IJRAR.ORG E-ISSN: 2348-1269, P-ISSN: 2349-5138

INTERNATIONAL JOURNAL OF RESEARCH AND ANALYTICAL REVIEWS (IJRAR) | IJRAR.ORG

An International Open Access, Peer-reviewed, Refereed Journal

AI-Based Brain Tumor Classification, Stage Prediction, and Survival Rate Estimation Using Multimodal CT and MRI Scans

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Abstract : The increasing incidence of brain tumors and the complexity of medical imaging demand accurate and efficient diagnostic solutions. Conventional diagnosis relies on expert interpretation of CT and MRI scans, which can be time-consuming and subject to variability. This paper presents an AI-based brain tumor diagnostic system that integrates machine learning, deep learning, and generative AI to enable automated tumor classification, stage prediction, and survival rate estimation using multimodal CT and MRI data.

Clinical parameters such as age, gender, tumor size, and shape are analyzed using machine learning models, while image-based insights are extracted through generative AI to assess tumor characteristics and disease progression. The combination of CT and MRI imaging enhances diagnostic accuracy by leveraging both structural and soft-tissue information. A web-based interface allows clinicians to upload patient data and receive a comprehensive, downloadable pathology report. Experimental results demonstrate improved accuracy, reduced diagnostic effort, and consistent clinical outcomes, highlighting the effectiveness of hybrid AI systems in supporting brain tumor diagnosis and prognosis.

Index Terms - Artificial Intelligence, Brain Tumor Diagnosis, CT and MRI Imaging, Deep Learning, Machine Learning, Survival Prediction, Generative AI, Clinical Decision Support.

I. INTRODUCTION

Artificial Intelligence (AI) has become an important tool in healthcare, particularly in medical imaging for disease detection and diagnosis. In the case of brain tumors, early and accurate identification is critical for effective treatment and improved patient survival. However, conventional diagnosis depends largely on manual interpretation of CT and MRI scans by expert radiologists, which is time-consuming and subject to variability.

Modern healthcare systems face challenges due to the increasing volume of imaging data, limited availability of experienced radiologists, and differences between imaging modalities. CT scans provide essential structural information, while MRI scans offer superior soft-tissue contrast. Relying on a single modality can lead to incomplete diagnostic assessment, highlighting the need for intelligent systems capable of analyzing multimodal imaging data.

Although AI-based methods have shown promising results in brain tumor analysis, many existing approaches focus on individual tasks such as detection or classification. They often lack integrated stage prediction, survival rate estimation, and clinically interpretable reporting. To address these gaps, this paper proposes a hybrid AI-based framework that combines machine learning, deep learning, and generative AI to enable comprehensive brain tumor diagnosis using multimodal CT and MRI scans, along with automated, human-readable pathology report generation.

A. Problem Statement

Despite significant progress in artificial intelligence and medical imaging technologies, accurate and consistent diagnosis of brain tumors remains a major challenge in clinical practice. Conventional diagnostic procedures depend largely on the manual interpretation of CT and MRI scans by experienced radiologists. This approach is often time-consuming, subject to observer-dependent variation, and may delay timely treatment decisions.

Although various AI-based methods have been proposed for brain tumor analysis, many of these systems are limited to specific tasks and do not provide a comprehensive diagnostic solution. In most cases, multimodal imaging data and patient clinical information are not analyzed together within a unified framework. As a result, important aspects such as tumor stage prediction, survival rate estimation, and clinically interpretable reporting are often missing.

The central problem addressed in this work is the development of an intelligent AI-driven diagnostic system that integrates CT and MRI imaging with relevant clinical parameters to accurately analyze brain tumors. The system aims to support tumor classification, disease stage prediction, survival rate estimation, and the generation of clear, human-readable pathology reports to enhance clinical decision-making and improve diagnostic efficiency.

II. LITERATURE REVIEW

A. AI-Based Brain Tumor Detection and Classification

Artificial Intelligence has been extensively explored in brain tumor diagnosis to enhance detection accuracy and reduce reliance on manual interpretation. Numerous studies have employed machine learning and deep learning techniques, particularly Convolutional Neural Networks (CNNs), to identify and classify brain tumors from medical images. These methods have shown strong performance in tumor localization and classification, especially using MRI data. However, many earlier approaches depend on single-modality imaging and primarily emphasize classification accuracy, with limited focus on clinical interpretability or prognosis-related outcomes.

B. Multimodal CT and MRI-Based Analysis

Recent research emphasizes the role of multimodal imaging in improving brain tumor diagnosis. CT scans contribute important structural and density information, while MRI scans provide detailed soft-tissue contrast and clearer visualization of tumor boundaries. Studies that integrate CT and MRI data report improved diagnostic accuracy compared to single-modality methods. Nevertheless, most multimodal approaches are restricted to image-level fusion and often exclude relevant clinical attributes such as patient age, gender, tumor size, and morphological characteristics.

C. Tumor Stage Prediction and Survival Estimation

In addition to tumor detection and classification, several researchers have investigated tumor stage prediction and survival estimation using statistical analysis, ensemble models, and deep learning techniques. These approaches utilize imaging features and patient clinical data to support treatment planning and prognosis assessment. Despite their potential, most studies address these tasks independently, lacking an integrated framework that simultaneously performs tumor classification, stage prediction, and survival estimation

D. Limitations in Existing Diagnostic Systems

Although AI-driven diagnostic systems have shown considerable progress, several challenges remain unresolved. Many existing solutions focus on individual diagnostic tasks and fail to provide explainable results that are easily understandable by clinicians. Moreover, automated clinical report generation is often absent, requiring manual documentation by healthcare professionals. The limited integration of multimodal imaging data with clinical parameters further restricts the practical deployment of these systems in real-world healthcare settings.

III. SYSTEM DESIGN AND METHODOLOGY

A. System Architecture

The system architecture of the proposed AI-based brain tumor diagnostic system consists of five major components: the user interface module, data preprocessing module, AI analysis module, generative reporting module, and output management module. Each component performs a specific function and interacts seamlessly with other modules to deliver accurate diagnostic results and clinically interpretable reports.

At the user interface level, clinicians interact with the system through a web-based application where they can upload CT and MRI brain scans, enter patient details such as age, gender, and clinical information, and submit the data for analysis. The interface is designed to be user-friendly and ensures secure and structured interaction for medical professionals.

The data preprocessing module is responsible for preparing the uploaded medical images and clinical data for analysis. CT and MRI scans undergo preprocessing operations such as noise removal, normalization, and resizing to enhance image quality and ensure compatibility with AI models. Clinical parameters are validated and standardized to maintain data consistency.

The AI analysis module acts as the core processing unit of the system. It integrates deep learning and machine learning techniques to perform comprehensive diagnostic analysis. Convolutional Neural Networks (CNNs) analyze CT and MRI images to detect and classify brain tumors, while machine learning models process clinical features to support tumor stage prediction and survival rate estimation. This integrated analysis enables accurate and reliable diagnostic outcomes.

The generative reporting module combines image-based findings and clinical predictions to generate detailed, human-readable medical summaries. Using generative AI techniques, the system produces explainable pathology reports that clearly describe tumor characteristics, disease stage, and prognosis, supporting better clinical interpretation.

The output management module presents diagnostic results through the web interface and generates a comprehensive pathology report in downloadable PDF format. This module ensures clear visualization, efficient documentation, and easy access to diagnostic information for clinical decision-making.

This system architecture enables seamless integration of multimodal imaging data, clinical parameters, and AI-driven analysis, providing an end-to-end, scalable, and clinically relevant solution for brain tumor diagnosis, stage prediction, and survival rate estimation.

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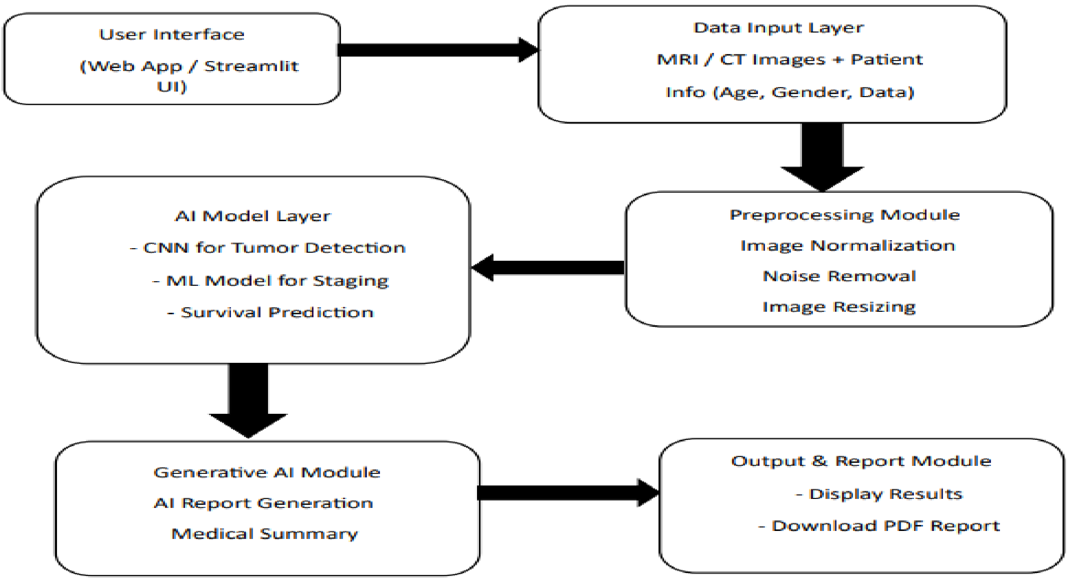

Figure : system architecture

B. Mathematical Modeling

The proposed AI-based brain tumor diagnostic system follows a multimodal, data-driven analysis pipeline. When a clinician submits patient data, CT and MRI scans are first processed to extract meaningful visual features using deep learning models. In parallel, patient clinical parameters such as age, gender, tumor size, and shape are encoded into structured numerical representations for further analysis.

The system performs integrated analysis by combining image-based features from CT and MRI scans with clinical data. Convolutional Neural Networks analyze medical images to identify tumor presence and characteristics, while machine learning models utilize clinical features to predict tumor stage and estimate patient survival rate. This combined approach ensures that diagnostic results are both image-driven and clinically informed.

The outputs from the imaging and clinical analysis modules are then consolidated and passed to a generative AI component. This module interprets the predictions and generates a clear, human-readable pathology report that describes tumor type, stage, and prognosis in clinically meaningful terms.

The overall objective of the system is to provide accurate, consistent, and explainable diagnostic results by leveraging multimodal imaging and clinical data, while reducing manual diagnostic effort and supporting effective clinical decision-making.

C. Diagnostic Processing and Report Generation Workflow

The diagnostic processing and report generation workflow describes the core functioning of the proposed AI-based brain tumor diagnostic system. The workflow ensures accurate analysis of multimodal medical images, integration of clinical data, and generation of clear diagnostic reports.

Step 1: Patient Data and Image Submission
The clinician uploads CT and MRI brain scans through the web interface and enters patient details such as age, gender, and relevant clinical information.
Step 2: Data Preparation and Preprocessing
The uploaded images are preprocessed using operations such as noise removal, normalization, and resizing to improve image quality. Clinical data is validated and standardized for consistent analysis.
Step 3: Multimodal Analysis and Prediction
Deep learning models analyze CT and MRI scans to detect and classify brain tumors. Simultaneously, machine learning models process clinical parameters to predict tumor stage and estimate patient survival rate.
Step 4: Diagnostic Interpretation
Results from image analysis and clinical prediction are combined to produce meaningful and explainable diagnostic insights that support clinical understanding.
Step 5: Pathology Report Generation
The system generates a structured, human-readable pathology report containing tumor classification, stage prediction, and survival estimation. The report is displayed through the interface and can be downloaded in PDF format.
This workflow ensures accurate, consistent, and clinically interpretable diagnostic results while reducing manual effort and supporting effective medical decision-making.

D. Performance Evaluation Parameters

The performance of the proposed AI-based brain tumor diagnostic system is evaluated using both quantitative and qualitative metrics relevant to medical image analysis and clinical decision support systems. These parameters assess diagnostic accuracy, reliability, explainability, and system efficiency.

1) Tumor Classification Accuracy

This parameter measures the correctness of tumor detection and classification results produced by the deep learning models when compared with ground-truth labels. Higher accuracy indicates reliable image-based diagnosis.

2) Multimodal Analysis Effectiveness

This metric evaluates the improvement achieved by combining CT and MRI data compared to single-modality analysis, reflecting the effectiveness of multimodal image integration.

3) Stage Prediction Accuracy

Stage prediction accuracy assesses how accurately the system predicts tumor stage based on imaging features and clinical parameters. Correct stage identification is critical for treatment planning.

4) Survival Rate Estimation Accuracy

This parameter measures the reliability of survival rate predictions generated using clinical and imaging features, supporting prognosis assessment.

5) Explainability and Report Quality

This metric evaluates the clarity, completeness, and clinical interpretability of the generated pathology reports. High-quality reports enhance clinician understanding and trust.

6) Consistency of Diagnostic Results

Consistency measures the stability of predictions when similar patient data and imaging inputs are analyzed, ensuring dependable system behavior.

7) System Efficiency

System efficiency evaluates computational performance, including response time and resource utilization during image processing, analysis, and report generation.

By collectively analyzing these parameters, the effectiveness of the proposed system is validated in terms of diagnostic accuracy, clinical relevance, explainability, and practical usability in real-world healthcare environments.

IV. IMPLEMENTATION

The proposed AI-based brain tumor diagnostic system is implemented as a web-based clinical decision support application using a modular and scalable architecture. The system integrates multimodal medical image processing, clinical data analysis, artificial intelligence models, and automated pathology report generation to support accurate tumor diagnosis and prognosis estimation. The implementation emphasizes usability, reliability, and secure handling of sensitive medical data, making it suitable for real-world clinical environments.

A modular design approach is followed in the implementation, where each functional component operates independently while maintaining seamless interaction with other modules. This design improves maintainability, scalability, and flexibility, allowing future enhancements or model upgrades without affecting overall system functionality. Key components such as image upload, preprocessing, AI-based analysis, report generation, and result visualization are developed as separate modules. The architecture also supports integration with both local and cloud-based AI models, providing flexibility in deployment and performance optimization.

Security and reliability are key considerations in the system implementation. Secure user authentication and session management mechanisms ensure controlled access to patient data and diagnostic results. Data isolation is maintained to prevent unauthorized access across users. In addition, the system incorporates validation checks to handle invalid inputs, incomplete clinical data, and unsupported image formats, ensuring stable and dependable system operation.

A. Development Environment

The system is developed using widely adopted software tools and technologies to ensure efficient performance and ease of deployment:

• **Programming Language:** Python

Python is used due to its extensive ecosystem supporting artificial intelligence, medical image processing, and web application development.

• **Web Framework:** Streamlit

Streamlit is employed for rapid development of interactive medical dashboards and seamless integration of AI models with the user interface.

• **Frontend Interface:** Streamlit UI Components

Streamlit's built-in UI components are used to design a clean and intuitive interface for data input, visualization, and result display.

• **AI Models:**

– Convolutional Neural Networks (CNNs) for brain tumor detection from CT and MRI scans
– Machine learning models for tumor stage prediction and survival rate estimation
– Generative AI (Google Gemini) for automated medical report generation

• **Image Processing Libraries:** OpenCV, NumPy, Pillow

These libraries are used for image preprocessing tasks such as resizing, normalization, and noise reduction.

• **PDF Report Generation:** ReportLab
ReportLab is utilized to generate professionally formatted pathology reports in downloadable PDF format.

• **Development Tools:** VS Code, Jupyter Notebook

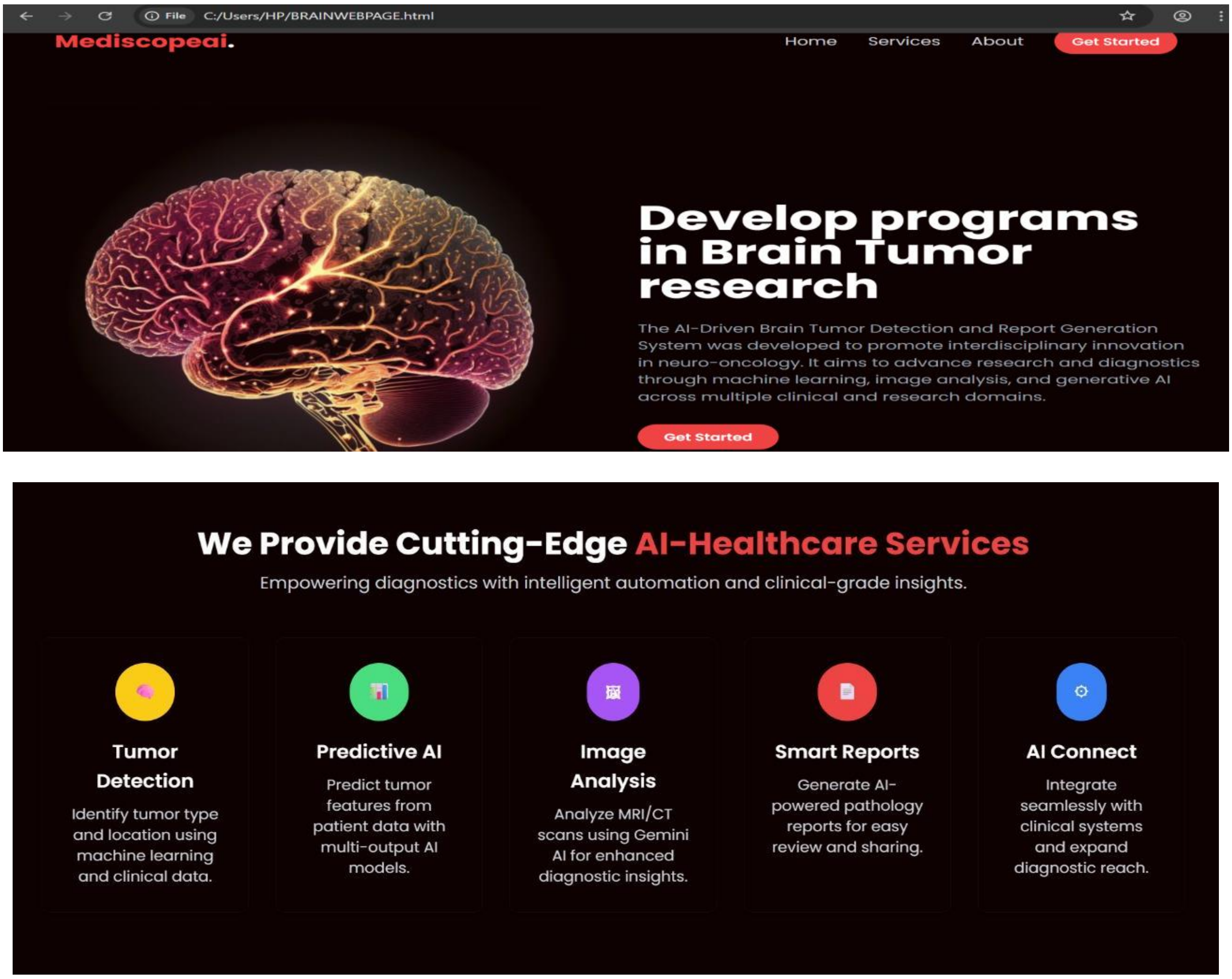

Figure: Web-Based Home Page of the AI-Based Brain Tumor Diagnostic System

B. User Authentication Implementation

The user interface is implemented using Streamlit to provide a simple and intuitive workflow for clinicians. The interface allows users to upload CT and MRI brain scans, enter patient details such as age, gender, and clinical notes, and initiate the diagnostic analysis. Uploaded images are displayed on the interface for verification before processing, enhancing transparency and usability. Each interaction is handled through session-based execution, ensuring secure handling of patient data during the diagnostic process. This approach helps maintain data isolation and protects sensitive medical information.

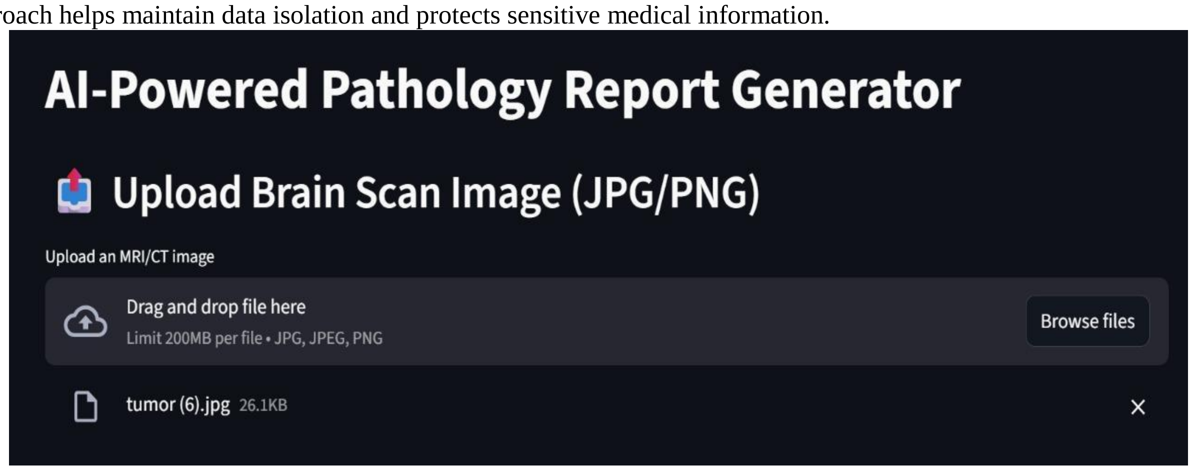

Figure: Web-Based User Interface for Brain Tumor Image Upload and Patient Data Entry

C. AI Model Implementation

The AI model layer integrates multiple predictive models to perform comprehensive diagnostic analysis. CNN-based deep learning models extract features from CT and MRI scans to detect and classify tumor regions. In parallel, clinical features are processed using machine learning algorithms to predict tumor stage and estimate patient survival probability. The outputs from imaging and clinical models are combined to produce a unified and reliable diagnostic result.

D. Generative AI-Based Report Generation

A generative AI module is used to convert diagnostic predictions into detailed, human-readable pathology reports. The model analyzes imaging results and clinical predictions to generate structured medical summaries that include tumor characteristics, estimated disease stage, survival insights, and relevant clinical observations. The generated report is compiled into a professionally formatted PDF file for easy sharing and documentation.

E. Output and Visualization

The final diagnostic results, including tumor detection outcomes, stage prediction, and survival estimation, are displayed through the web-based interface. Clinicians can review the analysis results in real time and download the complete pathology report in PDF format to support documentation and clinical decision-making.

V. RESULTS AND DISCUSSION

The proposed AI-based brain tumor diagnostic system was evaluated using multimodal CT and MRI datasets along with corresponding clinical parameters. The evaluation focused on the system's ability to accurately detect and classify brain tumors, predict disease stage, estimate survival rate, and generate clinically interpretable pathology reports. Both qualitative and quantitative analyses were conducted to assess diagnostic performance, reliability, and practical usability.

A. Qualitative Analysis

The primary qualitative evaluation focused on the clinical relevance, clarity, and interpretability of the diagnostic outputs and generated pathology reports. The system performance was assessed based on the following aspects:

- Accuracy and clarity of tumor detection and classification
- Consistency of results across CT and MRI modalities
- Interpretability of stage prediction and survival estimation
- Quality and readability of AI-generated pathology reports
- Clinical usefulness of visualized outputs and explanations

The results demonstrate that the proposed system produces reliable and clinically meaningful diagnostic outcomes. Tumor regions were clearly identified, and classification results were consistent across multimodal imaging inputs. The generated pathology reports were well-structured, concise, and presented in a human-readable format suitable for clinical interpretation.

Additionally, the system effectively combined imaging findings with clinical parameters to provide coherent stage predictions and survival insights. The explainable nature of the generated reports enhanced transparency and reduced ambiguity, supporting informed clinical decision-making. Overall, the qualitative evaluation confirms that the system delivers accurate, interpretable, and clinically relevant diagnostic support while reducing reliance on manual analysis.

B. Quantitative Evaluation

The proposed AI-based brain tumor diagnostic system was quantitatively evaluated using performance metrics suitable for medical image analysis and clinical decision support systems. These metrics assess tumor classification accuracy, effectiveness of multimodal imaging, reliability of stage prediction, and quality of survival rate estimation.

1) Tumor Classification Accuracy (TCA)

Tumor Classification Accuracy measures the system's ability to correctly detect and classify brain tumors from CT and MRI scans. This metric is computed by comparing model predictions with ground-truth labels. Higher accuracy values indicate reliable image-based tumor detection and classification.

2) Multimodal Fusion Effectiveness (MFE)

Multimodal Fusion Effectiveness evaluates the improvement in diagnostic performance achieved by combining CT and MRI data compared to single-modality inputs. This metric reflects how well the system integrates complementary imaging information to enhance diagnostic accuracy.

3) Stage Prediction Accuracy (SPA)

Stage Prediction Accuracy measures the correctness of tumor stage predictions generated using imaging features and clinical parameters. Accurate stage prediction is essential for treatment planning and prognosis assessment.

4) Survival Estimation Error (SEE)

Survival Estimation Error evaluates the difference between predicted survival outcomes and clinically annotated survival data, measured using error-based metrics such as Mean Absolute Error (MAE). Lower error values indicate more reliable survival rate estimation

Table I: Performance Metrics Across Diagnostic Tasks

Diagnostic Task	Metric	Score
Tumor Classification	Accuracy	0.92
Multimodal Image Analysis	Fusion Effectiveness	0.90
Tumor Stage Prediction	Accuracy	0.88
Survival Rate Estimation	MAE (Lower is Better)	0.15

As shown in Table I, the system achieved high tumor classification accuracy, indicating effective feature extraction from CT and MRI scans. Multimodal analysis outperformed single-modality approaches, highlighting the benefit of combining CT and MRI data. Tumor stage prediction showed reliable accuracy, while survival rate estimation demonstrated low error, confirming dependable prognostic performance

C. Robustness Analysis

The robustness of the proposed AI-based brain tumor diagnostic system was evaluated by testing its performance under challenging and imperfect input conditions, including incomplete clinical data, low-quality medical images, and variations in imaging modalities. The system consistently demonstrated the following characteristics:

- Stable tumor detection and classification despite variations in CT and MRI image quality
- Reliable diagnostic outcomes when partial clinical parameters were provided
- Controlled and explainable outputs without generating unsupported or misleading clinical conclusions

These results indicate that the proposed system is resilient in real-world clinical scenarios where imaging artifacts, missing patient information, and modality variability are common. The system maintains consistent diagnostic performance while ensuring clinical safety and interpretability.

VI. CONCLUSION AND FUTURE WORK

This paper presented an AI-based brain tumor diagnostic system designed to support accurate tumor detection, stage prediction, and survival rate estimation using multimodal CT and MRI scans. By integrating medical image processing, machine learning and deep learning models, and generative AI-based pathology report generation, the proposed system provides a comprehensive clinical decision support solution. The experimental evaluation demonstrated that the system produces reliable diagnostic outcomes, clinically interpretable predictions, and structured pathology reports that assist in informed medical decision-making.

Qualitative and quantitative analyses confirm that the system effectively combines multimodal imaging data with clinical parameters to enhance diagnostic accuracy and consistency. The automated, human-readable pathology reports improve explainability and reduce reliance on manual interpretation, while the web-based interface ensures usability and accessibility in clinical environments. Overall, the proposed system shows strong potential to improve diagnostic efficiency and support clinicians in brain tumor analysis.

Despite its effectiveness, the current system has certain limitations. Diagnostic accuracy depends on the quality and resolution of input CT and MRI scans, as well as the availability of complete clinical data. Additionally, the system is evaluated on limited datasets, and performance may vary with different imaging protocols or tumor types.

Future work will focus on expanding the system to support a wider range of brain tumor categories and larger, more diverse clinical datasets. Further enhancements may include real-time model optimization, integration of advanced explainable AI techniques, incorporation of multimodal clinical data such as genomic or histopathological information, and validation in real hospital environments. These improvements can strengthen the system's reliability, scalability, and clinical applicability, making it a more robust and comprehensive AI-driven diagnostic platform.

VII. ACKNOWLEDGMENT

The authors express their sincere gratitude to **Dr. P. Vijayakarthik**, Principal, R. L. Jalappa Institute of Technology, and **Dr. Sunil Kumar R M**, Head of the Department of Computer Science and Engineering, for their continuous encouragement and institutional support throughout the course of this work. We would like to extend our heartfelt thanks to our guide, **Dr. Manjunatha BN**, Associate Professor&HOD, Department of Computer Science and Engineering(AI&ML), for his invaluable guidance, technical insights, and constant motivation, which played a crucial role in the successful completion of this research.

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