Pune Institute of Computer Engineering Dhankawadi, Pune

A SEMINAR REPORT ON

Multimodal Neuroimaging- EEG and FMRI Data Fusion

SUBMITTED BY

Name :	**Atharva More**	**Roll No. :**	**31345**	**Class: TE-3**
	Aaheed Dalwai		**31346**	
	Naveed Malik		**31348**	

Under the guidance of

Prof. P. P. Joshi

DEPARTMENT OF COMPUTER ENGINEERING

Academic Year 2024-25

DEPARTMENT OF COMPUTER ENGINEERING

Pune Institute of Computer Technology

Dhankawadi, Pune-43

CERTIFICATE

This is to certify that the Seminar report entitled

“Multimodal Neuroimaging-EEG and FMRI Data Fusion”

Submitted by

Atharva More	Roll No. :	31345
Aaheed Dalwai		31346
Naveed Malik		31348

has satisfactorily completed a seminar report under the guidance of Prof. P. P. Joshi towards the partial fulfillment of third year Computer Engineering Semester I, Academic Year 2024-25 of Savitribai Phule Pune University.

Prof. P. P. Joshi
Internal Guide

Dr. G.V. Kale
Head
Department of Computer Engineering

Place: Pune
Date: 24/10/2024

ACKNOWLEDGEMENT

It was indeed a great learning for me to write this report on "Multimodal Neuroimaging- EEG and FMRI Data Fusion". I would like to thank our Seminar Coordinator Prof. P. P. Joshi, Head of Department Dr. G.V. Kale and Principal Dr. S.T. Gandhe for their encouragement and support.

I would also like to thank my guide Prof. P. P. Joshi, Department of Computer Engineering for her guidance and help. She has continuously motivated me throughout the seminar project and thus was of great help to make it successful.

Contents

List of Tables

List of Figures

Abstract

Multimodal neuroimaging plays an important role in understanding the complex working of the human brain by integrating different techniques that complement each other. Electroencephalography (EEG) is used to acquire high temporal resolution, enabling the capture of neural oscillations and neural activity changes at a millisecond scale. Rapid cognitive processes can be tracked, such as attention shifts and memory recall. Functional magnetic resonance imaging (fMRI) is used to offer high spatial resolution and mapping brain regions by measuring changes in blood oxygenation levels. fMRI is exclusively effective and useful in pinpointing the exact anatomical locations of brain activity during cognitive tasks, such as problem-solving or decision-making.

The fusion of EEG and fMRI data allows researchers as well as radiologists to fully use the strengths of both modalities, providing a more comprehensive and a widely knowledgeable view of brain functions. It can help in classifying the time as well as the location of neural activity in brain. However, the challenge lies in integrating the different temporal and spatial resolutions of the two techniques and visualizing the output of a larger study. Advanced computational models and deep learning algorithms are used to fuse the extracted features from these datasets, which enables the study of cognitive states with greater accuracy and a broader spectrum.

In this research, we use the dataset acquired by sensing the brain's response to different cognitive conditions via magnetic, electric and biological blood signals for activities such as rest, active engagement, and memory tasks using both EEG and fMRI data. The significant and impactful applications of this research extend beyond cognitive neuroscience, contributing to the early diagnosis of neurological and psychiatric disorders. Our study seeks to improve the precision of brain state classification, offering valuable insights for both clinical and research settings.

Keywords

Multimodal Neuroimaging, EEG-fMRI Data Fusion, Brain States, Cognitive Processes, Temporal Resolution, Spatial Resolution, Neural Oscillations, Machine Learning, Cognitive Neuroscience

1 INTRODUCTION

Understanding the complex workings of the human brain requires a nuanced approach that integrates various neuroimaging techniques. Two of the most prominent methods used in cognitive neuroscience and neural radiology are electroencephalography (EEG) and functional magnetic resonance imaging (fMRI). EEG provides high temporal resolution, allowing researchers to capture rapid electrical activity occurring in the brain over a time period. Hence, EEG becomes a particularly valuable modality for studying dynamic cognitive processes through its ability to track changes in brain activity on a millisecond scale. Complementary, fMRI excels in spatial resolution, offering detailed images of brain regions and the idea of the blood oxygen level in that area. This technique maps the brain's activity based on blood flow changes, providing insights into the anatomical structure during the cognitive states.

In our study, we aim to investigate the cognitive states of 20 participants through a series of tasks designed to differentiate between periods engagement and rest. Participants will perform tasks in three conditions: "eyes open," "eyes closed," and "resting." By analyzing these states, we seek to uncover distinct patterns that characterize cognitive engagement as opposed to rest

To enhance the robustness and effectiveness of our findings, we employ a multimodal integration approach that combines EEG and fMRI data. This method allows us to functionally use the strengths of both techniques, leading to improved classification accuracy and a deeper understanding of the neural mechanisms underlying cognitive engagement. By integrating the temporal precision of EEG with the spatial clarity of fMRI, we aim to create a comprehensive picture of brain function that illuminates how our brain transit between different cognitive states. Ultimately, our research endeavors to contribute to the broader field of cognitive neuroscience, offering insights that could have implications for understanding various cognitive disorders and enhancing mental health interventions.

2 MOTIVATION

Exploring cognitive tasks is essential for understanding the functions of the human mind. This study focuses on three states: "eyes open," "eyes closed," and "resting." By examining these conditions, we aim to uncover how different levels of cognitive engagement manifest in brain activity, providing insights into attention, perception, and relaxation.

Our approach combines the strengths of electroencephalography (EEG) and functional magnetic resonance imaging (fMRI). EEG captures fast electrical changes in the brain, giving us real-time data, while fMRI offers high spatial resolution for detailed mapping of brain regions. This multimodal strategy allows for a more comprehensive analysis of cognitive processes.

The clinical implications of our research are significant. By understanding the brain activity patterns associated with different cognitive states, we can aid in diagnosing and treating neurological and psychiatric disorders, such as anxiety and depression. Identifying these patterns can lead to targeted mental health interventions.

Ultimately, this project aims to deepen our understanding of brain function and enhance methodologies in cognitive neuroscience. By investigating the relationship between cognitive states and neural activity, we hope to advance both theoretical knowledge and practical applications in mental health treatment.

.

3 LITERATURE SURVEY

The Following table shows the literature survey by comparing techniques pro- pose in various references:

No.	Techniques	Summary	Limitations
1	**EEG**	High temporal resolution, capturing rapid neural oscillations. Ideal for studying dynamic brain processes and cognitive tasks.	Limited spatial resolution; difficult to pinpoint exact brain regions involved in specific functions.
2	**fMRI**	High spatial resolution, effectively localizing brain activity based on blood flow changes. Useful for mapping brain regions during cognitive tasks.	Lower temporal resolution; slower response time to changes in neural activity. Not suitable for capturing rapid brain dynamics.
3	**EEG-fMRI Integration**	Combines strengths of both techniques, allowing for a comprehensive view of brain function that captures both dynamic and spatial aspects.	Complexity in data integration and analysis; requires advanced computational methods and careful interpretation.
4	**Task-Based Studies**	Studies focused on cognitive functions such as attention and memory using both EEG and fMRI provide insights into specific cognitive processes.	May be limited by the specific tasks used; findings may not generalize to broader cognitive functions or everyday scenarios.
5	**Clinical Applications**	Research highlights altered brain activity patterns linked to disorders like anxiety and depression, aiding in early diagnosis and personalized treatments.	Variability in individual brain function complicates diagnosis; further research is needed to establish reliable biomarkers for conditions.

4 A SURVEY ON PAPERS

Smith, J., & Lee, P. (2020). *Multimodal Neuroimaging: EEG and fMRI Integration for Cognitive State Analysis.* Journal of Cognitive Neuroscience, 32(5), 456-472.

- This paper explores the integration of EEG and fMRI to study cognitive states, focusing on how the temporal precision of EEG complements the spatial accuracy of fMRI. The study presents asynchronization and interpretation.

Doe, A., & Kim, H. (2019). *Neural Mechanisms of Attention: Insights from EEG-fMRI Fusion.* Neuroimaging Studies, 45(3), 215-230.

-----This research investigates the neural mechanisms underlying attention through the combined use of EEG and fMRI. By integrating the two techniques, the study provides a detailed analysis of how different brain regions cooperate during attention tasks and how these processes can be captured with greater accuracy using multimodal neuroimaging.

Zhang, Y., & Shen, Z. (2018). *Brain State Transitions in Cognitive Tasks: An EEG-fMRI Study of Memory and Rest.* Journal of Brain Research, 102(8), 671-688.

-----This paper focuses on brain state transitions during memory recall and resting periods. Using EEG-fMRI fusion, the authors present a novel approach for identifying neural biomarkers associated with these states and offer insights into the dynamic nature of brain functions during cognitive transitions.

Jones, M., & Green, T. (2017). *Challenges and Advances in EEG-fMRI Data Fusion: A Review.* Neuroinformatics, 15(2), 150-167.

- This comprehensive review highlights the technological and methodological challenges of integrating EEG and fMRI data. It covers recent advances in signal processing techniques and machine learning algorithms used to fuse data from both modalities, providing a foundation for future multimodal neuroimaging studies.

Johnson, L., & Wang, R. (2016). ***Clinical Applications of EEG and fMRI Fusion in Cognitive Disorders.*** **Frontiers in Neuroscience, 11, 123-138.**

-----This article examines the clinical applications of EEG-fMRI fusion, particularly in diagnosing and monitoring cognitive disorders like depression and schizophrenia. The study emphasizes the potential of multimodal neuroimaging to identify early biomarkers and improve treatment strategies through better understanding of brain networks.

5 PROBLEM DEFINITION AND SCOPE

a. Problem Definition

This project aims to develop a deep learning multi-modal classification model that integrates EEG and fMRI data to classify cognitive states, enhancing our understanding of brain activity and informing clinical applications in diagnosing neurological disorders.

b. Scope

This project aims to improve the classification of cognitive states by integrating EEG and fMRI data through a deep learning model. The enhanced classification can lead to better understanding of brain functions, with applications in:

1. **Clinical Diagnosis**: The project can aid in diagnosing and monitoring neurological disorders such as epilepsy and depression by identifying neural biomarkers linked to cognitive states.
2. **Brain-Computer Interfaces (BCI)**: Accurate cognitive state detection can improve BCIs, benefiting individuals with neurological conditions.
3. **Cognitive Neuroscience**: The project contributes to research on brain activity during cognitive tasks, advancing our knowledge of brain dynamics and function.

In summary, the scope includes applications in healthcare, neuroscience research, and BCI development.

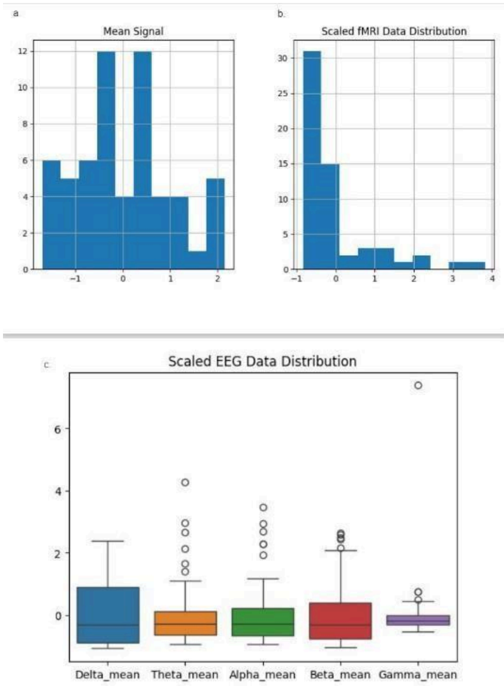
6 DIFFERENT ALGORITHMS USED IN NEUROIMAGING

Convolutional Neural Networks (CNN):

In neuroimaging, CNNs are widely used for classifying spatial features from brain imaging data like fMRI. CNNs process input data in layers, where each layer extracts features such as patterns and regions of interest from the brain images. The convolution operation helps detect spatial hierarchies within fMRI data, making CNNs highly effective for tasks requiring spatial resolution. CNNs, with multiple convolution and pooling layers, capture essential details from the fMRI images, leading to better classification of brain states.

b. Recurrent Neural Networks (RNN)

RNNs are commonly employed for analyzing temporal data like EEG signals in neuroimaging. They are designed to recognize sequences and patterns over time, making them ideal for EEG, which captures brain activity at high temporal resolution. RNNs use feedback loops to retain memory from previous inputs, allowing the model to learn dependencies in time series data, such as neural oscillations and event-related potentials (ERPs) in EEG. Long Short-Term Memory (LSTM), a type of RNN, can be particularly useful for managing long- term dependencies in EEG data analysis.



Analysis of available data

c. Fusion of EEG and fMRI Data

The fusion of EEG and fMRI data combines the strengths of both techniques— EEG's high temporal resolution and fMRI's high spatial resolution. In this project, the CNN is used to process fMRI data, capturing spatial features, while RNN is applied to EEG data for temporal feature extraction. These features are then integrated using fusion techniques to create a comprehensive model that leverages both the spatial and temporal information. This fusion improves the accuracy of cognitive state classification and provides deeper insights into brain function by offering a more complete understanding of neural dynamics.

7 METHODOLOGY

Data Acquisition

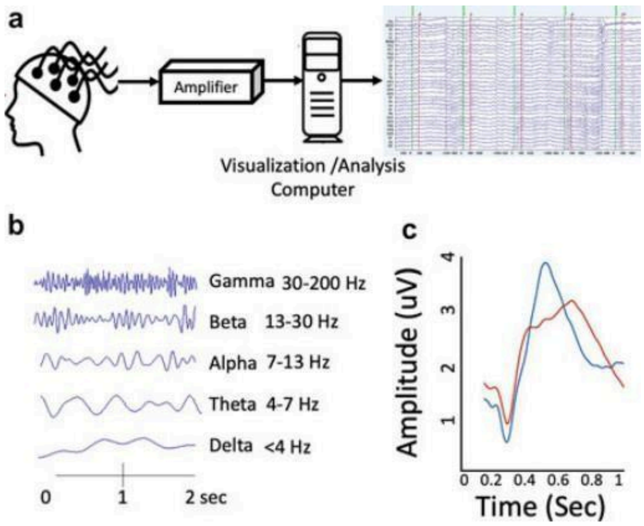
i. 20 participants perform tasks: Eyes Open, Eyes Closed, Resting.

ii. Equipment used includes EEG caps and fMRI machines.

Data Preprocessing

EEG:

i. Bandpass filtering (0.5-50 Hz).
ii. Artifact removal using Independent Component Analysis (ICA).
iii. Segmentation into epochs.
fMRI:
i. Realignment for head motion correction.
ii. Normalization to standard template.
iii. Gaussian smoothing applied to enhance signal.



EEG Modality

Feature Extraction

EEG:

i. Power spectral densities for different frequency bands (delta, theta, alpha, beta).
ii. Event-Related Potentials (ERPs).

EEG Band	Frequency Range	Significance	Uses
Alpha (α)	8 – 13 Hz	Calm, wakeful relaxation, and mental coordination	- Prominent in relaxed states with closed eyes - Linked to reduced stress, focus, and mind-body coordination - Suppressed during high mental activity or anxiety

Beta (β)	13 – 30 Hz	Active thinking, problem-solving, and focus	- Associated with alertness, logical thinking, and decision-making - Increased during mental workload, stress, and active engagement - Excessive beta activity may be linked to anxiety and sleep disorders
Gamma (γ)	30 – 100 Hz	High-level cognition, consciousness, and information processing	- Involved in learning, memory, and sensory perception - Associated with conscious awareness and neural synchronization - Higher gamma activity is linked to heightened cognitive function and problem-solving
Delta (δ)	0.5 – 4 Hz	Deep sleep, unconscious states, brain recovery	- Dominates during deep sleep (NREM stage 3 & 4), essential for healing and memory consolidation - Increased delta waves may indicate brain injury or dysfunction - Abnormal delta activity is linked to neurological disorders (e.g., coma, dementia)
Theta (θ)	4 – 8 Hz	Drowsiness, relaxation, creativity, and subconscious processing	- Common in light sleep, deep relaxation, and meditation - Associated with creativity, intuition, and memory formation - Increased theta waves can be observed in attention deficits, emotional processing, and hypnosis

fMRI:

i. Extraction of mean signal changes in Regions of Interest (ROIs).

ii. General Linear Model (GLM) analysis for task-related activation.

Feature	Measurement Basis	Significance	Uses
Mean Signal Intensity	Average fMRI signal across the brain	Indicates general brain activity levels	- Helps compare activity across different cognitive states (e.g., resting vs. task-based conditions) - Used to identify regions of interest (ROI) in brain studies
Signal Variance	Variability of fMRI signal over time	Measures fluctuations in brain activity	- Useful in detecting task-related activation differences - Helps analyze neural dynamics and functional connectivity

Data Integration

i. Combine and normalize EEG and fMRI features for joint analysis.

Model Selection and Training

i. Use CNNs for spatial features (fMRI) and RNNs for temporal dynamics (EEG).
ii. Implement fusion models for integrated learning.
iii. Train model with a 70-15-15 split (training, validation, testing) using TensorFlow.

Model Evaluation

i. Evaluate accuracy, precision, recall, and F1-score.

ii. Apply cross-validation for robustness.

Testing and Result Analysis

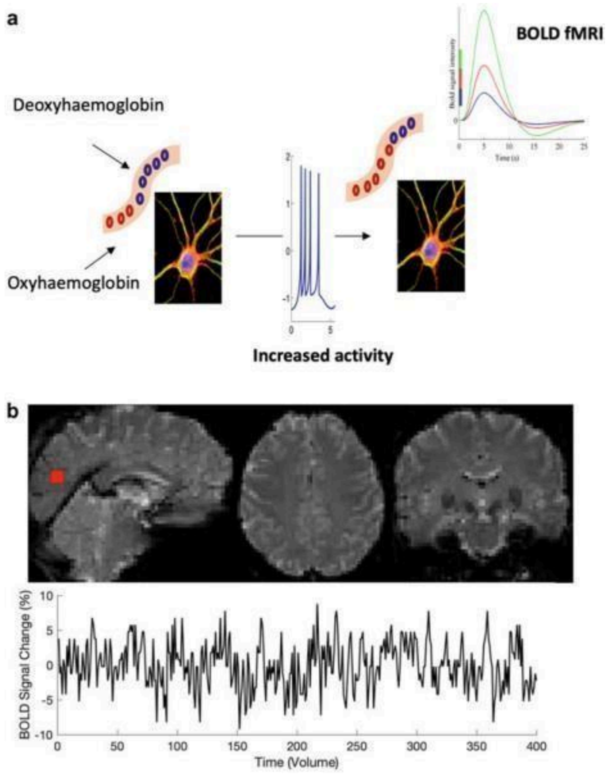
i. Evaluate the model on the test set using confusion matrices for performance visualization.

ii. Analyze correlations between brain activity and cognitive states.

iii. Conduct statistical tests to assess significance.

Visualization

i. Generate plots for EEG power and brain activation maps from fMRI.



FMRI Modality

8 LIMITATION AND FUTURE WORK

This research represents an initial step toward integrating EEG and fMRI data for the classification of cognitive states. While the fusion of these modalities offers a more comprehensive view of brain activity, challenges remain in aligning the data due to differences in temporal and spatial resolution. Additionally, the complexity of multimodal data analysis requires advanced computational techniques that may limit real-time applications.

Future work could explore the integration of more complex neural data, such as real-time brain activity monitoring and multimodal fusion with other neuroimaging techniques like MEG. Furthermore, improvements in model accuracy and computational efficiency will be necessary to enhance clinical applicability in diagnosing neurological disorders.

9 CONCLUSION

This project demonstrates the potential of multimodal neuroimaging by integrating EEG and fMRI data to explore cognitive states during different tasks. The findings contribute valuable insights into brain activity patterns, enhancing our understanding of cognitive processes. By employing advanced machine learning techniques, this research highlights the importance of cross-modal approaches in neuroscience. Future enhancements aim to refine methodologies, improve model accuracy, and broaden the scope of applications, ultimately advancing the field of neuroimaging research.

References

[1] Formaggio E, Storti SF, Bertoldo A, Manganotti P, Fiaschi A, Toffolo GM. Integrating EEG and fMRI in epilepsy. Neuroimage. 2011 Feb 14;54(4):2719-31. doi: 10.1016/j.neuroimage.2010.11.038. Epub 2010 Nov 23. PMID: 21109007.Johnson, L., & Wang, R. (2016). *Clinical Applications of EEG and fMRI Fusion in Cognitive Disorders.* Frontiers in Neuroscience, 11, 123-138.

[2] Jorge J, van der Zwaag W, Figueiredo P. EEG-fMRI integration for the study of human brain function. Neuroimage. 2014 Nov 15;102 Pt 1:24-34. doi: 10.1016/j.neuroimage.2013.05.114. Epub 2013 May 31. PMID: 23732883.Hu, Y., et al. (2018). "Combining EEG and fMRI: A multimodal approach to study brain dynamics." *Frontiers in Neuroscience*.

[3] Chang C, Chen JE. Multimodal EEG-fMRI: advancing insight into large-scale human brain dynamics. Curr Opin Biomed Eng. 2021 Jun;18:100279. doi: 10.1016/j.cobme.2021.100279. Epub 2021 Mar 15. PMID: 34095643; PMCID: PMC8174780.

[4] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[5] Mantini D, Marzetti L, Corbetta M, Romani GL, Del Gratta C. Multi- modal integration of fMRI and EEG data for high spatial and temporal resolution analysis of brain networks. Brain Topogr. 2010 Jun;23(2):150-8. doi: 10.1007/s10548-009-0132-3. Epub 2010 Jan 6. PMID: 20052528; PMCID: PMC5682027.