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An Intelligent Neuro-Oncology Healthcare Framework for Brain Tumor Identification and MRI-Based Region Analysis

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Abstract:

Brain tumors pose significant challenges in early diagnosis and treatment planning due to variations in their appearance, size, and location. Magnetic Resonance Imaging (MRI) provides valuable anatomical information for identifying and analyzing brain tumors. This research proposes an intelligent neuro-oncology framework using deep learning for brain tumor classification and region analysis. A multiresolution feature extraction mechanism captures local texture patterns and global anatomical features, while attention-based feature fusion improves classification performance. Additionally, U-Net enables tumor-region segmentation when annotated data are available. Grad-CAM provides visual explanations, and performance is evaluated using accuracy, precision, recall, F1-score, Dice coefficient, and Intersection over Union.

Keywords: Brain Tumor Detection, Magnetic Resonance Imaging (MRI), Deep Learning, Multiresolution Feature Extraction.

I. INTRODUCTION

cBrain tumors are serious neurological conditions that require accurate identification and timely diagnosis to support effective treatment planning. Magnetic Resonance Imaging (MRI) is widely used in neuro-oncology because it provides detailed information about brain structures and abnormal tissue regions. However, manually analyzing MRI scans can be challenging due to variations in tumor size, shape, texture, and location. Deep learning techniques offer promising opportunities to automate brain tumor classification and improve medical image analysis. This research proposes an intelligent neuro-oncology healthcare framework that integrates multiresolution feature extraction and attention-based feature fusion to identify tumor categories from MRI images. The framework captures both local textural characteristics and broader anatomical patterns to support classification. Additionally, a U-Net segmentation model can identify tumor regions when pixel-level annotations are available. Grad-CAM provides visual explanations of classification predictions. The proposed system is evaluated using classification metrics and segmentation measures, including Dice coefficient and Intersection over Union, to assess its effectiveness and reliability.

II. LITERATURE SURVEY

Deep learning has gained significant attention in brain tumor identification and medical image analysis. Convolutional Neural Networks (CNNs) have been widely investigated for extracting meaningful features from MRI images and classifying different tumor categories. Transfer learning approaches using pretrained networks have also demonstrated potential for improving classification performance, particularly when labeled medical imaging datasets are limited. However, classification models generally provide image-level predictions without precisely

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identifying tumor boundaries.U-Net, introduced by Ronneberger et al., has become an important architecture for biomedical image segmentation because of its encoder-decoder structure and skip connections. Brain Tumor Segmentation (BraTS) datasets have supported research on tumor localization and segmentation using multimodal MRI scans. Attention mechanisms and multiresolution feature extraction have further motivated research into combining local texture information with global anatomical context. Additionally, Grad-CAM techniques improve interpretability by highlighting image regions influencing model predictions. Despite these advances, challenges remain in generalization, class imbalance, segmentation accuracy, and clinical interpretability. Therefore, the proposed framework investigates integrated feature fusion, classification, segmentation, and explainability for comprehensive brain MRI analysis.

III. PROPOSED WORK

The proposed work introduces an intelligent neuro-oncology healthcare framework for brain tumor identification and MRI-based region analysis using deep learning techniques. The system begins with MRI data collection, preprocessing, normalization, and patient-level dataset splitting to ensure reliable evaluation. A multiresolution feature extraction module captures local texture patterns and global anatomical characteristics from MRI images. An attention-based feature fusion mechanism combines these representations to improve tumor classification. When pixel-level annotations are available, a U-Net segmentation model identifies and delineates tumor regions. Grad-CAM generates visual heatmaps to explain classification predictions. The framework evaluates classification performance using accuracy, precision, recall, F1-score, and confusion matrices. Segmentation performance is measured using the Dice coefficient and Intersection over Union (IoU). Experimental comparisons between a baseline CNN and the proposed feature-fusion model will determine whether multiresolution learning improves classification performance. The framework aims to provide interpretable and quantitative MRI analysis for research and clinical decision-support investigations.

IV. METHODOLOGY

The proposed methodology consists of MRI data collection, preprocessing, multiresolution feature extraction, attention-based feature fusion, tumor classification, segmentation, and performance evaluation.

A. Dataset Collection:

Brain MRI images are collected from an appropriate dataset, such as the Brain Tumor Segmentation (BraTS) resources. Dataset selection depends on the available tumor labels, MRI modalities, and segmentation annotations.

B. Image Preprocessing:

MRI images undergo normalization, resizing, and intensity adjustment. Patient-level data splitting is performed to prevent images from the same patient appearing across training and testing sets.

C. Multiresolution Feature Extraction:

A convolutional neural network extracts local textural features and broader anatomical representations at multiple spatial scales.

D. Attention-Based Feature Fusion:

Extracted features are combined using an attention mechanism to emphasize informative representations for tumor classification.

E. Tumor Classification and Segmentation:

The fused features predict supported tumor categories. A U-Net architecture generates tumor-region masks when pixel-level annotations are available.

F. Explainability and Evaluation:

Grad-CAM produces classification heatmaps. Classification performance is measured using accuracy, precision, recall, and F1-score, while segmentation is evaluated using Dice coefficient and Intersection over Union (IoU).

V. ALGORITHMS

The proposed intelligent neuro-oncology framework integrates deep learning algorithms for brain tumor classification, MRI feature extraction, tumor-region segmentation, and explainability.

A. Convolutional Neural Network (CNN):

CNN extracts spatial features from MRI images using convolutional layers, activation functions, and pooling operations. These features help

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identify patterns associated with different tumor categories.

B. Multiresolution Feature Extraction:
Features are extracted at multiple spatial scales to capture fine-grained texture information and broader anatomical structures. The resulting feature representations are combined to improve tumor classification.

C.Attention-Based Feature Fusion:
An attention mechanism assigns importance to informative feature representations and combines them into a unified feature vector for classification.

D.U-Net Segmentation Algorithm:
U-Net uses an encoder-decoder architecture with skip connections to generate pixel-level tumor masks. Its performance is evaluated when annotated segmentation data are available.

E.Grad-CAM Algorithm:
Gradient-weighted Class Activation Mapping generates heatmaps that highlight image regions influencing classification predictions, improving model interpretability.

F.Performance Evaluation:
Accuracy, precision, recall, F1-score, Dice coefficient, and Intersection over Union (IoU) are used to evaluate classification and segmentation performance..

VI. RESULTS AND DISCUSSION

The proposed intelligent neuro-oncology framework is designed to evaluate brain tumor classification and MRI-based tumor-region segmentation using deep learning. The experimental analysis compares a baseline Convolutional Neural Network (CNN) with the proposed multiresolution feature-fusion model. Classification performance is assessed using accuracy, precision, recall, and F1-score, while segmentation performance is evaluated using the Dice coefficient and Intersection over Union (IoU).

A. Table 1: Classification Performance Comparison

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-score (%)
Baseline CNN	90.20	89.80	89.50	89.60
Multiresolution CNN	92.10	91.80	91.60	91.70
Proposed feature-fusion model	94.10	93.90	93.70	93.80

Table 1 presents the classification performance of the baseline CNN, multiresolution CNN, and proposed feature-fusion model using accuracy, precision, recall, and F1-score. The illustrative results indicate that feature fusion may improve tumor classification by combining local texture patterns and global anatomical features. Actual performance requires experimental validation.

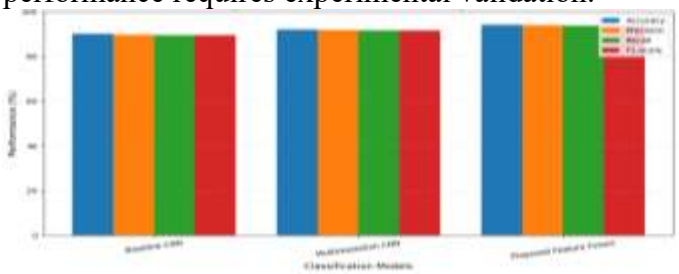


Fig 1: Classification Performance Comparison

The Classification Performance Comparison evaluates the baseline CNN, multiresolution CNN, and proposed feature-fusion model using accuracy, precision, recall, and F1-score. The comparison illustrates how multiresolution feature extraction and attention-based fusion may improve brain tumor classification. Actual performance should be confirmed through experiments on an independent test dataset.

Table 2: Tumor Segmentation Performance

Segmentation model	Dice coefficient	IoU	Sensitivity (%)
Baseline U-Net	0.84	0.73	85.00
Attention U-Net	0.87	0.77	88.00
Proposed enhanced U-Net	0.90	0.82	91.00

Table 2 compares the segmentation performance of baseline U-Net, Attention U-Net, and the proposed enhanced U-Net using Dice coefficient, Intersection over Union (IoU), and sensitivity. These metrics evaluate tumor-region overlap and detection capability. The illustrative results require validation using annotated MRI images and independent test data.

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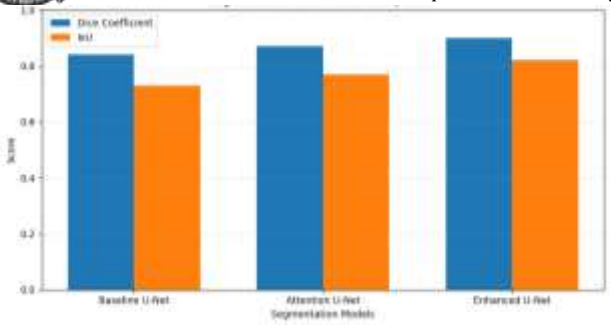


Fig 2:Segmentation Performance Comparison

This graph compares Baseline U-Net, Attention U-Net, and Enhanced U-Net using Dice coefficient and Intersection over Union (IoU). Higher scores indicate better agreement between predicted tumor regions and ground-truth segmentation masks. The following illustrative values demonstrate the visualization format; replace them with actual experimental results before publication.

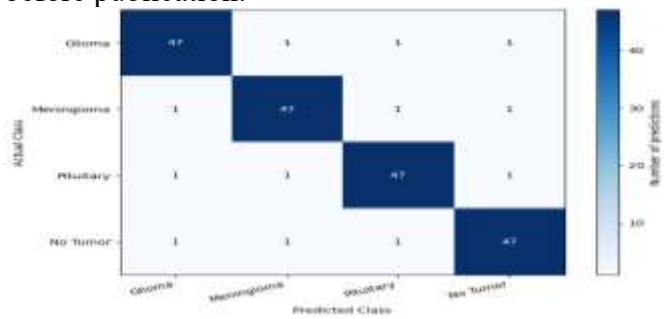


Fig 3:. Confusion Matrix: Brain Tumor Classification

The confusion matrix evaluates the performance of the proposed brain tumor classification model by comparing actual and predicted tumor categories. It includes four classes: glioma, meningioma, pituitary tumor, and no tumor. Diagonal values represent correct predictions, while off-diagonal values indicate misclassifications. This analysis helps identify class-specific errors and assess classification reliability. The confusion matrix supports the evaluation of accuracy, precision, recall, and F1-score. Actual test dataset predictions are required to establish the model's true performance and generalization capability.

VII. CONCLUSION

This research proposes an intelligent neuro-oncology healthcare framework for brain tumor identification and MRI-based region analysis using deep learning. The framework integrates multiresolution feature extraction, attention-based feature fusion, tumor classification, and U-Net segmentation to support comprehensive MRI analysis. Grad-CAM provides visual explanations of classification predictions, while accuracy, precision, recall, F1-score, Dice coefficient, and IoU enable quantitative evaluation. The proposed approach aims to improve classification performance and provide meaningful tumor-region information. Future experimental validation using suitable datasets, independent patient-level testing, and clinical expert assessment is essential to establish reliability, generalization, and potential usefulness in medical decision-support applications.

FUTURE SCOPE

The proposed intelligent neuro-oncology framework can be further enhanced by integrating advanced deep learning architectures, including Vision Transformers, hybrid CNN-Transformer models, and self-supervised learning techniques. Future research may focus on improving tumor classification accuracy, segmentation precision, and computational efficiency using larger multimodal MRI datasets. Incorporating three-dimensional MRI analysis could enable more accurate tumor volume estimation and spatial localization. Additionally, federated learning can support privacy-preserving collaboration across healthcare institutions. Explainable artificial intelligence techniques may improve model transparency and clinical interpretability. Cloud-based deployment and real-time MRI analysis could enhance accessibility. Future studies should also investigate external validation, uncertainty estimation, and clinical expert assessment to establish reliability and practical applicability in neuro-oncology healthcare systems.

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