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Detection of Brain Tumor using Medical Images: A Comparative Study of Machine Learning Algorithms – A Systematic Literature Review

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Abstract: Background: Brain tumors are a significant global health concern impacting both adults and children. Tumors are characterized by abnormal or excessive growth resulting from uncontrolled cell division. Diagnosing brain tumors poses various challenges, including limited funding, a shortage of qualified professionals, and insufficient access to medical facilities in remote regions. Different learning techniques for detecting brain tumors have been developed due to their ease of use, cost-effectiveness, and non-invasive nature, in contrast to other invasive methods.

Methods: This research conducts a systematic literature review to explore modern trends and concepts of machine learning in healthcare, aiming to identify effective techniques for brain tumor detection. It also compares and analyzes the most efficient machine learning methods currently in use, focusing on aspects such as machine learning algorithms, image augmentation, evaluation metrics, and the sizes of datasets employed. Results: The findings indicate that non-invasive methods, such as machine learning algorithms for brain tumor detection, are cost-effective and provide quick results. Conclusions: This systematic literature review offers a technical overview, demonstrating the efficiency and effectiveness of machine learning techniques in making brain tumor detection feasible. The study utilizes deep learning and machine learning methods to comprehensively analyse diagnosis, imaging, and clinical evaluations in medical fields related to brain tumor detection.

Keywords: Classification, Artificial Intelligence, Deep Learning, Machine Learning.

I. Introduction

The International Agency for Research on Cancer (IARC) reports that approximately 126,000 people are diagnosed with brain tumors annually, with an estimated 97,000 deaths (Al-Tamimi & Sulong, 2015). Abnormal human nervous system growth poses significant health risks (Sarkar, Alahe, & Ahmad, 2023). Brain tumors are among the most severe health challenges today due to the development of uncontrolled destructive cells in the nervous system. Early detection and treatment are crucial, as brain tumors can be particularly dangerous if not addressed promptly (Krishnapriya & Karuna, 2017). The World Health Organization (WHO) identifies malignant brain tumors as destructive and fatal neoplasms with high mortality rates across all age groups (Xie et al., 2022). Annually, 9.6 million people worldwide die from brain cancer, according to the WHO (Vimala, Srinivasan, Mathivanan, Jayagopal, & Dalu, 2023). Brain tumors are a prevalent and severe condition, reducing life expectancy across genders and age groups. Early detection and treatment are essential to prevent permanent organ damage (Williams, Appiahene, & Timmy, 2023). Common symptoms include poor communication, headaches, drowsiness, seizures, cognitive and personality changes, and delirium, often due to increased intracranial pressure (Susan M. Chang, Erin Dunbar, Virginia Dzul-Church, Laura Koehn, & Margaretta S. Page, RN, 2015). Factors contributing to brain tumors include hormonal factors, nutrition, smoking, alcohol, and aspartame (Farmanfarma, Mohammadian, Shahabinia, Hassanipour, & Salehiniya, 2019). Previous research indicates that MRI features of newly predicted brain tumors are used for diagnosis and treatment planning (Dong et al., 2011). Causes include inheritance, radiation exposure, metastasis, and medical history, with symptoms such as headaches, nausea, and other standard symptoms of brain tumors and cancers (Raghavapudi, Singroul, & Kohila, 2021). Symptoms also include seizures, vision changes, headaches, hearing issues, balance problems, cognitive difficulties, and sudden mood changes like aggression and hallucinations (Elshaikh et al., 2021). Common detection techniques include MRI, X-ray, and CT scans, which are critical for early brain tumor detection and effective treatment (Biswas & Islam, 2023). Non-invasive techniques are vital in treatment processes (Rasool et al., 2022). Manual MRI diagnosis can be time-consuming and prone to errors. Deep neural frameworks automate complex medical processes, aiding healthcare professionals in diagnosis (Kuraparthi, Reddy, Sujatha, Valiveti, & Duggineni, 2021). Non-invasive, smartphone-based devices show promise for addressing healthcare concerns related to brain tumors (Jia, Shkolyar, & Laurie, 2021). Various studies have developed robust, non-invasive techniques for brain tumor detection and diagnosis, utilizing medical imaging and machine learning to make accurate predictions. This research aims to review modern trends in adapting machine learning techniques in healthcare, identifying efficient methods for brain tumor detection and diagnosis using medical images. Additionally, the study compares effective machine learning techniques regarding image augmentation, evaluation metrics, dataset size, and model accuracy. Table 1 outlines the research questions in this systematic literature review, highlighting the motivation behind these questions to guide future research towards non-invasive, robust models for brain tumor prediction and diagnosis, emphasizing the role of machine learning in classification and detection.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue IX, September 2024

Table1 Research questions underlying this systematic literature review

1. What are the most extensively used and effective machine-learning techniques for brain tumor detection using medical images?	To examine the most utilized and effective machine-learning technique for brain tumor detection with the use of medical images
2. Size of the dataset (medical images) used: (a) What dataset (images) size is used or applied for the study? (b) What are effective preprocessing techniques adapted for machine learning models in brain tumor detection?	Machine learning techniques perform better with huge dataset sizes, and huge is dataset size examined with other preprocessing techniques which includes augmentation image extraction technique.
3. What is the accuracy of machine learning techniques for brain tumor detection using medical images?	To examine the machine learning technique performance used brain tumor detection using medical images, and to evaluate the efficiency of the technique in brain tumor detection.

Several Techniques for Brain Tumor Prediction and Detection

Various techniques are used for predicting and detecting brain tumors, including Computed Tomography (CT) scans and Diffusion Tensor Imaging (DTI). For this purpose, many brain scanning systems are employed such as Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and biopsies (tissue sample analysis). However, these methods, particularly MRI, can be time-consuming and heavily reliant on the expertise of the operator (Mangla, 2022; Shohag, Aktar, Science, & Imtiaz, 2015; Ali et al., 2022; Amin, Sharif, Haldorai, Yasmin, & Sundar, 2022). MRI is the most commonly used tool for detecting and diagnosing brain tumors, yet the interpretation of MRI images can be challenging due to the complexity and variability of brain anatomy (Suchetha, Bhat, Hegde, Mallikarjun, & Karthik, 2023). In treating brain tumors, neurosurgical resection is often the first step (Vermeulen et al., 2023).

Deep learning, particularly Convolutional Neural Networks (CNNs), has shown superior performance in computer vision tasks, including medical image analysis (Miah et al., 2024). These deep-learning models continuously mine significant image features, evaluate patterns, and classify these features (Ali et al., 2022). Computer-aided diagnostics (CAD) has significantly progressed with machine learning and deep learning techniques in medical image detection (Islam et al., 2022; Anagun, 2023). Since the introduction of artificial intelligence, there has been considerable technological advancement in healthcare over the past 15 years (Williams et al., 2023). Machine learning and image processing techniques have automated processes, resulting in efficient, accurate, and reliable outcomes in disease detection, planning, and diagnosis (Kitsios, Kamariotou, & Syngelakis, 2023). Deep learning excels in complex tasks such as speech recognition, image classification, and natural language processing, making it a valuable tool for predictive analytics (Aafreen, Zarreen, Ahmad, & Razzaque, 2022).

Contributions to Knowledge

This systematic literature review makes the following contributions:

Examined 20 original papers on machine-learning techniques for brain tumour detection using medical images, providing comprehensive knowledge in this domain.

Offers a detailed analysis of medical image segmentation, including:

(a) Evaluation techniques

(b) Machine learning techniques

(c) Dataset sizes used in research

(d) Performance of the adopted ML models

Provides findings that will guide future research and development in this field.

II. Method

This narrative review critically examines and analyses the current information on the application of machine-learning techniques for brain tumour detection. The review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) standards. The PRISMA checklist was followed, and the Mendeley data repository was registered on December 12, 2019. Research articles were sourced from Research Gate, Google Scholar, PubMed, and Directory of Open Access Journals databases, covering the period from 2010 to 2024. The search included all relevant investigations, clinical tests, and image-based brain detection studies. Only English-language literature was used. Papers lacking sufficient data for outcome assessment or those not including medical images were excluded.

The paper includes figures such as a conceptual framework (Fig. 1) summarising the research sections and subsections, a summary of the search criteria (Fig. 2), and a table (Table 2) detailing the number of studies and their machine learning models.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue IX, September 2024

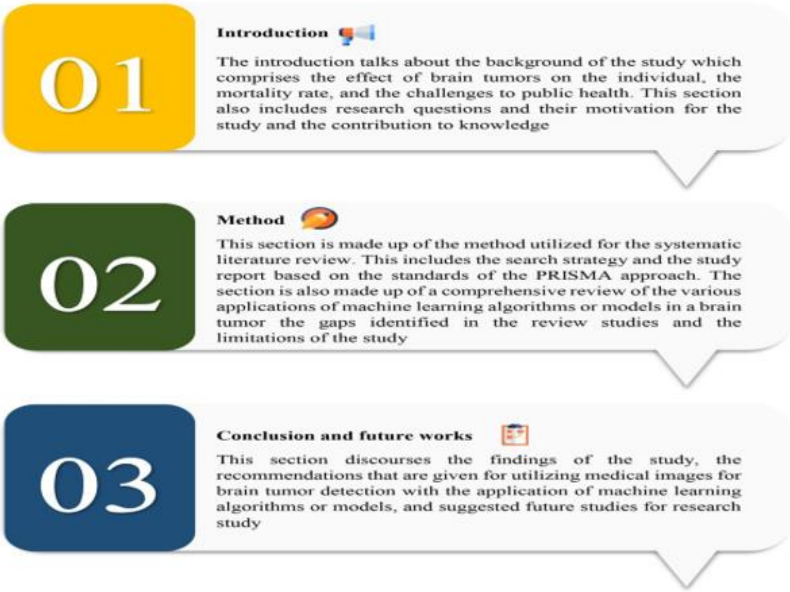

Figure 1: conceptual framework summarizing the sections/ subsections for this research work.

Applications of Machine Learning Models in Brain Tumor Detection

Artificial intelligence and deep learning are increasingly being integrated into various technological domains. In medical imaging, there has been a significant uptick in the use of AI, particularly convolutional neural networks (CNNs), which mimic the neurons in the human visual cortex (Gordon, 2021). CNNs can process vast amounts of data more quickly than humans, and in the context of brain tumors, they have demonstrated performance comparable to expert levels (Gordon, 2021). Recently, CNNs have become more prevalent in brain tumor classification due to their outstanding performance and extremely high accuracy in research environments (Xie et al., 2022).

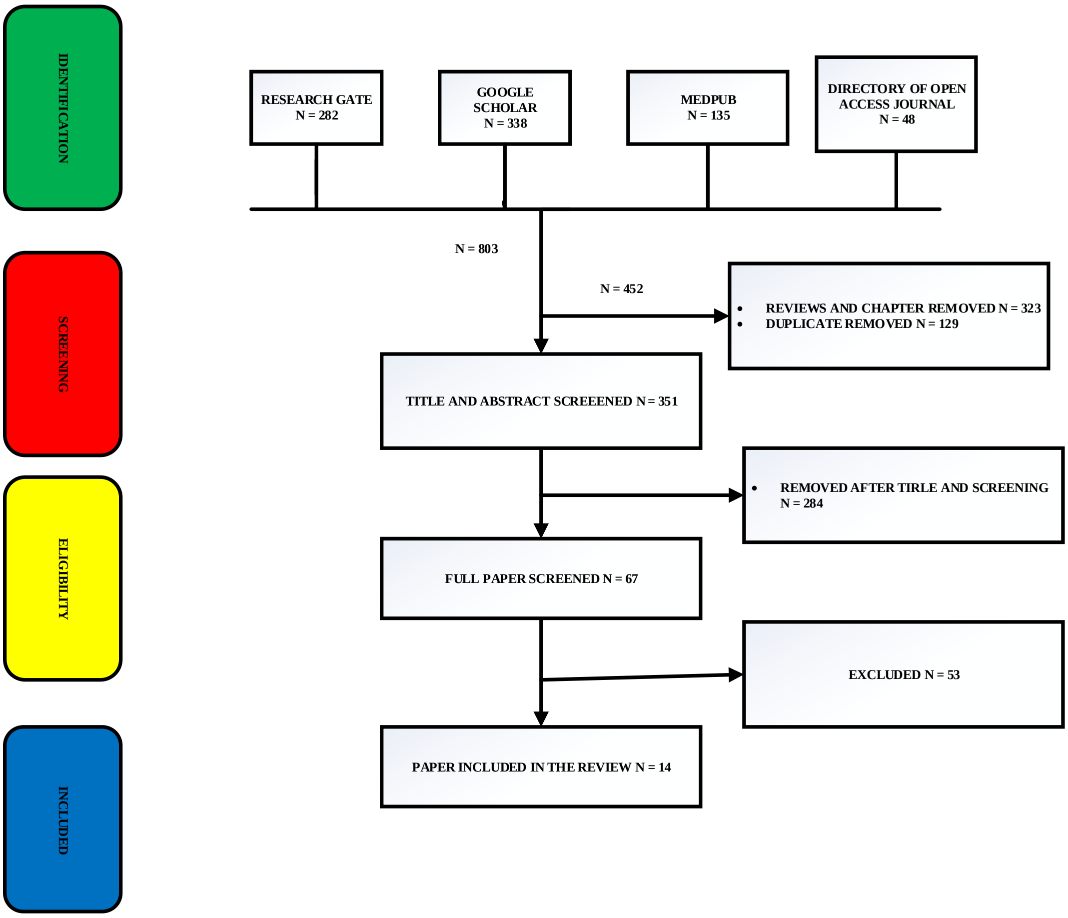

Figure 2: The flow diagram, based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), illustrates the review process, detailing the examination of papers, identification of duplicates, and removal of redundant papers. Additionally, it outlines the screening of abstracts and titles, as well as the inclusion and exclusion of full papers following the search across different databases.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue IX, September 2024

Table 2: This table presents the performance metrics of various machine learning techniques used for brain tumor detection, along with detailed information about each model. Furthermore, it provides an overview of current studies focusing on machine learning models and their respective summaries.

Publisher	Dataset size	Performance evaluation			Ref/ No	Dataset/ Source	Model / Technique	Image argumentation
		Highest Accuracy	sensitivity	specificity				
Journal Of Information Systems Engineering And Business Intelligence	2969	High 96.0	98.0	95.71	(Biswas & Islam, 2023)	Figshare	Alex Net, =93.05%	No
							Google Net= 89.39	
							VGG16=85.24	
							Vgg16=99.28	
Electronic Research Archive	2065	High 99.45	X	X	(Swarup, Singh, Kumar, & Pandey, 2023)	Radhamadhab Dalai,	Google Net =98.95 Alex Net=99.45	yes
Frontier In Human Neuroscience	253	High 99.48	98.76	X	(Krishnapriya & Karuna, 2017)	Kaggle	VGG19 =99.48 VGG16=99 ResNet50 =97.92 Inception V3 =81.25	yes
Journal Of Online And Biomedical Engineering (IJOE)								
	253	High 96.10	X	X	(Azshafarrah, Komar, Mahamad, Saon, & Mudjanarko, 2023)	Kaggle	Alexnet =96.10 VGG =94.6 ResNet50 =91.56	yes
Journal Of Positive School Psychology	3064	High 93.29	x	x	((Samee et al., 2022)	Br35H And Figshare	dense Net =93.29 ResNet149 =71.88	No
Entropy (M D P I)	1426	High 98.1	x	x	(Rasool et al., 2022)	Kaggle	google net+ s v m 98.1	yes
							Google Net fine-turning 93.1	

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IIETA	253	High 98.28	x	x	(Kuraparthi et al., 2021)	Kaggle & Brat’s	Alex Net=91.38	yes
							VGG16 =94.83	
							ResNet50=98.28	
							Alex Net CNN+ Bayes Net=88.75	
Hindawi (Journal Of Sensor)	3600	High 98.20	x	x	(Sarkar et al., 2023)	Kaggle	Alex Net CNN+SMO=98.15	no
							Alex Net CNN+NB =86.25	
							Alex Net CNN +RF=98.20	
Hindawi (Computational	3064	High 99.7	x	x	(Kibriya et al., 2022)	Online	Alex Net=98	yes
Intelligence And							Google Net=97.6	
Neuroscience)							ResNet18=98	
							ResNet18 +SVM+KNN=99.7	
Indonesian Journal Of Electrical Engineering And Computer Science	3000	High 95.8	X	X	(Abbood, Shallal, & Fadhel, 2021)	ROI	Alex Net 82.7 VGG16 =,86.4 Google Net=91 RestNet= 95.8	no
International Journal Of Academic Engineering Research (IJAER)	10000	High 99.88	x	x	(Almadhoun & Naser, 2022)	Kaggle	Inception 99.88 VGG16=99.86 Mobile Net =88.96 Res Net 98.14	yes
conference paper	27	Promising 66.6	x	x	(Al-ayyoub, Alabed-alaziz, & Darwish, 2012)	ROI	NN=66.6 J48=59.2 NB=59.2 Lazy-IBk =62.9	no
Medical Informatics And Decision-Making	3264	High 93.29	high 88.0	x	(Saeedi, Rezayi, Keshavarz, & Kalhori, 2023)	Br35H And Figshare	Dense net 169 =93.29 Res Net=7.	yes
Original Research Adult Brain	237	High 87.0	x	x	(Gutta, Acharya, Shiroishi, & Hwang, 2024)	ROI	GB= 64 CNN= 87.0 SVM =56 RF =58	no

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIII, Issue IX, September 2024

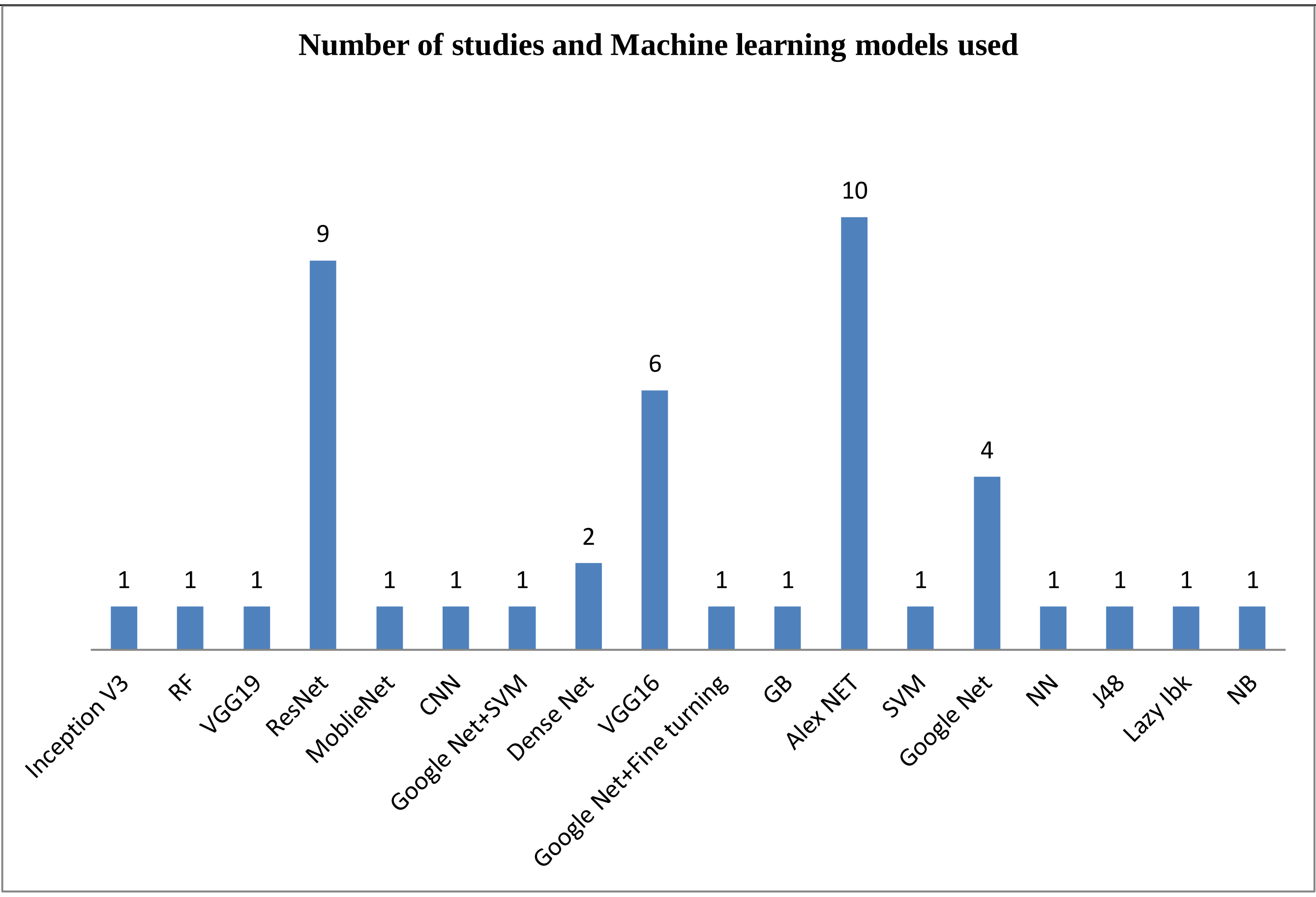

Figure 3 illustrates the number of studies corresponding to each machine learning model listed in the table.

Various machine learning techniques are utilized in the detection of a wide range of diseases, facilitating the discovery of relationships and predictions based on specific features. The architecture of Alex Net comprises a diverse series of average pooling convolutional units. ResNet demonstrates improved accuracy when abundant data with increased parameters and layers are available.The total number of filters equals the size of the output feature, and doubling the total number of filters results in halving the future maps to maintain time complexity on each layer. ResNet effectively resolves the issue of accuracy degradation.

Traditionally, brain tumor treatment and detection involve surgical resection and radio- and chemotherapy, yet these methods are limited by challenges such as difficulties in surgical resection and cellular damage from therapies. The significant impact of brain tumor statistics has prompted researchers to explore diverse techniques in brain tumor detection, aiming for effective and efficient classification, diagnosis, and therapy.

Deep learning techniques currently outperform conventional machine learning techniques and are predominantly applied in various healthcare delivery systems, including medical image analysis. Convolutional Neural Networks (CNNs), a deep learning approach frequently employed in medical imaging problems, are predominantly used in the detection of brain tumors and medical image analysis due to their high accuracy performance in research contexts.

Artificial Neural Networks (ANNs) consist of interconnected processing neurons, serving as mathematical equivalents to biological neural systems. ANNs are widely utilized in medicine, particularly in brain tumor detection, due to their high accuracy in image recognition and ability to discern complex data relationships.

Convolutional Neural Networks (CNNs) represent a class of deep learning methodologies predominantly utilized for data analysis and visualization, requiring minimal preprocessing strategies. CNNs have found extensive application across various domains, including natural language processing, image classification, and medical imaging. Presently, machine learning, particularly deep learning techniques, is adept at discerning patterns within medical images, as it excels in extracting and synthesizing knowledge from data rather than relying solely on scientific texts. Machine learning techniques have evolved into potent tools for medical applications, playing a crucial role in enhancing performance across diverse fields such as tissue segmentation, diagnosis, and molecular identification (Amin et al., 2022; Saeedi et al., 2023).

In a study conducted by Saad, Suliman, Bitar, and Bshara (2023), a hybrid model was employed for brain tumor detection using MRI images, achieving an accuracy of 96.6%. Similarly, MRI images were utilized in another study conducted by Earning, Ahmed, Ibrahim, Ahmed, and Hassan (2023) and Sarkar et al. (2023).

Bahadure, Ray, and Thethi (2017) employed medical image segmentation from Region of Interest (ROI) in brain tumor detection using MRI. The authors utilized wavelet transform to segment brain tumor images before applying machine learning techniques for tumor stage classification through feature vector analysis and region segmentation. CNNs demonstrate remarkable efficacy and efficiency in handling image datasets due to their fundamental principles allowing convolutional operations between kernels and

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image feature extraction (Aafreen et al., 2022). In this context, Hossain, Shishir, Ashraf, and Alpha (2019) proposed a CNN architecture for brain tumor detection consisting of 5 layers, 32 convolutional filters of 3*3, and 3 channels, achieving an accuracy of 97.87%. Kuraparthi et al. (2021) introduced a deep neural network for brain tumor detection, employing CNN models such as Alex Net, ResNet50, and VGG16 on Kaggle and Brats publicly available datasets. The proposed technique achieved accuracies ranging from 98.28% to 99.0% with and without data augmentation, respectively, with the ResNet model. Miah et al. (2024) investigated brain tumor detection using clustering and softmax for MRI image analysis. The performance of CNN was compared with Decision Tree (DT) and Radial Basis Function (RBF), with the softmax classifier demonstrating the best performance, achieving an accuracy of 99.52% on test data**.**

Gaps identified in the reviewed literature

(Al-ayyoub et al., 2012) (Krishnapriya & Karuna, 2017)(Acharya & Shiroishi, 2021) (Xu et al., 2022)(Azshafarrah et al., 2023) tilized relatively small datasets for predicting brain tumors. For example, (Al-Ayoub et al., 2012) employed only 27 MRI images for brain tumor detection. Although smaller datasets can suffice for brain tumor detection, techniques like transfer learning and validation (Menze et al., 2015; Deepak & Ameer, 2019) can enhance their effectiveness.

Data augmentation is a commonly employed technique to enhance the generalization of deep learning models. Smaller dataset sizes often lead to overfitting, where the model memorizes the training data (Nalepa, Marcinkiewicz, & Kawulok, 2019). (Biswas & Islam, 2023) conducted research using the CNN-SVM technique for brain tumor detection with a large dataset but without applying data augmentation, while (Gutta et al., 2024) utilized a sizable dataset obtained from Region of Interest. Conversely, (Swarup et al., 2023) employed a large dataset but utilized only two convolutional neural networks for brain tumor detection. Additionally, (Shohag et al., 2015), (Kibriya et al., 2022), and (Miah et al., 2024) utilized much larger datasets for detection but did not specify the origin or source of the datasets.

However, (Almadhoun & Naser, 2022), (Sarkar et al., 2023), and (Gutta et al., 2024) addressed these dataset gaps, as outlined in section 1.1. The study by (Saeedi et al., 2023) provided comprehensive details on data collection, including the source, preprocessing techniques, and introduction after image augmentation, along with the machine learning models used and their respective performance in the research study. Moreover, none of the research papers included in the studies of various models addressed time complexity, which is crucial for detecting and diagnosing diseases as it helps determine the efficiency of the applied model on the dataset.

Limitations of this study

This study encompasses a wide array of designs and data types, primarily drawn from published articles. It emphasizes utilizing medical images for brain tumor detection. However, it neglects materials not published in reputable peer-reviewed scientific journals, as these are not indexed and accessible through the databases searched.

III. Conclusion And Future Works

The utilisation of machine learning in medical image detection, such as for brain tumors, is cost-effective and highly efficient. Timely and accurate decision-making is crucial for medical practitioners, and machine learning excels in this domain. A study conducted by Naveen et al. (2021) achieved an accuracy of 95.42% in brain tumor detection using a convolutional neural network (CNN), while Abdelgawad (2023) reported a slightly lower accuracy of 93.3% with CNN. Tasci et al. (2022) employed a soft-voting-based ensemble technique on TCGA and CGGA datasets, yielding accuracies of 87.606% and 79.668%, respectively. However, Abbood et al. (2021) outperformed Tasci et al. (2022) with an accuracy of 95.58%.

Furthermore, Samee et al. (2022) achieved a 93.29% accuracy with a neural network, slightly lower than Anaraki et al.'s (2018) CNN accuracy of 94.2%. Similarly, Samee et al. (2022) achieved a 99.51% accuracy, lower than Reszke and Smaga's (2023) 92.59%. A. Rohini et al. (2023) utilized a multimodal hybrid CNN for brain tumor detection, obtaining an accuracy of 99.43%, slightly lower than Anagun's (2023) 99.85% with CNN. In Figure 2, representing the total number of papers used in the research studies, Alex Net emerged as the most utilized model (10 papers), followed by VGG16 and ResNet with 9 and 6 papers, respectively. Google Net was utilized in 4 studies, Dense Net in 2, and other models in single studies. Although the evidence supports the application of machine learning in brain tumor detection, the most effective model type remains uncertain.

Data augmentation is crucial in medical imaging to mitigate biases from uneven class distribution. It enhances the performance of machine learning models, facilitating efficient tumor detection and aiding in effective medical treatments. However, a significant limitation lies in using small datasets, which perform better and prevent overfitting when augmented with larger datasets.This study aims to illustrate the effectiveness of machine learning models in disease detection through a comprehensive analysis of medical images. It underscores the importance of utilizing machine learning to reduce costs and enable informed medical decisions.

The systematic literature review evaluated various machine learning models for brain tumor detection, analyzing dataset sources and augmentation techniques. Alex Net emerged as the most frequently used model, followed by ResNet and VGG16. The study recommends augmenting medical image datasets to improve accuracy and mitigate overfitting.

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