Attention-Enhanced EfficientNet Framework for Multi-Class Brain Tumor Classification: A Deep Learning Approach

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Abstract: Classification of brain tumors through Magnetic Resonance Imaging (MRI) is highly crucial for proper diagnosis, treatment plans, and prognosis. MRI offers better contrast between tissues and many types of images, which make it an ideal imaging method for the brain tumor. Nevertheless, manual interpretation is highly time consuming and relies heavily on the skills of the radiologists, with chances of getting different diagnoses. Deep learning algorithms have been proven efficient in automating brain tumor classification tasks. Even though they offer great results, many of the available methods can only handle three classes and have problems handling imbalanced data classes in medical applications. Moreover, the opacity of the Convolutional Neural Networks makes them unreliable when used in healthcare. A scalable deep learning system is proposed that will overcome the imbalances of classes and deliver accurate classification of brain tumor MRIs.

Keywords: Brain Tumor Classification; MRI; EfficientNetB4; CBAM; Explainable AI

Introduction

Among the deadliest diseases involving the central nervous system are brain tumors. In order to come up with an appropriate course of action in treating the disease, it is necessary to accurately diagnose brain tumors at an early stage. The MRI technique is now widely used in diagnosing brain tumors since it offers great soft tissue contrast, precise anatomical details, and various sequences like T1, T2, and FLAIR. The ability to determine tumor location, size, and structural composition is greatly facilitated by these features. The problem is that there has been an increase in MRI examinations, thus adding to the workload of radiologists. The manual reading of MRI images takes a lot of time, and the accuracy of the results depends on the level of experience of the professional[1].

With the advent of deep learning, especially CNNs, automated image processing of medical imaging has been transformed as deep learning enables direct learning of discriminative features from MRI images. Some of the architectures which have proven effective include VGG, ResNet, DenseNet, and EfficientNet. Even though great success has been achieved, many of the works in the literature only concentrate on the classification of few tumor classes and do not consider issues such as class imbalance and interpretability. The fact that deep learning models are often considered black boxes means that its predictions may not always be reliable[2]. Thus, there is an increasing demand for a framework that scales well and provides interpretable and accurate brain tumor classification.

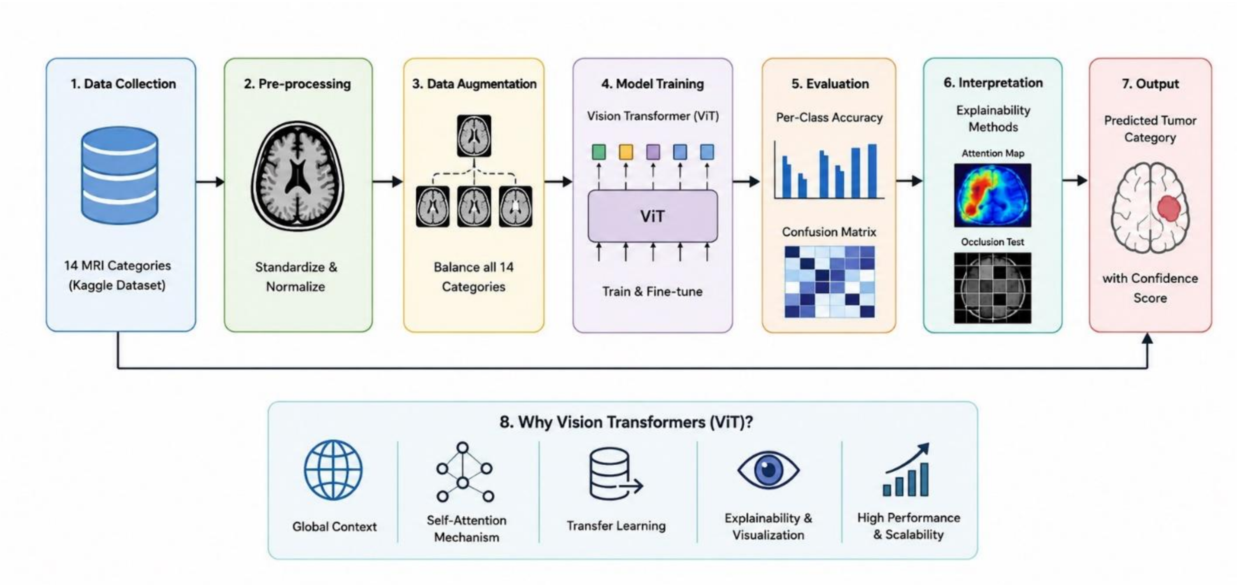

Fig1: Model Architecture

As shown in Fig. 1, the proposed framework begins with the collection of brain MRI images belonging to 14 tumor categories from a Kaggle dataset. The images are preprocessed through normalization, grayscale conversion, Gaussian blurring, thresholding, and morphological operations to improve image quality and reduce noise. Data augmentation is applied to address class imbalance and increase dataset diversity. The processed images are then used to train and fine-tune a Vision Transformer (ViT) model for multiclass brain tumor classification[3]. Model performance is evaluated using metrics such as accuracy and confusion matrices, while explainability techniques, including attention maps and occlusion analysis, help interpret predictions.

The dataset is divided into 80% training and 20% testing samples, with all images resized to 256×256 pixels for uniform processing. Class labels are automatically extracted, and valid image formats are retained to ensure data integrity. Contour detection and cropping are used to isolate the brain region and remove irrelevant background areas[4]. This preprocessing pipeline reduces scan variability, improves feature extraction, and enhances learning efficiency, enabling the ViT model to achieve accurate and robust classification across multiple brain tumor categories[5][6].

Key Contribution

A Vision Transformer (ViT-Base) model pre-trained on ImageNet was fine-tuned for multiclass brain tumor classification using MRI images. The architecture processes images by dividing them into smaller patches and learning spatial relationships through Transformer encoder blocks equipped with self-attention mechanisms. A CLS token is utilized to capture global image information, while a customized classification head with dropout improves model generalization and reduces overfitting. The extracted feature representations are mapped to 14 tumor categories through a final classification layer. Training is optimized using Focal Loss to address class imbalance, along with the AdamW optimizer and adaptive learning-rate scheduling. The model is trained over multiple epochs while preserving the best-performing checkpoint for robust performance. Evaluation is conducted using a confusion matrix and classification metrics, including precision, recall, and F1-score. Results demonstrate strong predictive capability across both frequent and less-represented tumor classes. The model achieves an overall accuracy of approximately 93%, with balanced macro and weighted performance measures. These findings highlight the effectiveness of Vision Transformer architecture for accurate, reliable, and consistent brain tumor classification from MRI scans.

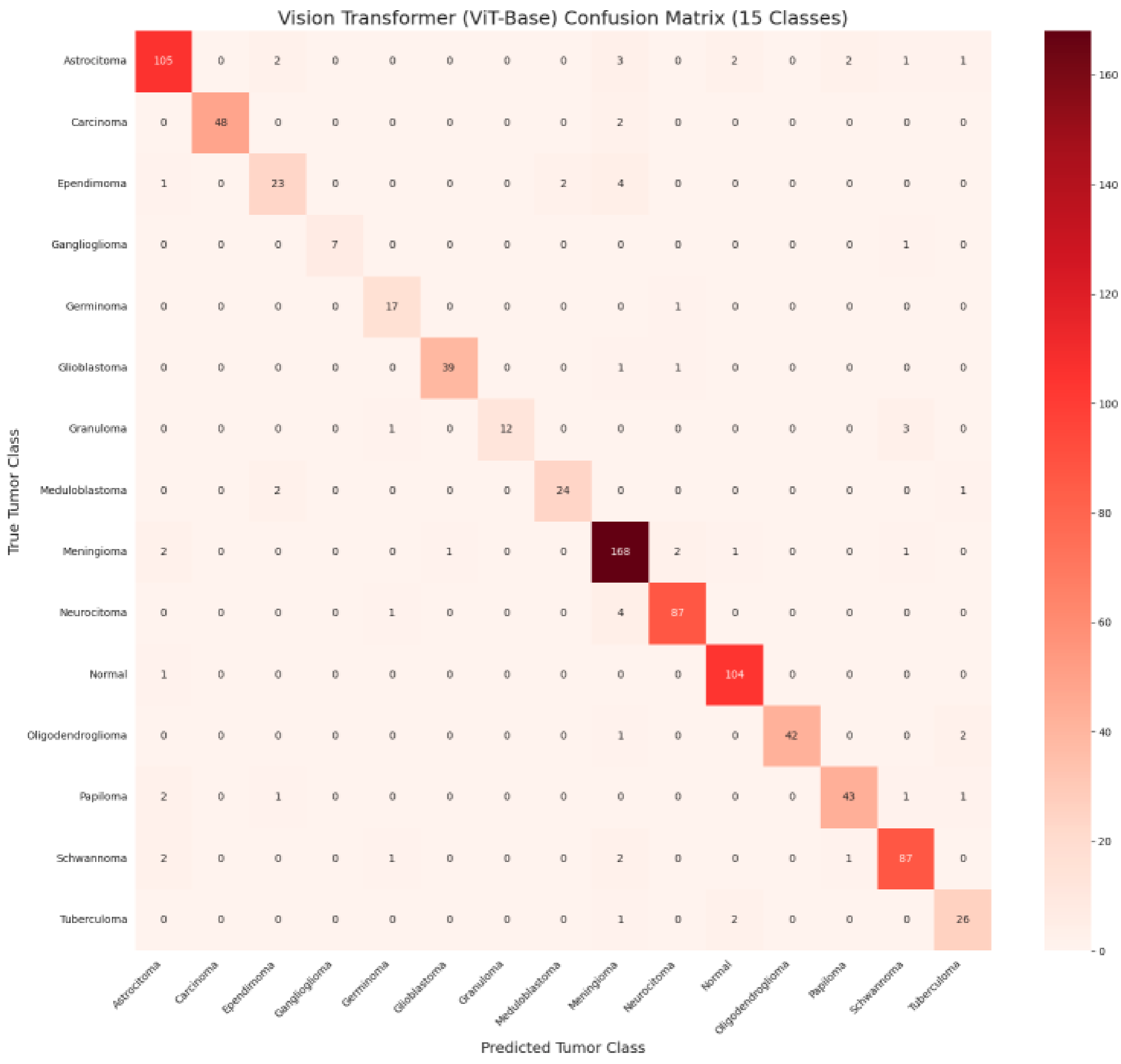

Fig 2. Confusion Matrix.

Applications

The proposed brain tumor classification system has significant potential in healthcare applications. It can assist clinicians through hospital decision-support systems, help radiologists by providing automated tumor classification, and support remote diagnosis through telemedicine platforms. The framework can also serve as a valuable tool for research and education in AI-based medical imaging and explainable healthcare. Future enhancements may include transformer-based architectures for improved performance, federated learning for privacy-preserving collaborative training, and multimodal data integration involving MRI scans, clinical records, and genomic information to enable more comprehensive and accurate diagnosis[7].

Conclusions

Manual classification of brain tumors from MRI images is a difficult and labor-intensive process that requires expert analysis. In order to solve this problem, an automated multiclass brain tumor classification system was built based on an Attention-Enhanced EfficientNetB4 model combined with CBAM attention module. Transfer Learning, Focal Loss, and Grad-CAM explainability methods were used in the framework in order to boost classification performance, overcome class imbalance, and make models explainable. The experiments have shown excellent performance of the proposed solution in multiple brain tumor classes with the help of Grad-CAM visualization, which revealed that the model was focusing on clinically significant brain parts when making decisions. The disadvantage of the study lies in the small size of the dataset used. Further research can include the use of transformer architecture, multimodal data fusion, and federated learning techniques.

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