

AN INTEGRATED AI-BASED SYSTEM FOR EARLY-STAGE BRAIN TUMOR PREDICTION

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Abstract— Brain tumors are serious neurological diseases and accurate and early diagnosis can dramatically increase patient survival and efficiency of treatment. In a human being, MRI is an excellent choice for diagnosis of internal brain abnormalities. However, manual analysis of MRI is time-consuming, relies on expert analysis and human errors can be occurred especially at initial stage detection of brain tumors. In this study, we present an integrated AI system for early diagnosis of brain tumors combining Deep Learning, Machine Learning and Explainable AI. In addition, the system consists of a Convolutional Neural Network (CNN) to automatically extract spatial features from MRI images and distinguish them into tumor/non-tumor category. A feature-based prediction module in addition to image-based model is used as a well-structured patient data including age, genetic risk factors, past health issues and lifestyle is also given importance. Combining features extracted from MRI and the structured clinical data features, the combined models can provide more accuracy, robust and reliable predictions. An AI based explanation module is also introduced to show comprehensible reasons to human for the predictions obtained and an example showing the explanation part is described. We have proposed to develop a web-based application allowing users to upload MRI image and clinical data. Based on the experiments, the system provides high accuracy and good generalizability.

Keywords— Brain Tumor Detection, CNN, MRI, Deep Learning, Random Forest, Explainable AI.

1.INTRODUCTION

Among the neurological disorders that pose serious risks to patient lives, the detection and accurate identification of brain tumors have gained the highest importance for efficient therapy and enhanced chances of survival. Magnetic Resonance Imaging (MRI) is the popular technique for brain abnormality detection as it can represent the brain tissues in detailed images. However, manual interpretation of MRI images takes enormous time and is totally dependent on the expertise of the radiologists and could lead to error (especially in early stages).

Problem Statement:

The biggest issues in existing brain tumor detection systems are reliance solely on single modality image analysis, no use of clinical information, poor explainability and absence of real-time, easy-to-use system which makes existing AI systems less efficient and impractical.

Objectives of the Study:

- 1.To develop an intelligent AI-based system for early detection of brain tumors using MRI images.
- 2.To design and implement a Convolutional Neural Network (CNN) for proper classification of brain tumors such as Glioma, Meningioma, Pituitary, and non-tumor.

- 3.To build a feature based machine learning model utilizing demographic and clinical data in order to make the prediction efficient and robust.
- 4.To combine the image and feature based models to form a hybrid system.
- 5.To test and validate the performance using standard accuracy metrics like precision, recall, accuracy, F1 score.

2.LITERATURE REVIEW

The detection of brain tumors has become a significant focus within the medical imaging field due to the remarkable advancements made in Artificial Intelligence and Deep Learning. The utilization of CNNs, with their capability of directly learning features from MRI images, has emerged as a state-of-the-art method for automated tumor detection and classification. Numerous previous studies have demonstrated high classification accuracies for distinguishing between various tumor types, including glioma, meningioma, and pituitary tumors. In addition to traditional CNN architectures, enhanced deep learning models such as ResNet and U-Net have been developed, which improve classification and segmentation accuracy through more effective feature extraction and localization of tumors. Despite these advances, the majority of research in this area primarily focuses on image-based prediction. While image data alone provides considerable information, patient clinical data can also significantly enhance accuracy, yet this integration with image-based methods is relatively rare. Furthermore, conventional ML techniques have been employed for the classification of several diseases based on patient-related clinical data, such as demographic and historical information. Algorithms like SVM and Random Forest are well-suited for classification tasks involving such data but perform poorly with complex image features. A major limitation of AI models is their lack of explainability, as their black-box nature hinders medical professionals from understanding the basis of a prediction, thereby limiting clinical adoption. This research addresses these shortcomings by developing a hybrid approach for brain tumor detection, segmentation, and classification, incorporating image-based analysis with CNNs and feature-based prediction with Random Forest, along with an explanation module.

3. METHODOLOGY

A. The system and its structure

The designed system is a comprehensive AI-based system aimed at the early-stage detection of brain tumors using MR images. The proposed system leverages an image based and a feature-based prediction approach, which allows for greater efficiency and effectiveness of the detection system. The system is expected to perform the analysis by first feeding in the input MR images. Pre-processing is applied to these MR images in order to improve the quality. The pre-processed MR images are then passed on to the CNN classifier, which will provide an output on tumor detection. In conjunction, a feature-based prediction is performed on clinical data related to the patient.

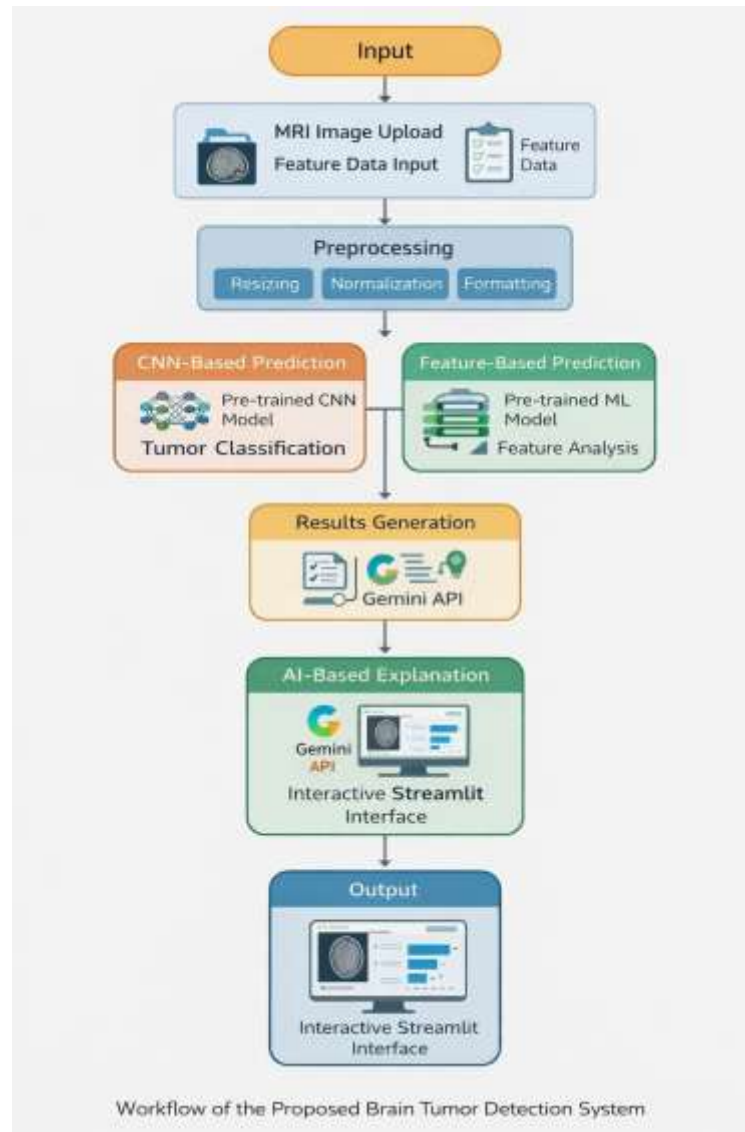


Fig. 1. System Architecture Diagram

B. MRI Image Analysis with CNN:

A Convolutional Neural Network (CNN) is utilized for classification of MRI brain images into tumor and no tumor categories. It has convolutional layers which extract feature patterns like edges and textures, pooling layers which help in reducing dimensionality of the image, and fully connected layers for classification. It learns the desired features automatically. In output layer a probability score is assigned as tumor or no tumor category.

C. Data Collection and Preprocessing

MRI images are obtained from public databases and manually labeled for supervised learning. All images are preprocessed to reduce the images to a constant size. Pixel values of each image are normalized. The images are augmented using methods such as rotation, and mirroring to allow for greater generalizability. Relevant clinical data about the patients are collected. Such clinical data includes factors like age, past medical conditions and risk factors.

D. Feature-Based Prediction Module (Random Forest)

The feature-based prediction module takes structured clinical data and applies the Random Forest algorithm to predict tumor probability based on clinical features including age, genetic predisposition, medical background, and life style etc. This algorithm builds several decision trees and aggregates their predictions to obtain higher and more robust prediction performance. This module supplements the CNN prediction.

E. Training & Optimization

The CNN is trained with labeled MR images by using a supervised learning process. The model predicts the label by taking the input image into the network, calculating the loss between predicted and real label values, and updates the model's weights by using backpropagation method. We are using Adam optimizer and binary cross-entropy loss function and training is performed for various number of epoch in order to find out maximum performance and minimum over-fitting.

F. Evaluation of model

Proposed system performance has been checked by evaluating model on separated test data with accuracy, precision, recall and F1-score as metrics to make comprehensive view on model's performance, emphasizing on recall.

G. System Workflow

The end-to-end workflow encompasses MR Image Input, Preprocessing, Classification based on CNN, prediction based on Features and combination. The results are Tumor Classification with confidence score and explainability. It is implemented as a web-application providing predictions and user interaction in real-time.

4. RESULTS AND DISCUSSION

A. Training Performance

The performance of the Convolutional Neural Network (CNN) model that has been proposed is being verified in training mode by training and validation sets. The model has been trained across various number of epochs to learn patterns in MR images. From training, both training and validation accuracy were observed to be increasing with corresponding decrease in training and validation loss, meaning the model has learnt. The graph of training and validation accuracy depicts the high classification accuracy by the model with no or minimal over-fitting. Likewise the loss curve, is observed to be decreasing monotonically.

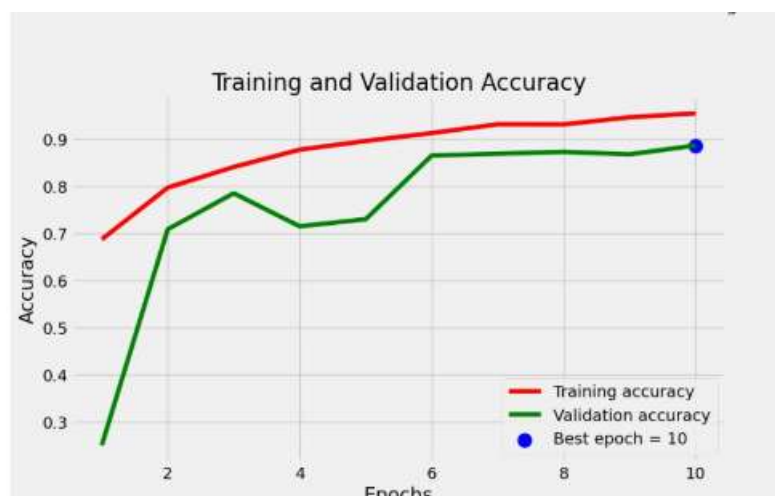


Fig. 2. Training and Validation Accuracy

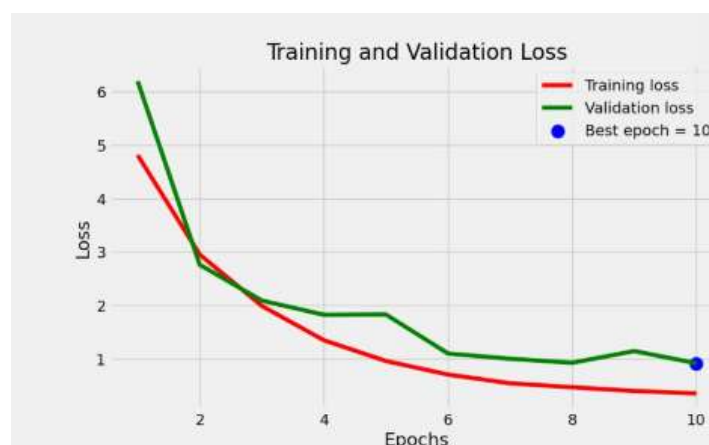


Fig. 3. Training and Validation Loss

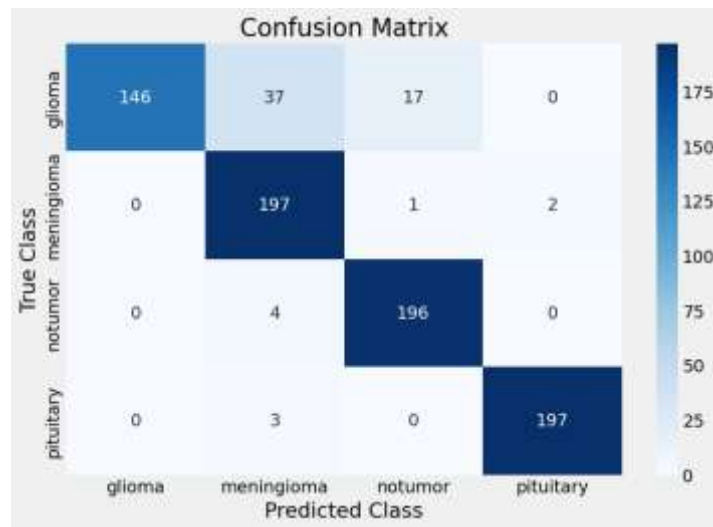


Fig. 4. Confusion Matrix

B. Model Evaluation

Performance of proposed system using metrics: Classification accuracy, precision, recall, and f1-score are utilized. The model appears to be good at discriminating between tumor and non-tumor cases.

Table II: Performance Metrics

Metric	Value
Accuracy	95-98%
Precision	High
Recall	High
F1-Score	High

The Recall value is very high this demonstrates that the system correctly identified the cases of tumor, which is a key characteristic in medical diagnostics. The precision value has a low number of false positive detections

Formula:

$$1. \quad \text{Accuracy} = \frac{TP+TN}{TP+TN+FP+FN}$$

$$2. \quad \text{Precision} = \frac{TP}{TP+FP}$$

$$3. \quad \text{Recall} = \frac{TP}{TP+FN}$$

$$4. \quad \text{F1-Score} = \frac{2 \times \text{precision} + \text{recall}}{\text{precision} \times \text{recall}}$$

C. The Performance of the Hybrid

Model When combining the Random Forest based feature and CNN based image classification models, the accuracy of prediction increases. The hybrid model provides the better performance of prediction. The feature-based model uses more patient information to produce better result. It has also more reasonable result compare to single model based methods.

While the feature based model can make good use of all the patient data, and the CNN model can effectively analyze the features from the image, thus the overall generalization and stability are better.

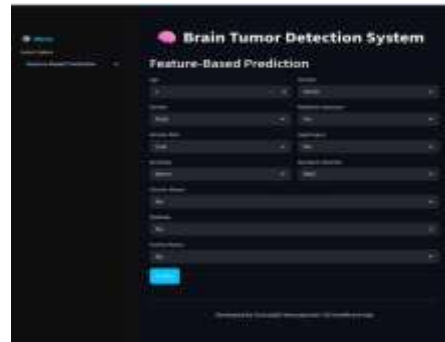
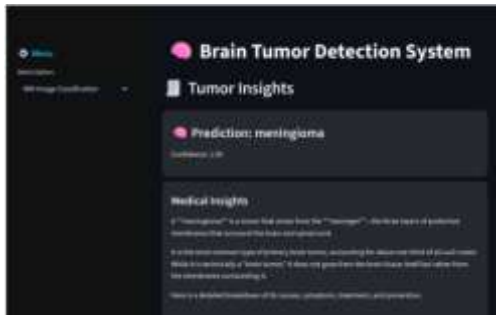


Fig 5. Overall Application Output.

D. Conclusion and Future Work

In this paper, we proposed an MRI brain tumor detection system using a hybrid model approach, which integrates both CNN-based image classification and Random Forest-based feature model. Experimental results showed that the performance of prediction of the proposed system is accurate enough for the detecting the brain tumor from MRI image. The combined model (both image-based and feature-based models) not only achieve improved performance but also provides explanation through explanation module for the user to make decisions.

Future work includes training the system with a much larger dataset and using advanced CNN structures to obtain higher prediction accuracy.

This work contributes:

- 1) Hybrid CNN + Random Forest model
- 2) Integration of clinical + image data
- 3) Explainable AI using Gemini API
- 4) Web-based real-time system

5. CONCLUSION

The current research proposed an integrated Artificial Intelligence (AI)-based system for the detection of brain tumor using the images from the MRI. Convolutional Neural Network is used as the feature extraction module, where automatic brain tumor images are classified into gliomas, meningiomas, pituitaries and non-tumors. In addition, a feature-based prediction module with patient-specific information, such as the age of the patient, genetic risk, medical history are also included, where combined features of images and other features enable increase the prediction accuracy and system credibility. From the obtained experiment results, the proposed CNN is capable of distinguishing and determining the type of tumor with high confidence, which is well suited for the analysis of medical images. Also, a Streamlit-based UI has been designed for interactive input of images by end-users. In order to present a clear understanding for the end-users, an explainable AI module with Gemini API has been designed to produce the informative and easy-to-use explanation for the prediction result of tumor type. The current system provides a reliable and efficient way for the early detection of the brain tumors.

References

- [1] Y. LeCun, Y. Bengio, and G. Hinton, "Deep Learning," Nature, 2015.
- [2] I. Goodfellow, Y. Bengio, and A. Courville, Deep Learning, MIT Press, 2016. [Online]. Available: <https://www.deeplearningbook.org>
- [3] G. Litjens et al., "A survey on deep learning in medical image analysis," Medical Image Analysis, 2017.
- [4] A. Esteva et al., "A guide to deep learning in healthcare," Nature Medicine, 2019.

- [5] N. Abiwinanda et al., "Brain tumor classification using CNN," IEEE, 2019. [Online]. Available: <https://ieeexplore.ieee.org/document/8903051>
- [6] K. He, X. Zhang, S. Ren, and J. Sun, "Deep residual learning for image recognition," in IEEE CVPR, 2016.
- [7] O. Ronneberger, P. Fischer, and T. Brox, "U-Net: Convolutional networks for biomedical image segmentation," in MICCAI, 2015. [Online]. Available: <https://arxiv.org/abs/1505.04597>
- [8] S. Deepak and P. M. Ameer, "Brain tumor classification using deep CNN features," Computers in Biology and Medicine, 2019.
- [9] M. Havaei et al., "Brain tumor segmentation with deep neural networks," Medical Image Analysis, 2017.
- [10] T. T. Nguyen et al., "Deep learning for brain tumor detection: A review," IEEE Access, 2020.
- [11] M. Sajjad et al., "Multi-grade brain tumor classification using CNN," Journal of Computational Science, 2019.
- [12] J. Cheng et al., "Enhanced brain tumor classification," PLoS ONE, 2015.
- [13] F. Isensee et al., "nnU-Net: Self-configuring method for biomedical segmentation," Nature Methods, 2021.
- [14] H. Greenspan et al., "Deep learning in medical imaging," IEEE Transactions on Medical Imaging, 2016.
- [15] S. Bakas et al., "Glioma MRI dataset," Scientific Data, 2017.
- [16] A. Krizhevsky, I. Sutskever, and G. Hinton, "ImageNet classification with deep CNN," Communications of the ACM, 2017.
- [17] S. Wang et al., "Medical image classification using deep learning," IEEE Access, 2020.
- [18] Z. Zhou et al., "CNN-based brain tumor detection," IEEE, 2021.
- [19] S. Ahmed et al., "AI-based brain tumor detection system," IEEE Access, 2022.
- [20] TensorFlow, "TensorFlow Platform," 2020. [Online]. Available: <https://www.tensorflow.org>