Project Proposal

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Deep Learning

Multimodal Brain-State Classification Using EEG and MRI with Deep and Traditional Machine Learning Approaches.

Introduction

Advancements in neuroimaging and machine learning have enabled new opportunities to decode complex cognitive, emotional, and demographic characteristics from brain data. This project leverages the **LEMON dataset**, which includes structural MRI, resting-state EEG (eyes-open and eyes-closed), and extensive behavioral labels, to explore **multi-task brain state classification** using **EEG wavelet**, **EEG scalograms**, **MRI features**, and **machine learning models**, including deep neural networks.

This project investigates how well structural MRI and resting-state EEG—captured on the same day as mood and demographic surveys—can classify internal brain states and individual traits

Objectives

- To build and compare models that classify:
    - 🧠 **Awake vs. Tired** (**Vigilance State)**
    - 😌 **Calm vs. Nervous** (arousal)
    - 👴 🧑 **Age Group** (young vs. old)
    - 🚻 **Gender** (male vs. female)
- To experiment with **EEG-only**, **MRI-only**, and **EEG+MRI fused** models

Dataset: LEMON

I will use the **LEMON dataset (Leipzig Mind-Brain-Body)**, which includes

- Resting-state EEG (62 channels, 8 mins EC + 8 mins EO, 250 Hz)
- 192 participants
- Structural MRI (MP2RAGE)

- Behavioral labels:
    - **MDBF Questionnaire**: Awake–Tired, Calm–Nervous
    - **Age**, **Gender**

Although the number of participants in the dataset is relatively limited, segmenting the EEG data into 5, 10, or 20-second windows significantly increases the number of training samples, making it suitable for deep learning models.

Models: What Deep Network Will You Use? Standard or Customized?

For this project, I will use a combination of standard and customized deep learning models. A ResNet-based CNN will be adapted to process EEG scalograms, capturing spatial and frequency-related patterns. For sequential EEG segments, RNNs or LSTMs will be explored to model temporal dependencies. As classical baselines, models like SVM and XGBoost will be applied to extracted features from EEG and MRI. Finally, a custom multi-branch CNN will be implemented to fuse EEG and MRI inputs at the feature level, allowing the model to learn complementary representations from both modalities.

Framework: What Will You Use and Why?

- **PyTorch**: Chosen for its flexibility and ease of building custom deep learning models (especially multi-branch architectures).
- **Scikit-learn**: Used for traditional ML baselines and feature-based classifiers.
- **MNE / PyWavelets**: EEG preprocessing and scalogram generation.
- **FreeSurfer or CAT12 (SPM)**: For extracting MRI-based structural features.

References: Where Will You Get Background?

- Babayan et al., 2019 – A mind-brain-body dataset of MRI, EEG, cognition, emotion, and peripheral physiology in young and old adults
- Roy et al., 2013 Mental fatigue and working memory load estimation: interaction and implications for EEG-based passive BCI
- Christian Goelz et al. Classification of age groups and task conditions provides additional evidence for differences in electrophysiological correlates of inhibitory control across the lifespan
- Huster et al., Methods for simultaneous EEG-fMRI: an introductory review

- PyTorch, Scikit-learn, and EEG/MRI processing libraries (documentation & tutorials)

Metrics: How Will You Judge Performance?

- **Classification Accuracy**
- **F1-score**
- **Precision/Recall**
- **ROC-AUC** (for binary classification)
- **Confusion Matrix**
- **Learning Curves**: Train/validation loss and accuracy

Comparisons will be made between:

- EEG-only vs. MRI-only vs. Combined models
- Eyes-open vs. eyes-closed EEG
- Classical ML vs. Deep Learning

4-Week Project Timeline

Week	Focus Area	Key Tasks
1	Data Prep & Labeling	- Generate labels (vigilance, arousal, age, gender) - EEG segmentation & scalogram generation
2	Single-Modality Models	- Extract MRI features -Train CNN on EEG scalograms - Train ML models on MRI (XGBoost/MLP)
3	Fusion & Comparisons	- Build EEG+MRI fusion model - Evaluate baseline results - Train & test across all tasks - Compare EEG vs MRI vs fused
4	Results & Reporting	- Plot training curves, confusion matrices - Summarize metrics - Prepare final report & presentation