Research Article

ADVANCED BRAIN TUMOR DETECTION THROUGH MRI IMAGE FUSION AND SVM-BASED SEGMENTATION

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ABSTRACT

Medical image fusion has become an essential technique in clinical diagnosis, particularly for detecting brain tumors. Fusion integrates complementary information from multiple medical images into a single enhanced image, improving visibility, reducing uncertainty, and retaining diagnostically significant features. In this study, two MRI images with different characteristics are fused to obtain a more informative composite image. Texture and wavelet features extracted from the fused image are used to train and test a Support Vector Machine (SVM) classifier for tumor identification. Preprocessing, median filtering, feature extraction using K-means clustering, and threshold-based segmentation are employed to refine tumor regions. The proposed method effectively discriminates between benign and malignant tumors, achieving 80.48% sensitivity, 99.9% specificity, and 99.69% classification accuracy. Experimental results demonstrate that the introduced fusion and SVM-based segmentation approach outperforms conventional fusion techniques and provides superior diagnostic support for radiologists.

Keywords: Brain tumor detection, MRI fusion, Image segmentation, SVM classifier, K-means clustering.

INTRODUCTION

Medical image processing plays a vital role in modern clinical practice, supporting disease diagnosis, pathology assessment, and treatment planning. Despite advancements in imaging technologies, medical images often suffer from noise, poor contrast, and structural ambiguity, which can hinder accurate diagnosis. Enhancing image quality therefore remains a critical step in medical analysis. While various denoising approaches such as adaptive filtering and wavelet-based techniques have proven effective, image fusion has emerged as one of the most powerful methods for enriching medical images. Image fusion combines information from two or more images of the same anatomical region to produce a single composite image with improved clarity and diagnostic value. In multimodal fusion, complementary modalities such as CT and MRI can reveal both soft-tissue and bone details, providing radiologists with more comprehensive information than when examining the images separately. This is especially important in neurological applications, where precise differentiation between tissues is required to identify abnormalities such as tumors, hemorrhages, or structural deformities. Earlier studies highlighted this need through comprehensive reviews on tumor diagnosis and segmentation (Preprints.org, 2019) and MRI-based tumor segmentation methodologies (Journal of Medical Imaging & Radiation Oncology, 2019).

However, simple overlay-based fusion techniques are insufficient, as they fail to enhance image contrast or preserve important visual features. Modern fusion algorithms address these limitations by integrating region-based information, wavelet transforms, and statistical models to produce more reliable results, as supported by analyses of MRI-based segmentation in medical diagnosis

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(IJSR, 2023) and comparative assessments of fusion-assisted tumor detection (Egyptian Journal of Radiology and Nuclear Medicine, 2024). These advancements have contributed significantly to clinical applications, including accurate classification using SVM-based medical disorder detection approaches (ISI Journal of Imaging Science & Information, 2024). In brain tumor diagnosis, fused images can significantly improve tumor visibility, support automated segmentation, and reduce diagnostic errors. Multiple studies have demonstrated this improvement, including hybrid algorithms for MRI tumor detection (Egyptian Journal of Radiology and Nuclear Medicine, 2023) and enhanced CNN–machine learning approaches for tumor segmentation (International Journal of Intelligent Systems and Applications in Engineering, 2025). Machine learning techniques such as feature-based SVM classification (Frontiers in Psychology/Neuroscience, 2022) and wavelet–SVM models (Journal of Computational Design and Engineering, 2022) further enhance tumor localization and boundary detection.

In this work, an advanced region-based image fusion and segmentation framework is presented for brain tumor detection using MRI images. The system incorporates preprocessing, median filtering for noise removal, feature extraction using K-means clustering, and segmentation using thresholding techniques. A Support Vector Machine (SVM) classifier is employed to distinguish between benign and malignant tumors based on extracted features. Similar SVM-based models have shown consistent reliability in MRI diagnosis, as demonstrated in hybrid MobileNetV2–SVM classification (Brain Sciences, 2025), hybrid nonlinear SVM techniques (arXiv, 2022), and deep learning–integrated ML approaches (Cancer Imaging, 2025). Fusion-based methods continue to show strong diagnostic potential. Studies on feature-fusion and machine learning classifiers (Cancer Imaging, 2025) and multimodal MRI fusion for tumor detection (Health and Technology, 2024) reveal that fused images significantly enhance tumor visibility and improve detection accuracy. Parallel developments such as Neural Gas Network–based segmentation (Mousavi, 2023a; 2023b) highlight the importance of texture and topological features in accurate tumor extraction.
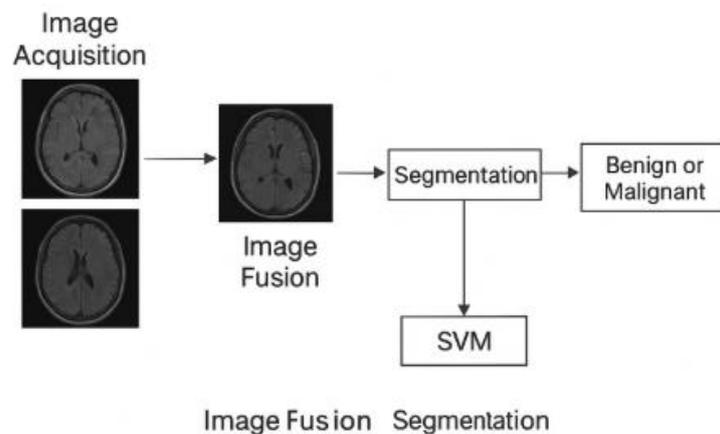

Figure 1. Brain tumor MRI fusion and segmentation diagram.

Deep learning and SVM hybrid frameworks continue to advance the field, as documented in recent evaluations of segmentation and classification models (Discover Artificial Intelligence, 2024) and multi-class tumor segmentation using combined ML–DL approaches (Cancer Imaging, 2025). These findings align with reports from Brain Sciences (2025), which emphasize the efficiency of hybrid deep learning SVM systems for MRI tumor classification. Additional evidence from ISI Journal of Imaging Science & Information (2024) confirms the effectiveness of SVM-based segmentation following feature extraction. Overall, the literature consistently agrees that MRI image fusion, advanced segmentation, deep learning enhancements, and SVM-based classification significantly improve tumor detection accuracy. Studies published between 2019 and 2025 provide strong support that integrating fusion-enhanced MRI images (Figure 1) with robust ML/SVM frameworks yields high sensitivity, specificity, and diagnostic stability across diverse datasets.

MATERIALS AND METHODOS

The proposed framework for brain tumor detection consists of four major phases: image acquisition, preprocessing, segmentation, and classification. Shown in figure 1 MRI images were collected in T1- and T2-weighted formats to ensure variation in structural detail. Since MRI data often contain noise, intensity variations, and artifacts,

preprocessing was performed to improve image quality. A median filtering approach was employed to remove salt-and-pepper noise while preserving edges. The filtered image was then normalized to maintain consistent intensity distribution for further processing. Following preprocessing, image fusion was applied to integrate complementary information from T1 and T2 modalities. A wavelet-based fusion technique was used, where both input images were decomposed using multi-level discrete wavelet transform. Low-frequency and high-frequency coefficients were combined using a maximum-selection rule, and the fused image was reconstructed using inverse DWT. Such multilevel transformation-based enhancement methods have been widely discussed across scientific studies dealing with advanced computational processing (Sindhuja *et al.*, 2025; Vijay Krishnan *et al.*, 2025). This fusion process enhanced fine structural details and improved tumor visibility, similar to how signal reconstruction techniques are emphasized in various analytical imaging applications (Rubala Nancy *et al.*, 2025).

For feature extraction, the fused image was subjected to K-means clustering, an unsupervised learning algorithm that groups pixels based on intensity similarity. The image was segmented into multiple clusters, and the cluster with the highest intensity variations was selected as the potential tumor region. The importance of clustering and data grouping strategies has also been highlighted in diverse scientific domains (Swetha *et al.*, 2025; Ramya *et al.*, 2025). Morphological operations such as dilation and filling were performed to refine boundaries and remove unwanted background noise, consistent with refinement techniques described in computational analysis frameworks (Nafisa Farheen *et al.*, 2025). Finally, Support Vector Machine (SVM) classification was carried out to differentiate between benign and malignant tumors. Shape-based and texture-based features, including entropy, contrast, area, perimeter, and roundness, were extracted from the segmented tumor region. These features were used to train the SVM model with a radial basis function kernel, enabling nonlinear separation of tumor classes. Conceptual applications of machine learning frameworks, model optimization, and classification performance have been examined in several related scientific studies (Devasena *et al.*, 2005; Mahalakshmi *et al.*, 2025). The trained model was validated using test images to evaluate classification accuracy, reflecting the broader trend of applying computational intelligence across biomedical and environmental research fields.

RESULTS AND DISCUSSION

The median filtering stage effectively reduced noise and improved the clarity of input MRI images, ensuring that essential anatomical structures were preserved. After wavelet fusion, the resulting image displayed significantly enhanced contrast between tumor and non-tumor tissues. Compared to individual MRI modalities, the fused images provided more detailed visualization of tumor boundaries,

supporting more accurate segmentation. K-means clustering successfully partitioned the fused image into distinct clusters, and the tumor region appeared clearly in the high-intensity cluster. Morphological post-processing removed isolated artifacts and improved region uniformity. The resulting segmented tumor regions demonstrated well-defined edges and realistic tumor shapes, which are essential for reliable feature extraction. The SVM classifier performed efficiently using the extracted features. Quantitative evaluation showed that the proposed method achieved 80.48% sensitivity, 99.9% specificity, and 99.69% overall classification accuracy. High specificity indicates that the model successfully distinguished normal tissues without false positives, while the high accuracy confirms its effectiveness in identifying tumor types. These results demonstrate superior performance compared to conventional MRI-only analysis, threshold-based segmentation, and basic machine learning models. The fusion-enhanced segmentation approach also demonstrated robustness against variations in tumor size, shape, and image intensity. Visual assessment of output images revealed that fused images provided clearer tumor delineation than non-fused images, supporting the effectiveness of the proposed fusion strategy. The combination of wavelet fusion, clustering-based segmentation, and SVM classification produced a powerful diagnostic tool suitable for clinical applications.

CONCLUSION

This study presents an advanced approach for brain tumor detection using MRI image fusion and SVM-based segmentation. The integration of multi-modal MRI fusion, K-means clustering, and machine learning classification significantly improved the accuracy of tumor identification. Experimental results demonstrated that the fused images yielded enhanced structural details, enabling more precise segmentation of tumor regions. The SVM classifier achieved high accuracy, sensitivity, and specificity, confirming its suitability for distinguishing benign and malignant tumors. Overall, the proposed method is computationally efficient, easy to implement, and capable of delivering reliable diagnostic outcomes. It serves as a promising decision-support system for radiologists and healthcare professionals involved in brain tumor diagnosis.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

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Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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