Multimodal Data Analysis for OCD Patients Under Deep Brain Stimulation

GitHub Repository Documentation

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About This Project

This repository contains the code developed for my **Master's Capstone Project** in Electrical and Computer Engineering at **Rice University**, in collaboration with the **Provenza Lab** at **Baylor College of Medicine**.

The project aims to develop tools for analyzing multimodal data from patients with treatment-resistant OCD undergoing Deep Brain Stimulation (DBS). The ultimate goal is to identify neural biomarkers that could enable closed-loop, adaptive DBS systems that respond to patient anxiety states in real-time.

Research Context

Obsessive-Compulsive Disorder (OCD) affects millions worldwide, and for some patients, traditional treatments are ineffective. Deep Brain Stimulation offers hope, but current systems deliver constant stimulation 24/7—regardless of the patient's actual needs.

Our research works toward **closed-loop DBS**: a smarter system that monitors brain signals and adjusts stimulation automatically based on detected anxiety levels. This requires identifying reliable **biomarkers**—measurable brain signals that correlate with anxiety states.

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1. Repository Structure

Directory/File	Description
`audio_video_sync/`	Stage 1: Audio-Video Synchronization (Arduino + MATLAB)
`video_lfp_pipeline/`	Stage 2: Real-Time Multimodal Pipeline (MATLAB)
`lfp_analysis/`	Stages 3-5: Neural Analysis & ML (Python)
`classes/LFPData.py`	Data loading and preprocessing class
`classes/BandAnalysis.py`	Frequency band power analysis class
`plot_functions.py`	Visualization utilities
`analysis.ipynb`	Main analysis notebook

2. Project Components

2.1 Audio-Video Synchronization System

Language: Arduino + MATLAB

A custom synchronization system that enables frame-accurate alignment between audio and video recordings during clinical sessions. Uses an Arduino-based serial encoder that embeds timing markers into both audio and video streams.

Key Features:

- Custom PCB design for signal routing
- Serial frame ID encoding in audio channel
- Automated decoding and alignment in MATLAB
- Sub-frame timing accuracy

2.2 Video-LFP Synchronization Pipeline

Language: MATLAB

Creates synchronized visualization videos that display clinical recordings alongside real-time neural data (LFPs, theta oscillations, and spectrograms). Essential for correlating patient behavior with neural activity.

Key Features:

- Real-time synchronized playback of video + neural data
- Bilateral LFP signal visualization
- Theta band (4-8 Hz) extraction
- Live spectrogram display (0-30 Hz)
- FFmpeg audio integration

2.3 LFP Analysis Pipeline (Python)

Language: Python

Object-oriented framework for analyzing Local Field Potentials and their relationship with anxiety states (measured via SUDS - Subjective Units of Distress Scale).

Key Features:

- Modular OOP architecture for scalability
- Automated preprocessing (NaN interpolation, demeaning, artifact removal)
- Band power calculation (Theta, Alpha, Beta)
- SUDS-LFP alignment and correlation analysis
- Machine learning classification (Logistic Regression, Random Forest)

3. Quick Start Guide

Prerequisites

For MATLAB components:

- MATLAB R2020a or later
- Signal Processing Toolbox
- FFmpeg (for audio processing)

For Python components:

```
pip install numpy pandas scipy matplotlib seaborn plotly scikit-learn
```

Running the Python Analysis

```
from classes import LFPData, BandAnalysis

# Load and preprocess patient data
patient = LFPData("AA002", "2025-04-10")
patient.load_data(lfp_csv_path, task_csv_path)
patient.preprocess(artifact_start_sec=10, artifact_end_sec=5)

# Analyze frequency bands
analysis = BandAnalysis(patient, window_sec=2.0)
analysis.calculate_all_bands()
analysis.print_summary()
```

4. Key Findings

Our preliminary analysis of a single patient revealed:

Finding	Details
Biomarker Candidate	Left-hemisphere Theta power (4-8 Hz) shows significant negative correlation with anxiety (SUDS)
Phase Discrimination	Relief phase shows highest Theta power; Exposure phase shows lowest
ML Performance	Phase-based stress detection: 61.5% accuracy (above 50% chance level)
Feature Importance	Theta_left is the most predictive feature (importance = 0.22)

These findings suggest that **left-lateralized Theta activity** may serve as a potential biomarker for anxiety states in OCD patients with DBS.

5. Data Format Requirements

Neural Data (.mat file)

Expected structure from Percept PC recordings:

- `data.neural.combined_data_table` - LFP channels with timestamps
- `data.neural.fs` - Sampling frequency (typically 250 Hz)
- `data.behavior.events` - Event markers including sync beep (Event Code 10)

Task Data (.csv file)

Required columns:

- **Timer** - Format MM:SS:ms
- **Event** - Contains 'SUDS' and 'Note' entries
- **Entry** - Phase markers: 'Task Start', 'exposure', 'compulsions', 'relief'

6. Experimental Protocol

The ERP (Exposure and Response Prevention) task consists of four phases:

Phase	Duration	Description
Baseline	2 min	Rest period, calibration
Exposure	6 min	Patient exposed to anxiety trigger
Compulsions	4 min	Patient performs compulsive behaviors
Relief	4 min	Recovery period

SUDS ratings (0-10) are collected throughout the session via tablet.

7. Future Directions

1. **Scale to More Patients** - Generalize the OOP pipeline across multiple subjects
2. **Richer Neural Features** - Add bursting dynamics, band ratios, asymmetry indices
3. **Multimodal Integration** - Incorporate video-based facial affect and audio features
4. **Biomarker Validation** - Identify consistent neural signatures for closed-loop DBS

8. Publications & Presentations

- **WSSFN 2025** (Buenos Aires, Argentina) - Poster: *"DBS Data Synchronization with Continuous Audio and Video for Psychiatric Biomarker Discovery"*

9. Acknowledgments

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