BCI Car Competition Report

Group Number: 2

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Project GitHub

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1. Method

1.1 Signal Acquisition & Features

- **Signal Source:** Cygnus BCI Headset. Data was acquired from electrodes placed at positions **FP1** and **FP2**.
- **Target Signals:** We focused on **Electrooculography (EOG)** signals generated by eye movements and blinks. Unlike typical EEG frequency analysis (e.g., Alpha/Beta waves), this system utilizes the time-domain amplitude changes caused by eye dipole movements.
- **Feature Extraction:** Instead of frequency power, we calculated two derived time-domain features using a sliding window of the last 100 data points:
    - Difference(FP1 - FP2): To determine horizontal directionality (Left vs. Right).
    - Sum(FP1 + FP2): To measure the overall blink intensity. Classification is based on the extreme values (peaks and troughs) of these two features.

1.2 Preprocessing

- **Filtering:** Applied a **2nd-order Butterworth bandpass filter** with a frequency range of **0.5 Hz - 10 Hz**.
- **Artifact Removal:** This specific frequency band was chosen to effectively remove DC offset drift (< 0.5 Hz) and high-frequency muscle artifacts or power line noise (> 10 Hz), thereby isolating the clean EOG signal components required for accurate blink detection.

1.4 Control Method

- **Mapping:** The system translates specific eye blink patterns into car movements using a threshold-based classifier.
- **Extreme difference, extreme sum** is from the extreme values of the last 100 data points.
- A **1-second cooldown** is applied after each command to prevent signal overlap and ensure smooth control.

Classification Table

Blink Type	Extreme Difference (FP1 - FP2)	Extreme Sum (FP1 + FP2)	Car Action
Left Blink	< -500	< -500	Turn Left (0.2s)
Right Blink	> 500	< -500	Turn Right (0.2s)
Double Blink	$abs < 200$	> 250	Drive Straight (0.2s)

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2. Discussion 1: Challenges & Solutions

- **Challenges with SSVEP:** Initially, we attempted to use SSVEP to control the car. However, the captured EEG signals lacked clarity, and we observed no distinct changes in the signal during stimulation. We analyzed the SSVEP Benchmark Dataset from Kaggle using FFT and observed clear peaks at frequencies such as 8.0 Hz, 10.0 Hz, 12.0 Hz, 13.8 Hz, and 15.8 Hz. These peaks were visible in individual subjects and became even more pronounced after averaging across 40 subjects. However, when we analyzed our own signals from the O1 and O2 electrodes, we failed to replicate these results. We attribute this to the high environmental noise levels in our setting, which SSVEP is sensitive to. Consequently, we abandoned the SSVEP approach.

- **EOG Variability and Strategy:** Regarding EOG, we found that blink signal patterns vary significantly between subjects. For instance, one member exhibited a weak Fp2 signal during right blinks but a strong Fp1 signal during left blinks, while another member showed the opposite pattern. For the competition, we selected the team member who demonstrated strong signal responses at both Fp1 and Fp2.

- **Environmental Factors and Final Implementation:** There are many uncontrolled variables in EOG signals, such as electrode placement and subject fatigue. For example, we achieved perfect control on Wednesday using one specific headset, but on Friday, using a different unit, the double-blink signal was not as distinct as in previous experiments. Due to this inconsistency, we decided to rely solely on left and right blinks to steer the car and complete the race during the competition.

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3. Discussion 2: Contributions

- **Real-time Signal Visualization & Feedback**: We implemented a **real-time signal display** system that visualizes the filtered data from electrodes **FP1 and FP2**. This feature allows users to immediately observe the waveform changes corresponding to their eye blinks. By providing this visual biofeedback, the user can adjust their blink intensity and verify signal quality before driving, ensuring the system is responsive and the headset is correctly positioned.

- **Robust Control Logic with Debouncing**: To ensure smooth and precise driving, we designed a stable control mechanism:
  - **Precision Control:** Each motor command is executed for a short duration of **0.2 seconds**. This allows for "micro-adjustments" to the car's trajectory, enabling fine-grained steering on winding tracks.
  - **Signal Debouncing:** We implemented a **1-second cooldown (refractory period)** after each command. This prevents a single long blink or artifact from being erroneously detected as multiple commands, effectively eliminating "double-triggering" issues and improving overall system stability.

- **EOG Classification Strategy**: We analyzed the physiological differences between left and right eye blinks and developed a classifier based on the relationship between FP1 and FP2:
  - We utilized the **Difference(FP1 - FP2)** to determine the horizontal directionality of the eye movement.
  - We utilized the Sum ($FP1 + FP2$) to validate the overall intensity of the blink.

  By combining these two features, our system effectively distinguishes between Left Blinks (for turning left) and Right Blinks (for turning right), translating distinct physiological signals into accurate steering controls.

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4. Contribution Chat

Member Name	**Specific Role & Contributions**
111550040 曾紹幃	Experiments with SSVEP bench mark dataset, check SSVEP availability, Car control threshold design.
313553022 戴晨安	Developed SSVEP visualization, experimented with EOG signals, and implemented car control for the final competition.
10801118 張瀚仁	Developed code for hybrid control, real-time monitoring system for signal processing and calibration during implementation.
313554038 張書豪	Developed SSVEP visualization, experimented with EOG signals

313554038 孫念慈	Experimented with EOG signals, assisted in testing and tuning the hybrid control code.
111550080 曾煥宗	Experimented with EOG signals, assisted in developing codes