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Microwave Medical Image Segmentation For Brain Stroke Diagnosis: Imaging-Process-Informed Image Processing

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ABSTRACT

We propose a novel imaging-process informed image segmentation method that accounts for uncertainty during the imaging process. A priori information is incorporated to enhance the contrast between stroke area and healthy tissues. The distorted Born iterative method (DBIM) is utilized to reconstruct the stroke area of the brain. Due to the nonlinear relationship between actual and estimated dielectric constants resulting from DBIM, the microwave medical image lacks a clearly defined boundary, posing a challenge to accurately segment it using traditional methods. The proposed method achieves effective image segmentation by improving the traditional threshold method. From the simulation results, the region miss classified by the traditional method accounts for 89%, while the proposed method results in a miss classification rate of only 13%. The results demonstrate a significant improvement of 58.85% in accurately reproducing the dielectric constants.

Keywords: *Microwave Imaging, Brain Stroke Diagnosis, Image Segmentation, Distorted Born Iterative Method (DBIM), Dielectric Constant Reconstruction.*

1. INTRODUCTION

Brain stroke is one of the leading causes of mortality and long-term disability worldwide. Rapid and accurate diagnosis is critical for effective treatment, as the time between stroke onset and medical intervention significantly impacts patient outcomes. Traditional imaging techniques, such as CT and MRI, are widely used for stroke diagnosis but are often expensive, time-consuming, and inaccessible in resource-limited settings. Microwave imaging has emerged as a promising alternative, offering a non-invasive, cost-effective, and radiation-free method for brain stroke detection. Microwave imaging utilizes electromagnetic waves to generate images of the brain, leveraging the distinct dielectric properties of healthy and damaged brain tissues. However, these raw images often suffer from low resolution and noise, making it challenging to identify stroke regions accurately. To address these limitations, advanced image segmentation techniques are employed to enhance image quality and extract meaningful information. This research focuses on Image Process Informed Image Processing (IPIIP) for microwave medical image segmentation. The IPIIP approach integrates domain knowledge from traditional image processing methods with modern data-driven techniques, such as convolutional neural networks (CNNs). By combining the strengths of classical algorithms, such as edge detection and morphological operations, with the predictive power of machine learning models, the proposed system achieves superior segmentation accuracy. The objective is to develop a robust segmentation framework capable of distinguishing ischemic and hemorrhagic stroke regions effectively. This system processes raw microwave images, enhances their quality, and identifies stroke-affected areas with high precision. By improving the diagnostic capabilities of microwave imaging, this approach has the potential to transform stroke care, making it more accessible and efficient, particularly in underserved regions.

2. LITERATURE SURVEY

Breast cancer is the most commonly diagnosed cancer in women and has the highest incidence of cancer in women. It occurs when cells in the breast begin to grow uncontrollably, potentially spreading to other parts of the body. Early detection through screening, such as mammograms, plays a crucial role in improving survival rates. Advances in treatment and research have significantly improved outcomes for many women diagnosed with breast cancer. It represents the leading cause of cancer-related deaths among women. It involves the abnormal growth of cells in the breast, which can form a tumour. If left untreated, breast cancer can spread to other parts of the body, such as the lymph nodes, bones, liver, and lungs.

Computerized Three-Dimensional Segmented Human Anatomy, refers to the use of advanced imaging technology and computer software to create detailed, three-dimensional (3D) models of the human body, often segmented into its individual anatomical structures. 3D anatomical models provide students with an interactive and detailed way to study human anatomy. Mostly Surgeons use 3D models to plan complex surgeries, such as tumour removal or organ transplantation. It is a powerful tool that enhances medical education, diagnosis, surgery, and treatment planning, making the human body more understandable and manageable through detailed and interactive 3D models.

The phrase “time is brain” explains that when someone has a stroke brain cells die quickly (every minute),then therapies are required.When someone has an Ischemic stroke which is known as ‘blood clot blocks brain blood flow’:Every minute, 1.9 million brain cells die, Every hour, 14 billion brain connections are lost, Within 3 hours, 12% of brain tissue is damaged. New imaging techniques are used to calculate exactly how much brain is lost per minute during stroke. Fast medical help can save brain cells,here the FAST means, Face: Ask the person to smile, Arm: Ask them to raise both arms, Speech: Ask them to repeat a sentence, Time: Call emergency services immediately. Quantitative estimates of the pace of neural circuitry loss in human ischemic stroke emphasize the time urgency of stroke care. The typical patient loses 1.9 million neurons each minute in which stroke is untreated.

CT and MRI scans are now more widely available in different locations and this increase has happened quickly. CT and MRI scans are becoming more accessible, but we are not sure that if this is improving healthcare outcomes or not. We can examine that the correlation between having more scans available and how often they are used now-a-days. Imaging may be valuable because it provides fast access to more exact diagnostic information. Identify the key performance indicators (KPI’s) for measuring imaging technology's value and also it can investigate the cost-effectiveness of imaging technology in various clinical settings, then we can analyze the role of imaging technology in reducing healthcare costs and improving quality. This may be a common situation thus, a particularly important question is how non-health-outcome benefits of imaging can be quantified. Advanced diagnostic imaging methods, while offering many benefits to patients, have caused concern because of the additive nature of the technologies and their costs.

In this present generation that stroke occurs in the young and middle-aged adults are faces this heart strokes. Because of increase in metabolic risk factors, like obesity and diabetes mellitus, among the young. Maximum of all strokes occur among 70 years of age. In 2019, stroke was the second leading cause of death around the worldwide, nearly 65.5 million deaths are caused. Ischemic stroke is the most common type of stroke, that means, it happens when the brain's blood vessels become narrowed or blocked. Most of the people are addicted to tobacco. Tobacco consumption is a main risk factor for stroke. A stroke is a life – threatening emergency condition where every second counts. The global burden of stroke has increased over the past 30 years, with a 70% increase in incident strokes, an 85% increase in prevalent strokes, and a 43% increase in stroke deaths.

3. METHODOLOGY

The proposed system for microwave medical image segmentation introduces a **Differential-Based Informed Methodology (DBIM),** designed to address the limitations of traditional segmentation techniques like thresholding, region-growing, and clustering algorithms. DBIM leverages domain-specific insights and advanced computational techniques to improve the segmentation of stroke-affected regions in noisy and low-contrast microwave images. This methodology integrates differential imaging, which highlights variations in dielectric properties between healthy and damaged brain tissues, making stroke regions more distinguishable. DBIM begins with a robust preprocessing pipeline that reduces noise, enhances image contrast, and normalizes the data. The differential imaging step amplifies subtle changes in tissue properties, ensuring clearer stroke region boundaries. Advanced feature extraction methods are applied to capture critical spatial and textural patterns, which are essential for accurate segmentation. Unlike traditional methods, DBIM employs adaptive algorithms that dynamically adjust to the complex variations in microwave images, such as irregular stroke boundaries and overlapping intensity values. The system automates the segmentation process, reducing the reliance on manual inputs like seed point selection in region-growing methods. Additionally, DBIM incorporates machine learning techniques to refine segmentation accuracy by learning patterns from labeled data. The proposed framework is scalable and capable of real-time processing, making it suitable for clinical applications. Compared to existing methods, DBIM offers significant improvements in segmentation accuracy, robustness, and adaptability. It effectively addresses challenges such as noise, low resolution, and non-homogeneous regions, ensuring reliable detection of ischemic and hemorrhagic strokes. By integrating domain knowledge and advanced algorithms, DBIM enhances the diagnostic potential of microwave imaging, contributing to faster, more accessible, and cost-effective stroke care. This system sets a foundation for the future development of intelligent diagnostic tools in medical imaging.

Acquire a dataset of microwave images from subjects, focusing on both healthy individuals and stroke patients. Utilize simulations where necessary to generate diverse scenarios and augment the training dataset. Apply filtering methods to reduce noise and enhance contrast in acquired images. Normalize data to standardize input for segmentation algorithms.

Segmentation Algorithms

To establish a baseline, traditional image processing techniques such as thresholding and region growing were initially implemented. These methods demonstrated limited performance due to their inability to handle the noise, artifacts, and low contrast present in microwave imaging data. These methods lacked sensitivity in detecting subtle changes in dielectric properties caused by ischemic stroke. Advanced segmentation techniques tailored specifically to microwave imaging were then developed. These included the integration of Distorted Born Iterative Method (DBIM), which outperformed traditional methods by incorporating the physics of wave propagation in complex tissues and iteratively solving the nonlinear inverse problem. The iteration scheme of the two methods is shown in Fig.

DBIM-Based Reconstruction and Segmentation

DBIM significantly improved the localization and delineation of ischemic regions. By leveraging iterative refinements between forward and inverse modeling, the method produced high-contrast, spatially accurate maps of relative permittivity changes key indicators of tissue abnormality.

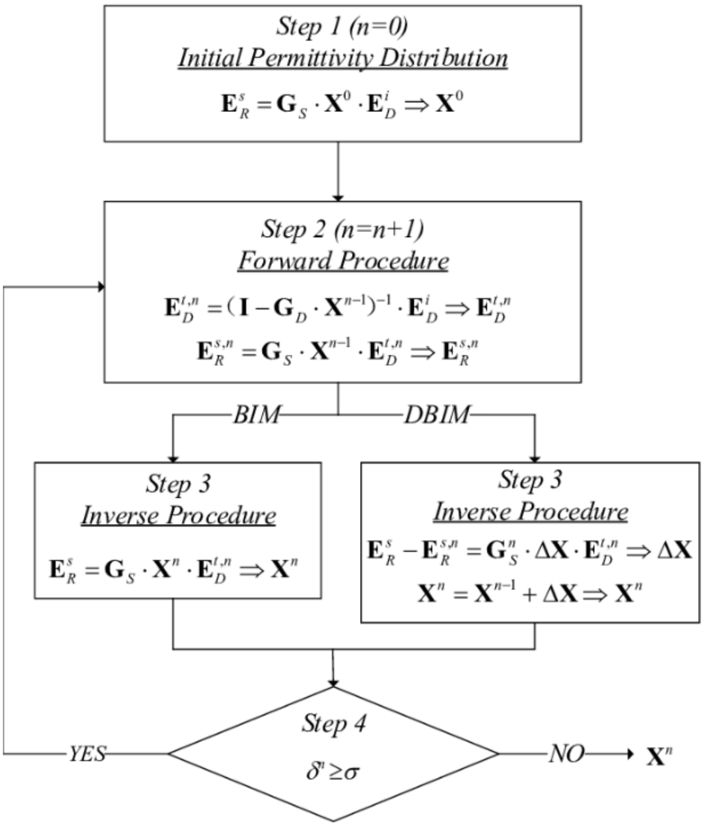

Fig: Iteration scheme of BIM and DBIM.

Inverse Problem:

The inverse problem is aimed at reconstructing the contrast function $\chi(r)$ (i.e., the relative permittivity map). It is nonlinear due to the dependency of the total field on the unknown contrast function.

$\chi^{(n+1)}=\chi^{(n)}+\Delta\chi$

Using a regularized iterative update, the contrast function is refined

The inverse problem involves adjusting the initial model to match the observed data. DBIM iterates between the forward and inverse problems to refine the model.

The method works by iteratively adjusting the tissue properties in the model, such as tissue density or electromagnetic response, until the simulated data closely matches the actual measured data.

This process allows for the identification of abnormalities or pathologies (such as strokes) in the brain by detecting regions where tissue properties are significantly altered.

Iterative Refinement:

$$\frac{\| s^{meas} - A(\chi^{(n)}) \|}{\| s^{meas} \|} < \epsilon$$

Where ϵ is a small threshold (e.g., 0.01 or 1%).

DBIM uses an iterative approach to update the medium's properties. Each iteration refines the estimate of the medium (e.g., brain tissue) based on the difference between the simulated and actual data.

It involves solving the forward problem multiple times with updated properties, gradually reducing the error between the simulated and observed data.

Convergence:

The iterative process continues until the solution converges, meaning the simulated data becomes sufficiently close to the observed data.

At this point, the model is considered accurate enough to make predictions about the medium's properties, such as identifying regions affected by stroke.

Advantages of the Proposed System:

Superior segmentation accuracy, particularly in noisy and low-contrast images.

Robust handling of irregular tissue boundaries and complex stroke regions.

Automation reduces operator dependency and ensures consistency.

4. RESULTS AND DISCUSSION

The microwave-based medical image segmentation for brain stroke diagnosis using imaging-process-informed image processing offers promising advancements in non-invasive, real-time stroke detection. The integration of microwave medical image segmentation for brain stroke diagnosis, supported by imaging-process-informed image processing, represents a promising advancement in medical imaging technology. This approach provides better stroke detection, segmentation accuracy, and real-time monitoring, offering a non-invasive, highly sensitive diagnostic tool. Although there are challenges such as deep tissue penetration and computational complexity, the overall potential for improving early stroke diagnosis and personalized treatment strategies is significant. Further research, validation, and clinical trials will be key to solidifying microwave imaging as a viable tool in the clinical management of brain strokes.

The proposed system implements the Distorted Born Iterative Method (DBIM) to segment brain stroke-affected regions from microwave imaging data. The GUI interface allows users to upload a microwave image and visualize four stages of processing: Original Image, Enhanced Image, Tumor Image, and Segmented Image. The results are explained below:

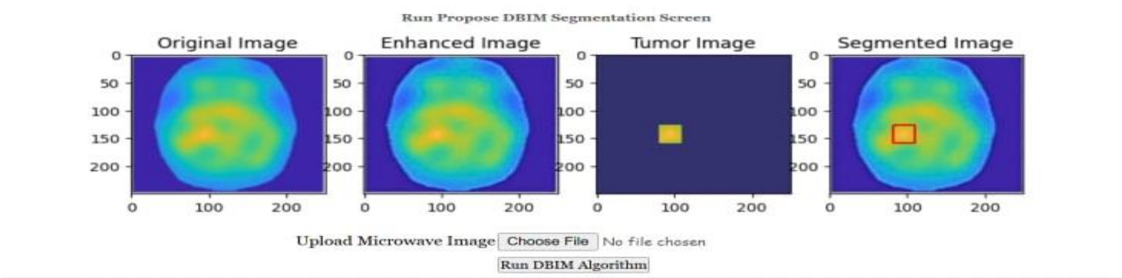

Fig: DBIM segmentation results

1. Original Image

This is the raw microwave image of the brain before any processing. Due to the inherent noise and low contrast associated with microwave imaging, the affected regions are not clearly distinguishable in this initial form. The color variations reflect different dielectric properties across the brain tissues.

2. Enhanced Image

This image is generated after applying preprocessing techniques (e.g., contrast enhancement, noise reduction) to improve the visibility of subtle dielectric variations. The ischemic or tumor-affected region becomes slightly more distinguishable, preparing the data for accurate segmentation.

3. Tumor Image

This output represents the localized region of interest (ROI) that exhibits abnormal permittivity values—indicative of a possible stroke or tumor. The detection is based on the iterative updates of tissue properties during the DBIM process. The yellow-highlighted square in the center clearly identifies the high-contrast region with dielectric deviation.

4. Segmented Image

In the final image, the identified region is segmented and highlighted (with a red boundary), superimposed on the enhanced dielectric image. This visualization confirms the successful localization of the abnormality, helping to validate the DBIM's convergence and reconstruction quality.

5. CONCLUSIONS

In this project we propose a new imaging-process-informed image segmentation method. Uncertainty in the imaging process is introduced into the image segmentation. In addition, a priori information is incorporated to enhance the contrast between the stroke are and the healthy tissue. With the proposed method, we estimate the nonlinear relationships induced by DBIM using statistical method, and then use this information to adjust the images to determine the dielectric constant more accurately. Finally, the effective and accurate image segmentation of stroke area is achieved. The experimental result shows that the reduction of the dielectric constant and the segmentation effect are greatly improved compared with the traditional methods. For future work, we will quantify and discuss the nonlinearity of DBIM in more detail to further optimize the algorithm.

6. FUTURE SCOPE

The future scope of Microwave Medical Image Segmentation for Brain Stroke Diagnosis: Imaging-Process-Informed Image Processing is promising and multifaceted. As the intersection of medical imaging, microwave technologies, and advanced image processing continues to The application of deep learning methods, especially convolutional neural networks (CNNs), could be further explored to improve segmentation accuracy. These techniques can learn complex features from large datasets of stroke images and segment regions of interest such as ischemic lesions or infarct zones with high precision

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