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An Investigation of Microwave Tomography Technique to Image Brain Tumour Through Cross-Section Imaging with Different Number of Electrode

Anisah Abd Wahab[1], Ummi Amira Rosli[1], Nur Syahirah Harun[1], Nurul Amira Mohd Ramli[2], Mimi Faisyalini Ramli[3*], Lam H.Y.[1], Mohd Hafiz Fazalul Rahiman[2]

[1]Faculty of Engineering Technology,
Universiti Tun Hussein Onn Malaysia, Pagoh, Johor, 84600, MALAYSIA

[2]Faculty of Electrical Engineering & Technology,
Universiti Malaysia Perlis, Perlis, 02600, MALAYSIA

[3]Faculty of Electrical & Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, Parit Raja, Johor, 84600, MALAYSIA

*Corresponding Author

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Abstract: Brain tumours resulted from the irregular growth and cell division within the skull, indicating a high risk for malignancies to develop and can lead to brain injury or even death. The brain tumour can affect nervous system's function based on the tumour's growth rate and location. Early detection of brain tumour is essential to improve patients' survival rates through appropriate medical care. As the current clinical imaging has a few impediments e.g. radiation-based and expensive, tomography technique is seen possible to provide safe and inexpensive technology. The aim of this research is to investigate the feasibility of brain tumour detection using microwave tomography technique with different numbers of electrodes. The 2D finite element modelling approach is applied, and the images are reconstructed using a linear back projection (LBP) algorithm in MATLAB. A different number of rectangular sensing electrodes are arranged around the head phantom in an elliptical array, working in pairs as transmitters and receivers. The simulation shows that the system is able to detect the permittivity difference, thus detecting the existence of the tumour in the head phantom.Theimage reconstruction presented promising tumour images with an 8-antenna microwave tomography system at all locations, i.e. left, right, top, centre, and bottom, in comparison to 4-antenna and 12-antenna systems.

Keyword: Brain tumour, microwave tomography, imaging, finite element modelling, linear back projection, signal processing

1. Introduction

Brain tumour is one of the brain diseases that has a very high rate of fatality and can cause disability that significantly affects life quality. Each year, an estimated 350,000 new cases of brain tumour across the world with only 36% of 5-year survival rate for patients diagnosed with brain tumour [1]. In human anatomies, the brain is the most complex organ [2] used as a body control centre that controls all parts of our body, such as the nervous system that

Corresponding author: faisyalini@uthm.edu.my

involves the spinal cord and other nerves and neurons. Thus, when the brain is impaired, many things including memory, sensations, and even personality, may be affected. Brain disease diagnosis can then be classified into various categories, including infection, stroke, trauma, tumour, and seizure.

Brain tumour could be malignant or benign, and their symptoms depend on the tumour's size and location. The malignant tumour is dangerous because it can spread faster and more aggressively to other areas compared to a non-malignant tumour. Usually, abnormality of the brain can be detected by the contrast of dielectric properties inside the brain, such as conductivity and permittivity between normal and abnormal tissues [3,4]. Present clinical imaging diagnostics that used to detect brain tumour are microwave resonance imaging (MRI), computed tomography (CT scan) and positron emission tomography (PET).

MRI is one of the most secure clinical imaging methods since it can work without ionising radiation exposure. However, it has some limitations as it is costly and not portable. Some people will also experience claustrophobia due to the enclosed space inside the MRI machines. Meanwhile, the CT scan uses ionising radiation because an x-tray is used to create head tissue details. Current technology in medical imaging produce the variety resolution, higher implementation cost and apply complexity with some of them using ionizing radiation [5]. However, one researcher commented that excess radiation exposure can impact the patient's health risk and contribute to cancerous tissues production [6]. To address the above issues, this research proposes a microwave tomography approach as early detection of brain tumour. [7] presented microwave imaging technique that provides a compact and cost-effective system. There are also other non-medical applications utilising microwave strategies, for example, weapon discovery and through-divider imaging framework because the microwave can enter through an alternate medium. Because of this reason, the industry has huge interest in executing microwave imaging in biological tissues [5,7]. Many studies based on microwave imaging have been carried out in recent years, such as brain stroke detection, brain injuries and breast cancer detection [4,8]. Study in [9] present the potentiality of Microwave imaging to differentiate between two different locations of a hemorrhagic stroke in a realistic head phantom.

Microwave imaging required the application of antenna array in order to evaluate hemorrhagic stroke [10]. Recently ten triangular patches are set up as an antenna inside a helmet for an experimental microwave setup to diagnose brain stroke and it has been built to distinguish between hemorrhagic stroke and ischemic stroke [11]. In research [12], the patient wear microwave helmet which mounted by ten antennas during the examination. Furthermore, as the microwave imaging technique is lightweight, it can be used for quicker diagnosis and care in ambulances or emergency rooms [13]. In this study, the 2D Finite Element Model (FEM) approach is used for brain tumour detection, and an analytical approach is used to conduct dielectric parameter reconstruction. The 2D modelling is constructed using COMSOL Multiphysics for 4 electrodes, 8 electrodes and 12 electrodes sensor system. The electrodes work in pairs, as transmitters and receivers. Because of the difference in dielectric properties of various substances, the magnitude of the electric field changed. The electric field data from the Comsol Multiphysics is then used for image reconstruction in Matlab using the Linear Back Projection (LBP) algorithm. From the obtained images, analysis is done to define the best number of electrodes that can provide the most significant image in comparison to the real phantom.

2. Methodology

Figure 1 shows the entire research process consists of two phases. The first phase uses the simulation package Comsol Multiphysics software to apply the numerical approaches through solving the forward problem. The head phantom is designed using Comsol Multiphysics software. The second phase is using data obtained from Comsol to solve inverse problem. The algorithm is run by using Matlab software for image reconstruction. The algorithm used for this research is the Linear Back Projection (LBP). Optimisation of design is done with Comsol until desired results are obtained. The process is repeated three times for 4,8, and 12 electrode configurations.

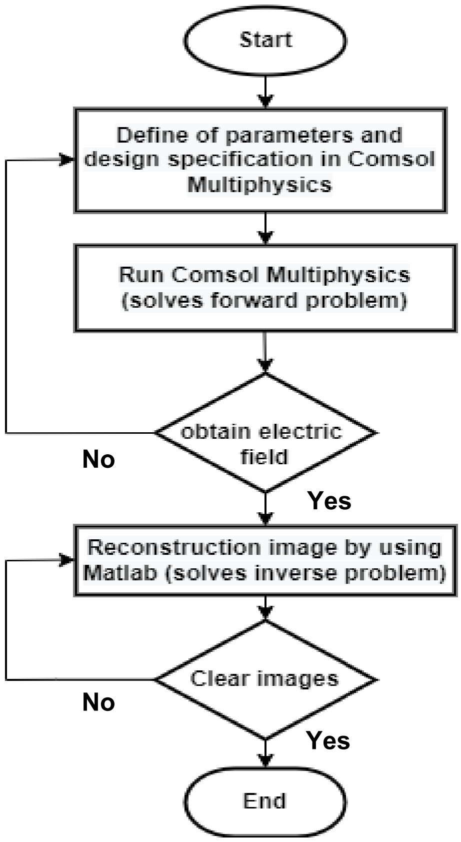

Fig. 1 - Flowchart of the entire system

2.1 Parameters and Specifications

The human head modelling used in this research consists of skin, skull, cerebral spinal fluid (CSF), grey matter, and tumour. Each of the substances has a unique relative permittivity. Table 1 shows the relative permittivity and conductivity of the substances that are used in the simulation [14,15]. Higher permittivity indicates a substance with higher water content, hence higher conductivity. The microwave imaging approach is used as it is capable of measuring the electric field of significant permittivity contrast as well as it works on higher conductivity material. As frequency plays a crucial role in the penetration of waves [16], the penetration depth of microwave signal could be reduced by signal attenuation of biological tissue as the frequency increases [17]. Considering this significant role of frequency, the desired result are able to be obtained by applied the correct frequency [18]. Every tissue has different dielectric properties, which can be determined in terms of their electrical conductivity, σ, and relative permittivity ε_r.

Table 1 - Dielectric Properties of substance at 1 GHz [14,15]

Tissue	Relative Permittivity (s_r)No	Conductivity, ∑[S/m]
Skin	41	0.89977
Skull	12	0.15566
CSF	68	2.4552
Grey Matter	52	0.98541
Tumour	62.8	1.24

Figure 2 shows the head phantom's modelling with different thickness of tissue is being constructed based on [17]. According to the zubal head phantom MRI database slice 36 [19], the brain size is approximately 150mm x 200mm. The frequency applied in this simulation is 1 GHz which recognized as best frequency for brain tumour detection based on the simulation and image reconstructed [19]. For thermal safety, the transmission power is limited to 1mW or 0dBm [20]. The technique is foreseen to be able to cater with a massive difference of permittivity. Using the data obtained from Comsol simulation, the image reconstruction with Linear Back Projection algorithm (LBP) should display 2D images of the brain tumour in the head phantom according to the location (left, right, top, bottom or centre).

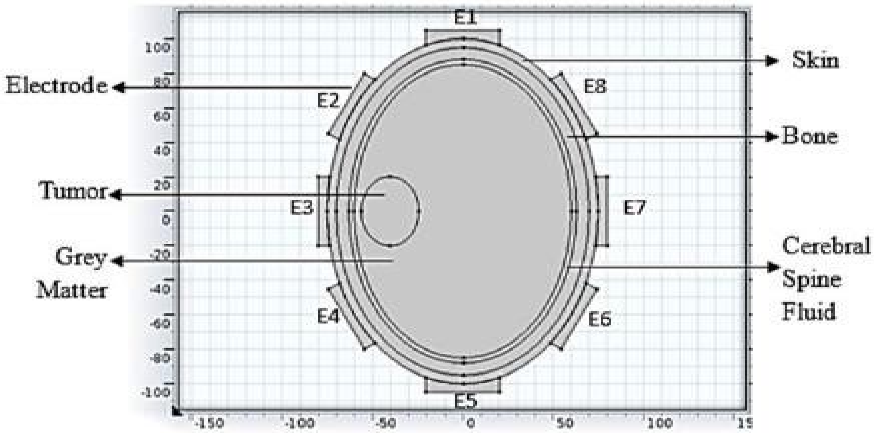

Fig. 2 - Modelling in Comsol

2.2 Modelling of The Antenna

The technique used for forward problem solver in frequency domain are finite element method (FEM) which is recommended based on its flexibility to locate irregular geometries, anisotropic dielectric materials and inhomogeneous background medium with least discretization errors over other numerical methods [23]. By solving the forward problem, it will produce the major output called as the scattered electric field [17]. Electric field values of transmitted and backscattered microwave signals were resulted from solving the Helmholtz vector wave equation in (1) below which derived from Maxwell's equations that represents the whole of electromagnetic theory [21], in time-harmonic form using FEM [23].

$$\nabla \times \mu_r^{-1}(\nabla \times \vec{E}) - k_0^2\left(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0}\right)\vec{E} = 0 \tag{1}$$

Where μr is the relative permeability (H/m), εr the relative permittivity (F/m), ω the angular frequency (rad/s), σ the electric conductivity [S/m], and $k0= \omega\sqrt{\ }\mu 0\varepsilon 0$ the free-space wavenumber $(m-1)$. The value of scattered electromagnetic field obtained from forward problem solver which in form of dielectric properties of the object of interest [17], is used for solving the inverse scattering problem. Image reconstruction process produce using the inverse problem solver. The function of electrodes in microwave imaging is for transmitting and receiving waves. The electrode generates the electric field perpendicular to the transverse plane of the head causing Transverse Magnetic (TM) polarization. Perfect electric conductor is applied to correspond with an electrical field where all tangential components are zero [21]. The electromagnetic waves interact with the tissues which have different dielectrical properties and electrode sensor around the head phantom where the wave is transmitted and received. Therefore, microwave imaging are able to detect the abnormal tissue in their position because different tissues have dielectrical properties. So, when electrode is surrounding with abnormal tissues it will reflect a portion of the EM waves. The greater the difference between the properties of the abnormal tissue and the surrounding material, the stronger the reflected waves. The electrode will compute the electric field scattering at the receiving point when the electrode is transmitted. Antenna architecture associated with medical application varies from standard antenna research because it is concerned with radiation into a lossy medium. This has a significant influence on the impedance, bandwidth, and antenna losses. The setting of different number of electrode in Comsol is shown in Figure 3.

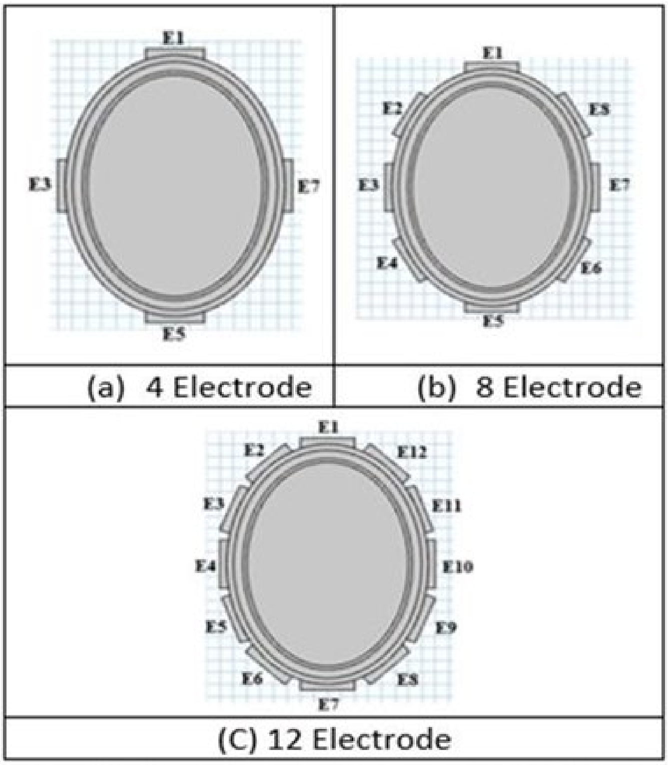

Fig. 3 - Electrode arrangement

2.3 Images Reconstruction

The image reconstruction for brain phantom is run on the MATLAB software using Linear Back Projection (LBP) algorithm. Firstly, the data was obtained from the Comsol software. The data was obtained from the electric field scattering at the electrode during transmitting and receiving. Then, the inserted data are being measured and calibrated. Calibration data and measurement data is the data set of each electrode for phantom without a tumour and the data set from each electrode for phantom with a tumour respectively. This data will be flip up and down. Next in the second part, the multiplication process happens between each of data set brain without phantom and the summation of the calculation. Then the process of calculation attenuation between each of brain tumour with data set is also occurred. The images reconstructed will be presented as the output from the last part of LBP algorithm process.

3. Result and Discussion

Figure 4 presents the comparison of electric field value between brain phantom with tumour and without tumour for 4, 8 and 12 electrode at position left . The value of electric field received by 4 electrodes between without tumour and with tumour shows uniformity. It is difficult to analyse the tumour image as there is low value of electric field penetrate through the brain phantom. Although both 8 and 12 number of electrode shows the difference value of electric field obtained, the detail value from graph express electric field for brain with and without tumour absorbed by 8 electrodes are more precise than 12 electrodes. The value of electric field obtained for tumour placed at Right, Top, Centre, and Bottom interpret the same pattern.

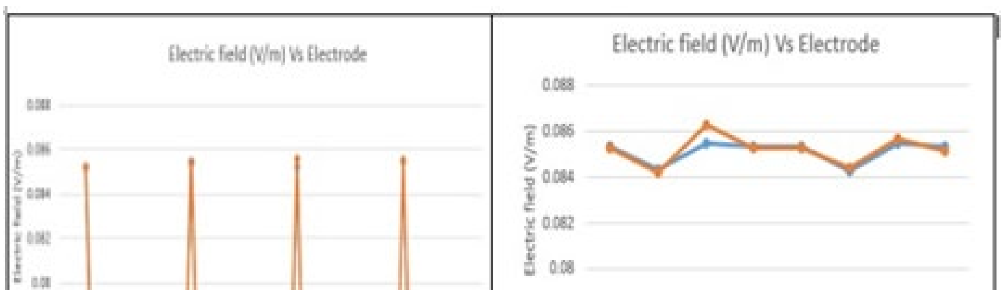

Fig. 4 - Comparison of electric field value for 4, 8 and 12 electrode at position left

Figure 5 shows the reconstruction of brain tumour at left, right, top, bottom, and centre with different numbers of electrodes. From this figure we can see that the images with 8-electrode are the most reasonable at all location, in comparison to 4 and 12 electrodes. It can detect the tumour with the most accurate images at the centre location. This is because the antenna transmitted and received at the centre are equal, so the electric field value scattered is equal. Meanwhile, the tumour images located at the boundary are distorted because it is located very near to the point source that has caused solid dispersing. 4- electrode sensor is the second best after 8- electrodes, however the tumour size looks significantly smaller than the real phantom.

With 12-electrodes sensor, no reasonable images is reconstructed at any location. This is perhaps due to the location of the antenna which is too near to each other that creates interference or dispersion of wave. Moreover, the transmitter and receiver system become more complex because many electrodes need to be transmitted and received the electromagnetic waves. The images quality is decrease at 12- electrode because the accuracy of the collected signal is degraded due to many electrodes need to receive the electric field scattering at one time.

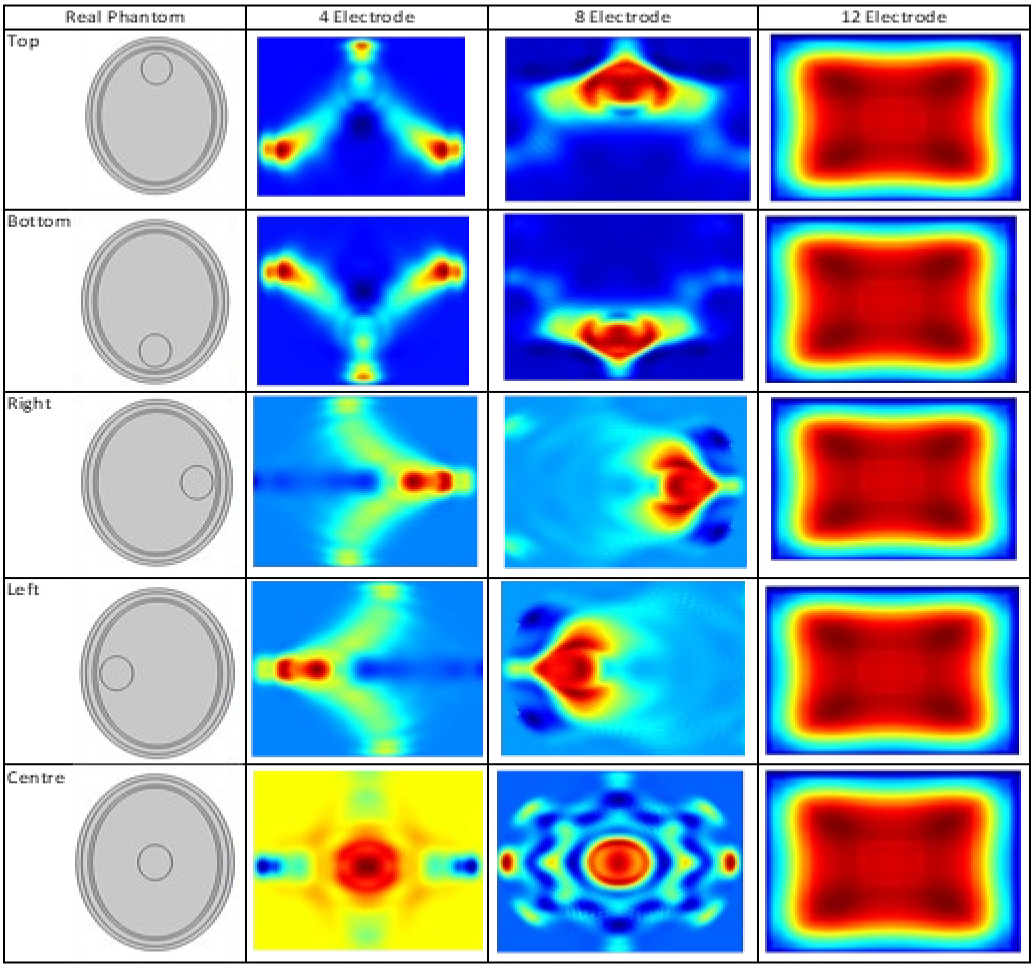

Fig. 5 - Reconstruction of brain tumour atdifferent positions with numbers of electrodes

4. Conclusion

In conclusion, the microwave tomography technique is proven feasible to be used as an early detection of brain tumour through the determination of complex permittivity distribution. Promising reconstructed images are present with an 8-antenna microwave tomography system at all locations, i.e. left, right, top, centre, and bottom, compared to 4- antenna and 12-antenna systems. The best-obtained image is at the centre of the head modelling. This research has the potential of a significant contribution for medical use to increase the survival rate of patients who have brain tumour. Additionally, the device as hardware is foreseen to be inexpensive and portable which would highly benefit people with low income and those living in rural areas. This researchdemonstrated several limitations as the reconstructed images are not yet accurate enough. Thus, future work will include optimization of the sensor design and also the adoption of an iterative algorithm or artificial intelligence based method to increase image quality.

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