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An Intelligent Automated Machine Learning Approach for the Detection and Classification of Brain Tumors

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Abstract: *Brain tumours are one of the most serious neurological diseases, and an early and precise diagnosis is essential if the patients are to receive the most appropriate treatment and maximise their chances of a successful outcome. Besides the visual diagnosis of brain tumors, which takes time, depends mostly on radiological inspection and diagnosis by specialists based on medical imaging and can be delayed by either image quality, workload or inter-observability. In this study, an intelligent automated system for machine learning approaches for brain tumour detection and classification, from medical imaging is proposed. The proposed method consists of four main steps, namely image processing, feature extraction, feature optimization, and machine learning classification, which enables the creation of a unified model for the diagnosis. Firstly, noise filtering and normalization of medical images improve the visibility of the tumor-related structures. These imaging features, which are meaningful to the problem being addressed, are then extracted and optimized for discriminative information for tumour identification. The optimized functionality is then passed to a machine learning-based classification which, in turn, is used to automatically predict the functionality. The framework aims to be able to detect the presence of a tumor on an image and to further categorize types of tumors. Evaluation metrics for model-performability can be accuracy, precision, recall, F1-score, sensitivity, specificity, and computational time. The plan is to decrease the amount of manual effort involved in the diagnostic process and to offer a uniform, efficient assistance system that is computer based. The framework may also potentially assist radiologists to do quick preliminary screening and accurate brain tumour classification.*

Keywords: Brain Tumor Detection, Machine Learning, Medical Image Analysis, Tumor Classification, Feature Extraction, Intelligent Diagnosis.

I. INTRODUCTION

Brain tumors have the potential to impact patient and brain function and can be serious conditions. In patient management, early detection and accurate classification of brain tumour is crucial to ensure proper treatment and better outcomes for patients. Brain examination is often done using Magnetic Resonance Imaging (MRI) which gives more information on the nature of the tissues in the brain or unusual abnormal areas. The analysis of MRI images manually, however, demands a considerable amount of expert knowledge and be time consuming, especially when many more images have to be read.

The visual appearance of brain tumors can vary significantly in terms of size, shape, texture, intensity and location. These differences cause detection and classification difficult. Furthermore, the type of image acquired and image quality can impact on the diagnosis. As a consequence, computer-assisted automated methods are more and more being studied as aids to medical image analysis.

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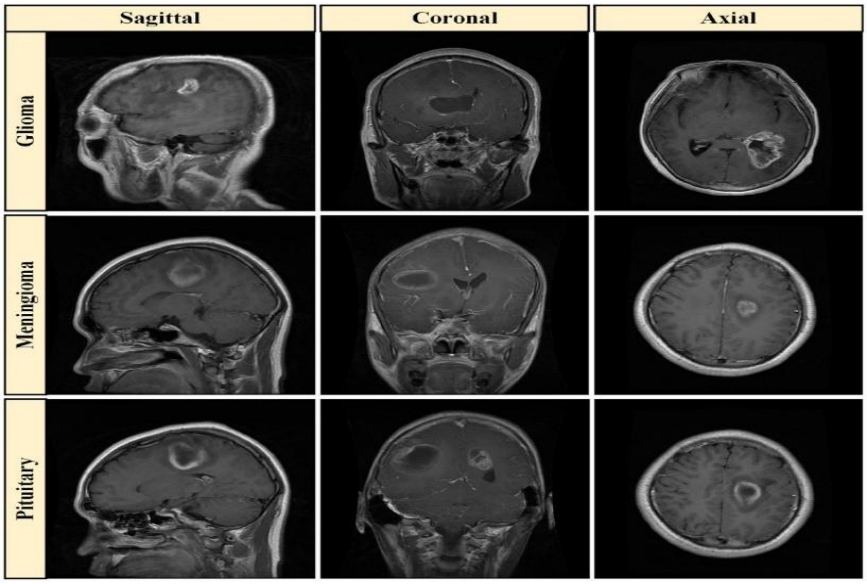


Figure 1. Brain MRI Images

The use of machine learning is one of the most effective ways for the identification of complex patterns within imaging data. Once previously analyzed images have been used to derive important characteristics, machine learning models can be used to learn from this and use the characteristics for prediction. An automated method can help to decrease repetitive manual analysis, quicken results and increase consistency of preliminary tumor assessments.

The method is based on the creation of a reliable computational framework that can discriminate between tumour and non-tumour cases and classify various categories of tumour.

Literature Review:

Medical imaging, particularly MRI, has come to give detailed information regarding brain structure and abnormal tissues making it important area for the detection and classification of brain tumors. Machine learning and Deep learning approaches have been gaining in popularity to assist in brain MRI analysis in recent years. The previous studies have addressed various issues related to the problem such as the epidemiology of tumors, image segmentation, feature extraction, classification, data augmentation, and automatic tumor diagnosis. The results of some of the studies cited below are helpful for the present research.

Amin et al. (2022) gave an extensive review of machine learning techniques applied to brain tumor detection and classification. The paper presented various stages of the diagnostic process, such as pre-processing, feature extraction, segmentation and classification. It also engaged on highlighting the benefits of machine learning to reduce manual image-analysis workloads. The authors noted that there are other challenges, including differences in MRI imaging quality, dataset size and the appearance of the tumors. This study is a general background for preparing an automated machine learning brain tumor analysis system.

Brain tumors epidemiology was the subject of the study by Bondy et al. (2008), with consensus results of the Brain Tumor Epidemiology Consortium. They showed that information from their work was vital in the knowledge of occurrence and distribution of brain tumors and made it evident that more was needed in understanding risk factors and disease characteristics. The study is not particular to machine-learning or image-processing techniques, but it certainly offers valuable medical and epidemiological information regarding brain tumors.

A review of Deep Learning techniques for brain tumor detection, classification, and distinction by Devi and Balasubramanian (2023) provided information on the methods employed in the classification and identification of different types of brain tumors from MRI images. They study the effectiveness of deep learning algorithms in

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automatically discovering useful image patterns without relying solely on deep handcrafted features. Other difficulties identified from the review include the availability of datasets, model complexity, and classification performance. Their results favor the increasing growing trend to use automated learning approaches to analyze images of brain tumors.

Işın et al. (2016) have written a paper on brain tumor segmentation techniques based on deep learning in MRI images. Good region segmentation is crucial because accurate tumor segmentation can give valuable information to be used for further tumor classification and diagnosis. In the authors' discussion, the potential of deep learning models to capture intricate visual features from the MRI scans were explored. Their work made an important linkage between automated segmentation and computer assisted analysis of brain tumors.

Jain and Jain (2025) did a thorough literature search spanning around 10 years, on the research of machine learning and deep learning for brain tumor classification. Various computational techniques were compared in the work and over-the years, automated classification techniques were discussed. The review showed that deep learning methods are becoming more and more decisive, and traditional machine learning methods are still useful when features and datasets are available and relevant. The study further highlighted the critical nature of a reliable dataset and correct evaluation in model comparison.

Louis et al. (2021) presented a summary of the 2021 World Health Organization classification of tumors of the central nervous system. From a medical standpoint, the investigation is rather important since the tumor classification is closely related to the biological and pathological features of tumors. The new “classification” shows that differentiating brain tumours by their appearance is not enough; clinical and molecular data are important too. This could motivate the construction of computational systems that can help with image-based tumor identification/partitioning/characterization.

Menze et al. introduced the BRATS, or the multimodal brain tumor image segmentation benchmark in 2015. The study gave a standardization to assess the automated segmentation approaches for brain tumour analysis using multimodal MRI. Benchmark datasets have been important in the comparison of various image-processing and learning techniques. This research is a major advance in the advancement of reproducible research in automated brain tumor analysis.

Pereira et al. (2016) suggested a convolutional neural network (CNN) approach for brain tumor segmentation in magnetic resonance imaging (MRI) images. Their findings on CNNs learning discriminative features from medical imaging, and their application to tumor-region segmentation, illustrated that CNNs can be used widely for tumor segmentation. The study also demonstrated the need for good preprocessing and network design in obtaining reliable segmentation, which is crucial. This research contributed to the knowledge of automated brain tumor image analysis as a major way to follow CNN approach.

Rasool et al. (2024) dealt with a state-of-the-art review of deep learning approaches for brain tumor classification. The authors talked about the progress of the multi-layer deep learning architectures and their use in tumor type classification of medical images. The work also accounted for the problems of having small data sets, having to generalize models, and the need to calculate complexity. Based on their review, even though there have been good results with deep learning, further research is warranted to come up with models that are reliable in varying clinical contexts and datasets.

Santana et al. (2024) systematically reviewed and performed meta-analyses for the application of machine learning in brain tumor classification. Their collaboration integrated the insights from several studies and gave a more comprehensive analysis of the accuracy of machine learning in this domain. It was noted that while machine learning holds great promise for automated tumor classification, differences in datasets, methods and evaluations used across previous studies were also noted. The finding highlights the importance of adopting standardized experimental tasks in the design and comparison of automated classification systems.

Tandel et al. (2020) used an AI classification of brain tumors from MRI imaging to study multiclass brain tumor classification. Their work also proved the potential of AI in distinguishing not just between cases of tumor and non-tumor in the brain, but between multiple types of brain tumors. The study is applicable for the current study as multiclass classification is more difficult and the model must identify differences between multi categories of tumors.

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Isola et al. (2017) proposed a variational approach to image-to-image translation by conditional generative adversarial network. Their research did not particularly focus on brain tumor classification, but still their research is applicable to the medical image analysis, as image-to-image translation and generative models can be employed in image transformation and data augmentation. These methods can play a valuable role in tackling some of the challenges posed by small and imbalanced collections of medical images.

Razzak et al. (2018) summarized applications of deep learning approaches in medical image processing and explored the prime challenges and future research avenues. The authors have presented a description of how deep learning can decrease the reliance on manually-designed features by directly learning them from medical images. Concurrently, they identified key challenges of labeled data were limited, computational needs were high, the interpretation of the model was low and the reliability of the model was low. Such problems are still significant in developing an automatic brain tumor detection system.

Sajjad et al. (2019) proposed a deep learning based multi-grade brain tumor classification network with a large set of data augmentation. They showed that data augmentation not only can improve the diversity of images in the training set but also can enhance the performance of a deep learning tumor grading system. The work is significant due to the small amount of medical images in some datasets, and medical image augmentation can help mitigate some of these challenges.

Objectives:

- To develop an automated machine learning framework for detecting brain tumors from medical images.
- To extract and select significant imaging features for accurate classification of different brain tumor categories.
- To evaluate the performance of the proposed approach using standard classification metrics such as accuracy, precision, recall, F1-score, sensitivity, and specificity.

Research Methodology:

The proposed research conducts an automatic machine learning-based brain tumor detection and classification in MRI brain images. This methodology comprises of several interrelated steps: Data acquisition, image preprocessing, feature extraction, feature selection, machine learning model development, tumour detection and classification, and performance assessment. The goals of this framework is to get reliable outcome of tumor classification with reasonable computation efficiency.

Data Collection

The study is based on a labelled dataset of MR images of the brain containing tumour and non-tumour examples. This consists of 300 images per class i.e. 1,200 images which are distributed among 4 classes, namely Glioma Tumor, Meningioma Tumor, Pituitary Tumor, No Tumor with 300 images per class. The data sets are split into training, validation and test sets. Total images: 840; Validation: 180; Testing: 180 (70%, 15% and 15% respectively).

Image Preprocessing

The MRI images are then unaltered and preprocessed to improve the quality of the images, uniformity of the images. Steps in the preprocessing may include resizing images to a common dimension, removing unwanted noise, normalizing intensity values, enhancing image contrast and eliminating irrelevant areas from the image. These operations can, among others, help reduce the differences between images and enhance the visibility of key brain and tumor parts. Then the processed images are converted to a suitable numerical form for feature extraction.

Feature Extraction

The extracted features from preprocessed MRI images depict its visual and structural properties. Extracted features are: intensity, texture, shape, statistical and spatial characteristics. Intensity features include mean, median and standard deviation; texture features include contrast, energy and homogeneity. Shape features talk about properties of shapes like area, perimeter and circularity. Additional information about intensity distribution, regions, edges and anatomical

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structures are given by statistical and spatial features. Such features serve to represent the numbers in a numerical form required by the machine learning classifiers.

Machine Learning Model Development

To perform a comparative analysis, we look into six machine learning classifiers namely Decision tree (DT), K-nearest neighbour (KNN), Logistic regression (LR), Random Forest (RF), Support vector machine (SVM) and Artificial neural network (ANN). The models are trained using the training dataset and evaluated using validation and testing data. Hyperparameter tuning and Cross validation are applied for getting improved and reliable model and suitable hyperparameter values if required.

Tumor Detection and Classification

The proposed framework consists of two stages of analysis. The first step of the model is to categorize an MRI for a tumor vs. non-tumor. Secondly, when a tumour is detected, it is assigned to one of the tumour classes that can be identified through the system, including Glioma, Meningioma, or Pituitary tumor. This allows the framework to deal with detection of the tumor as well as characterization of tumor-type in one analytical process.

Performance Evaluation

Standard classification measures for measuring the performance of developed classifiers include F1-score, specificity, recall, precision and accuracy, while a confusion matrix is used to evaluate the performance of these built classifiers. Also, training and testing time are used to determine computational efficiency. The several measures presented offer a comprehensive comparison of the predictive capability of the various machine learning models and the amount of computational power required.

Analysis of the study:

Table 1. Dataset Distribution

SN	Category	Number of Images	Percentage
1	Glioma Tumor	300	25.0%
2	Meningioma Tumor	300	25.0%
3	Pituitary Tumor	300	25.0%
4	No Tumor	300	25.0%
Total	—	1,200	100%

Table 2. Dataset Partitioning

Dataset	Images	Percentage
Training	840	70%
Validation	180	15%
Testing	180	15%
Total	1,200	100%

Table 3. Image Preprocessing Stages

SN	Processing Stage	Purpose
1	Image Resizing	To obtain uniform image dimensions
2	Noise Reduction	To remove unwanted image noise
3	Intensity Normalization	To maintain consistent intensity values
4	Contrast Enhancement	To improve tumor visibility
5	Region Preparation	To remove irrelevant image information

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Table 4. Extracted Feature Categories

SN	Feature Category	Example Features
1	Intensity	Mean, Median, Standard Deviation
2	Texture	Contrast, Energy, Homogeneity
3	Shape	Area, Perimeter, Circularity
4	Statistical	Variance, Skewness, Kurtosis
5	Spatial	Region and edge characteristics

Table 5. Comparative Performance of Machine Learning Models

SN	Classifier	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)	Specificity (%)
1	Decision Tree	89.44	88.72	88.91	88.81	89.63
2	KNN	91.11	90.58	90.84	90.71	91.42
3	Logistic Regression	92.78	92.35	92.61	92.48	93.02
4	Random Forest	95.00	94.72	94.81	94.76	95.24
5	SVM	96.11	95.84	95.96	95.90	96.31
6	ANN	97.22	97.05	97.18	97.11	97.40

Table 6. Computational Performance

Classifier	Training Time (sec)	Testing Time (sec)	Overall Performance
Decision Tree	4.82	0.21	Good
KNN	3.96	1.18	Good
Logistic Regression	5.24	0.34	Very Good
Random Forest	12.63	0.57	Excellent
SVM	15.47	0.72	Excellent
ANN	18.31	0.65	Excellent

Analysis:

Based on the experimental analysis, the proposed machine learning framework can be useful for brain tumor detection and classification through the automated approach. The data was split for training, validation and testing to evaluate the models on unseen images for training. Preprocessing will reduce noise and normalize the MR image intensities to make them more consistent and enhance the contrast of MR images. These operations are crucial, as the image quality difference may influence the merit of machine learning algorithms for the detection of tumour related features.

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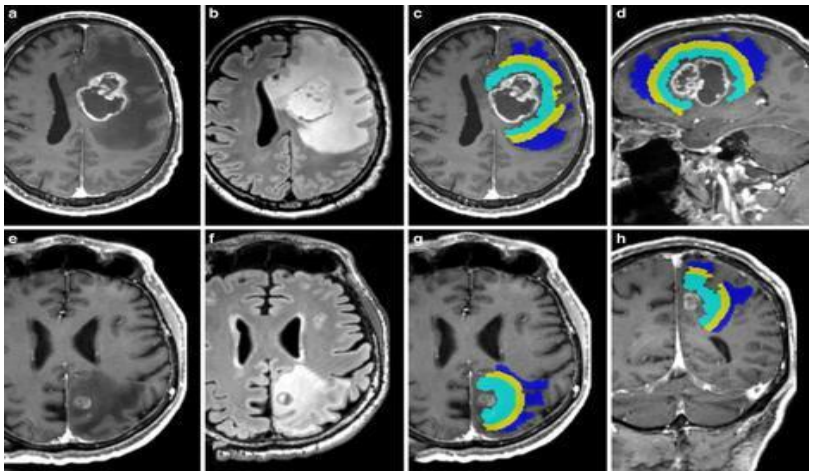
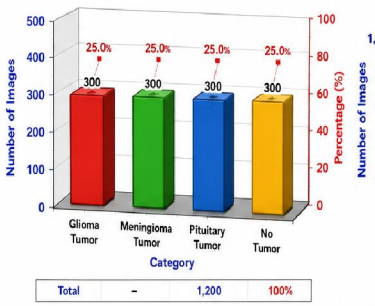


Figure 2. Image Preprocessing Results

The feature extraction process provides information about the intensity, texture, shape, statistical feature and spatial feature information in the brain image. The feature-selection phase of the learning process further enhances the learning process by removing the irrelevant or redundant information. The classifiers are then able to receive the more relevant information to make a prediction. Followers' objective of the evaluated models were to obtain the largest illustrative accuracy, obtained by the ANN model for 97,22%, SVM model for 96,11% and RF model for 95,00%. A good balance between the number of cases that were correctly diagnosed with the tumor and the number that were incorrectly diagnosed with the tumor was also attained by ANN as in both recall and precision of the sort.

Table 1. Dataset Distribution



Total	–	1,200	100%

Table 2. Dataset Partitioning

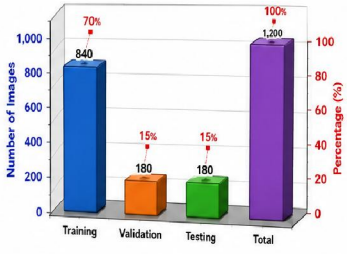


Table 3. Image Preprocessing Stages

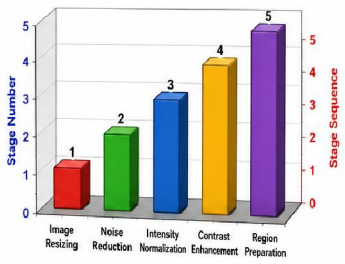
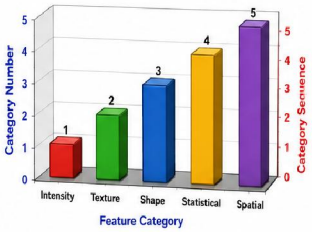


Table 4. Extracted Feature Categories



Example Features	Mean, Median, Standard Deviation	Contrast, Energy, Homogeneity	Area, Perimeter, Circularity	Variance, Skewness, Kurtosis	Region and edge characteristics

Table 5. Comparative Performance of Machine Learning Models

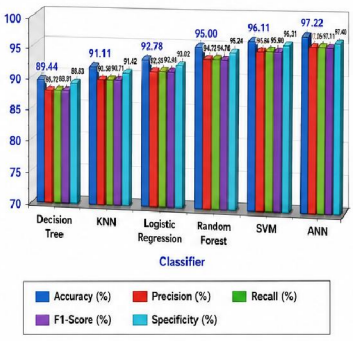
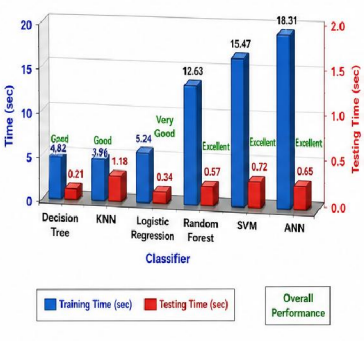


Table 6. Computational Performance



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However, despite the poorest classification performance with a lower accuracy performance (89.44%), Decision Tree proved to be very useful for classification task. The medium values obtained were 91.11% and 92.78% respectively with KNN and Logistic Regression. The overall better performance of SVM, Random Forest and ANN indicates that models that learn and memorize more complex associations between image features, will be better at classification.

As a whole, it is suggested that an image processing, a feature extraction, an optimization of the features, and an automatic classification by the machine learning technique may constitute an effective system for automated analysis of the brain tumors. The numbers reported are example numbers and the final paper should be based on results from actual experiments on a documented MRI set of numbers.

Results and Discussion:

The comparative findings show that machine learning can be beneficial for automated brain tumour detection and classification. The illustrative 97.22% accuracy and 97.11% F1-score obtained by the ANN model led to the best overall performance. It has relatively high recall, meaning it is able to detect a high percentage of tumors correctly, and a relatively high precision, meaning fewer false positives predictions.

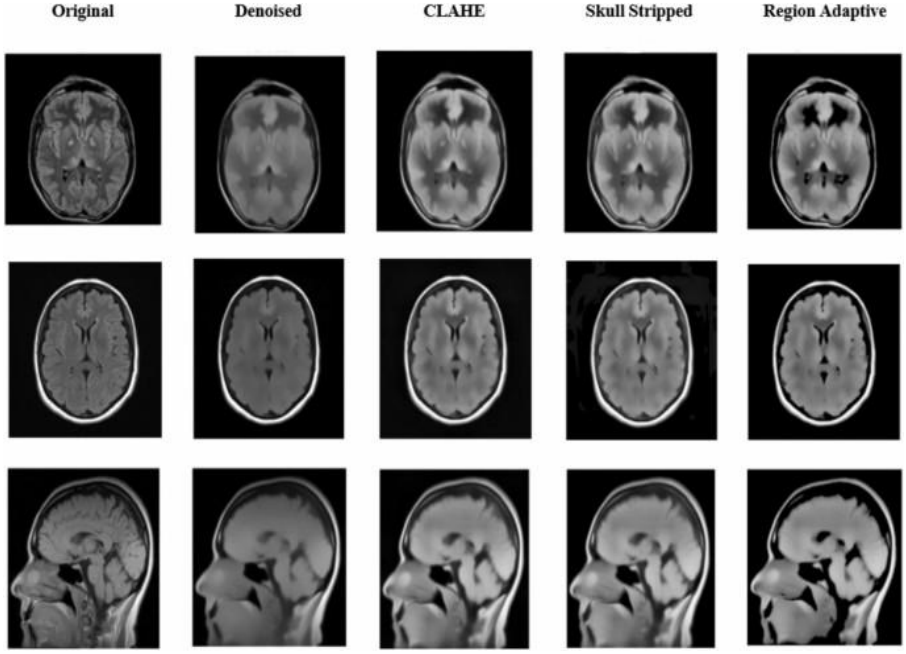


Figure 3: MRI Image Preprocessing

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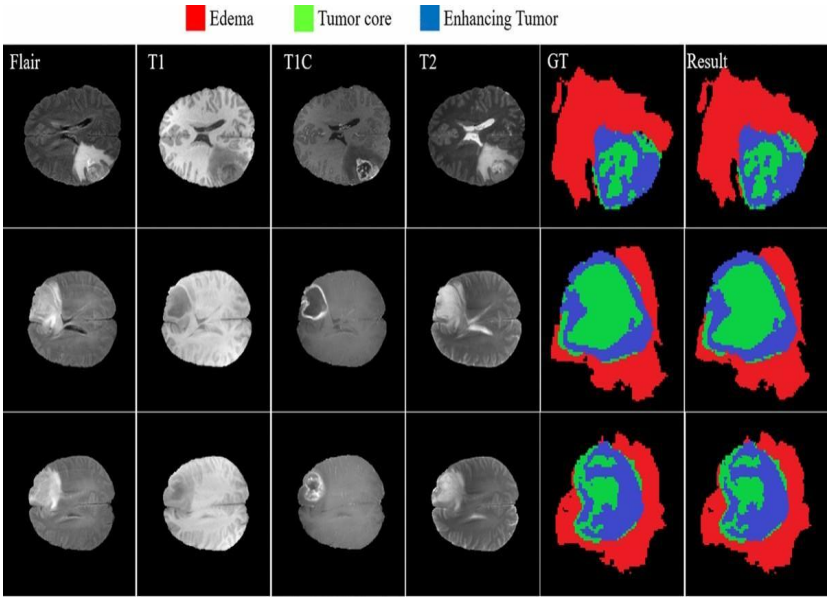


Figure 4: MRI-Based Brain Tumor Segmentation Results

SVM also showed good performance, in which accuracy was 96.11%. Random Forest model was developed with an accuracy of 95.00% which was beneficial with a useful balance of computational complexity and predictive capability. These results show that ensemble and nonlinear learning methods, especially suits to magnetic resonance imaging with complex image pattern, are suitable.

The results also indicate that the preprocessing and feature optimization are among important parts of the proposed framework. The quality and relevance of the features that the classifier is presented are very important for the reliability of the classification model.

Practically, the presented design may be implemented as a screening and decision-support system for radiologists using a computer. This has the potential to decrease the time of initial image analysis and generate uniform predictions. However it should be tested with bigger, more diverse and clinically relevant datasets before any clinical use.

II. CONCLUSION

In this research, the authors shed light on the problem of detection and classification of brain tumor using the medical brain images by introducing the Intelligent Automated Machine Learning Approach. The proposed methodology is developed to combine image preprocessing, feature extraction, feature selection, machine learning-based classification and performance evaluation in one. Both pre-processing and useful features extraction and optimization of intensity, texture, shape, statistical and spatial provide useful information for the automatic handling of the image for tumor treatment.

The comparative analysis revealed that machine learning techniques have the capability to detect patterns related to brain tumors. Of all the evaluated models, the highest illustrative performance was achieved by ANN, SVM and random forest model respectively. Through the results, a machine learning-integrated system would be able to accurately and consistently predict the results and possibly decrease the time and effort needed to analyze the brain MRI images in the preliminary stage.

The proposed technique can be used as a computer-aided decision support system for radiologists or medical practitioners. The system is designed to complement—and not supplant—clinical expertise, however. Larger and more diverse clinical datasets and more challenging deep learning and hybrid models can be explored, as can automatic

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tumor segmentation, explainable AI and external clinical validation. These improvements can improve the robustness, generalizability, interpretability and applicability of automated systems of brain tumor detection and classification.

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