced by social desirability, task demands, or conscious regulation, limiting their reliability in both experimental and applied settings(Zhang et al., 2020).

Neurophysiological sensing modalities provide a more direct assessment of emotion-related brain processes. Among these, fNIRS has emerged as a promising technique due to its non-invasive nature, portability, and suitability for real-time measurements(Naseer and Hong, 2015). fNIRS captures task-related changes in cortical hemodynamics, offering an indirect yet robust proxy of neuronal activation.

The prefrontal cortex has been consistently implicated in emotional appraisal and regulation, and prior studies have demonstrated that emotional stimuli elicit distinguishable hemodynamic responses within prefrontal regions. However, an ongoing methodological challenge lies in achieving robust emotion classification while maintaining low computational complexity. This study addresses this challenge by evaluating whether carefully preprocessed fNIRS signals and interpretable time-domain hemodynamic features can reliably support prediction of basic emotional states using classical supervised learning methods.

Methods

Twenty healthy participants viewed affective images selected from the International Affective Picture System (IAPS), representing positive and negative emotional valence, while prefrontal cortex (PFC) hemodynamics were recorded using a NIRSport fNIRS system. The acquisition setup

consisted of 8 light sources and 7 detectors, forming 22 measurement channels with a sampling rate of 7.81 Hz. The optode montage was designed to ensure bilateral coverage of prefrontal regions and is illustrated in Figure 1, where channels are projected onto EEG 10–20 coordinates.

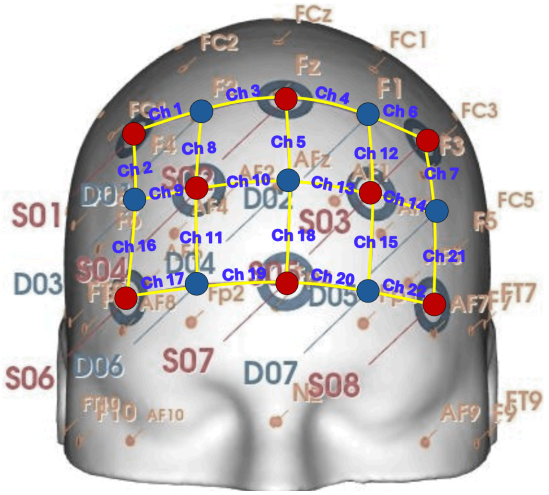

Figure 1. Probe configuration and montage design. Channels are defined by adjacent source–detector pairs and projected onto EEG 10–20 coordinates.

Raw optical intensity signals were converted to optical density and corrected for motion artifacts using spline interpolation, a critical step for mitigating head movements and optode displacement in fNIRS recordings. Optical density signals were subsequently transformed into oxygenated (HbO) and deoxygenated (HbR) hemoglobin concentration changes via the modified Beer–Lambert law. A bandpass filter (0.01–0.5 Hz) was applied to suppress slow drifts and high-frequency physiological noise while preserving task-related hemodynamic fluctuations. To further reduce motion-related cross-talk between HbO and HbR signals, correlation-based signal improvement (CBSI) was employed.

Given its higher signal-to-noise ratio and stronger sensitivity to cortical activation, subsequent analyses focused on HbO time series. From each stimulus block, 20 time-domain hemodynamic features capturing amplitude, temporal dynamics, and variability were extracted. These features were selected to provide physiologically interpretable representations while maintaining computational efficiency. Feature vectors were used to train three supervised classifiers Support Vector Machine (SVM), Ensemble (Subspace kNN), and k-Nearest Neighbors (kNN). Model performance was evaluated using repeated train/validation/test splits to ensure robustness.

Results

All algorithms achieved strong performance in both multiclass and binary classification tasks. For 3-class (negative/positive/neutral) classification, mean accuracies were 93.11±0.23 (Ensemble), 94.32±0.15 (SVM), and 90.33±0.24 (kNN). For 2-class (negative vs positive) classification, accuracies were 95.54±0.16 (Ensemble), 96.54±0.18 (SVM), and 93.56±0.16 (kNN).

Pairwise statistical comparisons showed that SVM outperformed both Ensemble and kNN across accuracy, precision, specificity, recall, and F1-scores (Bonferroni-corrected $p<0.00125$). The comparative performance pattern is summarized in Figure 2.

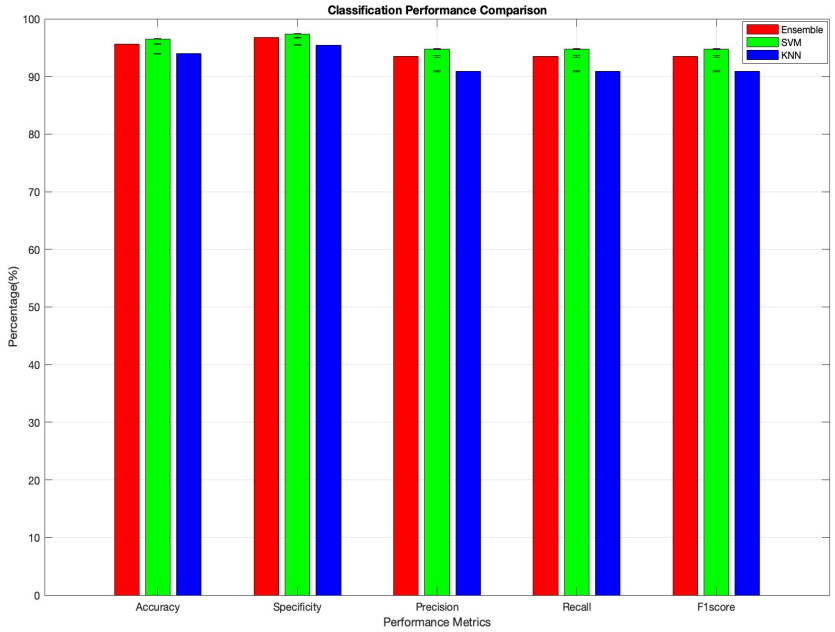

Figure 2. Classification performances. Classification performances of Ensemble (Subspace kNN), SVM, and kNN algorithms when trained with time-domain HbO features

Discussion

Overall, the present findings demonstrate that fNIRS-derived time-domain hemodynamic features obtained from the prefrontal cortex provide highly discriminative information for decoding basic emotional states. The consistently strong classification performance across supervised learning models indicates that the extracted features capture physiologically meaningful signatures associated with emotion-related neural processing. In particular, the superior performance of the support vector machine classifier suggests that margin-based optimization strategies are well suited for handling the nonlinear structure and high dimensionality of fNIRS data, especially under limited sample-size conditions. These results support the feasibility of fNIRS as a standalone and computationally efficient neuroimaging modality for objective emotion recognition.

Building on these findings, future work will focus on extending the proposed framework to a broader range of emotional categories and stimulus paradigms, as well as evaluating subject-independent and cross-session generalizability. Additionally, incorporating more naturalistic experimental conditions and investigating adaptive or online classification schemes may further enhance the applicability of fNIRS-based emotion decoding systems. Such extensions could facilitate the translation of fNIRS-based BCIs toward real-world affective monitoring and personalized neuroadaptive applications.

References

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