Voxelmind: An Explainable Radiomics and Clinical Intelligence Framework for Automated Neuro-Imaging and Prognostic Decision Support

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ABSTRACT

VoxelMind is an explainable artificial intelligence (AI) framework designed to deliver integrated neuro-imaging analytics and prognostic prediction for clinical decision support. The growing complexity and volume of neuro-imaging data from modalities such as MRI, CT, and DICOM scans create challenges for manual interpretation and consistent diagnosis. VoxelMind addresses these challenges by integrating automated image preprocessing, lesion segmentation, and radiomic feature extraction within a unified and scalable platform. Quantitative features, including lesion area, estimated volume, tissue heterogeneity, and symmetry index, are utilized to compute a complexity score for disease severity assessment and risk stratification.

The framework further incorporates a machine learning–based prognostic module to estimate disease progression and survival probability, supported by explainable outputs through feature importance analysis. A Natural Language Processing component analyzes unstructured clinical notes to enhance diagnostic insight, while interactive visualization dashboards, electronic health record integration, and automated report generation support transparent clinical workflows. Deployed as an offline-capable web-based system, VoxelMind is suitable for both advanced and resource-constrained healthcare environments, demonstrating the effectiveness of explainable AI in improving diagnostic accuracy and clinical decision-making.

Keywords— Explainable Artificial Intelligence, Neuro-Imaging Analytics, Radiomics, Prognosis Prediction, Clinical Decision Support, Medical Image Processing.

1. INTRODUCTION

Neurological disorders such as brain tumors and degenerative brain diseases pose significant challenges to modern healthcare due to the complexity of diagnosis and treatment planning. Neuro-imaging modalities including MRI and CT scans play a critical role in identifying abnormalities; however, manual interpretation of these images is time-consuming and highly dependent on clinical expertise. Although artificial intelligence techniques have recently improved automated medical image analysis, many existing systems function as black-box models and lack integration with prognosis prediction and clinical workflow support, thereby limiting their practical adoption in healthcare environments.

To address these challenges, this paper proposes **VoxelMind**, an explainable AI framework for integrated neuro-imaging analytics and prognosis prediction. The system performs automated preprocessing, lesion segmentation, and radiomic feature extraction to compute disease severity and risk classification while employing machine learning models to estimate prognosis outcomes. Additionally, the framework incorporates clinical note analysis, interactive visualization, and electronic health record integration to support transparent and efficient clinical decision-making. The proposed framework aims to enhance diagnostic accuracy, reduce clinician workload, and provide interpretable AI-driven insights suitable for real-world healthcare deployment.

3. LITERATURE REVIEW

3.1 AI in Neuro-Imaging Analysis

Artificial intelligence has significantly advanced automated neuro-imaging analysis in recent years, particularly in detecting brain tumors and neurological abnormalities using MRI and CT scans. Deep learning models, especially convolutional neural networks (CNNs), have demonstrated strong performance in tumor detection and segmentation tasks. However, many of these systems primarily focus on classification accuracy and lack integration with broader clinical workflows. Moreover, high computational requirements and dependence on large annotated datasets limit their adoption in smaller or resource-constrained healthcare settings.

3.2 Radiomics and Quantitative Image Analysis

Radiomics has emerged as an important approach for extracting quantitative features from medical images to support clinical decision making. Features such as lesion area, texture heterogeneity, and morphological characteristics enable objective assessment of disease severity and progression. Several studies have demonstrated the potential of radiomic features in tumor grading and prognosis prediction. Nonetheless, most implementations operate as standalone analytical tools without integration into clinical record systems or decision support environments, reducing practical usability.

3.3 Prognostic Modeling in Neurological Disorders

Machine learning–based prognostic models have been explored to estimate disease outcomes and survival probability using imaging and clinical data. Algorithms such as Random Forest, Support Vector Machines, and ensemble learning techniques have shown effectiveness in predicting disease progression. Despite promising results, many systems lack interpretability and transparency, which is critical in medical contexts where clinicians must understand prediction reasoning before trusting automated recommendations.

3.4 Explainable AI in Healthcare Systems

Explainable AI (XAI) has gained increasing attention in medical applications due to the need for transparent decision-making processes. Feature importance analysis, heatmaps, and interpretable prediction models are commonly used to improve trust in AI systems. While recent works incorporate XAI techniques into diagnostic models, integration with complete clinical pipelines—including imaging analytics, prognosis estimation, and reporting—remains limited. Thus, explainability is often treated as an add-on rather than a core component of healthcare AI systems.

3.5 NLP Applications in Clinical Decision Support

Natural Language Processing (NLP) techniques have been applied to extract structured information from unstructured clinical notes. These methods help identify symptoms, treatment histories, and diagnostic cues that are otherwise difficult to analyze automatically. However, NLP systems are typically deployed independently and rarely integrated with imaging analytics or prognostic tools, resulting in fragmented clinical decision support.

3.6 Limitations of Existing Systems and Research Gap

Existing research predominantly addresses isolated aspects of neuro-diagnostic workflows such as image classification, segmentation, or prognosis modeling. Few systems combine radiomic analysis, explainable prediction models, clinical note interpretation, and electronic health record management into a unified framework. Additionally, offline deployment capability and clinician-friendly interfaces are often overlooked, limiting real-world adoption.

To overcome these challenges, the proposed **VoxelMind framework** integrates explainable radiomics-based imaging analytics, prognostic modeling, NLP-based clinical interpretation, and electronic health record support within a single clinical decision support platform, thereby addressing practical gaps in current neuro-imaging AI systems.

4. OBJECTIVE

The primary objective of this study is to develop **VoxelMind**, an explainable artificial intelligence framework that integrates neuro-imaging analytics and prognostic prediction to support clinical decision-making in neurological diagnosis. The system aims to improve diagnostic accuracy, workflow efficiency, and transparency by combining automated image analysis, machine learning–based prediction, and clinical data processing within a unified platform.

The specific objectives of this research are as follows:

1. To develop an automated framework for analyzing neuro-imaging data such as MRI, CT, and DICOM scans using advanced preprocessing and segmentation techniques.
2. To extract quantitative radiomic features including lesion area, estimated volume, tissue heterogeneity, and symmetry index for objective disease assessment.
3. To compute a complexity score for automated disease severity estimation and risk classification.

4. To design a machine learning–based prognostic model capable of predicting disease progression and survival probability.
5. To incorporate explainable AI mechanisms that provide interpretable prediction outcomes for clinical transparency.
6. To integrate Natural Language Processing techniques for extracting diagnostic insights from clinical notes.
7. To support electronic health record management for longitudinal patient data tracking.
8. To enable visualization and automated report generation for improved clinical documentation and decision support.
9. To deploy a scalable and offline-capable framework suitable for real-world clinical and research environments.

5. PROPOSED AND EXISTING

Proposed system:

VoxelMind is an explainable artificial intelligence framework developed to provide integrated neuro-imaging analytics and prognostic prediction for clinical decision support. The system combines medical image preprocessing, automated lesion segmentation, radiomic feature extraction, and machine learning–based prognosis estimation within a unified platform. Neuro-imaging data such as MRI, CT, and DICOM scans are processed to extract quantitative features including lesion area, estimated volume, tissue heterogeneity, and symmetry index. These features are used to compute a complexity score that classifies cases into risk categories, assisting clinicians in prioritizing treatment decisions while ensuring interpretable outputs through explainable AI mechanisms.

In addition, the framework incorporates Natural Language Processing to analyze clinical notes and enhance diagnostic insights. Visualization dashboards present tumor characteristics and disease progression trends, while an integrated electronic health record module maintains longitudinal patient data. Automated report generation reduces documentation workload, and the entire system is deployed as an offline-capable web-based platform suitable for diverse healthcare environments. Together, these components enable VoxelMind to provide a scalable and practical neuro-clinical decision support solution.

Existing system:

The existing neuro-diagnostic systems used in many healthcare environments rely largely on conventional medical imaging workflows and partially automated analysis tools. The major characteristics and limitations of current systems are outlined below:

- Medical image interpretation is primarily performed manually by radiologists and neurologists, making the process time-consuming and dependent on expert availability.
- Conventional diagnostic workflows rely heavily on visual assessment rather than automated quantitative measurement of tumor characteristics.
- Many imaging systems provide scan visualization but lack automated segmentation and radiomic feature extraction capabilities.
- Existing tools often focus only on image storage and retrieval without offering integrated analytical or decision support functions.
- Prognosis estimation and disease severity evaluation are frequently based on clinician experience rather than data-driven predictive models.
- Clinical notes and patient history are typically stored separately and are not automatically analyzed for diagnostic insights.
- Current hospital systems often lack explainable AI support, reducing clinician trust in automated or semi-automated predictions.
- Integration between imaging systems and electronic health records is limited, resulting in fragmented patient information management.
- Automated generation of standardized clinical reports is generally unavailable, increasing documentation workload.

Comparison Table:

Aspect	**Existing System**	**Proposed System**
Image Analysis	Manual or semi-automated image interpretation by clinicians	Fully automated neuro-imaging analysis using AI techniques
Tumor/Lesion Detection	Mostly manual identification	Automated segmentation and detection of abnormal regions

Quantitative Feature Extraction	Limited or unavailable	Automated extraction of radiomic features such as area, volume, symmetry, and heterogeneity
Risk Assessment	Based on clinician experience	Automated complexity scoring and AI-based risk classification
Prognosis Prediction	Rarely available or manual estimation	Machine learning–based prognosis and survival prediction
Explainability	Limited explanation in automated tools	Explainable AI with feature importance and visualization support
Clinical Notes Analysis	Manual interpretation of notes	NLP-based automated symptom and diagnostic extraction
Data Integration	Imaging and patient data stored separately	Integrated imaging analytics with electronic health records
Visualization Support	Basic scan viewing tools	Interactive dashboards, heatmaps, and analytical visualization
Report Generation	Manual report preparation	Automated generation of standardized clinical reports
Workflow Efficiency	Time-consuming and manual	Automated workflow reducing clinician workload
Deployment Capability	Often requires high-end infrastructure	Offline-capable and deployable in resource-limited settings
Decision Support	Limited clinical decision assistance	Comprehensive AI-driven clinical decision support system

6. IMPLEMENTATION

The implementation of **VoxelMind** is carried out using a modular and scalable software architecture that integrates neuro-imaging processing, machine learning–based prognosis prediction, and clinical data management. The system is developed using Python as the core programming language, leveraging libraries for medical image handling, numerical computation, and machine learning. Neuro-imaging data in MRI, CT, and DICOM formats are ingested through a secure web interface and stored in a structured database. Image preprocessing techniques such as normalization, contrast enhancement, noise reduction, and grayscale conversion are applied to standardize scan quality. Automated segmentation is implemented using thresholding and contour detection methods to identify abnormal regions, from which radiomic features such as lesion area, volume, heterogeneity, and symmetry index are extracted.

For prognostic analysis, the extracted radiomic features are provided as input to a trained machine learning model that estimates disease severity and survival probability. Explainable AI mechanisms are integrated to compute feature importance scores, ensuring transparency of predictions for clinical users. In parallel, a Natural Language Processing module processes unstructured clinical notes to extract relevant symptoms and diagnostic indicators, which are correlated with imaging-based predictions. Visualization dashboards are implemented to display segmentation outputs, risk levels, and prognostic trends. The system also supports electronic health record management and automated generation of standardized diagnostic reports. Finally, VoxelMind is deployed as an offline-capable web-based platform, enabling reliable operation in both advanced hospital infrastructures and resource-constrained healthcare environments.

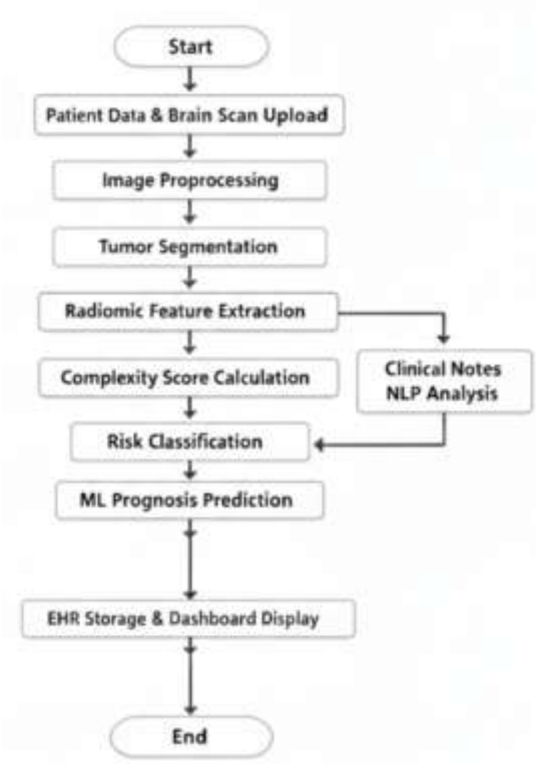

Fig1:Flow diagram

7. RESULT

Fig 1

Fig 1 illustrates an MPR (Multi-Planar Reconstruction) simulation dashboard for neuroimaging analysis, displaying axial, coronal, and sagittal views of a brain scan. The interface highlights specific internal regions in blue and provides quantitative metrics, including an area of **35,287 px**, a volume of **6,628.60 cm³**, and a symmetry score of **83.2%**. This clinical tool is designed to facilitate 3D topographic mapping and symmetry assessment, featuring integrated options to archive the findings directly to an Electronic Health Record (EHR).

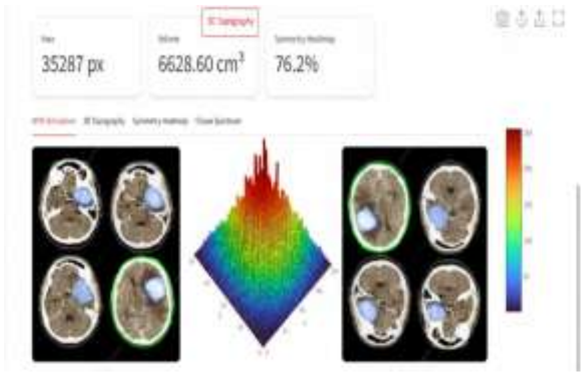

Fig2

Fig 2 displays a neuroimaging analysis dashboard showcasing the **3D Topography** of a brain scan, where a prominent lesion or region of interest is highlighted in blue across multiple axial slices. The interface provides critical quantitative data, including a calculated area of **35,287 px**, a volume of **6,628.60 cm³**, and a symmetry heatmap score of **76.2%**. Centered in the display is a 3D bar graph representing tissue density or signal intensity across a spatial grid, paired with a color-coded reference scale to assist in precise diagnostic mapping and tissue characterization.

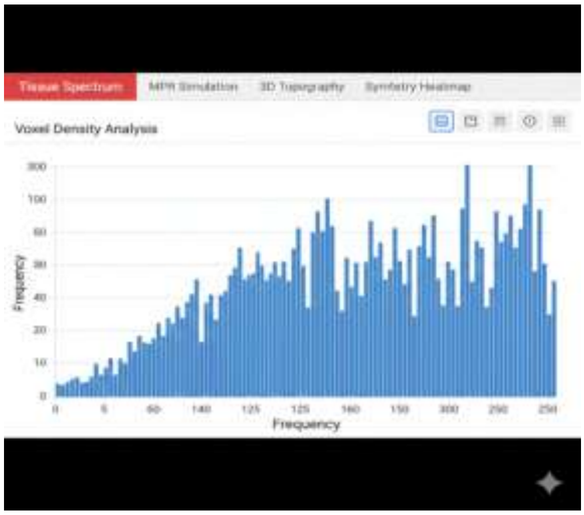

Fig 3

Fig 3 presents the **Tissue Spectrum** interface of the diagnostic dashboard, specifically highlighting a **Voxel Density Analysis** histogram. The chart plots frequency against density values, showing a progressive increase in voxel distribution that peaks at various intervals across the spectrum. This visualization serves as a quantitative tool for tissue characterization, allowing clinicians to analyze the composition of segmented brain regions by examining the distribution of signal intensities or Hounsfield units.

Fig 4

Fig 4 details the **Molecular Prognostics & Virtual Biopsy** interface, which utilizes texture-based imaging analysis to predict genomic markers and survival outcomes. The dashboard displays a **5-Year Survival Probability** of **10.5%** via a gauge graphic, alongside a "Molecular Virtual Biopsy" section that predicts key genetic markers: an **IDH Mutation** is rated as **85% Highly Likely**, while **MGMT Methylation** shows a **42% Moderate Probability**. This predictive model represents a non-invasive radiomics approach to identifying tumor characteristics that typically require physical tissue sampling.

8. CONCLUSION

This paper presented **VoxelMind**, an explainable artificial intelligence framework designed for integrated neuro-imaging analytics and prognostic prediction to support clinical decision-making. The proposed system effectively combines automated image preprocessing, lesion segmentation, radiomic feature extraction, and machine learning–based prognosis estimation within a unified and scalable platform. By generating quantitative metrics such as lesion area, volume, symmetry index, and complexity score, VoxelMind enables objective disease assessment and automated risk stratification while reducing the reliance on manual interpretation.

Furthermore, the integration of explainable AI mechanisms, Natural Language Processing for clinical note analysis, and interactive visualization dashboards enhances transparency and clinical usability. The inclusion of electronic health record management and automated report generation supports efficient and consistent clinical workflows. Deployed as an offline-capable web-based system, VoxelMind demonstrates strong potential for adoption in both advanced and resource-constrained healthcare environments, contributing toward reliable, interpretable, and data-driven neuro-clinical decision support.

9. FUTURE ENHANCEMENT

Although the proposed **VoxelMind** framework demonstrates effective integration of neuro-imaging analytics and prognostic prediction, several enhancements can further improve system performance and clinical applicability.

Future research may focus on incorporating deep learning–based segmentation techniques to improve detection accuracy for complex and small lesion regions. Integration of multi-modal imaging data, such as functional MRI and PET scans, can further enhance diagnostic insights and disease characterization. Expanding the training datasets with diverse clinical populations would also improve the robustness and generalization capability of prognostic models.

Additionally, future developments may include cloud-enabled collaboration for remote clinical consultation, integration with hospital information systems, and adaptive learning mechanisms that continuously improve model performance using new clinical data. Deployment optimization for mobile or edge-computing environments, along with the incorporation of genomic and molecular biomarkers, could further support personalized treatment planning. These enhancements aim to evolve VoxelMind into a comprehensive next-generation neuro-clinical decision support ecosystem.

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