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TRENDS AND CHALLENGES IN BRAIN TUMOR DETECTION USING MRI: A REVIEW OF AI AND ML-BASED APPROACHES

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ABSTRACT

Brain tumors are truthfully one of the scarier things out there and are still a major reason behind illness and death worldwide. That's why catching them early and knowing precisely where they are is super imperative on the off chance that specialists need to treat them right and give patients a much better shot. The traditional method of interpreting MRI scans is laborious and time-consuming. It is for the foremost portion manual and takes a though, and let's confront it, presently and after that it reasonable isn't that reliable or fast.

To create the things a bit more astute (and less dull), we've put it together this framework that the inclines on AI and machine learning to do the overwhelming lifting when it comes to the detecting and the classifying brain tumors using the MRI scans. In addition, it is not just basic automation we are talking about – solid image pre-processing, feature picking magic, and models that know what to look for. The system is laid out to spot and sort out differing tumor sorts like Gliomas, Meningiomas, and those dubious Pituitary tumors. What really makes it tick is the way it grabs a bunch of features—stuff like texture, shape, and even deep-level data— using CNNs trained on MRI images. Then, for classifying the tumors, we tested out different models—like SVMs and Random Forest—and compared them to deep learning ones. Spoiler alert: deep learning rather crushed it, with better accuracy and more reliable results overall. The big takeaway? MRI scan data plays a huge role here, especially since it captures all those tiny spatial patterns and details that traditional methods might miss. And inside the

conclusion, this whole setup may be a honest to goodness game-changer for doctors—speeding things up, diminishing the riddle, and giving way more exact comes almost without having to go full manual every time.

KEYWORDS: Brain Tumors, MRI Scans, Artificial Intelligence (AI), Machine Learning (ML), MRI Scan, Feature Extraction, CNNs.

1. INTRODUCTION

There are several types of the brain tumors, all the changing in behaviour and the treatment. Some of the most frequent ones are gliomas (tumors based on supportive cells in the brain called glial cells), meningiomas (tumors that develop in the membranes that cover the brain and spinal cord) and pituitary tumors (growths that form in the pituitary, affecting hormone levels in the body). Knowing the type of the tumor is the important in the decisive treatment.[1]

1.1 Overview of Brain Tumors and Importance of Early Detection

Tumors in the brain: Brain tumors are a deadly disease which involved not only the child but the adults of all ages one year. These tumours can be place pressure on the significant areas of the brain, subsequent in issues that affect the body, intelligence and emotions.

The chances of survival for patients diagnosed with brain tumors are influenced by several critical factors, such as the type of tumor, its size, and its precise location within the brain. Due to these variables, detecting brain tumors at an early stage is essential, as it can significantly improve treatment success and patient prognosis.

To identify brain tumors, healthcare professionals and typically rely on the combination of methods. These include the comprehensive physical and neurological taxations to the evaluate symptoms, surgical procedures like the biopsies to examine tissue samples, and the advanced imaging knowledge. Fig. 1. Showing global brain tumor. Magnetic Resonance Imaging (MRI) is the most widely used imaging tool in this process because it provides highly detailed images of the brain's internal structures without using harmful radiation.[1]

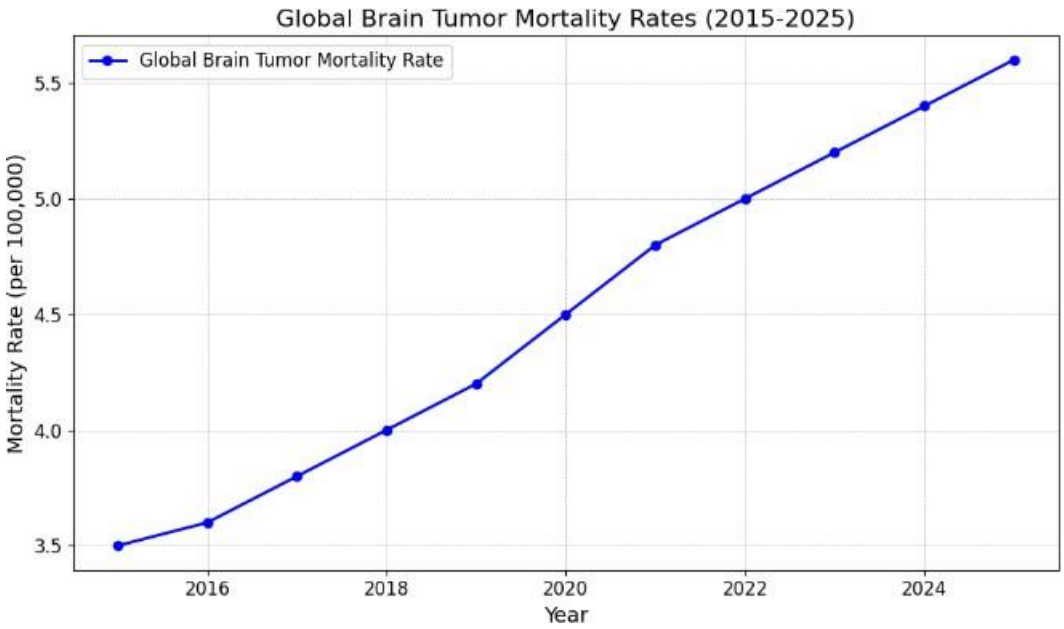

Fig. 1: Global Brain Tumor Mortality Rates (2015- 2025).

Contempt the advantages of MRI, accurately interpretation these scans requires specialized knowledge. Manual review of the MRI images can be used time-intensive and the prone to oversight, potentially delaying diagnosis and the treatment. To address these types of challenges and there is emergent to the interest in using automated systems and the artificial intelligence tools to assist radiologists in recognizing abnormalities more quickly and the reliably.[3] Table 1 showing the mortality rate and observation of last 10 years.

Table 1: Mortality rate and observation over the year (Last 10 Years).

Year	Mortality Rate (per 100,000)	Observation
2015	3.5	To the standard year with least mortality within the extent.
2017	3.8	Continuous rise: likely due to late location or constrained get to medications.
2019	4.2	To proceed with increment, highlighting the developing worldwide burden.
2021	4.8	To soak rise from 2020, imaginably connected to the symptomatic delays or the infection spreading.
2025	5.6	The most of the elevated anticipated rate, Demonstrating for pressing to the pressing need for early discovery frameworks.

1.2 Challenges in Traditional Methods

The traditional approaches for detecting and brain tumors often for they rely on the manual interpretation of the MRI scans for experienced radiologists. While this is method remains a cornerstone of the diagnostic practices, it is not with or without its

limitations. To the process of visually analysing MRI slices can be highly challenging, primarily because brain tumors vary greatly in shape, size, texture, and intensity across different patients. This is visual variability, or heterogeneity, often results in the inconsistent or subjective the interpretations among the medical professionals, and especially in the borderline or complex is cases.

Furthermore, the labour-intensive examination of the MRI information be situated as it were labour-intensive but furthermore expends a critical sum of the time. Radiologists must carefully look at different cross-sectional pictures to distinguish and classify anomalous locales, which increment the probability of oversight or demonstrative delay, especially in high- volume clinical situations. The convolution of the involved, mutual through the plausibility of the weakness or cognitive preference, makes the whole handle of the defence less to human mistake, possibly in this Distressing, the unconditional and convenient of the theory.[3]

For these challenges, they emphasise the pressing requirement for the improvement and integration of computerised discovery frameworks within clinical workflows. Such a frameworks, frequently fuelled by machine learning and fake insights, to have the potential to dissected expansive volumes of imaging information quickly and with tall accuracy. By the helping of the radiologists in the identifying the abnormal designs and disintegrating tumors for productively, these inaugurations can altogether for exaltation demonstrative uniformity, to diminish turnaround time, and eventually development understanding care and results. For these challenges they emphasize the pressing require for the improvement and integration of the computerized discovery frameworks within the clinical workflows. Such a frameworks, frequently fuelled by machine learning and fake insights, to have the potential to dissected expansive volumes of imaging information quickly and with tall accuracy.[4]

1.3 Role of AI and Machine Learning in Medical Imaging

Artificial Intelligence (AI) and Machine Learning (ML) have made a big difference in the field of therapeutic imaging, advertising, and medical devices, helping to improve accuracy and efficiency in diagnosis. Among the different ML strategies, profound learning models, especially Convolution Neural Systems (CNNs), have appeared exceptional potential within the location, classification, and investigation of brain tumors. These models are designed to learn from a wide range of imaging data, making

them very useful for tasks like recognizing patterns and interpreting images. AI and ML are smooth tools that can switch large amounts of imaging data rapidly, approximately that would take a human proficient much longer to do. Their dimensions to prepare and analysed high- dimensional information certifications them to identify unremarkable designs and discrepancies that can be as well complex or swoon for radiologists to diagnose through visual review alone. This makes them important apparatuses in recognizing early- stage tumors and in separating between tumor sorts with a tall degree of precision. By curtailing human oversight and reorganization the diagnostic process, AI- powered systems clutch great capacity in improving diagnostic consistency and associate clinical decision-making in neuro- oncology.[5]

1.4 Objective of the Review

The purpose of this review is to examine and find a system that can detect and categorize brain tumors using AI and machine learning techniques, with a focus on 3D MRI images. The system intention should be to improve symptomatic accuracy and reduce the dependence on manual translation, and it gives a quick, solid, and mechanized strategy for tumor discovery.

2. TYPES OF BRAIN TUMORS

The brain is basically separated into three primary districts: the cerebrum, cerebellum, and the system uses AI and machine learning to find and sort brain tumors by where they are located and their characteristics. It flinches by conduct the less dangerous types first and then interchanges on to the supplementary careful ones. It plays a key role in planning engine measurements such as adjustments, pose, promenading, and common body expansions. Both the cerebrum and cerebellum comprise of an external lean gray matter cortex, internal white matter, and little, profoundly found gray matter districts.[6]

The cerebellum is a large part of the brain located at the back, and it is connected to the brainstem. It is mindful for directing basic body dimensions, counting development, tangible preparation, circulatory action, breath, and reflex activities. The brainstem is at the bottom of the brain and acts as a link between the brain and the spinal cord. The brain tumor is the mentions an unusual and for the uncontrolled development of the cells inside to the brain. Tumors are grouped according to where they are found, the type of tissue they come from, and whether they are benign or malignant. They can also be classified as primary, which means they start in the brain, or secondary, which means they spread

from other parts of the body to the brain. The World Wellbeing Organization (WHO) has recognized and classified over 120 sorts of brain tumors. These classifications help show how quickly the tumor is growing and how likely it is to spread.[7]

Brain tumors are also rated on a scale, with Grade I being the least aggressive, like meningiomas and pituitary tumors, and Grade IV being the most aggressive. These ratings tell how fast the tumor is growing and how likely it is to spread. Among the grown- ups, the foremost the commonly analyzed brain tumors are Gliomas, which are assisted isolated into the low-grade Gliomas (LGG) and the high-grade Gliomas (HGG). Concurring to WHO classification, LGGs incorporate Review I and II tumors, whereas HGGs incorporate Review III and IV. Knowing the exact type of tumor is very important for choosing the best treatment and avoiding mistakes in diagnosing symptoms. A comprehensive diagram of different brain tumors and sorts is the summary in Table 2.

Table 2: Summary of different types of brain tumor.

Category	Type	Description
Nature	Benign	For Less aggressive and grows slowly
	Malignant	The Life- threatening and the rapidly expanding
Origin	Primary Tumor	Originates in the brain directly
	Secondary Tumor	For this tumor develops in another area of the body like lung and the breast before migrating to the brain tumor
Grading	Grade I	The Basically, regular in shape, and they develop slowly
	Grade II	For Appear strange to the view and grow more slowly
	Grade III	These tumors grow more and quickly than grade II cancers
	Grade IV	For Reproduced with greater rate
Progressio n Stage	Stage 0	For Malignant but do not invade neighbouring cells
	Stage 1	For Malignant and quickly spreading
	Stage 2	
	Stage 3	
	Stage 4	To Malignancy invades every part of the body

2. LITERATURE REVIEW

Various experts have studied brain tumor using machine learning and deep learning methods, especially looking at MRI scans. Different ways of dividing data, such as fluffy rationale, clustering calculations, support vector machines (SVMs), and convolutional neural systems (CNNs), have been used to improve the accuracy of demonstrations.

A 2024 paper by Usharani Bhimavarapu and others looks at a mixed method for finding and categorizing brain tumors using MRI images. It coordinates the picture pre-processing, division, and classification procedures to move forward with demonstrative precision. Strategies such as K-means clustering, local development, and crunch division are exploited to separate tumor locales. The importance of pre- processing steps, like noise removal and normalization, is highlighted as they help improve the overall performance. This combination of classical and deep learning strategies demonstrates promising results in accurately identifying and classifying brain tumours from MRI scans.[8]

In another study from 2025, Nahiduzzaman and others suggested a combined method that uses Graph Neural Networks and Random Forest to find weaknesses in smart contracts. This method uses GNNs to remove semantic and assistant markers from control flow charts, which helps in better understanding of contract code. These are the highlights are at that point that the classified utilizing a subjective approach for forest illustration, promoting the advanced is the interpretability and vigor. Evaluated on the massive dataset of savvy contracts, they illustrate the scolded routine techniques in terms of precision and the Explainability. This work highlights the potential of joining profound learning with classical machine learning for secure and interpretable smart contract examination.[9]

I think about by Md. Driss Lamrani1 et al., 2022, found that convolutional neural systems (CNNs) work well in classifying medical images, especially for identifying brain tumors. One considers proposed a CNN-based model that viably recognized between tumor and non-tumor brain MRI pictures. The show utilized numerous convolution and pooling layers taken after by thick layers, accomplishing over 95% precision. The approach emphasized pre- processing strategies, counting picture normalization and resizing, to improve execution. The study shows how deep learning can help in early tumor detection and suggests future work with bigger datasets and better models, like transfer learning, to improve results. Boost precision and unwavering quality.[10]

A consideration by Ananta Raha, et al., 2024, later headways in brain tumor detachment have emphasized the constraint for exactness and computational efficiency. A novel approach coordinating Region-based Convolution Neural Systems (RCNN) with an altered U-Net design to improve detachment execution while lessening complexity. This is the crossover to demonstrate the localization quality of RCNN and the pixel-wise

accuracy of U-Net, accomplishing moved forward exactness with fewer parameters. The plan centres on optimizing asset utilization, and construction it appropriate for real-time applications. Tests illustrate the prevalent execution compared to conventional strategies, to best bit the potential of lightweight profound to learning designs in therapeutic picture to the examination.[11]

A think around by the Ananta Raha, et al., 2024 Progressions, for the attention-based significant learning to the methods has shown up basic for the ensure into the invigorating picture examination. A remaining commitment is the outfit contemplation instrument proposed for brain tumor classification, which synchronizes numerous contemplation modules to upgrade highlight representation and classification exactness. This approach efficaciously captures spatial and channel-wise conditions, driving to make strides symptomatic accomplishment. To think about the additional for stresses the strength of the outfit shows over dissimilar for the MRI datasets, indicating it's for the generalizability. Such techniques highlight the potential of coalescing outfit learning with consideration techniques to boost demonstrate accuracy, especially in complex restorative imaging errands like tumor location and classification.[12]

A consider by Kamleshwar Dubey., et al., 2024, Future advancements in machine education have altogether upgraded the exactness and aptitude of brain tumor location. An inclusive investigation by the creators for the highlights different machine learning calculations, for the counting back trajectory machines, for the convolutional neural systems, and for the philosophical learning models, which have given the idea for the agreement in therapeutic for the picture examination. The paper emphasizes the significance of pre-processing, emphasizing extraction, and classification strategies in making symptomatic accuracy strides. It witnesses the qualities and obstacles of existing styles, reimbursement the way for future inquiry about edge representations and real-time emotional contexts to bolster clinical decision-making.[13]

3. EXISTING APPROACHES FOR TUMOR DETECTION

Afterwards, most of them have used machine learning models to identify and classify brain tumours. Important models, like CNNs, have been widely studied because they can learn and remember different features from messy image data. Some methods focus on 2D slices of MRI images, while others try to work with 3D volumes, as shown in table 3. Techniques like transfer learning, where models already trained on other tasks

are adjusted for tumour classification, have also been looked into.[14]

Table 3: Summary of different types of brain tumor.

S.No.	CNN-based Approach	Advantage	Limitation
1	Deep Fusion Model (ResNet152V2 + modified VGG16 CNNs) (arxiv.org/abs/2406.19690)	Achieved 98%+ accuracy - Gradient preservation and quantization reduce model size	Due to the low dataset diversity, and there is a risk of overfitting.
2	Optimized CNN with hyper parameter tuning (mdpi.com/diagnostics)	High validation accuracy - Improved over traditional CNN models with automated optimization	To Hyper parameter tuning for the computationally expensive - Depends heavily on data quality
3	Multi-Layer Customized CNN (Frontiers in Computational Neuroscience)	Designed for better adaptability in different MRI settings - Competitive accuracy (~86%)	Still not real-time - Needs the validation on the arge- scale datasets
4	Deep Learning + Sine-Cosine Optimized VGG16/VGG19 CNN (MDPI Bioengineering)	Accuracy up to 97.8% on benchmark datasets - Enhances edge and tumor region detection	For optimization adds complexity - Sensitive to dataset quality
5	Multimodal Hybrid CNN with VGG-19 (BMC Bioinformatics)	99.43% accuracy - Combines multiple imaging features and CNN layers effectively	The dataset used was relatively small (407 images) - Generalization might be limited

4. DISCUSSION

This review talks about many different ways that people use to split and categorize brain tumors. It also covers the different ways to measure how well these methods work, from old techniques to machine learning and deep learning methods. Figure 2 illustrates the number of research papers reviewed between 2015 and 2025.[14]

Grown-up ways of unbearable brain tumors in images mostly relied on modern image processing methods, such as region-based techniques and unsupervised machine learning.

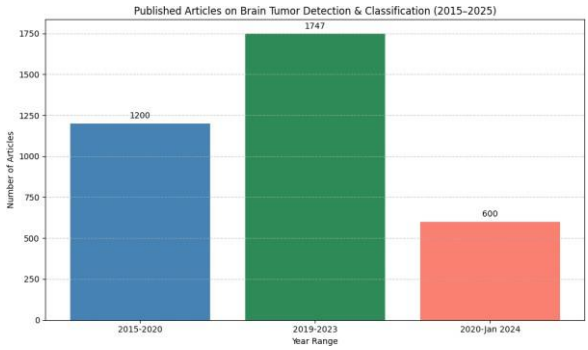

Fig. 2: Published Articles on Brain Tumor Detection & Classification (2015- 2025).

We can say that these systems often thrashed with images that were raucous or not very clear. They similarly be conditional a lot on the starting environments or setup. Later, people commenced using unsupervised learning approaches comparable Fuzzy C- Means (FCM) and K-Means clustering to assemblage image pixels into different categories. Even though these methods worked better, they unmoving had problems with being affected by noise and not so long as accurate enough segmentation results.

To address these issues, more up-to-date approaches use directed ML models for pixel-wise arrangement in division. These models often use highlight building to find important features of tumor areas, which are then used to train the classifiers. And, to the post processing steps for the habitually coordinated to improve the division's consequences.

Thoughtful learning has presented an end-to- end pipeline for tumor and division utilizing the use of MRI filters, viably streamlining the method by robotizing highlight the extraction. These Deep learning-based strategies are capable of learning tumor-specific highlights specifically from the information, in this method diminishing reliance on handcrafted highlights. In any case, despite their focal points, the down-to- earth sending of these models still postures a few contests, especially concerning transferability and computational prerequisites.[15]

5. CONCLUSION

Brain tumors speak to anomalous tissue development inside the brain that can disturb ordinary neurological work. In restorative imaging, a key objective is to extricate important and exact data from pictures utilizing computational calculations whereas minimizing mistakes. The ordinary workflow for brain tumor discovery and classification

utilizing MRI incorporates four essential stages: preprocessing, division, including extraction, and classification. Computerizing these forms can altogether progress symptomatic precision, illuminate treatment choices, and upgrade quiet observing. Making a totally robotized framework for clinical application is still a complex assignment, primarily because of the tumors' different highlights, unpredictable shapes, and changing visual designs. Computer-aided design (CAD) frameworks. Associated with the traditional region-growing and the methods and simple machine learning for the models of the deep learning approaches for which they perform better and informative because of the strong and fully utilize their ability to learn from data. Even though they have to be lot of potential, there is still a need for general and the dependable systems that can be used in different way of medical situations. Also, 45 study factors were involved in the consideration, focusing on the using machine learning and deep learning to the classify brain tumors with MRI data. The study also discusses ongoing challenges and limitations that prevent CAD systems from being widely used in clinical practice. In addition, it highlights key components influencing correct classification and joins a layout of openly available MRI datasets and their person sources.

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