Jyoti Gahora, 2026, 14:3
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

A Comprehensive Review of Deep Learning Techniques for Brain Tumor Detection and Classification Using MRI Images

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Abstract- Brain tumor detection and classification are among the most critical challenges in medical image analysis due to the complexity and variability of tumor structures in Magnetic Resonance Imaging (MRI) scans. Early and accurate diagnosis is essential for effective treatment planning and improving patient survival rates. In recent years, deep learning techniques have significantly transformed the field of medical imaging by providing automated, efficient, and highly accurate diagnostic systems. This review paper presents a comprehensive analysis of recent advancements in machine learning and deep learning approaches for brain tumor detection and classification using MRI images. The study examines various Convolutional Neural Network (CNN) architectures, transfer learning models, attention mechanisms, hybrid frameworks, explainable artificial intelligence (XAI), and IoT-enabled healthcare systems. Additionally, the paper discusses preprocessing methods, segmentation techniques, classification strategies, and performance evaluation metrics used in recent research. The review also identifies major challenges such as limited annotated datasets, computational complexity, overfitting, lack of interpretability, and generalization issues across medical datasets. Finally, the paper highlights emerging trends and future research directions, including lightweight deep learning models, federated learning, multimodal imaging integration, and real-time clinical deployment. This review provides researchers and healthcare professionals with a detailed understanding of state-of-the-art deep learning techniques for intelligent brain tumor diagnosis systems.

Keywords— Brain Tumor Detection, Deep Learning, MRI Images, Convolutional Neural Network (CNN), Transfer Learning, Explainable AI, Attention Mechanism, Medical Image Analysis, Brain Tumor Classification, IoT Healthcare Systems.

I. INTRODUCTION

Brain tumors are abnormal growths of cells within the brain that can severely affect the nervous system and human health. Brain tumors are generally classified into benign and malignant tumors, with malignant tumors being more dangerous due to their rapid growth and invasive nature. Early diagnosis of brain tumors is extremely important because delayed detection may reduce treatment effectiveness and increase mortality rates. Magnetic Resonance Imaging (MRI) is widely used for brain tumor diagnosis because it provides detailed images of brain tissues without harmful radiation exposure.

Traditional methods of brain tumor diagnosis rely heavily on radiologists for manual analysis of MRI scans. However, manual interpretation is time-consuming, prone to human error, and dependent on clinical expertise. To overcome these limitations, artificial intelligence (AI), machine learning (ML), and deep learning (DL) techniques have been increasingly adopted in medical image analysis. Among these approaches, deep learning has shown remarkable success in automatically extracting features and improving tumor detection accuracy.

Convolutional Neural Networks (CNNs) are the most commonly used deep learning models for brain tumor detection due to their ability to learn

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hierarchical image features directly from MRI data. Recent advancements have introduced transfer learning, hybrid deep learning frameworks, attention mechanisms, and explainable AI models to improve classification accuracy and interpretability. Transfer learning techniques help address the challenge of limited medical datasets by utilizing pre-trained models such as ResNet, VGG, DenseNet, and EfficientNet. Attention mechanisms further enhance model performance by focusing on critical tumor regions within MRI images.

In addition, emerging technologies such as Internet of Things (IoT)-based healthcare systems and cloud-integrated deep learning models are enabling real-time brain tumor monitoring and intelligent medical diagnosis. Despite these advancements, several challenges remain, including dataset imbalance, high computational cost, lack of model transparency, and difficulties in clinical deployment.

This review paper aims to provide a comprehensive overview of recent deep learning techniques for brain tumor detection and classification using MRI images. The paper discusses different architectures, methodologies, advantages, limitations, research challenges, and future directions in this rapidly evolving field.

II. LITERATURE REVIEW

1. Machine Learning and Deep Learning Approaches for Brain Tumor Detection

Brain tumor detection has become one of the most significant applications of artificial intelligence in medical imaging. Traditional machine learning methods initially focused on handcrafted feature extraction techniques combined with classifiers such as Support Vector Machines (SVM), Random Forest, and K-Nearest Neighbors. However, recent studies demonstrate that deep learning techniques provide superior performance in detecting and classifying brain tumors from MRI scans.

Kaur et al. (2026) emphasized the importance of early brain tumor prediction using both machine learning and deep learning techniques. Their study highlighted how deep learning models improve diagnostic efficiency and reduce manual intervention in medical imaging analysis. Similarly, Ghorbian et al. (2026) reviewed advancements in machine learning for brain tumor classification and discussed the growing adoption of convolutional neural networks (CNNs) due to their ability to automatically extract discriminative features from MRI data.

Chaudhary et al. (2026) proposed an automated brain tumor detection system using CNN architecture and achieved high detection accuracy with reduced computational complexity. Ye et al. (2026) further demonstrated that deep learning-based approaches can significantly enhance detection precision in MRI images by learning complex tumor patterns directly from datasets. Uniyal et al. (2026) also reported that advanced deep learning models outperform conventional approaches in terms of accuracy, sensitivity, and specificity.

Recent research has increasingly focused on hybrid and optimized frameworks. Shivahare et al. (2026) developed a hybrid deep learning framework capable of high-precision tumor detection and classification in MRI scans. Durinec et al. (2026) explored the optimization of neural networks using evolutionary computing techniques to improve model efficiency and detection accuracy. These studies confirm that deep learning has become a dominant approach in automated brain tumor diagnosis systems.

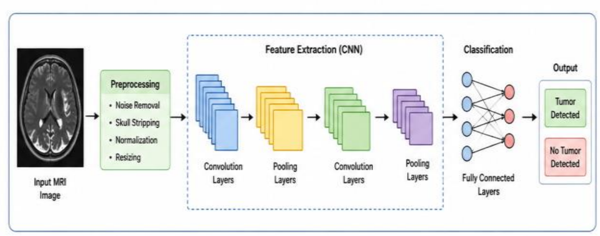

Figure 1: Architecture of CNN-Based Brain Tumor Detection System

This figure 1 illustrates the general workflow of a Convolutional Neural Network (CNN) used for brain tumor detection. It includes MRI image input, preprocessing, feature extraction through convolution and pooling layers, classification using fully connected layers, and final tumor prediction output.

2. Transfer Learning and Attention-Based Models in MRI Brain Tumor Classification

Transfer learning has emerged as an effective solution for brain tumor classification, especially when limited annotated medical datasets are available. By utilizing pre-trained models such as VGG, ResNet, EfficientNet, and DenseNet, researchers have significantly improved classification performance while reducing training time and computational cost.

Nawar and Dinar (2026) proposed an MRI-based brain tumor diagnosis framework using preprocessing pipelines combined with transfer learning models. Their research demonstrated that preprocessing techniques such as noise removal and image normalization improve model performance. Similarly, Soomro et al. (2026) applied transfer learning with a fine-tuned DeepLabv3+ model and achieved enhanced tumor detection accuracy in MRI images.

Attention mechanisms have also gained considerable importance in improving model interpretability and performance. Aiya et al. (2025) introduced an optimized hybrid deep learning model integrated with attention mechanisms and clinical explainability. Their work showed that attention modules help models focus on critical tumor regions, thereby improving classification accuracy and supporting clinical decision-making. Qasimi and Acar (2026) also utilized attention-based transfer learning models for brain tumor detection and reported improved feature extraction and localization capabilities.

Furthermore, Hussain et al. (2026) proposed the NeuroBlend-3 framework, which combines hybrid deep learning with explainable AI techniques for multi-class brain tumor detection. Their study highlighted the importance of explainability in medical diagnosis, enabling clinicians to better understand AI-generated predictions. These advancements indicate that transfer learning and attention-based approaches are highly effective for accurate and interpretable brain tumor classification.

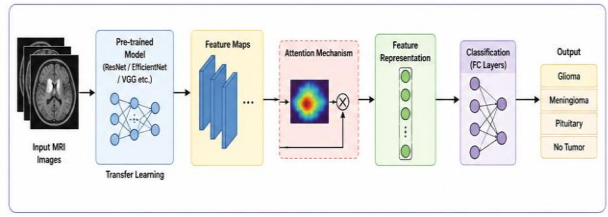

Figure 2: Transfer Learning Framework with Attention Mechanism for MRI Classification

This figure 2 represents a transfer learning-based brain tumor classification model integrated with attention mechanisms. The diagram shows the use of pre-trained networks (such as ResNet or EfficientNet), attention modules for focusing on tumor regions, feature extraction, and final tumor classification stages.

3. Emerging Trends, IoT Integration, and Challenges in Brain Tumor Detection

Recent advancements in brain tumor detection research have expanded beyond conventional CNN architectures toward IoT-enabled healthcare systems, explainable AI, and adaptive learning frameworks. Ahad et al. (2026) introduced a lightweight minimal-net CNN model designed for IoT-based brain tumor detection and monitoring systems. Their approach demonstrated the feasibility of deploying efficient deep learning models on resource-constrained devices for real-time healthcare applications.

Meruga et al. (2026) proposed the “Neuro Vision” framework, which integrates deep learning for automated tumor detection and classification. Their system showed promising results for intelligent medical diagnosis systems capable of assisting radiologists in clinical environments. Pasunoori et al. (2026) further developed a multi-scale and adaptive deep learning framework for tumor detection and segmentation, emphasizing the importance of precise tumor boundary identification in treatment planning.

Another important trend involves the integration of alternative imaging and analytical modalities.

Almomany et al. (2026) reviewed advances in artificial intelligence and thermal analysis for brain tumor detection and highlighted how multimodal approaches can improve diagnostic reliability. Prabhale and Mane (2026) also provided a comprehensive review of deep learning advancements and identified major challenges such as limited annotated datasets, high computational requirements, model overfitting, and lack of interpretability.

Despite substantial progress, several challenges remain in practical implementation. Ghorbian et al. (2026) noted that issues such as data imbalance, privacy concerns, and generalization across different MRI datasets continue to affect model robustness. Future research directions focus on explainable AI, federated learning, lightweight architectures, and real-time clinical deployment to make brain tumor detection systems more reliable and accessible.

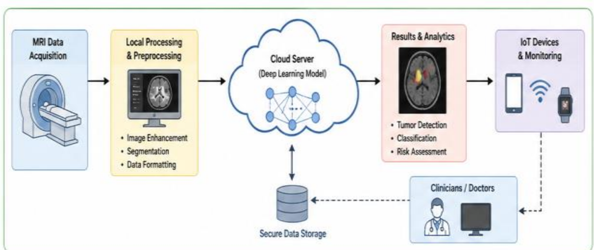

Figure 3: IoT-Enabled Smart Brain Tumor Detection and Monitoring System

This figure 3 demonstrates an IoT-based intelligent healthcare framework for brain tumor detection and monitoring. It includes MRI data acquisition, cloud-based deep learning analysis, real-time monitoring through IoT devices, and communication of diagnostic results to healthcare professionals.

Recent studies by U. Singh and co-authors have focused extensively on artificial intelligence, deep learning, machine learning, computer vision, cybersecurity, and healthcare applications. Nagar and Singh (2025) proposed an AI-powered secure soccer penalty detection and performance recommendation system, while Shakyawar and Singh (2024) developed a deep learning model for facial expression recognition in crowds. Prajapati et al. (2023) and Patel and Singh (2023) worked on gender and age recognition using deep learning techniques. Gupta et al. (2023) and Baghel et al. (2022) focused on human face mask recognition using ResNet and OpenCV-based deep learning approaches. Vishwakarma et al. (2023) introduced an EfficientNetB3-based brain tumor segmentation and detection framework, whereas Singh and Songare (2022) developed a GoogLeNet-based monkeypox detection model. Research by Ranjan et al. (2022) explored cancer prediction using Random Forest and deep learning techniques. In recommendation systems, Singh et al. (2023) proposed a job recommendation model using machine learning and deep learning, while Taiwade et al. (2022) implemented a hierarchical K-means clustering approach for friend recommendation systems. Ray and Singh (2023) applied Hybrid Task Cascade Region-Based CNN for cricket score analysis. In cybersecurity and networking, Waskle et al. (2020) proposed an intrusion detection system using PCA with Random Forest, and Nihale et al. (2020) developed an LSTM-based network traffic prediction model. Additionally, Saxena et al. (2020) presented a CNN-based glaucoma detection system, while Bamne et al. (2020) explored transfer learning-based object detection using convolutional neural networks. Rajput et al. (2023) also conducted a comparative study of cloud providers including Azure, Amazon, and Oracle based on service availability and pricing.

Table 1: Systematic Review of Literature on Brain Tumor Detection Using Deep Learning Techniques

Ref. No.	Author (s) & Year	Technique/ Model Used	Key Contribution	Limitation
1	Kaur et al. (2026)	Machine Learning & Deep Learning	Early prediction of brain tumors using AI techniques	Limited discussion on real-time implementation
2	Prabhale & Mane (2026)	Deep Learning Review	Comprehensive review of deep learning methods	Lack of experimental validation

			for tumor detection	
3	Ahad et al. (2026)	Minimal-Net CNN, IoT	Lightweight CNN for IoT-based tumor monitoring system	Limited dataset evaluation
4	Chaudhary et al. (2026)	CNN	Automated tumor detection using convolutional neural networks	Computational complexity not addressed
5	Ghorbian et al. (2026)	Machine Learning Review	Review of ML advancements, challenges, and future directions	Limited focus on real-time deployment
6	Ghorbian et al. (2026)	Machine Learning Review	Analysis of classification and diagnostic techniques	Repetition of existing methodologies
7	Almomany et al. (2026)	AI & Thermal Analysis	Review of AI models and multimodal detection methods	Thermal imaging integration still limited
8	Shivahare et al. (2026)	Hybrid Deep Learning	High-precision MRI tumor detection and classification	Requires high computational resources
9	Durinec et al. (2026)	Evolutionary Computing & Neural Networks	Optimization of neural networks for MRI analysis	Increased model training complexity
10	Aiya et al. (2025)	Hybrid DL with Attention Mechanism	Improved accuracy and explainability using attention modules	Complex architecture design
11	Nawar & Dinar (2026)	Transfer Learning	MRI diagnosis using preprocessing and transfer learning	Dependence on pretrained models
12	Meruga et al. (2026)	Deep Learning Framework	Automated tumor detection and classification framework	Limited multiclass evaluation
13	Qasimi & Acar (2026)	Attention-Based Transfer Learning	Enhanced tumor localization and classification	Requires large annotated datasets
14	Pasunoori et al. (2026)	Multi-scale Adaptive Deep Learning	Tumor detection and segmentation framework	High computational cost
15	Ye et al. (2026)	Deep Learning	High-accuracy brain tumor detection model	Lack of explainability analysis
16	Uniyal et al. (2026)	Advanced Deep Learning Models	Automated detection with improved performance metrics	Dataset generalization issues
17	Soomro et al. (2026)	Transfer Learning & DeepLabv3+	Fine-tuned segmentation model for improved detection accuracy	Model complexity and training time

18	Hussain et al. (2026)	Hybrid DL + Explainable AI	Explainable multi-class tumor detection framework	Limited real-time clinical validation

III. RESEARCH GAP

Although deep learning techniques have achieved significant improvements in brain tumor detection and classification, several research gaps still exist that limit their practical implementation in real-world healthcare systems.

One of the major challenges is the limited availability of large-scale annotated MRI datasets. Most deep learning models require extensive labeled data for training; however, medical datasets are often small, imbalanced, and difficult to obtain due to privacy concerns and clinical restrictions. This limitation affects the generalization capability of models across different hospitals and imaging environments.

Another important research gap is the lack of explainability in deep learning systems. Many CNN-based models operate as black-box systems, making it difficult for healthcare professionals to understand how predictions are generated. Although explainable AI techniques have recently gained attention, further research is required to improve transparency and clinical trust in automated diagnostic systems.

Computational complexity and high training costs also remain major concerns. Advanced deep learning architectures often require high-performance GPUs and large memory resources, making deployment difficult in low-resource healthcare settings. Lightweight and energy-efficient models suitable for real-time clinical applications are still under development.

In addition, most existing studies focus primarily on classification accuracy while paying less attention to real-time implementation, robustness, and cross-dataset validation. Many models perform well on specific benchmark datasets but fail to maintain accuracy when applied to diverse real-world MRI data.

Another gap exists in multimodal integration and IoT-based healthcare systems. Although some studies have explored IoT-enabled monitoring systems, the integration of cloud computing, edge AI, and real-time remote diagnosis remains limited. Security, privacy, and interoperability challenges also require further investigation.

Therefore, future research should focus on explainable and lightweight AI models, federated learning approaches, multimodal imaging analysis, real-time deployment, and clinically reliable systems that can support intelligent brain tumor diagnosis in practical healthcare environments.

IV. CONCLUSION

Brain tumor detection and classification using MRI images have become one of the most promising applications of deep learning in medical imaging. This review paper analyzed recent advancements in machine learning and deep learning techniques, including CNN architectures, transfer learning models, hybrid frameworks, attention mechanisms, explainable AI systems, and IoT-based healthcare applications.

The reviewed studies demonstrate that deep learning techniques significantly improve diagnostic accuracy, reduce manual intervention, and support automated medical decision-making. Transfer learning and attention-based models have shown remarkable performance in extracting meaningful tumor features even with limited datasets. Furthermore, explainable AI and IoT integration are contributing toward more intelligent, transparent, and real-time healthcare systems.

Despite these advancements, several challenges remain unresolved, including limited annotated datasets, computational complexity, model interpretability, and lack of generalization across clinical environments. Addressing these limitations is essential for achieving reliable and scalable AI-based brain tumor diagnosis systems.

Overall, deep learning continues to play a transformative role in medical image analysis, and ongoing research is expected to further enhance the efficiency, accuracy, and clinical applicability of automated brain tumor detection systems.

Future Work

Future research should focus on developing lightweight and explainable deep learning models for real-time brain tumor detection. Integration of federated learning, IoT, cloud computing, and multimodal imaging can improve accuracy, security, and remote healthcare support. Additionally, large-scale clinical validation and robust cross-dataset testing are needed to enhance the reliability and practical implementation of AI-based brain tumor diagnosis systems.

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