

Harnessing Artificial Intelligence in Microwave Imaging for Brain Abnormality diagnosis: A Systematic Review

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Abstract: Brain abnormalities are a major cause of disability and loss of life, worldwide. The field of microwave approaches for medical diagnostics has made significant strides in recent years, and it is emerging as a viable option owing to its capacity for non-invasive, cost-effective, portable, and real-time brain abnormality detection. This research examines the most recent advances in employing microwave imaging for brain disease diagnosis. This also emphasizes the possibility of integrating the microwave technique and Artificial Intelligence to create a dependable and efficient tool for early abnormality identification, perhaps leading to improved treatment results and a reduction in disability. Microwave imaging offers numerous benefits including portability, safe imaging with non-ionizing radiation, quick acquisition time, and improved patient comfort. It has the potential to diagnose brain abnormalities by leveraging the dielectric characteristics of both normal and unhealthy tissues. This study explores recent advancements and limitations that must be overcome to establish clinical systems for brain disease diagnosis with robust and reliable outcomes.

Keywords: Microwave imaging; Brain diagnostics; Antenna; Image reconstruction; Artificial Intelligence.

Introduction

Brain tissue disorders induce profound distress in humans because of the pivotal role of the brain as the body's central organ and its role in cognitive processes and additional functions. Brain injuries, both traumatic and non-traumatic, are medical emergencies that occur due to various incidents such as accidents, tumors, and stroke [1]. A brain tumor is merely an uncontrolled proliferation of abnormally numerous cells. The local blood supply for normal tissue may not be able to meet the demands of a rapidly expanding tumor in terms of oxygen and nutrients. Stroke remains a leading cause of disability and death worldwide, making early and correct diagnosis crucial for effective treatment. This occurs when a specific region of the brain's blood flow is disrupted or diminished, preventing it from receiving the necessary oxygen and nutrients. Quick treatment is essential to reduce damage and prevent lasting disability or death. However, prompt and accurate diagnosis is critical for effective stroke treatment.

Upon clinical suspicion of an abnormality, radiological imaging is necessary to ascertain its location, size, and impact on surrounding regions. Gold-standard imaging techniques such as CT, PET, and MRI, provide accurate diagnostics. However, these techniques also have several limitations [2]. CT and PET imaging uses ionized rays that are harmful to human beings. MRI requires injection of radioactive substances and is unsuitable for patients with metallic implants or claustrophobia. Microwave Imaging is a potential option because of its portability and non-ionizing radiation. Considerable disparities in electromagnetic properties between healthy and diseased tissues have been applied in microwave imaging [3]. The electromagnetic properties of a wave are significantly affected by the relative permittivity and conductance of the medium in which it interacts. Extensive research conducted at several levels has shown that the water content of tissues determines their relative permittivity. Tissues that are rich in

water, such as tumors, exhibit a greater relative permittivity than other tissues, such as fat (with less water content). The brain's scattering response at microwaves can be processed to detect any abnormal tissue by a process flow as depicted in Figure 1. It basically involves three phases namely data acquisition, image formation and classification of abnormality.

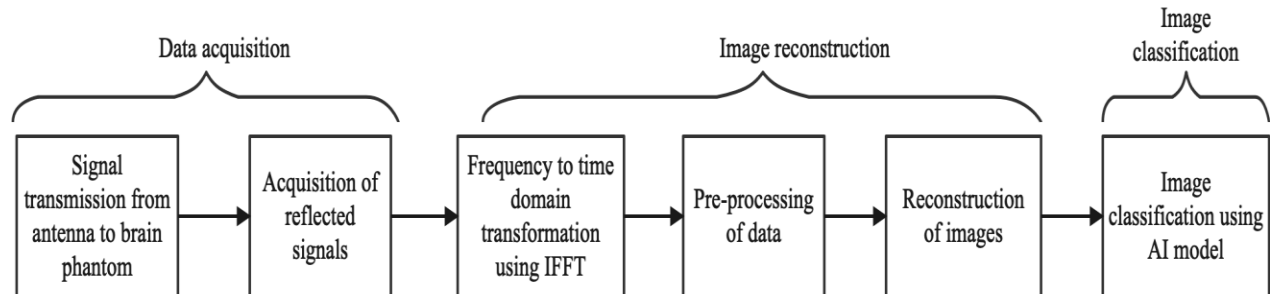


Figure 1. Process flow diagram for Microwave based Diagnosis

Three common goals are kept in mind when developing technologies for brain imaging:

1. Identify aberrant tissue.
2. Ensure accurate location of aberrant tissue.
3. Characterizing anomalies for diagnosis. A perfect technique would achieve all three goals; unfortunately, in practice, not all goals are met. In most circumstances, one goal is given priority over the other two.

In this comprehensive review, a vast body of literature related to the advancements and key aspects of microwave diagnostics is presented.

Enhancing Microwave Imaging Through Artificial Intelligence

AI's integration with healthcare has enabled substantial advancements in medical diagnoses and therapy. AI can improve accuracy and efficiency in various medical imaging modalities, thanks to massive datasets and advanced computational approaches. Microwave Imaging is a cost-effective technique with promising applications in biomedical imaging. The combination of Microwave Imaging and AI has revolutionized biological imaging research. This collaboration is transforming healthcare diagnostics by enabling non-invasive, real-time evaluation of many medical disorders. Integrating AI algorithms and techniques with microwaves allows for enhanced data processing, image construction, and categorization of abnormality. Classification of brain tumors using microwave imaging requires the identification and characterization of tumors through the analysis of microwave images which is created from the signals that interact with brain tissues. The evaluation of brain tumor dimensions and morphology is critical for the accurate identification and progression of brain cancer. Graph theory, machine learning and deep learning procedures are the different approaches utilized to distinguish between various types of tumors based on features extracted from the microwave scattering parameters during the classification process.

A. Classification of brain abnormality using Graph approach

Graph based symmetrical crossing method is used to localize and characterize brain injury. In this approach, symmetrical healthy brain (left and right side are symmetrical) is taken as reference to detect the brain which is affected by injury (Asymmetrical in terms of amplitude and phase response) [4]. This method is not preferred for clinical prototype.

B. Classification of brain abnormality using Machine Learning Approach

The process of categorizing benign and malignant tumors in microwave imaging is done in two steps, the first step is to extract features, and the second step uses classifiers such as k-nearest neighbours (KNN), tuned Naive Bayes (NB), and decision trees (DT) for classification. On the other hand, the presence of abnormality was detected by using reflection and transmission coefficient (S_{11} and S_{21}) without the creation of images [5]. But extracting meaningful features from electromagnetic imaging set up is non-trivial.

The Born iterative approach is used to first calculate the brain's dielectric profile, and the amplitude of the profile is then used as the input for k-means clustering. For the purpose of building and testing the SVM, the cluster is chosen as the feature vector. In the classification process, a database of realistic head phantoms obtained from MRI at various signal-to-noise ratios is used. A. Brankovic et al. [6] developed an unsupervised algorithm for classification of stroke. This method utilizes the characteristic of the brain's left-right symmetrical anatomy to identify and find the location of the affected area. But this method cannot function independently as it requires database from MRI.

A methodology for the localization and categorization of strokes using microwaves and machine learning method is suggested by Majid Roohi et al. [7]. The results of the proposed multi-static imaging system demonstrate the effectiveness of this machine learning-based method in identifying and classifying intracranial bleeding (stroke). But the classification is based only on the size of the lesion.

C. Classification of brain abnormality using deep learning Approach

Brain tumor classification by neural network plays a vital role in disease prediction [8]. Brain tumor categorization from MRI images was demonstrated by Muhammad Aamir et al. [9] in which three types of tumor categories are distinguished such as Meningiomas, Pituitaries, and Gliomas using MRI head images. This can't be directly applied to electromagnetic imaging. C. Dachena et al.[10] developed a detection method using experimental data with Artificial Neural Networks .It is used to analyse scattering data from neck phantoms. But the analysis is carried out only to detect the disease and the classification is not done. YOLOv5 is used to optimize network training in the electromagnetic inverse scattering problem by incorporating deep learning approach [11].

The different automatic detection methods involved in brain imaging is represented in table 1.

Table 1. Performance Comparison of Existing methods for abnormality classification

Ref No	Method	Imaging domain	Application	Accuracy
[9]	Feature Vector Extraction based Deep learning Model	MRI Imaging	Brain tumor	98.95%
[17]	Logistic Regression	Microwave Imaging	Alzheimer	98.7%
[16]	Support Vector Machine	Microwave Imaging	Stroke Imaging	88%
[10]	Fully connected Artificial Neural Network	Microwave Imaging	Neck diagnostics	Numerical Analysis.
[11]	YOLOv5	Microwave Imaging	Brain tumor	95.6%

Conclusion

The suggested microwave diagnostics can also be applied to circumstances where quick and point-of-care diagnosis are critical, such as the early detection of haematomas induced by traumatic intracranial injuries in an emergency vehicle. This synergy of microwave imaging and deep learning holds promise to revolutionize brain abnormality detection, potentially saving lives and reducing the long-term burden of stroke-related disabilities.

References

- [1] Q. T. Ostrom, H. Gittleman, J. Xu, C. Kromer, Y. Wolinsky, C. Kruchko, et al., "CBTRUS statistical report: primary brain and other central nervous system tumors diagnosed in the united states in 2009–2013", *Neuro-oncology*, Vol. 18, no. 15, pp. 1-75, 2016.
- [2] R. Krishnan, I. U. Khan, and S. K. Oruganti, "A Review on Non-invasive Blood Glucose Monitoring using RF Sensors", *SGSES*, vol. 1, no. 1, May 2025.
- [3] K. B. Walsh, 2019, "Non-invasive sensor technology for prehospital stroke diagnosis: Current status and future directions", *International journal of stroke: official journal of the International Stroke Society*, 14(6), pp. 592–602. <https://doi.org/10.1177/1747493019866621>
- [4] L. -Y. Zhao, L. -Y. Xiao, Y. Cheng, R. Hong and Q. H. Liu, "Machine-Learning-Based Inversion Scheme for Super-Resolution Three-Dimensional Microwave Human Brain Imaging," *IEEE Antennas and Wireless Propagation Letters*, Vol. 21, no.12, pp. 2437-2441, 2022.
- [5] Guo.L. and A. Abbosh, "Stroke localization and classification using microwave tomography with k-means clustering and support vector machine," *Bioelectromagnetics*, Vol. 39, no. 4, 312-324, May 2018.
- [6] A.Brankovic et al., "Unsupervised Algorithm for Brain Anomalies Localization in Electromagnetic Imaging," *IEEE Transactions on Computational Imaging*, Vol. 6, pp. 1595-1606, 2020.
- [7] Majid Roohi, Jalil Mazloun, Mohammad-Ali Pourmina, and Behbod Ghalamkari, "Machine Learning Approaches for Automated Stroke Detection, Segmentation, and Classification in Microwave Brain Imaging Systems," *Progress In Electromagnetics Research C*, Vol. 116, 193-205, 2021.
- [8] Sultan H.H., Salem N.M., Al-Atabany W., "Multi-classification of brain tumor images using deep neural network." *IEEE Access.*, Vol.7, pp. 69215–69225, 2019.
- [9] Muhammad Aamir et al., "A deep learning approach for brain tumor classification using MRI images," *Computers and Electrical Engineering*, Vol. 101, pp.108105-108115, 2022.
- [10] Al-Saffar, A. Bialkowski, M. Baktashmotlagh, A. Trakic, L. Guo and A. Abbosh, "Closing the Gap of Simulation to Reality in Electromagnetic Imaging of Brain Strokes via Deep Neural Networks," *IEEE Transactions on Computational Imaging*, Vol. 7, pp. 13-21, 2021.
- [11] K, L., J, M. Dielectric Characterization of Dispersive Head Tissue for Detection and Classification of Tumour Using Microwave Imaging Technique and Deep Learning Model. *Arab J Sci Eng* 49, 12305–12316 (2024). <https://doi.org/10.1007/s13369-023-08666-z>.