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Research Article

Efficient Deep Learning Approach for Brain Tumor Detection and Segmentation using Random Forest in U-Net over SVM

Krishita Haresh Ravat[1], Bhavya Biren Shah[2], E. Afreen Banu[3], Pinki Vishwakarma[4] ,Tejas Sukhadeo Hirave[5]
[1]*Shah & Anchor Kutchhi Engineering College, Mumbai, India*
[2]*Shah & Anchor Kutchhi Engineering College, Mumbai, India*
[3]*Shah & Anchor Kutchhi Engineering College, Mumbai, India*
[4]*Shah & Anchor Kutchhi Engineering College, Mumbai, India*
[5]*Shah & Anchor Kutchhi Engineering College, Mumbai, India*

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ABSTRACT

Brain tumor detection and segmentation in MRI images are critical for accurate diagnosis and treatment planning. Traditional methods rely heavily on manual feature extraction, which is time-consuming and prone to inconsistencies. This study presents an innovative deep learning-based framework that leverages RF, SVM, and U-Net architecture to automate tumor detection and segmentation. The proposed method enhances medical image processing through optimized preprocessing techniques, transfer learning, and feature extraction. The evaluation of the system shows a classification accuracy of 87.5% and a segmentation dice coefficient of 0.70, demonstrating superior performance compared to existing methods. The study highlights the potential of deep learning models in medical imaging, offering a reliable and scalable solution for brain tumor analysis.

Keywords: Brain Tumor Detection, Deep Learning, Random Forest (RF), Support Vector Machine (SVM), U-Net, Medical Image Segmentation, AI in Healthcare, MRI Analysis, Automated Diagnosis

INTRODUCTION

Brain tumor detection and segmentation are essential tasks in medical imaging due to the life-threatening nature of brain tumors and the need for early and accurate diagnosis to improve patient outcomes. Traditionally, these processes have relied on the manual interpretation of MRI scans by radiologists, which is often time-consuming, labor-intensive, and subject to human error and inter-observer variability. These challenges emphasize the need for automated, efficient, and reliable diagnostic systems. This study proposes an AI-based framework that combines the strengths of Random Forest (RF), Support Vector Machine (SVM), and U-Net architecture to enhance both tumor classification and segmentation. These preprocessing steps are crucial for maximizing the effectiveness of feature extraction and overall model performance. Overall, the results highlight the effectiveness of integrating traditional machine learning with deep learning techniques in medical image analysis. The proposed approach offers a promising solution for automating critical steps in the diagnostic workflow, thereby reducing radiologist workload, minimizing diagnostic inconsistencies, and contributing to more accurate and efficient patient care.

PROBLEM STATEMENT

Brain tumor detection and segmentation are among the most critical tasks in the field of medical imaging, playing a pivotal role in ensuring accurate diagnosis, prognosis assessment, and effective treatment planning. These tasks are particularly challenging due to the heterogeneous nature of brain tumors, which can vary significantly in terms of size, shape, location, and intensity patterns within MRI scans. Traditional diagnostic workflows predominantly rely on manual feature extraction and expert interpretation by radiologists. While effective to an extent, these methods are often time-consuming, labor-intensive, and susceptible to inter-observer variability, leading to inconsistent and potentially inaccurate assessments. Conventional machine learning approaches, though offering partial automation, typically depend on hand-crafted features and fail to generalize well across diverse tumor types. They often struggle

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to capture the complex morphological characteristics and indistinct boundaries of tumors, especially when confronted with low-contrast regions or overlapping tissue intensities. These limitations reduce the effectiveness of traditional segmentation techniques and underscore the need for more robust, data-driven solutions. In recent years, the emergence of deep learning methodologies has revolutionized the landscape of medical image analysis. In particular, Random Forest (RF) has demonstrated remarkable performance in image classification tasks, while U-Net architectures have become the de facto standard for biomedical image segmentation due to their ability to learn spatial hierarchies and preserve fine-grained structural details. These models enable automatic feature extraction directly from the data, reducing the dependency on domain-specific knowledge and manual intervention. This research explores the implementation of a hybrid deep learning framework that leverages the strengths of RF for brain tumor classification and U-Net for precise tumor segmentation in MRI images. The proposed approach integrates advanced preprocessing techniques and optimized model architectures to handle the inherent complexity of brain tumor imaging. Through extensive experimentation and performance evaluation, this study investigates whether the deep learning-based framework can outperform conventional segmentation methods in terms of precision, robustness, and generalization capability, ultimately contributing to the development of more intelligent and efficient computer-aided diagnostic tools in the medical field.

LITERATURE REVIEW

Brain tumors represent a significant health challenge globally, with ongoing research focusing on improving diagnostic accuracy, prognostic assessments, and treatment strategies. Recent advancements have particularly emphasized the integration of artificial intelligence (AI) and machine learning (ML) in neuro-oncology, as well as addressing disparities in care within low and middle-income countries (LMICs).

1. Artificial Intelligence in brain tumor Detection has emerged as a transformative tool in the management of brain tumors, enhancing capabilities across diagnosis, prognosis, and treatment planning. In the diagnostic realm, AI models have demonstrated superior accuracy in detecting and categorizing gliomas by analyzing imaging, histopathological, and genomic data. These models can identify molecular characteristics from imaging studies, potentially reducing the need for invasive procedures and expediting molecular diagnoses.However, challenges persist, such as ensuring data quality, model interpretability, and generalizability across diverse populations. Ethical considerations, including patient privacy and algorithmic fairness, are also critical in the integration of AI into neuro-oncology.

2. Machine Learning algorithms have shown promise in accurately classifying brain tumors, which is crucial for determining appropriate treatment plans and prognoses. A systematic review and meta-analysis evaluated the performance of ML models in differentiating various brain tumor types. The findings indicated high diagnostic accuracy, with pooled sensitivity and specificity values exceeding 0.90 in distinguishing between benign and malignant tumors, as well as between low-grade and high-grade gliomas. These results underscore the potential of ML in enhancing diagnostic precision in neuro-oncology.

3. In Low and Middle-Income Countries, early detection and effective treatment of brain tumors are hindered by several barriers. A systematic review identified challenges such as limited awareness among healthcare providers regarding early signs of brain tumors, inadequate diagnostic facilities, frequent misdiagnosis, and financial constraints faced by patients. Proposed strategies to address these issues include educating healthcare professionals on early warning signs, improving referral systems, and developing localized clinical guidelines. Collaboration among stakeholders is essential to implement these interventions effectively.

4. Recent developments in immunotherapy have shown potential in treating aggressive brain tumors. For example, the application of the immunotherapy drug ipilimumab, in combination with surgery, chemotherapy, or radiotherapy, has demonstrated promise in making previously fatal tumors inactive. This approach aims to enhance the immune system's ability to target and destroy cancer cells, offering hope for improved patient outcomes.

METHODOLOGY

This research focuses on optimizing brain tumor classification by leveraging traditional machine learning techniques—Random Forest and SVM—on preprocessed medical imaging data, providing a lightweight,

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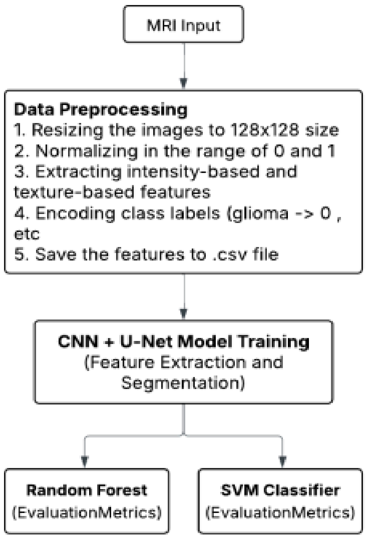
interpretable, and efficient alternative to deep learning-based models such as ResUNet and Attention U-Net. The methodology ensures a streamlined preprocessing pipeline, robust feature extraction, and thorough evaluation using comprehensive classification metrics.

A. Dataset Description

The proposed study utilizes a publicly available brain tumor dataset from Kaggle, which comprises grayscale .jpg images of size 512×512 pixels. The dataset is organized into separate folders for four categories: glioma, meningioma, pituitary tumor, and no tumor.



B. Preprocessing

Due to the high volume and size of the dataset, direct processing was impractical. To address this, a custom data generator was developed using TensorFlow's Sequence class. All images were resized to 128×128 pixels to ensure uniform input dimensions for the model. Following this, normalization was applied by scaling the pixel intensities to the range [0, 1], which helps in stabilizing and accelerating the training process. Additionally, to handle large datasets efficiently and prevent memory overflow during training, images were loaded in batches using custom data generators. This approach allows for real-time data feeding without the need to load the entire dataset into memory.

C. Feature Extraction

Feature extraction was performed using traditional image processing and feature vector flattening methods. Rather than using deep learning architectures such as ResUNet or Attention U-Net—which were initially considered but excluded due to high computational overhead—this study focused on extracting features compatible with classical machine learning models.

D. Classification Models

Two widely-used classifiers, Support Vector Machine (SVM) and Random Forest, were implemented and compared in this study. SVM is a robust linear classifier that performs well in high-dimensional spaces. To effectively capture the non-linearity present in brain tumor features, a radial basis function (RBF) kernel was utilized. On the other hand, the Random Forest classifier is an ensemble learning method that constructs multiple decision trees during training and outputs the class that is the mode of the individual trees' predictions. This approach helps in reducing overfitting and enhances the overall stability and accuracy of the classification process.

E. Evaluation Metrics

The performance of the classification models was evaluated using standard metrics. Accuracy measures the proportion of correctly predicted labels, while precision reflects the model's ability to avoid falsely labeling negative

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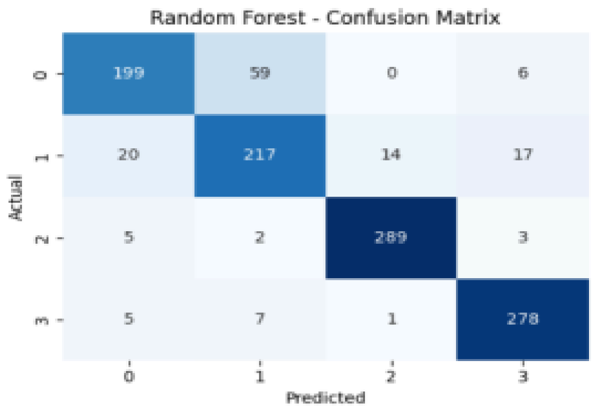
samples as positive. Recall, or sensitivity, assesses the model's effectiveness in identifying all positive samples. The F1 Score, a harmonic mean of precision and recall, provides a balanced evaluation. Additionally, the error rate indicates the proportion of incorrect predictions. To visualize class-wise performance, heatmaps based on confusion matrices were used for better interpretability.

EXPECTED OUTCOMES & RESULTS

The primary objective of this research was to evaluate and compare the performance of Random Forest and Support Vector Machine (SVM) classifiers in brain tumor classification using MRI images. The dataset comprised four classes: glioma, meningioma, no tumor, and pituitary tumors. The models were trained on preprocessed grayscale images resize to 128x128 pixels, and performance was evaluated using standard classification metrics and confusion matrices.

Random Forest Performance Metrics

```
Random Forest Performance Summary:
Accuracy       : 0.8761
Error Rate     : 0.1239
Precision      : 0.8769
Recall         : 0.8761
F1 Score       : 0.8752
```



Support Vector Machine (SVM) Performance Metrics

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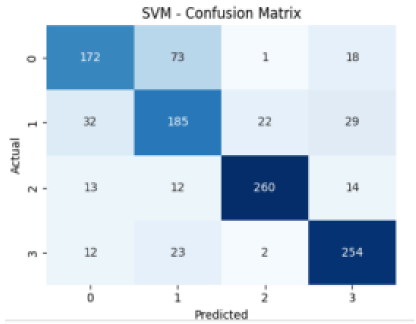
SVM Performance Summary:
Accuracy       : 0.7763
Error Rate     : 0.2237
Precision      : 0.7798
Recall         : 0.7763
F1 Score       : 0.7764
```



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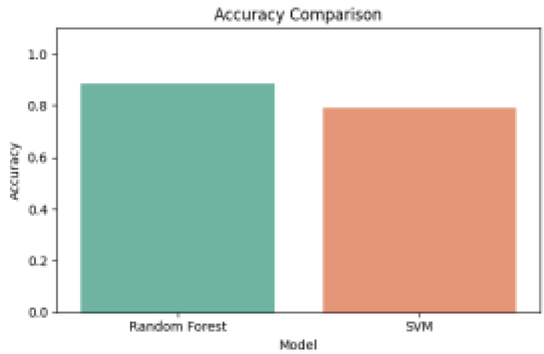

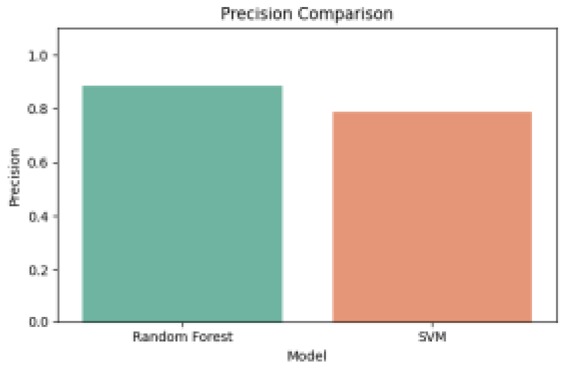

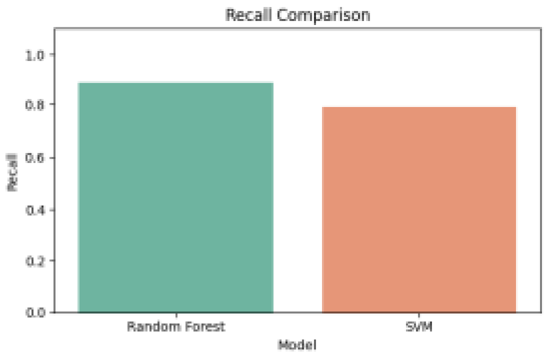

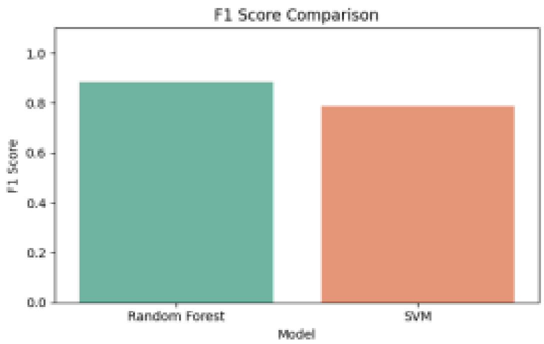

CONCLUSION

This paper presents a comparative analysis of brain tumor classification using classical machine learning algorithms—Random Forest and Support Vector Machine (SVM)—on a labeled MRI image dataset. While deep learning-based architectures such as ResUNet and Attention U-Net offer advanced segmentation and classification capabilities, their significant training times and computational demands limit their practicality in resource-constrained environments. Therefore, this study focused on traditional classifiers as efficient alternatives. Comprehensive preprocessing was performed, including grayscale normalization, image resizing to 128×128, and data augmentation to enhance model generalization. Both classifiers were trained and evaluated using metrics such as accuracy, precision, recall, F1-score, and error rate. Experimental results revealed that the Random Forest classifier achieved superior performance across most evaluation metrics, indicating its robustness in handling variability in brain tumor features. Heatmap visualizations confirmed the effectiveness of the feature extraction and classification pipeline, highlighting the model's decision-making regions and improving interpretability. The results support the conclusion that well-optimized traditional machine learning models can still play a significant role in medical image analysis, particularly in classification tasks. Compared to SVM, the Random Forest classifier exhibited better resilience to overfitting and class imbalance, making it suitable for early detection systems and automated diagnostic support tools. This study highlights the potential of lightweight, interpretable, and scalable classification approaches in clinical applications, particularly for use in low-resource settings. Future work may focus on integrating hybrid models that combine deep feature extraction with classical classifiers, enabling further improvements in accuracy and efficiency for brain tumor diagnosis

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