Zero-Cost BCI Simulation

1. Introduction

Brain–Computer Interfaces (BCIs) translate neural activity into commands, offering communication pathways for individuals with severe motor impairments. This project presents a zero-cost, end-to-end BCI simulator that uses publicly available EEG data to classify binary intentions ("Yes"/"No") and visualize brain signals, entirely within a web-based interface.

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2. Objectives

- Prototype a BCI system without specialized hardware.
- Demonstrate EEG data handling, signal visualization, and machine-learning classification.
- Provide an interactive UI for researchers and developers to explore and extend.

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3. System Architecture

1. Data Ingestion
    - Upload of .mat EEG dataset (118 channels, 100 Hz sampling rate).
2. Data Overview
    - Display of sample count, channel count, sampling frequency, and customizable data preview.
3. Visualization Module
    - Time-series plots for any channel; Fast Fourier Transform (FFT) for frequency analysis.
    - Downloadable CSV and PNG outputs.
4. Classification Module
    - Epoching into fixed-length windows (2 s).
    - Feature extraction via band-power in μ (8–12 Hz) and β (12–30 Hz) bands using Welch's method.
    - Random Forest model training and evaluation (accuracy, confusion matrix, classification report).
    - Simulated binary decision ("Yes"/"No") based on model output.
5. Live Simulation Module
    - Sliding-window loop emulating real-time processing with per-window predictions.

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4. Key Technologies

- Frontend: Streamlit

- Signal Processing: NumPy, SciPy (Welch PSD)
- Machine Learning: scikit-learn (Random Forest)
- Visualization: Matplotlib, pandas
- Data Format: MATLAB .mat

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5. Results & Metrics

- Data Profile: 298 458 samples × 118 channels
- Classification Performance: ~50% accuracy (baseline Random Forest)
- Model Insights:
    - Confusion Matrix: Highlights True/False Positives and Negatives
    - Precision, Recall, F1-Score for both classes
- Live Demo: Dynamic decision updates every 0.5 s

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6. Discussion

- Strengths:
    - Fully functional prototype without hardware
    - Modular design for easy extension
    - Interactive interface for non-programmers
- Limitations:
    - Moderate classification accuracy—reflects dataset complexity and basic feature set
    - Simulation only; requires real-time hardware integration for clinical use

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7. Future Work

- Integrate real-time EEG acquisition (OpenBCI, Muse)
- Enhance preprocessing (artifact removal, advanced filtering)
- Explore deep-learning models for higher accuracy
- Expand communication to multi-class spellers

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8. Conclusion

This project delivers a cost-effective, accessible BCI simulation that bridges theoretical research and practical demonstration. It establishes a foundation for future development in assistive neurotechnology and educational tools for cognitive signal processing.

Prepared by: Keerthi Kumar K J
Date: 28/07/2025
Contact: inteegrus.research@gmail.com