

## Interactive Brain Interface for Multimodal EEG Visualization and Disease-Specific Neural Dynamics

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### INTRODUCTION & AIM

Electroencephalography (EEG) provides a noninvasive way to observe brain activity and detect alterations associated with neurological and neurodevelopmental disorders. Conditions such as epilepsy, Alzheimer's disease, dementia, and autism are often characterized by specific changes in neural oscillations, spectral power, and functional connectivity. However, the high dimensionality and complexity of EEG signals make these patterns difficult to interpret, particularly when analyzing dynamic brain states. Interactive visualization and computational modeling can help transform raw EEG data into interpretable representations that reveal underlying neural dynamics.

This work aims to develop an interactive brain interface that enables the visual exploration of disease-specific EEG patterns. By integrating spectrograms, scalp topographic maps, and connectivity graphs, the proposed system highlights key biomarkers associated with different brain disorders and provides an intuitive platform for analyzing and comparing neural activity patterns.

### METHOD

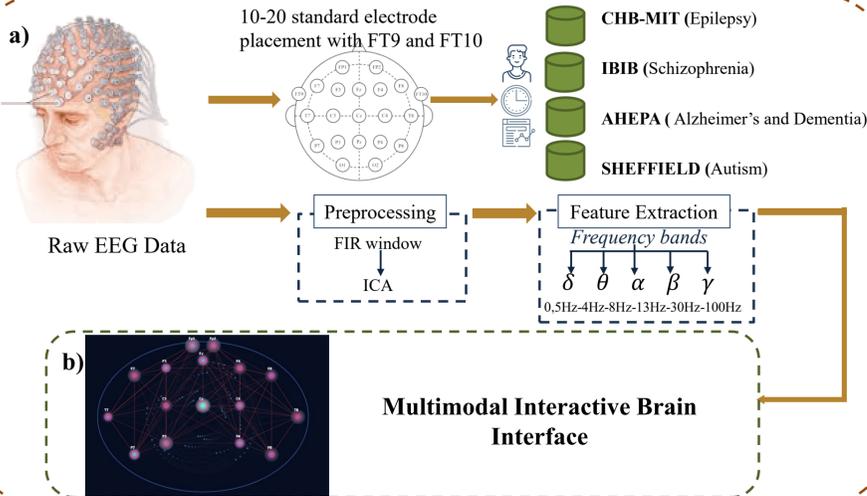
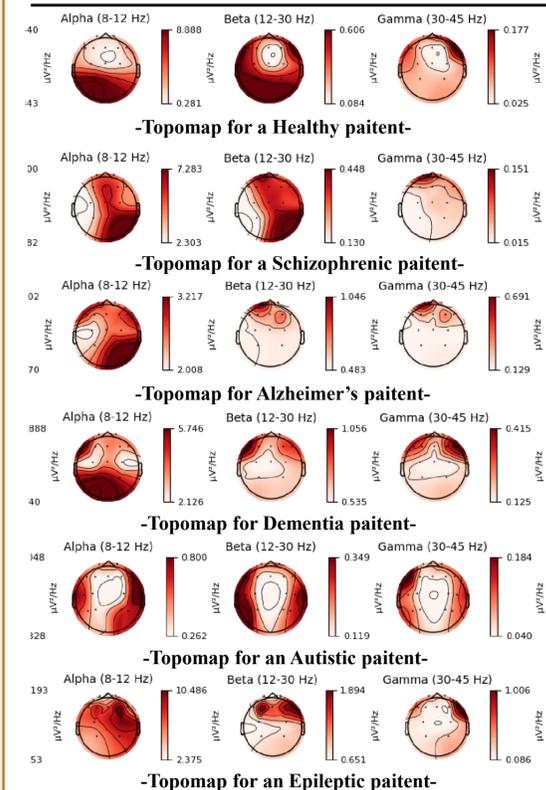


Figure.1 Proposed model. a) Block diagram of an EEG-based diagnostic system: Data acquisition and preprocessing b) Multimodal Interactive Brain Interface



**Correlation:** measures linear relation between signals  $x$  and  $y$

$$r_{xy} = \frac{\text{cov}(x,y)}{\sigma_x \sigma_y}$$

**Coherence:** frequency-domain connectivity

$$C_{xy} = \frac{|S_{xy}|^2}{S_{xx} S_{yy}}$$

**Phase-Locking Value (PLV):** phase synchronization

$$PLV = \frac{1}{T} \left| \sum_t e^{j(\phi_x(t) - \phi_y(t))} \right|$$

**Power Spectral Density (PSD):** signal power vs. frequency

$$P_{xx} = \frac{|X(f)|^2}{T}$$

**Graph Measures:** network connectivity

**Degree:**  $k_i = \sum_j A_{ij}$

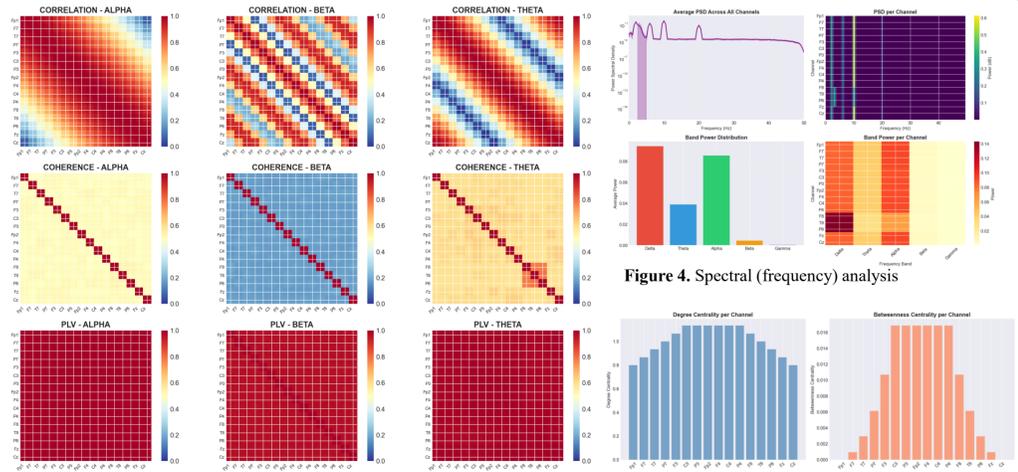
**Betweenness:**  $BC(i) = \sum_{s \neq t \neq i} \frac{\sigma_{st}(i)}{\sigma_{st}}$

FIGURE 2. Topographic map (topomap) representation for various pathological illnesses. (Alpha, Beta & Gamma subbands)

### REFERENCES

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- 3, Khalfallah, S. and Bouallegue, K., 2025, February. Novel Enhanced ChronoNet Model for Epileptic Seizure Detection: A Comprehensive Methodological Study. In *2025 IEEE 22nd International Multi-Conference on Systems, Signals & Devices (SSD)* (pp. 1161-1168). IEEE.

### RESULTS & DISCUSSION



- Spectral analysis shows dominant Alpha power = 0.085, followed by Delta and Theta, while Beta and Gamma  $\approx$  0.001 remain low, indicating a resting-state EEG pattern.
- Functional connectivity analysis (Correlation, Coherence, PLV) reveals strong synchronization between EEG channels, particularly in the alpha and theta frequency bands.
- Network analysis shows a high clustering coefficient (0.915) and short average path length (1.125), indicating an efficient small-world brain network organization.
- Centrality measures identify central and parietal electrodes (C3, P3, F4, C4) as key hubs facilitating information flow across the network.

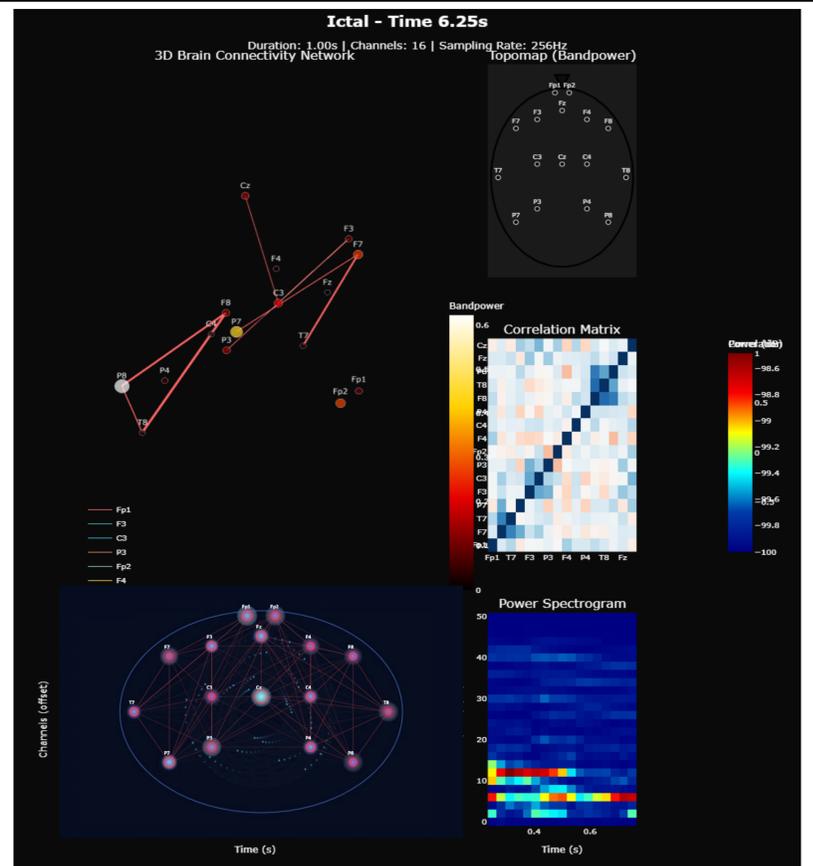


Figure.6 Multimodal Interactive Brain Interface consisting of: 1. 3D Brain Connectivity Network, 2. Topomap (Bandpower), 3. Correlation Matrix, 4. Power Spectrogram, 5. Multichannel time series.

### CONCLUSION

- In this work, we successfully acquired and preprocessed EEG datasets from various neurological pathologies, performing functional connectivity, spectral, and brain network analyses. We also developed an interactive multimodal EEG interface to streamline exploration and analysis for technicians and neuroscience researchers.

### FUTURE WORK

- We aim to extend the EEG analysis to additional neurological conditions and integrate advanced AI models for automated pattern recognition. Future developments will also enhance the interactive interface with real-time visualization and user-friendly analytics for researchers and clinicians.