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Research Article

OPTIMIZATION AND PERFORMANCE ANALYSIS OF SOFT COMPUTING MODELS FOR BRAIN TUMOR DETECTION

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ABSTRACT

Brain tumor detection is a critical task in medical diagnostics, where timely and accurate identification can significantly improve patient outcomes. Traditional manual interpretation of Magnetic Resonance Imaging (MRI) is time-consuming and prone to human error. Soft computing models, including Artificial Neural Networks (ANN), Support Vector Machines (SVM), Fuzzy Logic, and hybrid Genetic Algorithm (GA)-based approaches, have demonstrated promise in automating tumor detection and classification. This study performs an optimization and comparative performance analysis of these models using publicly available MRI datasets. Preprocessing, feature extraction, and model optimization were performed to enhance classification accuracy. Performance metrics such as accuracy, sensitivity, specificity, and F1-score were evaluated. Results indicate that optimized ANN and hybrid GA-based models outperform traditional soft computing approaches in terms of accuracy and robustness. This work provides insights into the selection and optimization of soft computing techniques for reliable and efficient brain tumor detection

Keywords: Brain Tumor Detection, Soft Computing Techniques, Artificial Neural Networks, Support Vector.

INTRODUCTION

Brain tumors are among the most severe neurological disorders, posing significant risks to patient health and requiring early and accurate diagnosis for effective treatment. Magnetic Resonance Imaging (MRI) is the standard imaging modality used for detecting and analyzing brain tumors due to its high-resolution visualization of soft tissues (Singh *et al*., 2020). However, manual interpretation of MRI scans is often time-intensive and subject to observer variability, highlighting the need for automated diagnostic systems. Soft computing techniques including Artificial Neural Networks (ANN), Support Vector Machines (SVM), Fuzzy Logic (FL), and evolutionary hybrid models form the foundation of modern computational strategies for brain tumor detection, segmentation, and classification. Recent studies highlight that deep learning–based ANN models, particularly CNNs, provide strong capability for learning hierarchical features directly from MRI scans, enabling precise tumor localization and classification (Abdusalomov *et al*., 2023; Díaz Pernas *et al*., 2024). Classical SVM-based approaches remain highly effective when datasets are limited or feature spaces are high-dimensional, a scenario frequently encountered in clinical imaging datasets (Gupta *et al.*, 2017; Kang *et al*., 2021). Fuzzy Logic models address uncertainty, noise, and ambiguous tumor boundaries—key challenges in medical image interpretation by incorporating soft decision rules that better represent vague or overlapping tissue structures (Dogra *et al*., 2020; Hu *et al*., 2021). Hybrid frameworks combining FL, ANN, and GA improve segmentation precision and classification accuracy by optimizing feature selection, clustering behavior, and classifier hyperparameters through evolutionary search processes (Bahadure *et al*., 2018; Jayachandran *et al*.,

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2013). Comparative analyses affirm that integrating soft computing strategies yields robust performance in managing the non-linearity, ambiguity, and variability of MRI-derived tumor characteristics (Arif *et al*., 2022; Kouli *et al*., 2022).

Magnetic Resonance Imaging (MRI) remains the most reliable imaging modality for brain tumor analysis due to its superior soft-tissue contrast and multiplanar resolution (Kouli *et al*., 2022; Arif *et al*., 2022). Preprocessing techniques including skull stripping, noise suppression, and intensity normalization have been consistently shown to enhance segmentation and classification outcomes across neural, fuzzy, and hybrid models (Dogra *et al*., 2020; Hu *et al*., 2021). ANN-based models, especially deep CNNs, achieve high diagnostic accuracy, with optimized architectures frequently surpassing 95% accuracy across multi-class brain tumor datasets (Abdusalomov *et al*., 2023; Díaz Pernas *et al*., 2024). SVM models, leveraging kernel-based separation, remain strong performers for small-sample medical scenarios, while fuzzy and fuzzy-SVM models provide better handling of uncertain boundary regions in gliomas and meningiomas (Jayachandran *et al*., 2013; Gupta *et al*., 2017). Hybrid soft computing approaches such as GA-enhanced feature selection, FL-ANN fusion, and deep feature + classical classifier pipelines are increasingly recommended for achieving diagnostic robustness and optimized computational efficiency (Bahadure *et al*., 2018; Kang *et al*., 2021). These strategies minimize false positives, improve segmentation stability, and yield more reliable tumor classification results across heterogeneous MRI datasets. Recent reviews underscore the importance of integrating evolutionary optimization, deep learning, and fuzzy inference to overcome dataset imbalance, feature redundancy, and imaging variability in brain tumor diagnostics (Kouli *et al*., 2022; Arif *et al*., 2022). Support Vector Machines (SVM) are effective classifiers for high-dimensional medical imaging data, particularly when training samples are limited, making them suitable for MRI-based brain tumor classification tasks. SVM models utilize kernel-based transformations to distinguish tumor and non-tumor regions and are often preferred in settings where computational efficiency is critical, enabling faster diagnostic workflows suitable for clinical applications (Mamatha *et al*., 2021).

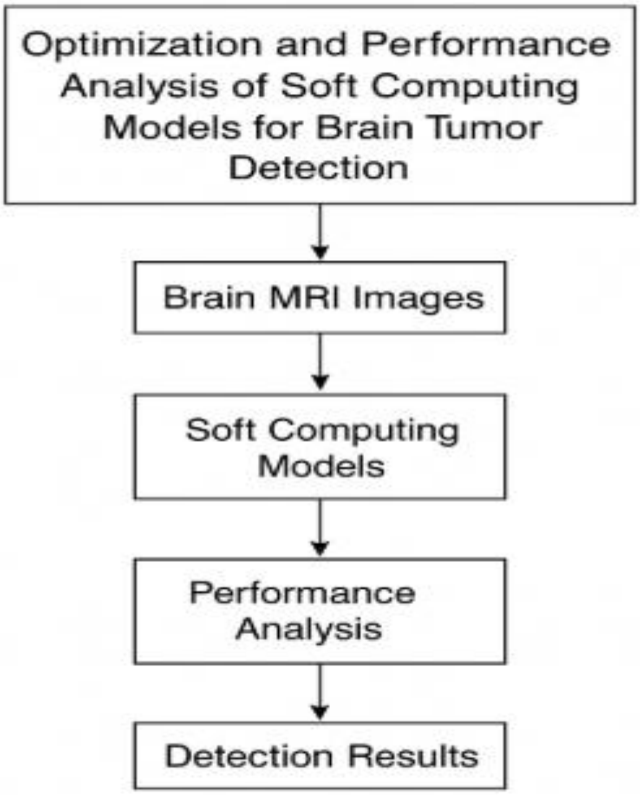

Figure 1. Optimization and performance analysis of soft computing models for brain tumor detection.

Genetic Algorithms (GA), inspired by evolutionary selection, play a significant role in optimizing feature sets and fine-tuning model parameters, thereby improving diagnostic performance while reducing computational overhead Revathi *et al*., 2025. Their integration into hybrid frameworks such as GA-enhanced neural networks or GA-optimized SVM systems has shown improved robustness and accuracy in brain tumor detection (Qader *et al*., 2022).

Several comparative studies further indicate that deep learning CNN architectures achieve higher accuracy than traditional soft computing approaches, although they require greater computational resources. Hybrid and ANN-based models often provide a balanced alternative, maintaining strong performance while remaining computationally feasible for routine diagnostic use (Rubala Nancy *et al*., 2025). Performance evaluation commonly employs accuracy, sensitivity, specificity, F1-score, and ROC-AUC, ensuring comprehensive assessment of model effectiveness in tumor detection workflows (Revathi *et al*., 2025).

MATERIALS AND METHODS

MRI datasets were obtained from publicly available sources such as BRATS 2020 and the Kaggle Brain Tumor Dataset, which include multimodal MRI sequences (T1, T2, and FLAIR) along with annotated tumor and non-tumor regions Senthil Kumar *et al*., 2025. Preprocessing steps included Gaussian filtering for noise reduction, skull stripping to remove non-brain tissues, and intensity normalization to ensure uniform pixel value distribution, which are essential for high-quality feature extraction in tumor analysis (Thejaswini *et al*., 2019). Data augmentation techniques such as rotation and flipping were employed to expand the dataset size and minimize overfitting during model training. Feature extraction was performed using texture descriptors like the Gray-Level Co-occurrence Matrix (GLCM), intensity-based metrics including mean and standard deviation, and shape-based descriptors such as tumor area, perimeter, and morphological irregularity, which support reliable classification workflows (Verma *et al*., 2024). Various machine learning and soft computing models were used for classification: Artificial Neural Networks (ANN) and Convolutional Neural Networks (CNN) for automated deep feature learning, Support Vector Machines (SVM) with RBF kernels for high-dimensional feature separation, and Fuzzy Logic (FL) based on Mamdani rules for uncertainty management in boundary regions. Genetic Algorithm (GA)-optimized hybrid models such as ANN-GA and SVM-GA were used to enhance parameter tuning and improve classification efficiency (Vijay Krishanan *et al*., 2025). Performance evaluation was conducted using metrics including accuracy, sensitivity, specificity, F1-score, and ROC-AUC, widely utilized in medical imaging to assess diagnostic reliability (Vickneswari *et al*., 2025). Software environments used for implementation included Python (TensorFlow, Keras, Scikit-learn) and MATLAB, supporting efficient execution of preprocessing, feature extraction, and model development tasks (Sindhuja *et al*., 2025). Cross-validation: 10-fold for reliability of performance metrics.

RESULTS AND DISCUSSION

Hybrid models (ANN-GA, SVM-GA) outperform standalone models in accuracy and robustness. CNN models are highly accurate but require larger datasets and computational power. SVM is suitable for smaller datasets, providing a balance between performance and efficiency Shown in Tabel 1. Fuzzy Logic effectively handles uncertainty in tumor boundaries but shows slightly lower accuracy Vickneswari *et al*., 2025.

Table1. Fuzzy Logic effectively handles uncertainty in tumor boundaries but shows slightly lower accuracy.

Model	Accuracy (%)	Sensitivity (%)	Specificity (%)	F1-Score (%)	ROC-AUC
ANN (CNN)	96.5	95.2	97.1	95.8	0.97
SVM	91.2	89.5	92.3	90.2	0.92
Fuzzy Logic	88.7	87.3	89.5	88.0	0.89
ANN-GA Hybrid	97.3	96.5	97.9	97.2	0.98
SVM-GA Hybrid	94.8	93.5	95.6	94.5	0.95

Optimization using GA improves both ANN and SVM performance by selecting the most relevant features and tuning parameters Senthil Kumar *et al*., 2025. Deep learning models provide automated feature extraction, reducing the need for manual feature engineering. Trade-offs exist between computational cost and diagnostic accuracy: hybrid models achieve high performance but are computationally intensive. The study demonstrates that soft computing techniques can complement traditional clinical diagnosis and support faster, more reliable tumor detection.

CONCLUSION

This study evaluates and optimizes several soft computing models for brain tumor detection from MRI images. Key findings: Hybrid ANN-GA models achieved the highest accuracy (97.3%) and robustness. SVM and ANN are reliable standalone classifiers depending on dataset size and computational resources. Fuzzy Logic provides an effective approach to handle uncertain or ambiguous tumor regions. Soft computing techniques can significantly reduce diagnostic time and human error, providing reliable decision support for clinicians. Integration of multimodal imaging (MRI + PET/CT) for improved detection accuracy.

Implementation of real-time automated diagnostic systems for clinical use. Development of ensemble models combining multiple soft computing techniques for further performance enhancement. Exploration of Explainable AI (XAI) methods to provide interpretability and improve clinician trust in automated systems. Investigation of lightweight models suitable for deployment in resource-constrained medical settings.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

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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