EXPLAINABLE AI FOR EEG-BASED EARLY DIAGNOSIS OF ALZHEIMER'S DISEASE

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INTRODUCTION

- **Alzheimer's Disease (AD)** is a progressive neurodegenerative disorder and the most common cause of dementia.
- Early symptoms: Short-term memory loss, decrease in problem-solving, often mistaken for normal aging or stress.
- Early and accurate diagnosis is critical for effective management and intervention.

CURRENT DIAGNOSTIC LANDSCAPE AND LIMITATIONS

GOLD STANDARD METHODS (DEFINITIVE BUT LIMITING):

- **Cerebrospinal Fluid (CSF) Analysis:** Measures beta amyloid and Tau proteins. Highly accurate, but invasive (lumbar puncture) and expensive.
- **PET Imaging:** Detects Amyloid and Tau plaques. Highly specific, but extremely costly and involves radiation exposure.
- **MRI:** Detects structural changes like hippocampal atrophy. Valuable, but structural changes often manifest after the optimal intervention window.

THE GAP

The current landscape lacks an accessible, affordable, non-invasive tool that is sensitive enough for early screening and provides objective, interpretable results.

- **The Accessibility Barrier:** Gold-standard methods (PET, CSF) are expensive and invasive.
- **The Timeliness Barrier:** Current structural imaging (MRI) confirm AD only after irreversible brain changes have occurred.
- **The Trust Barrier:** DL models have "black box" nature, lacking neurophysiological explanation, preventing clinicians from trusting the AI for critical decision-making.

PROBLEM STATEMENT

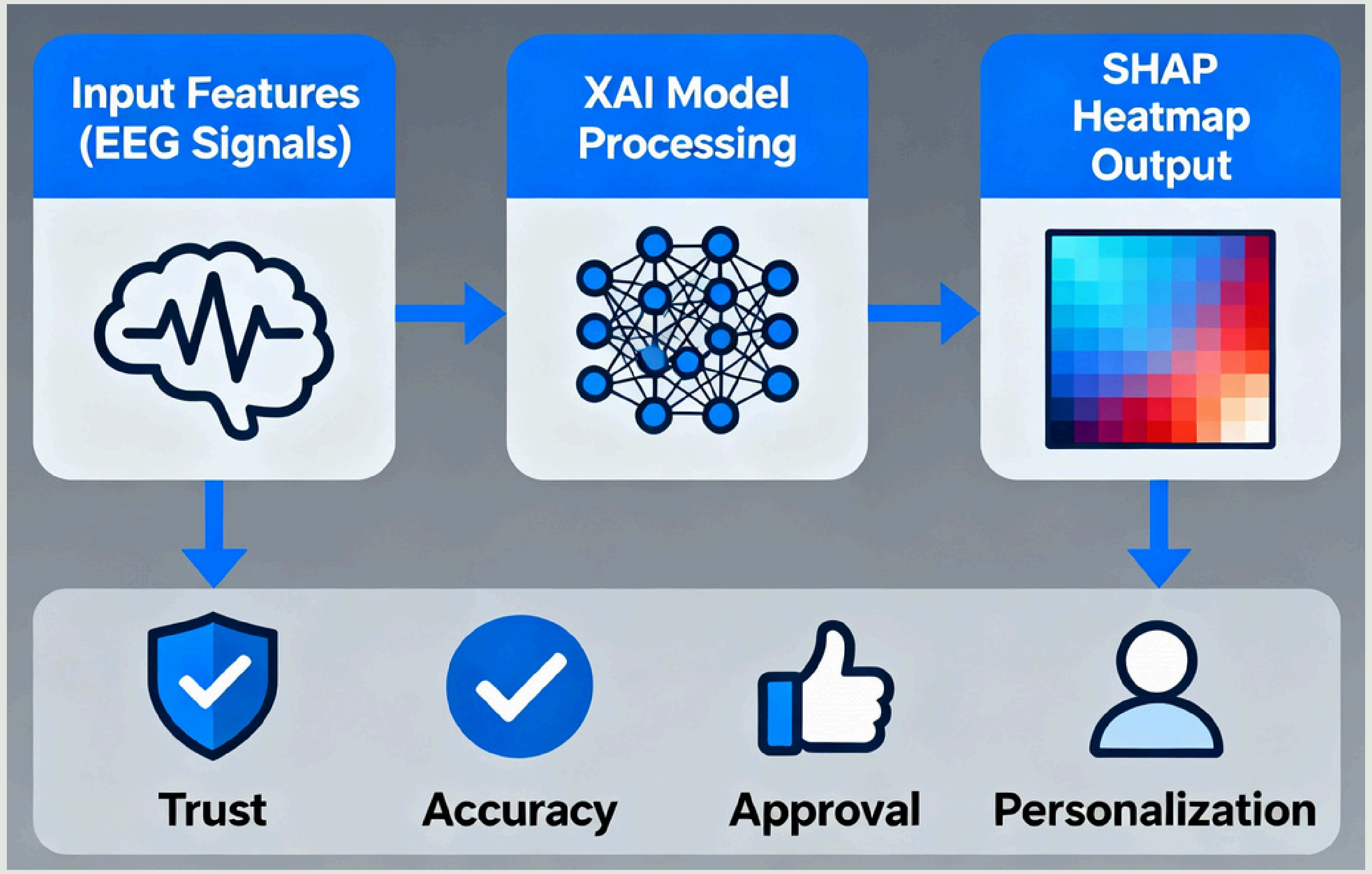
Early diagnosis of Alzheimer's Disease (AD) remains challenging due to subtle initial symptoms, lack of sensitive and affordable screening tools, and complexities in interpreting non-invasive tests like EEG. Furthermore, the 'black box' nature of highly accurate deep learning models limits clinician trust and hinders their adoption in real-world clinical settings.

SOLUTION

1. **Data Source:** Utilize low-cost, non-invasive Electroencephalography (EEG) data.
2. **Processing Engine:** Employ sophisticated Deep Learning (DL) models optimized for AD-related biomarkers in the EEG signal.
3. **Trust Enabler:** Integrate Explainable AI (XAI) techniques to open the black box and provide clinically meaningful, evidence-based explanations for every AD diagnostic prediction.

THE ROLE OF EXPLAINABLE AI (XAI)

- XAI clearly illustrates which input features mattered most and how each one contributed to the model's prediction, often with intuitive visuals like feature importance graphs or heatmaps.
- Techniques like SHAP (SHapley Additive exPlanations) or LIME (Local Interpretable Model-agnostic Explanations).



SUPPORTING RESEARCH

"An explainable and efficient deep learning framework for EEG-based diagnosis of Alzheimer's disease and frontotemporal dementia"

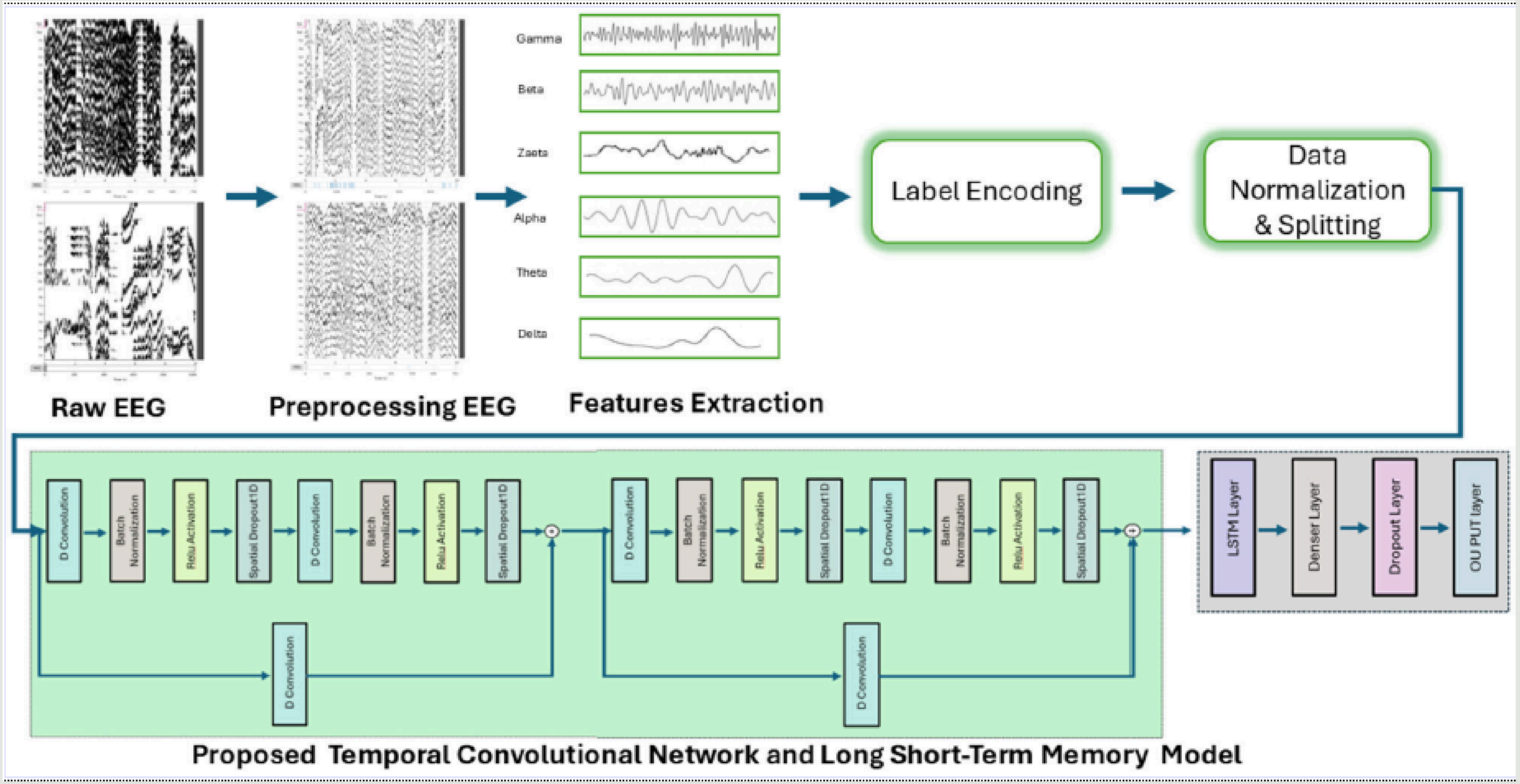
(Khan et al., 2025)

- Introduces an EEG-based feature extraction approach using Relative Band Power (RBP) analysis for feature engineering & proposes a lightweight hybrid DL classifier for accurate & robust classification of frontotemporal dementia, Alzheimer's disease, and health.

- SHAP is integrated to explain which EEG features most influenced each prediction—making model decisions transparent and trustworthy for clinicians.

SUPPORTING RESEARCH

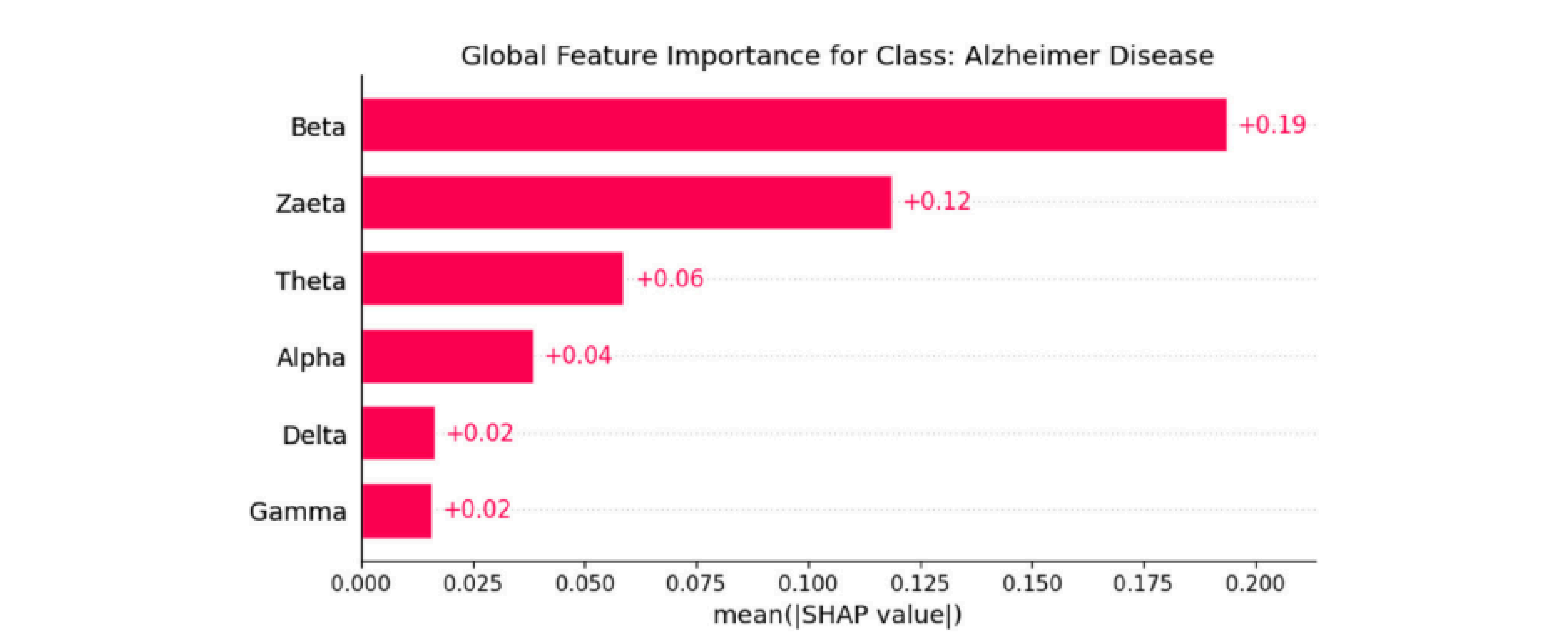
Khan et al., 2025



Proposed TCN and LSTM Hybrid Architecture

SUPPORTING RESEARCH

Khan et al., 2025

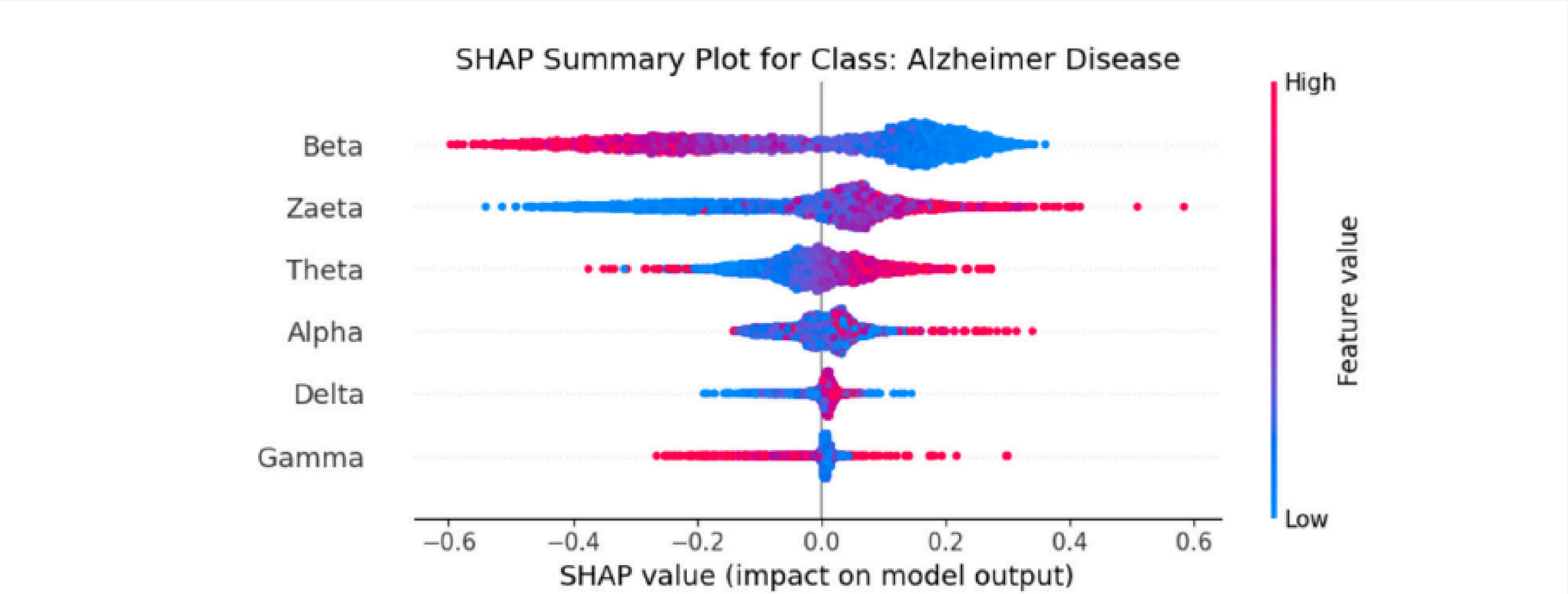


- Delta: $0.5 \leq f < 4$ Hz
- Theta: $4 \leq f < 8$ Hz
- Alpha: $8 \leq f < 16$ Hz
- Zaeta: $16 \leq f < 24$ Hz
- Beta: $24 \leq f < 30$ Hz
- Gamma: $30 \leq f \leq 45$ Hz.

Beta exhibits the highest importance (+0.19), followed by Zaeta (+0.12) and Theta (+0.06). These results suggest that Beta and Zaeta bands play a critical role in distinguishing Alzheimer's Disease from other classes.

SUPPORTING RESEARCH

Khan et al., 2025



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Features such as Beta and Zaeta wave characteristics show a stronger positive or negative influence on predictions, with higher feature values (red points) generally pushing predictions in one direction.

PRODUCT CONCEPT

Hypothetical Product Concept: The Neuro-Explain Platform

A hypothetical, cloud-based platform for:

- Standardized EEG data upload.
- Automated DL analysis and AD risk scoring.
- Generation of clinician-friendly, XAI-driven reports showing which EEG features or brain regions drove the AD diagnosis.

PRODUCT DEVELOPMENT CONCEPT

EEG data acquisition → Data upload to cloud platform → AI model analysis → XAI interpretation → Clinical report generation

- Features: Disease risk scoring, visual explanations of EEG features
- Technical details: Relative Band Power (RBP) analysis, lightweight hybrid deep learning classifier

CHALLENGES AND SOLUTIONS

CHALLENGE	SOLUTION
Data Privacy & Security	Implement end-to-end encryption and mandatory compliance with international health data regulations (e.g., HIPAA, GDPR).
Model Generalisability	Train models on large, diverse, multi-center datasets. Use transfer learning and domain adaptation techniques to validate performance across various patient populations and devices.
Clinician Adoption	Focus on intuitive, simple visualizations and reports. Provide comprehensive training and validation studies.
Validation of XAI	Rigorously validate the biological plausibility of the XAI outputs against known pathological changes (e.g., comparing regions highlighted by XAI with known atrophy in AD).

CONCLUSION AND FUTURE DIRECTION

By tightly coupling Deep Learning with Explainable AI, we transform the accessible EEG signal into a trustworthy, early, and accessible diagnostic tool for AD.

Future research may include the use of large and diverse datasets focusing on the exploration of additional EEG characteristics Vascular and Lewy Body Dementia data can be used to train and validate the model with an XAI approach while maintaining patient data privacy and security.

REFERENCE

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- Ehteshamzad, S. (2024). Assessing the Potential of EEG in Early Detection of Alzheimer's Disease: A Systematic Comprehensive Review (2000-2023). In Journal of Alzheimer's Disease Reports (Vol. 8, Issue 1, pp. 1153–1169). IOS Press BV. https://doi.org/10.3233/ADR-230159
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Thank You