EEG Preprocessing for Real-Time SSVEP-Based Brain–Computer Interface

In this project, students will design and implement a real-time EEG preprocessing pipeline optimized for steady-state visual evoked potential (SSVEP) decoding. The focus is on filtering, artifact suppression, normalization, and segmentation to produce clean, stable EEG data for frequency-domain analysis. Students will process EEG signals collected from occipital and parieto-occipital regions—where visual responses to flickering stimuli are most prominent—and prepare them for downstream classification in a BCI system.

Key Objectives:

1. **EEG Channel Selection:**
   Work with occipital and parieto-occipital channels (Oz, O1, O2, PO7, PO8, POz) to capture visual cortex activity associated with SSVEPs.
2. **Filtering:**
   Implement a digital band-pass filter between 5–40 Hz to isolate steady-state visual responses while minimizing low-frequency drift and high-frequency noise.
3. **Windowing:**
   Segment the continuous EEG signal into overlapping windows (1–2 s) to enable real-time frequency-domain processing.
4. **Artifact Rejection:**
   Apply **Artifact Subspace Reconstruction (ASR)** online to remove transient noise from blinks, muscle activity, and motion artifacts without distorting the SSVEP signal.
5. **Baseline Correction and Re-referencing:**
   Perform baseline correction and re-reference the EEG to the common average across channels to improve spatial consistency and signal clarity.
6. **Normalization:**
   Normalize each cleaned segment to zero mean and unit variance to stabilize input scaling for subsequent machine learning or classification algorithms.
7. **Visualization and Validation:**
   Visualize raw versus preprocessed EEG signals, compare frequency spectra, and evaluate signal stability before and after ASR filtering.

Deliverables:

- A working Python or MATLAB script implementing real-time filtering, ASR artifact rejection, and normalization.
- Time-domain and frequency-domain plots showing signal improvements after preprocessing.
- A brief report describing each preprocessing step, its purpose, and its effect on signal quality (e.g., improvement in SNR).

Learning Outcomes:

By completing this project, students will:

- Understand how SSVEP signals are generated and used in visual BCI systems.
- Gain hands-on experience with EEG preprocessing methods suitable for real-time applications.
- Learn how to implement and tune ASR for robust online artifact suppression.
- Develop practical skills in EEG signal normalization, segmentation, and spectral visualization.