BRAIN COMPUTER INTERFACE

FINAL REPORT: CAR COMPETITION

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I. Method

1. Overview

Our project implements an EEG-Only Brain-Computer Interface (BCI) system to control a robot car based on user-modulated alpha wave activity. The system does not rely on hybrid signals (e.g., gyroscope, EOG), nor does it classify simplistic eye states. Instead, it leverages a more nuanced control logic: users are trained to consciously shift their mental states such as relaxation or focus to generate distinct alpha wave patterns which map to car control commands.

2. EEG Signal Accquisition

- Device: A 14-channel EEG headset connected via Lab Streaming Layer (LSL).
- Channel Count: 14 channels of raw EEG data. However, we selected only four channels Fp1, Fp2, O1, and O2 based on their sensitivity to alpha wave modulation and reduced susceptibility to artifacts.
- Sampling Frequency: Automatically determined via the EEG device metadata.
- Recording Duration: Each EEG trial lasts 8 seconds, sufficient to capture user-generated alpha activity.

3. Preprocessing and Filtering

To extract meaningful alpha activity and minimize noise:
- A bandpass filter (8–30 Hz) was applied to each channel using a 4th-order Butterworth filter.
- Filtering removes low-frequency drift and high-frequency muscle artifacts, isolating the alpha band (8–13 Hz) for signal analysis.

4. Alpha Wave Ratio Analysis

- The alpha ratio is used as a marker for the user's mental state high alpha is typically associated with calm, unfocused mental states; low alpha with mental concentration.
- In our final implementation, we limited our analysis to four specific EEG channels: Fp1, Fp2, O1, and O2. For each channel, we compute the alpha ratio using Welch's method:

$$Alpha\ Ratio = \frac{Power_{8-13Hz}}{Power_{3-30Hz}}$$

- These values serve as indicators of the user's mental state.

5. Command Generation Strategy

Our system performs two 8-second trials per control cycle:

- Users are instructed to mentally relax or mentally engage, producing distinguishable alpha patterns.
- Each trial uses a fixed voting mechanism based on the 4 chosen channels:
  o If at least one channel has an alpha ratio below the threshold (0.5), the system classifies the user as being in an **engaged** state.
  o Otherwise, it is classified as **relaxed**.
- Each trial yields a binary value:
  o 0 = relaxed
  o 1 = engaged
- Two consecutive trials form a 2-bit control code (e.g., 01, 10, 11), which is mapped to directional actions for the robot car.

6. **Real-Time Control Loop**

Each cycle follows this structure:
- Trial 1 (8s) – User performs a chosen mental state.
- Pause (3s) – Transition time.
- Trial 2 (8s) – User performs a second mental state.
- Control Code Generation – Combined binary result triggers directional command.
- Cooldown (5s) – Reset period before the next cycle.

This rhythm balances responsiveness with signal stability, allowing consistent BCI operation. To assist the user, we integrated auditory feedback using beep sounds before each phase. After each pair of trials, a control code (e.g., 01, 10) is generated and translated into serial commands, which are sent to the robot car via COM<PORT> using an Arduino. Each code maps to directional motion such as forward, left, or right.

7. **System Structure**

- main.py – Handles EEG stream, trial control, and output display.
- utils.py – Implements EEG connection, bandpass filtering, alpha ratio calculation, and ensemble classification logic.
- The final system includes:
  o Real-time logging of alpha ratios and classification decisions
  o Serial command output to control the robot car via Arduino
  o Sound cues (beeps) to guide user timing between trials

II. Discussion 1: Challenges & Solutions

1. **Voluntary Alpha Modulation**

- Issue: Not all users can reliably increase alpha activity on demand.

- Solution: Trained users with pre-experiment sessions using visualization techniques and relaxed breathing. Feedback from console logs helped with learning.

2. **Channel Reduction Simplification**

- Issue: Using 14 channels introduced unnecessary noise and computation.
- Solution: We reduced to 4 fixed channels (Fp1, Fp2, O1, O2) to improve stability and cognitive relevance.

3. **External Noise**

- Issue: Noise (muscle artifacts, ambient motion) distorted alpha readings.
- Solution: Carefully selected channels with the most consistent trends; used majority voting among lowest-alpha channels to reduce sensitivity to outliers.

4. **Interpretation of States**

- Issue: Simple open/closed-eye classification was unreliable in noisy environments.
- Solution: Shifted from binary eye detection to continuous, user-driven alpha modulation, giving more nuanced control and resilience to distraction.

III. Discussion 2: Additional Reflections

- BCI Design Philosophy: We prioritized real cognitive engagement over passive triggers like eye blinks or gyroscope movement.
- EEG-Only Compliance: We strictly followed course rules by excluding physical sensors or keyboard input only EEG-based inference was used.
- Generalization: The system is modular and extensible future improvements could include machine learning classifiers or real-time spectral visualization.
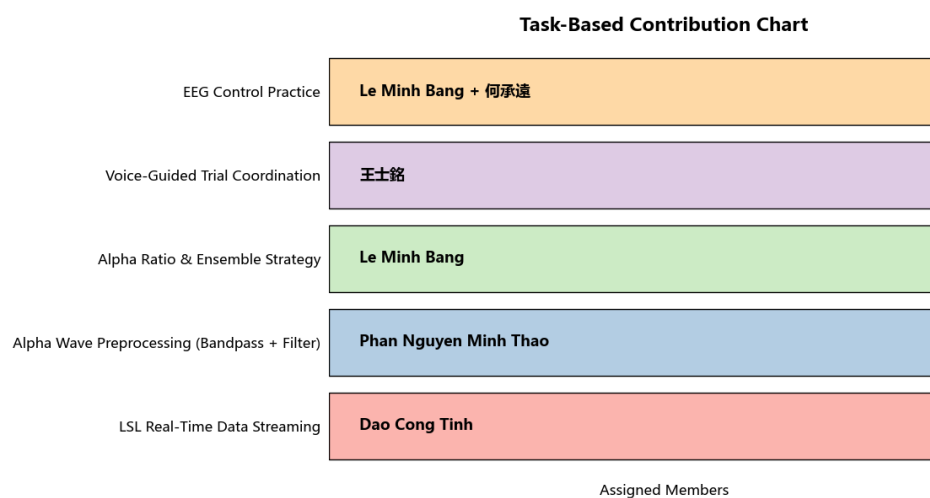
IV. Contibution Chart

Figure 1: Contribution Chart

Table 1: Contribution Explanation

Task	Assigned Member(s)	Description	Challenges
LSL Real-Time Data Streaming	Dao Cong Tinh	Connect to EEG via LSL, stream real-time data, validate channels, maintain stable data acquisition.	Handling unstable connections; stream sync; verifying correct sampling and channel count.
Alpha Wave Preprocessing (Bandpass + Filter)	Phan Nguyen Minh Thao	Apply bandpass filter to isolate alpha band (8–13 Hz) and clean EEG signal for analysis.	Avoiding distortion; dealing with signal artifacts; balancing clarity vs. response time.
Alpha Ratio & Ensemble Strategy	Le Minh Bang	Compute alpha ratios, apply ensemble logic to classify mental state, convert to control codes.	Setting robust thresholds; handling noisy channels; building reliable ensemble detection.
Voice-Guided Trial Coordination	王士銘	Read trial instructions, manage session timing, guide user through relax/focus phases.	Maintaining timing accuracy; avoiding user distraction; synchronizing with system feedback.
EEG Control Practice	Le Minh Bang + 何承遠	Train and perform mental modulation of alpha waves to control car, refine consistency through practice.	Staying mentally consistent; minimizing fatigue; maintaining useful alpha patterns.

V. Appendices

- All source code and documentation are included in the file lab3_GroupX.zip.
- Python package dependencies are listed in requirements.txt.
- Github Repo: https://github.com/MinhBang1000/NCYUBCI2025_Final-Car-Competition.git