SIGNATURE WORK
CLASS OF 2024

APPLICATION OF BRAIN-COMPUTER INTERFACE: IDENTIFICATION MODEL OF DIFFERENT PHYSIOLOGICAL STATES

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- Major: Applied Mathematics
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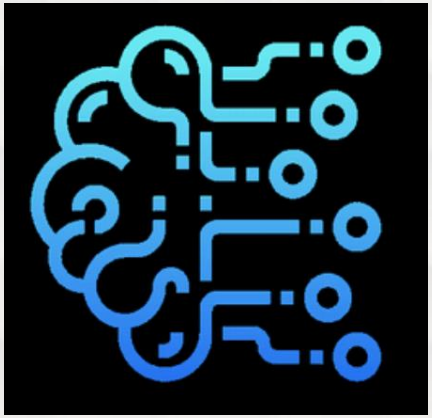
Introduction

- Background & Motivation
- Project Purpose

Background & Motivation



- Brain-Computer Interface (BCI)
  - a groundbreaking communication system facilitating bidirectional communication between the human brain and a computer through biosensing and electronic signal exchange.
- Electroencephalogram (EEG) based BCIs
  - considerable applications for controlling devices, such as wheelchairs, robotic arms, and game controllers
  - help disabled people with neuromuscular disorder
- Gaps
  - limited applications in recognizing sensory signals of physiological state perception and emotional control
  - cannot provide support to individuals who almost completely lose movement and/or oral expression, especially those in Locked-in State.

Project & Purpose

Project

This project is designed to build a classification model to interpret EEG signals to identify the two basic needs: hunger and thirst, and temperature differentiation.

Implementation:

We designed and conducted a series of experiments to collect data for the 5 physiological states. Then we built a classification model to interpret data to summarize features.

Purpose

The purpose is to apply BCI technology to aiding people who hardly capable to move or speak to communicate their needs to caregivers in a convenient and timely way and thus fill in those gaps.

Experiment Setup

- Headset
- Data Collection Method

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Experiment Setup

Headset

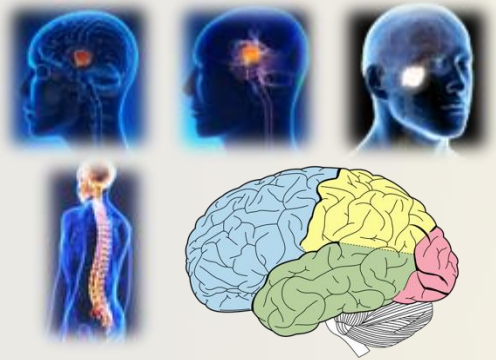
Specific brain regions to detect

Hunger & Thirst:

Hypothalamus (in the medial temporal lobe)

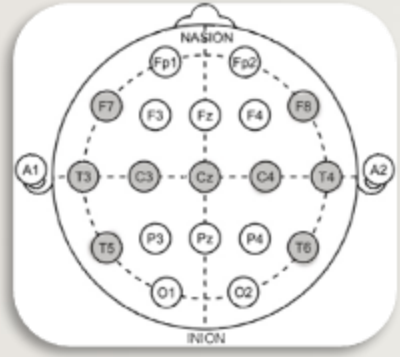
Temperature perception and regulation:

Sensory ganglia, spinal cord, pons, and the hypothalamus (all in the medial temporal lobe and the region near the cerebellum.

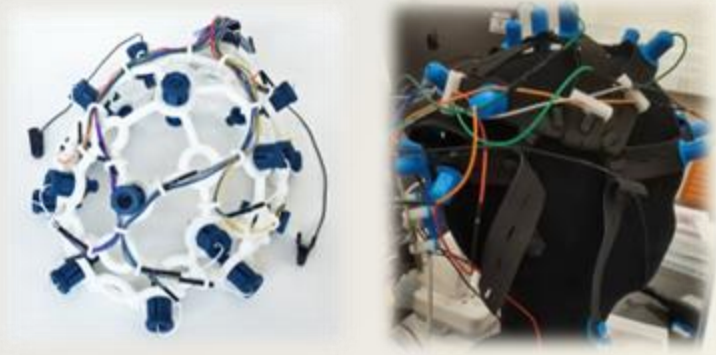


Headset

10-20 Electrode System



The Ultracortex Mark IV headset from OpenBCI



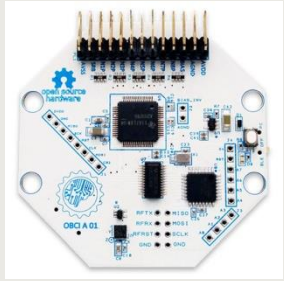
Experiment Setup

Data Collection Method

Equipment and Data Collection

- Use of OpenBCI soft Electrode Cap and GUI software to collect EEG data.
- Cyton + Daisy board for 12-channel EEG recording.
  Such arrangements are pivotal in enhancing signal-to-noise ratios due to enhanced spatial resolution capabilities.
- Notch filter: 50Hz
  It reduces AC noise, thus preserving the completeness of the EEG signals.
- Brainwave data saved in BDF+ format.

  Record three 2-minute data sets for each individual in each state.



Experiment Procedures

- Subject
- Procedures

Subject

The subjects recruited are undergraduate students from Duke Kunshan University

- were all over 18 years old
- were informed of the research intent and experimental instructions
- signed the written informed consents for each experiment
- Were under a screening process to prevent confounding variables conferred by neurological disorders or substances known to significantly influence cortical electrical activity, such as psychoactive medication and also to protect the subjects from the potential harm

Procedures

Phase I: Baseline

- record brainwave activity in a resting state without any applied stimuli
- serve as the control condition

Phase II: Hunger and Thirst

- Subjects were refrained from caloric intake for a specified duration of 10 hours
- a combination of physical exertion and the consumption of mildly saline water
- subjects were required to focus on the sensation and enhance it by imagining

Phase III: Temperature Differentiation for Cold and Heat Responses

- trigger the participants' bodily responses to cold and heat by modulating environmental temperature conditions
- subjects were required to focus on the temperature differentiation

Data Analysis

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Data Analysis

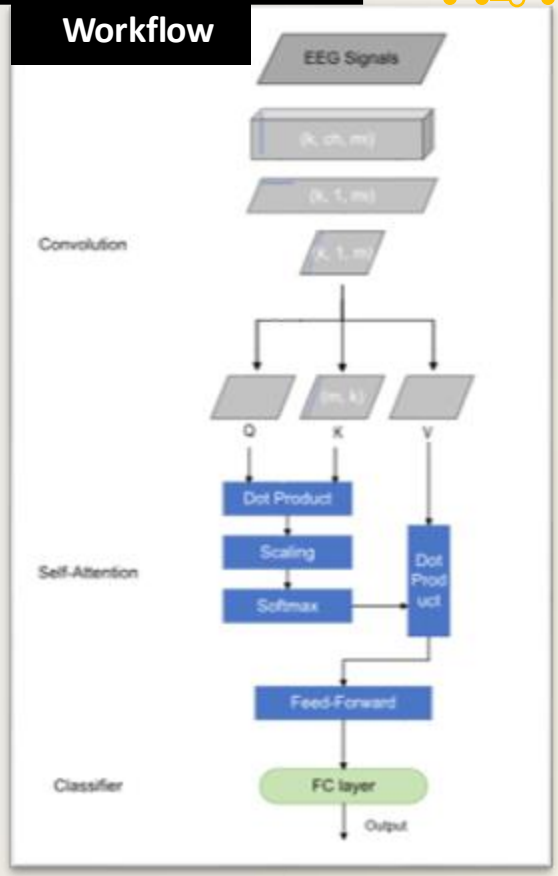
Collected Data

- Recruited around 50 subjects. 38 of them successfully finished all the three phases.
- Collected around 400 brainwave data sets.
- Sliced each 2-mintue recording into 10-second pieces, increasing the data set while ensuring the completeness .
- 90% of the data pieces were used as training sets, and the other 10% were used as testing sets.

Conformer Model

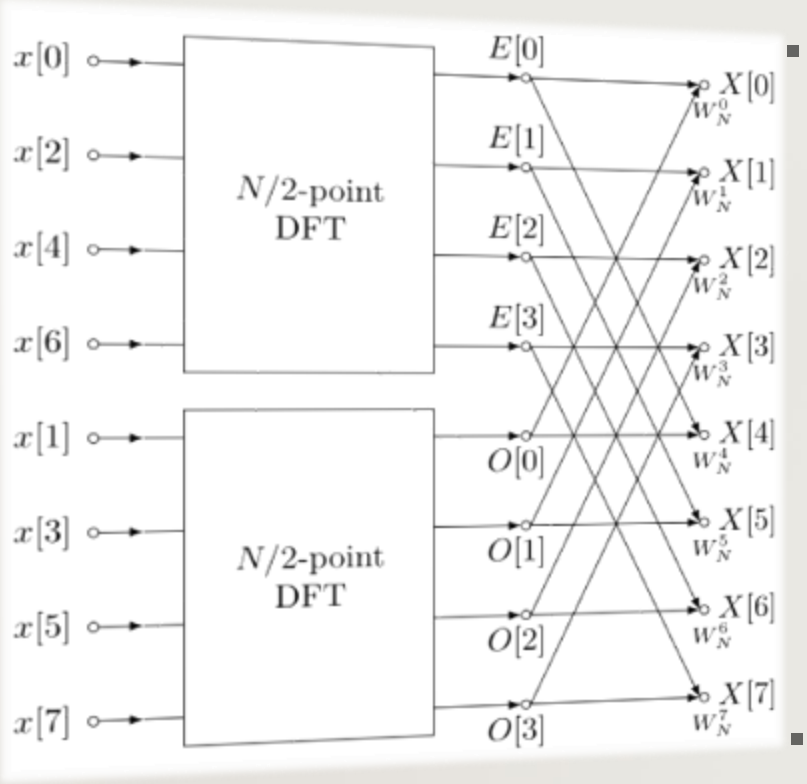
- A hybrid network structure
- Capture local representations and global features well at the same time, combining the advantages of convolutional operations and cascaded self-attention modules
- Key performance indicators:
  accuracy and mean loss during iterations important in the optimization

Workflow



IDENTIFICATION MODEL OF DIFFERENT PHYSIOLOGICAL STATES

Result Visualization



Visualization

Fast Fourier Transform (FFT)

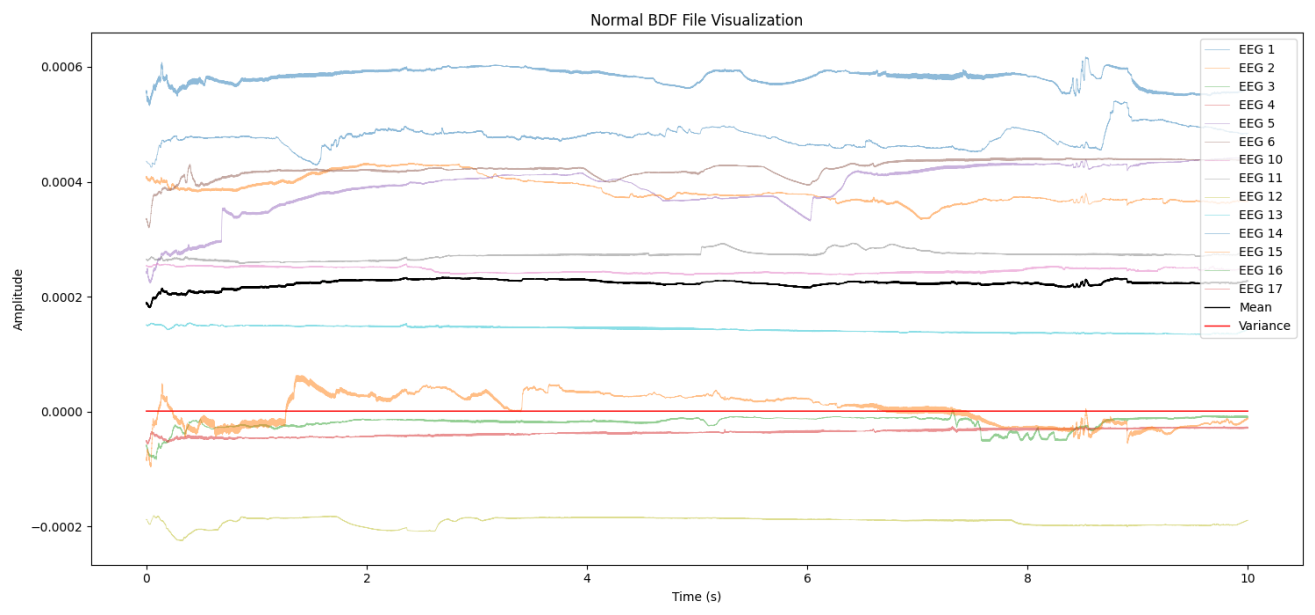
an algorithm that computes the Discrete Fourier Transform (DFT) of a sequence, or its inverse (IDFT)

The DFT is defined by the formula:

$$X_k = \sum_{m=0}^{n-1} x_m e^{-i2\pi km/n} \qquad k = 0, \ldots, n-1,$$

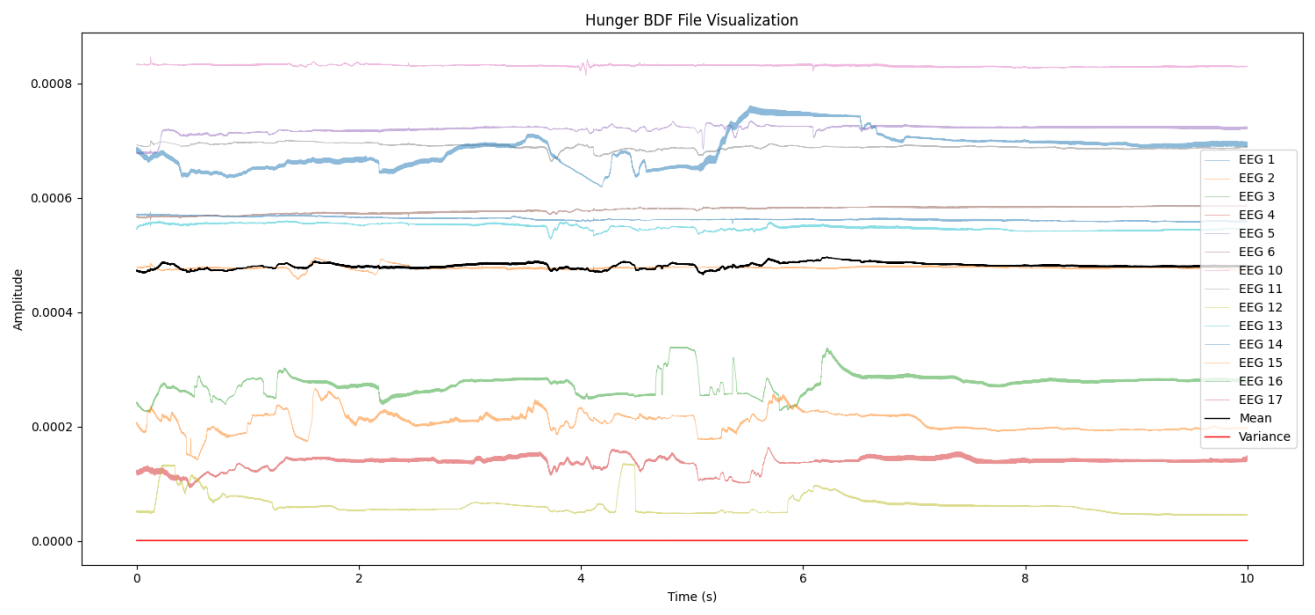
Then general wave patterns under each state are identified by averaging the EEG signals collected from all individual subjects across channels.

Normal State



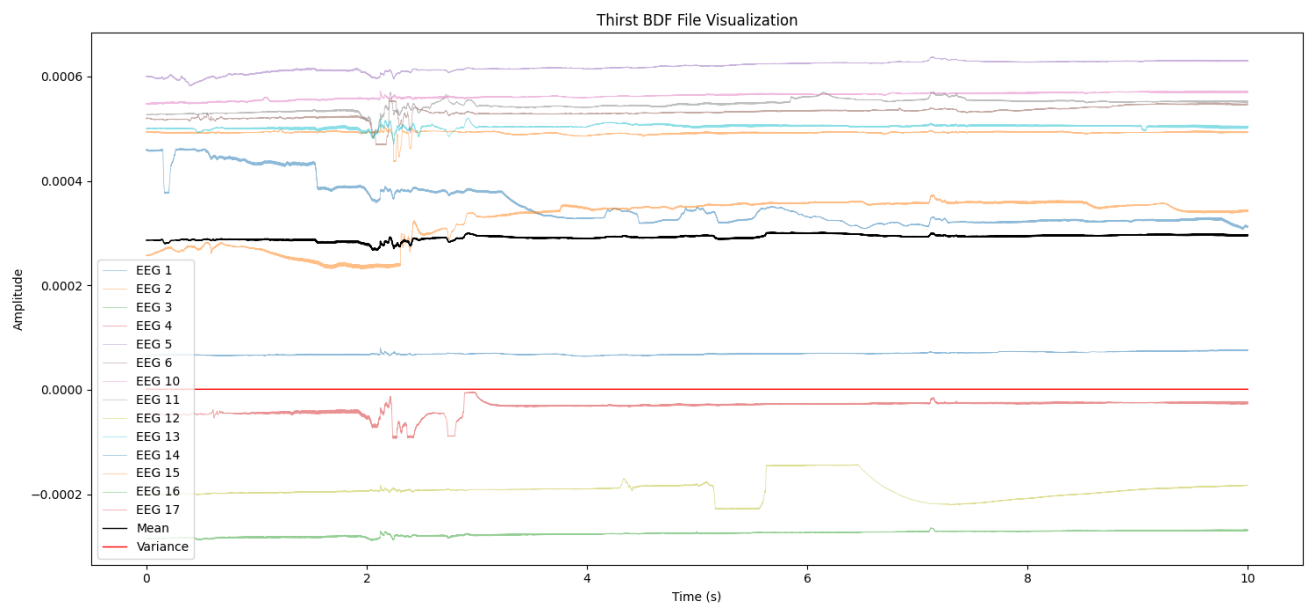
In normal state where the subjects receive no external stimuli, the EEG signals exhibit a relatively steady.

Hunger State



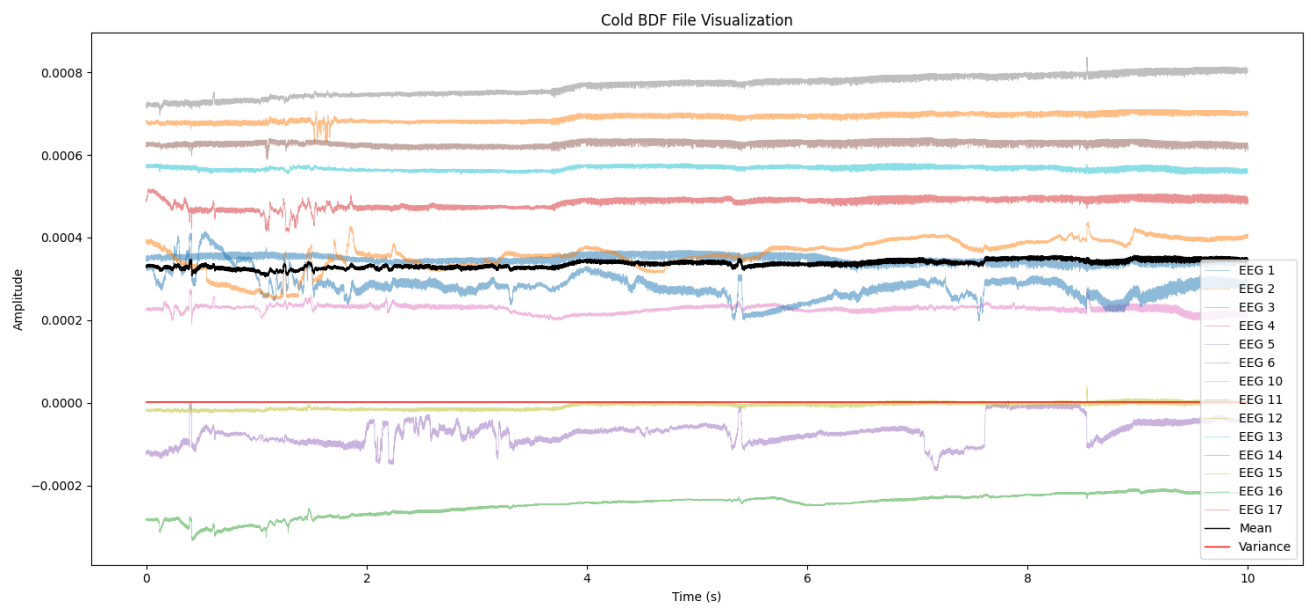
In hunger state, we can observe a special feature of wave fluctuations, which is located at the middle of the plot.

Thirst State



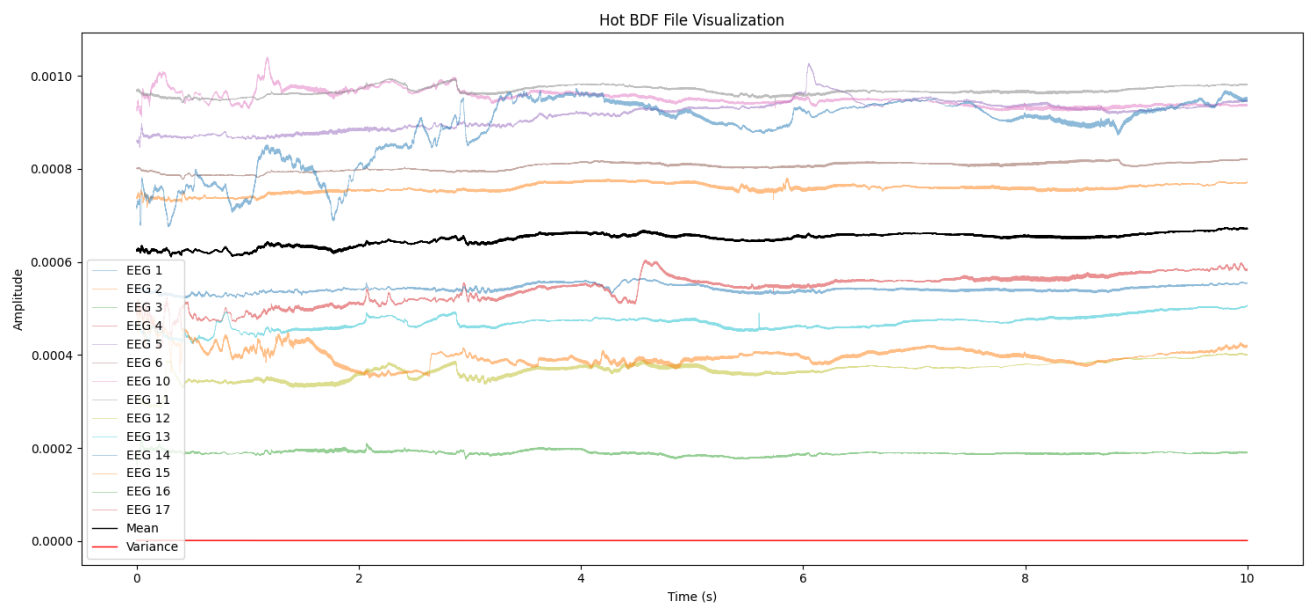
In thirst state, we can observe an overall smooth curve pattern, with slight wave fluctuations which are located in the left part. It is interesting to notice that the patterns for thirst state is generally even more stable than normal state.

Cold State



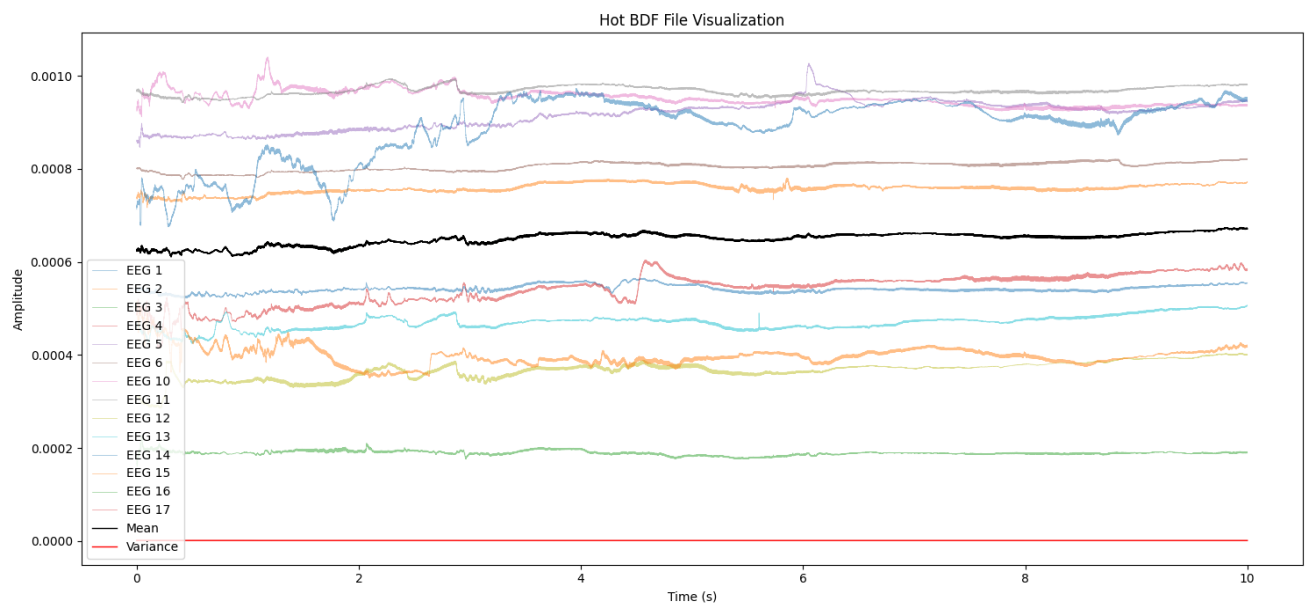
The wave curves for cold state are relatively unsteady compared to patterns under other states, with more fluctuations in each individual wave. It may indicate that the responses of brainwaves to cold stimuli is less uniform among different individuals than other stimulus.

Hot State



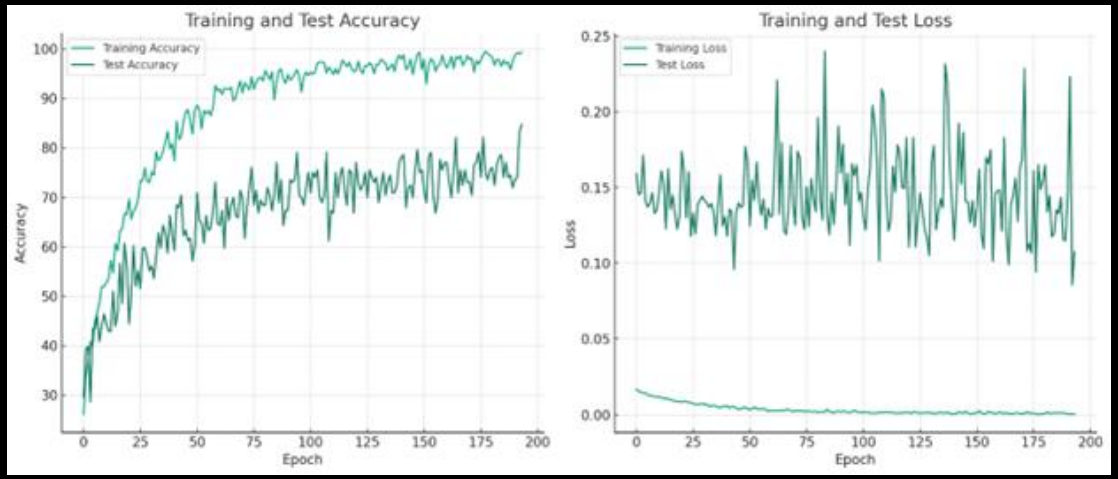
The wave patterns for the hot state are the most distinct than those in other states, with various EEG channels showing considerable undulations.

Hot State



On the one hand, this observation may suggest that the perception of heat involves multiple regions on the brain. On the other hand, it could also be attributed to the usage of a hot water bag not only provides heat but also imparts unexpected tactile stimulation to the subjects.

Overall Performance



Measured by the accuracy and average loss

The accuracy reaches around 91.9% in training sets and 71.7% in testing sets. While the loss is around 0.3% in in training sets and 15.4% in testing sets, indicating that although the model is trained well, there is space for improvement in the application.

Conclusion & Discussion

Conclusion

- Construct a classification model to analyze EEG signals and identify among the physiological states of hunger, thirst, and temperature differentiation.
- Demonstrate the applicability of Brain-Computer Interface (BCI) technology as an innovative tool for aiding communication
- Classification model eventually reaches the accuracy of 91.9% in training sets and 71.7% in testing sets.

Conclusion

The feature and the unique contribution of our project is to emphasize the extension of BCI usability into the field of expressive communication beyond the mere device manipulation.

Discussion

- The observation of the model accuracy declining to 71.7% in testing sets implies that models may require further refinement thus to deal with diverse inputs and potentially stressful real-world scenarios more accurately.

- In the EEG wave patterns, the temperature perception induced the most variabilities among subjects, highlighted by uneven, fluctuant wave patterns. A hypothesis can be supposed that this phenomenon may be caused by subjective responses to environmental temperatures, indicating that thermal sensory processing is highly individualistic.

Potential Limitations

- Homogenous representativeness of the sample:
  The subjects belong to a relatively homogenous age group. To improve the efficacy and applicability of the model for more general subjects, we need to collect data from more diverse samples and hence encompass broader demographic profiles.

- Experimental setup:
  Variations in head shape and hair types are possible to affect the strength and quality of EEG signals. In future iterations, adjustable sensor technology or more personalized headset fittings for diverse individuals may be necessary.

- Reliance on only EEG data:
  To enrich signal interpretations and reduce misclassification, multiple biosensing data can be combined, such as EMG signals, eye-tracking, and even galvanic skin responses.

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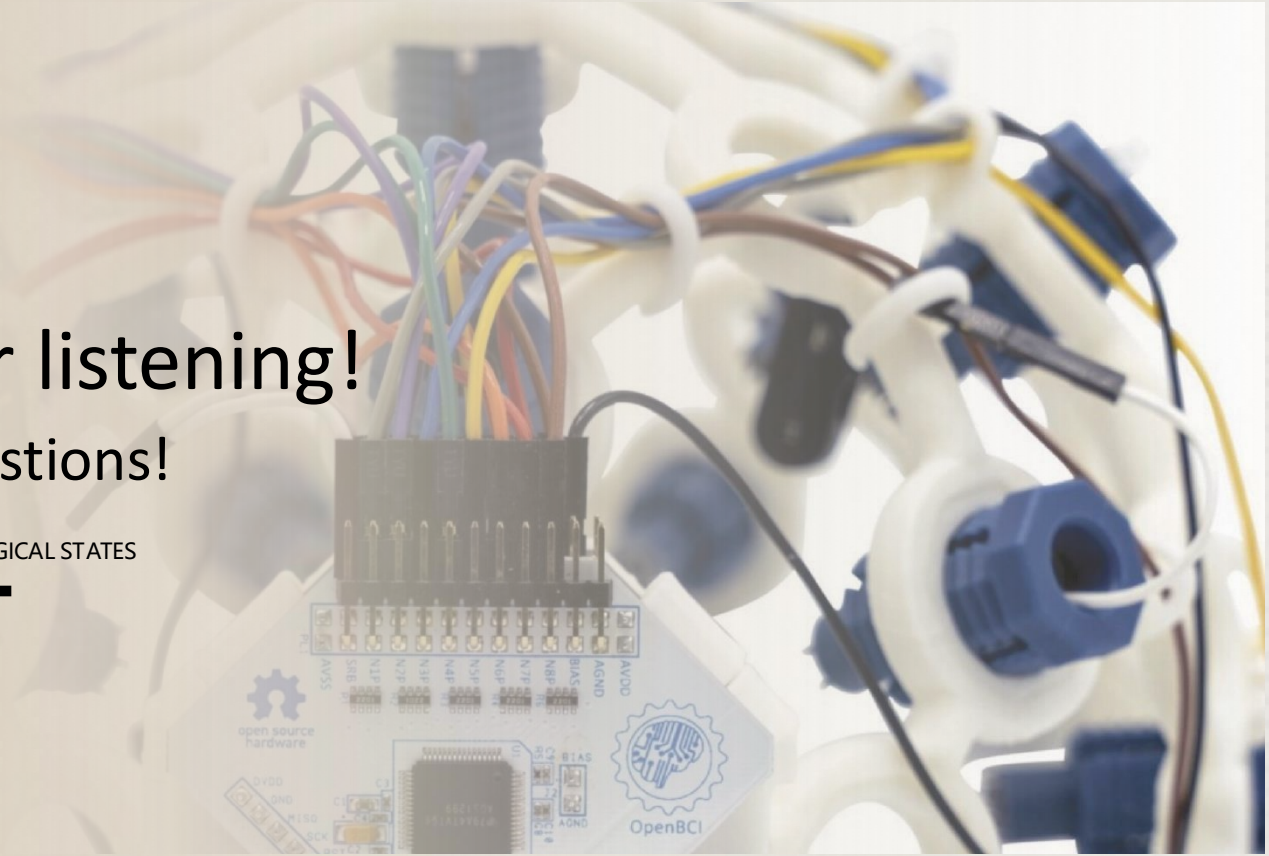

Thanks for your listening!

Feel FREE to ask questions!

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