Journal of Advanced Research in Applied Mechanics 126, Issue 1 (2025) 178-187

SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Mechanics

Journal homepage:
https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895

Brain Tumor Detection and Size Estimation using Microwave Imaging

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ARTICLE INFO

Article history:
Received 13 September 2024
Received in revised form 15 October 2024
Accepted 21 October 2024
Available online 30 October 2024

Keywords:
Magnetic Resonance (MRI); Computed Tomography (CT) scan; X-ray scan; Microstrip Patch Antenna, Return Loss; Specific Absorption Rate (SAR) value; Electromagnetic Software

ABSTRACT

This project focuses on developing an antenna that utilising microwave imaging technology for visualising, detecting, and estimating the size of human tumors using simulation approach. A rectangular microstrip patch antenna is chosen for its advantages of low cost, convenience, efficiency, and compactness, offering a non-ionised alternative. To meet the antenna specifications, rectangular slots are incorporated into the design. The antenna performs effectively at 7.5 GHz, exhibiting a return loss of -24.20383 dB, well below the -10 dB threshold. Placing the antenna 15 mm away from the human brain model results in a specific absorption rate (SAR) value of 0.2 W/kg for 10g, indicating its safety for brain imaging. By scanning a human head phantom with and without a tumor, the antenna captures reflected signals from different locations, enabling the generation of tumour images. A 10-mm-radius tumor is introduced to the phantom, and the unique reflected signal serves as an indicator for tumor detection, using the signal without a tumor as a reference. MATLAB software is employed for image processing, allowing the generation of tumour images and the estimation of tumor size. The simulation results demonstrate 63% accuracy in tumor size estimation. In conclusion, the antenna proves to be a safe and effective brain imaging system for tumor detection.

1. Introduction

One of the most serious public health problems worldwide is known as brain cancer and known as a brain tumor which the most vital organ of a human body was affected [1,2]. It arises from various types of brain cells or when cancer cells from other parts of the body spread which may cause it to occur. Two main types of brain tumor which are malignant tumors and benign (non-cancerous) tumors which are classified as the primary and secondary tumors [3,4]. The cause of most of the brain tumors remains unknown. Moreover, death caused by brain tumors is reducible if it is detected at an early stage, but the tumor can often come back. A few commonly known imaging devices that are

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https://doi.org/10.37934/aram.126.1.178187

used to detect brain tumors cancer are X-ray screening, magnetic resonance imaging (MRI scanning), computed tomography scans (CT scans), ultrasound imaging and positron emission tomography (PET). Unfortunately, most of these common imaging devices offer a non-safe, high cost, non-accurate result, noninvasive and involves on ionizing radiation.

Microwave imaging technology is an alternative technology which potentially be used for cancer detection [5–13]. Microwave imaging technology is known as an active wave-based noninvasive imaging method that can penetrate the human tissues that have been evolved to detect and locating techniques [14]. The non-ionizing electromagnetic waves from the microwave signals can detect brain tumors without creating health hazards. The principal of the operation for a microwave imaging system is the contrast in electrical properties between the health and malignant tissues. There are four large groups that can be considered as the branches of currently active microwave systems for tissue imaging which are optimization-based microwave imaging, confocal radar-based imaging, microwave tomography and microwave holography. Most of the common tumor detection techniques do not classify size for each of the tumor. Therefore, the pros and cons show that the concern of overhead cost which is non-affordable, health risk and the limitation of tumor imaging technique is the reason why it is essential for implementing a better imaging technique which is microwave imaging because it is a safe, affordable low cost, high accurate system, mobile a nonionizing radiation.

Antenna is known for an aerial interface in between the radio waves propagating throughout the space and electric current moving in the metal conductors that use a transmitter or receiver in the radio engineering. Overall, this section has various types of antennas shown which has different design and material of antenna have been implemented to design the antenna with more advantages and disadvantages which can be analyzed for comparison to choose a more suitable antenna in terms of the size, simplicity, the efficiency and more. The advantages of EBG Based Microstrip Patch Antenna (Resonant frequency=7.3 GHz) is the imaging process is without effecting the health of a patient and the antenna comes with low volume, low fabrication cost and light weight [11]. However, the disadvantages are limited area of detection (requires moving the antenna to certain parts for detection) and the tumor size estimation is inaccurate. Ultra-Wide Band Directional Antenna Array (Operating frequency = 5 GHz) [8] is much simpler in design, lower cost and effectiveness but having long signal acquisition times and has a slower adoption rate and the tumor size estimation is low quality. In other hand, the Wideband Microwave Imaging System (0.75 GHz-2.55 GHz) [15] offer simplicity and the system are compact and light weight but it requires more data acquisition and long computation time and the tumor size estimation not applicable. Finally, Ultra-Wide Band Slot Antenna (3.1 GHz-106 GHz) [12] has potential for low cost and simplicity in design but if inappropriate image processing techniques will be leading to unrecognize target that effect to the wrong size estimation.

Phantom modelling for simulation is important as it enhances the understanding for educational goals and training methodology to optimize learning as well as skills transfer [8]. Phantom modelling purpose to help in terms of training for image interpretation, training in image acquisition, training in the performance of ultrasound, self-learning and proctored ultrasound examinations in clinical settings and proof of learning and competency [8]. As for tumor detection and tumor size estimation, phantom modelling is used for the simulation study for tumor image generating and estimating the size of the tumor. The human head phantom model is mostly used for purposes such as brain cancer detection [11].

Specific absorption rate (SAR) is known as the rate measured at which the energy is absorbed for each unit mass from a human’s body when it is exposed to a radio frequency electromagnetic field. Another form which is also referred to is the absorption of the other forms of energy by tissue which also includes ultrasound [16]. The SAR value is usually either averaged over the whole body or over the small sample volume typically 1g or 10g of tissue. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommends that the maximum SAR for the head is 2W/kg over any 10g [17,18]. As for the calculation the SAR for the electromagnetic energy can be calculated from the electric field with the tissue by referring to Eq. (1) below,

$$SAR = \frac{\sigma E^2}{\rho} \tag{1}$$

where, σ is the sample electrical conductivity, E is the RMS electric field, ρ is the sample density.

This work presents a brain tumor detection and size estimation using microwave imaging. The presented antenna is proposed to allow it to be used directly near to the human body for imaging purpose. The size analysis will be done based on the generated image.

2. Antenna Design

2.1 Design Specification

The frequency selection plays curial role to design the antenna especially for biomedical applications. This due to the absorption and reflection capabilities by the human body which will affect the wave penetration capability. The preferred frequency of the human brain is around 15 GHz and below [1]. However, the lower frequency of operation is ideal for low data capacity which leads to low image quality [19,20]. For that reason, this paper will focus on 7.5 GHz as a resonant frequency that will compensate for wave penetration and image quality. In addition, the antenna will be designed on the basis of a narrow band due to its ability to avoid distorted images due to unwanted waves. In addition to frequency, the physical profile of the antenna is also an important parameter that needs to be considered to enable mobility in biomedical applications. As in [1], the microstrip patch antenna proved to be suitable for biomedical applications especially in tumor detection due to its low profile features. Material used for this antenna design is FR-4 for the substrate and ground is copper respectively with a thickness of 0.035 mm.

As shown in Figure 1(b), the top layer of the proposed antenna is designed based on the modified rectangular patch shown in Figure 1(a). Two vertical slots with dimension of 1 x 3.3 mm^2 applied at both side of the feeding line. Next, two rectangular slots are implemented on the top edge of the patch with dimension of 3.2 x 4 mm^2. All the slots introduced to improve the impedance matching and maximize efficiency by minimize the signal reflection. The final antenna parameters are tabulated in Table 1. Based on the S-parameter shown in Figure 2, the reflection coefficient obtained is -24.20383 dB working at the operating frequency of 7.5 GHz.

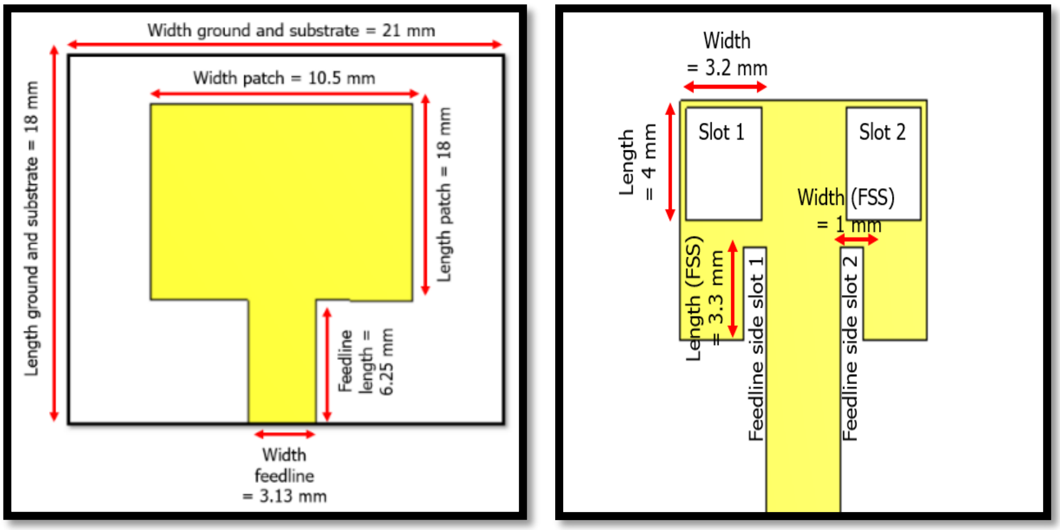


Fig. 1. Front view of the (a) Rectangular patch antenna with dimension (b) Modified rectangular microstrip patch antenna with feedline side slots and slot dimension

Table 1
The dimension based on the analytical calculation for the 7.5 GHz

Dimension	Result (mm)
Width patch	10.5
Length patch	8.5
Width ground	21.0
Length ground	18.0
Width substrate	21.0
Length substrate	18.0
Feedline length	6.25
Feedline width	3.13
Width (slot 1)	3.2
Length (slot 1)	4.0
Width (slot 2)	3.2
Length (slot 2)	4.0
Width side feedline slot 1	1.0
Length side feedline slot 1	3.3
Width side feedline slot 2	1.0
Length side feedline slot 2	3.3

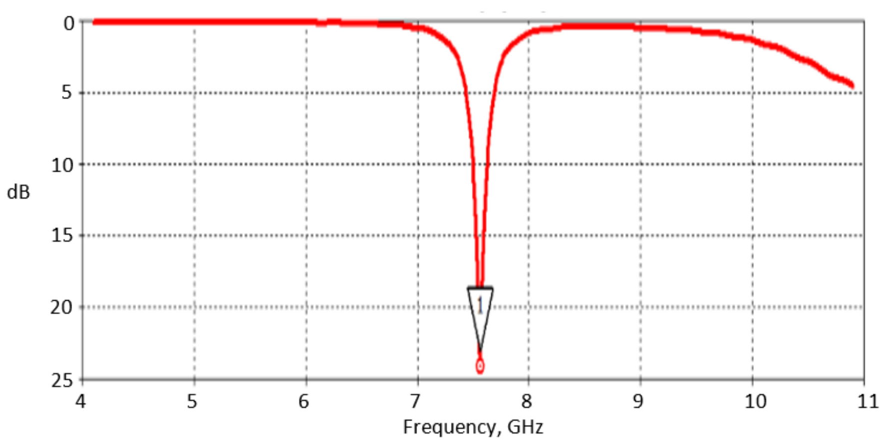
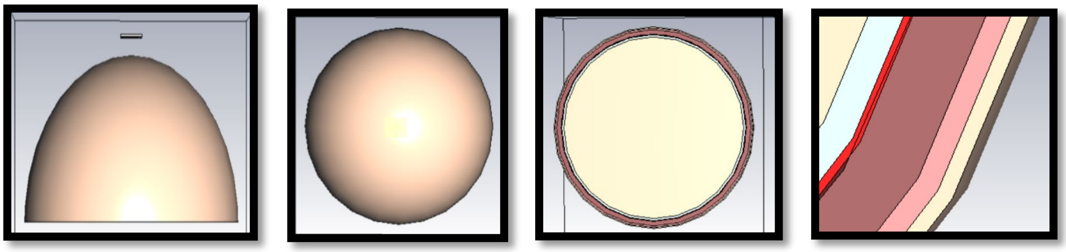


Fig. 2. S-parameters obtained from the simulation of antenna for 7.5 GHz with two feedline side slots and two slots added

2.2 Phantom Specification and Setup

In [15], a human phantom modelled to imitate the properties of real human head in order to ensure proper analysis. Six different layers proposed in [12,15] to mimics each layer of realistic human head. Each of these layers have unique dielectric properties and thickness [12]. Figure 3 and Table 2 shows the healthy human brain phantom used in the simulation. Table 2 and 3 below summarized the layers and the dielectric parameters that represents human's head tissues used for modelling [11].



(a) (b) (c) (d)

Fig. 3. Head phantom (a) Rear view (b) Top view (c) Bottom view (d) Tissue layers

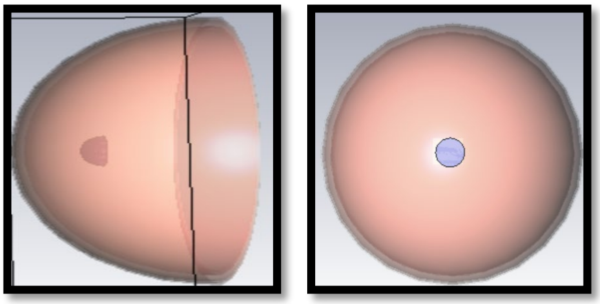
Table 2
Tissue layers based on colours shown on Figure 2(d)

Colour	Tissue	Colour	Tissue
Cream:	Skin	Bright blue:	CSF
Pink:	Fat	Pink chocolate:	Bone
Red:	Dura	Cream:	Brain

Table 3
Phantom properties

Tissue	**Radius (mm)**	**Permittivity (ε_r)**	**Conductivity, (S/m)**
Brain	81	43.22	1.29
Cerebrospinal fluid (CSF)	83	70.1	2.3
Dura	83.5	46	0.9
Bone	87.6	5.6	0.03
Fat	89	5.54	0.04
Skin	90	45	0.73
Tumor	10	55	7

For detection purpose, a tumor model with a diameter of 20 mm with electric parameters of 55 F/m will be introduced to the healthy human brain. The tumor will be insert into the phantom which is located at between CSF and dura which is close to the bone. The tumor is place near the bone to ease the detection as proof of concept. Figure 4(a) below shows the side view of the tumor placed inside the head phantom and Figure 4(b) shows the bottom view of the tumor placed inside the head phantom. Reflected signal of phantom without tumor will be used as reference signal to generate the image. The position of the antenna is placed on top of the phantom with a distance 15 mm for a suitable penetration of microwave signal inside the tissue layers. Figure 5 below shows the antenna placed on top of the human head phantom.



(a) (b)

Fig. 4. (a) Side view of the tumor placed inside the head phantom (b) Bottom view of the tumor placed inside the head phantom

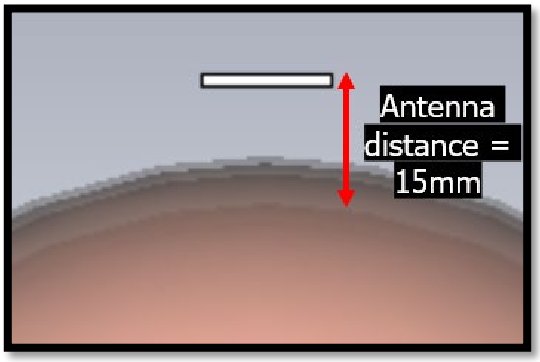


Fig. 5. Antenna placed on top of the human head phantom

In terms of safety regulation for the antenna to be used for brain imaging system, the exposure to radiation which is the specific absorption rate value must not exceed the value recommended to prevent severe health hazard. When human body is exposed to the Electromagnetic radiation, based on reference the standard limit for SAR varies which according to the national reporting, testing requirement and the network band is that the average 10g SAR limit is 2.0 W/kg set by the US and EU standard [11]. The SAR value for the maximum solver as depicted in Figure 6 is 0.2 W/kg for 10g. The value obtain are well below the maximum standard SAR limit recommended which it is safe to be considered as the microwave brain imaging system. Based on the study for MRI scanner-independent specific absorption rate measurements [21] which is the study to measure SAR during MRI scanning using a human torso phantom. The results obtain for five different clinical MRI systems shows the result in the range 1.3 W kg-1 to 2.5 W kg-1 [21]. Based on the comparison, it shows that the refer study SAR value of the MRI is higher than the SAR value obtained for the microstrip patch antenna analysed with the head phantom. Therefore, there is no health risk to occur for the designed microwave brain imaging system.

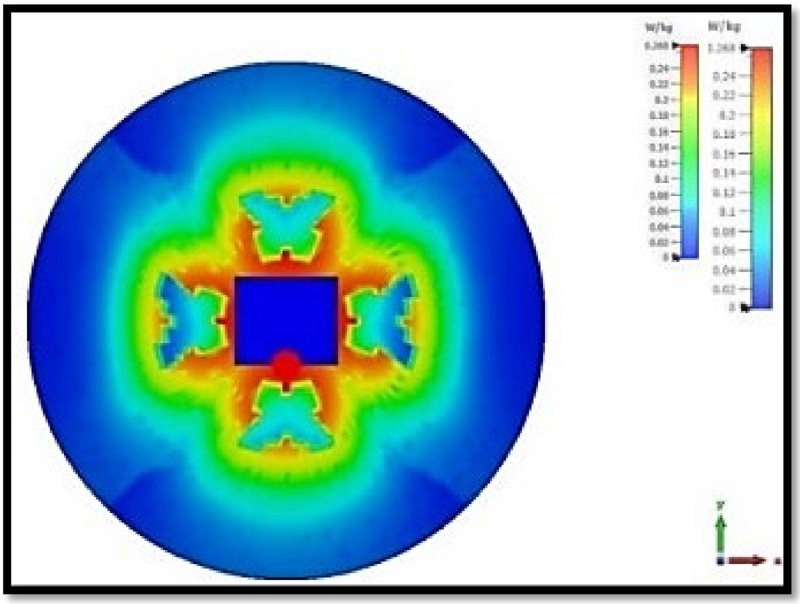


Fig. 6. SAR result at 7.5 GHz

Next, the antenna is moved in the form of mechanical rotation for 15 sequential locations named as scanning process. Figure 7 illustrate the scanning process to cover the entire targeted phantom which the antenna will be placed 15 mm from the skin for each location. In terms of radar-based microwave imaging technique, the microstrip patch antenna is used to scan the human head phantom with backscattering signal that are recorded to each of the antenna position. These collected signals will be used to generate the image as shown in Figure 8(a). The reflected signals are used for image generating as the reflected signals from the simulation for without tumor head phantom is used as reference. Tumor is detected by detecting special or unique reflected signa of the tumor by the comparison of signal between the signals from phantom with tumor and the signal from without tumor which is the reference signal. Based on the generated image, size estimation is obtained by detecting the tumor and calculating the differences between the coordinates from tumor detected. Tumor detection and size estimation is obtained by using image processing method using MATLAB software. Image processing method is the analysis and the manipulation of digitized image which is specially for improving the quality as well as detecting. The process of size estimation consists of converting through a from grayscale which grayscale is the range of monochromatic shades from black to white or called as black and white. Grayscale image used as it simplifies the algorithm and reduces the computational requirement makes it easier for image processing and easily converted to binary image. Binary image is known as images with pixels that have only two possible intensity values which allows easy separation of object from the background for easier tumor detection and then clear border image. As the tumor detected, blue mask layered will covered the tumor detected and coordinates for the tumor detected will be generated and calculated for size estimation as shown in Figure 8(b)-(c). The generated red outlined circle enables for coordinates to be shown manually as the size can be calculated. The size estimation will be observed by subtracting the x-axis coordinates and then divided by two to obtain its radius. Next, it will then be converted to millimeter as the coordinate is in the unit of pixel. The calculation for the red outlined circle summarized in Table 4. The difference between the real and estimated size is 5.789 mm which indicate 63% of accuracy.

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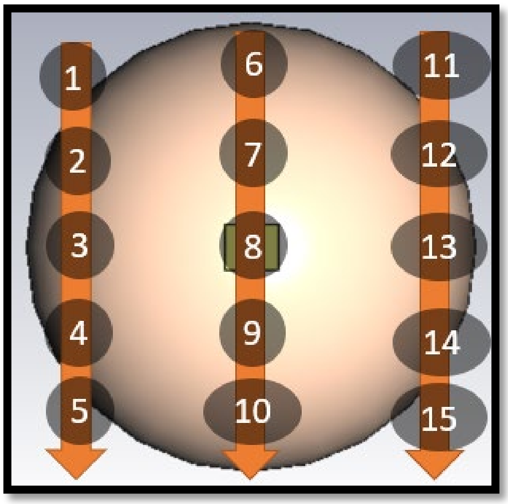
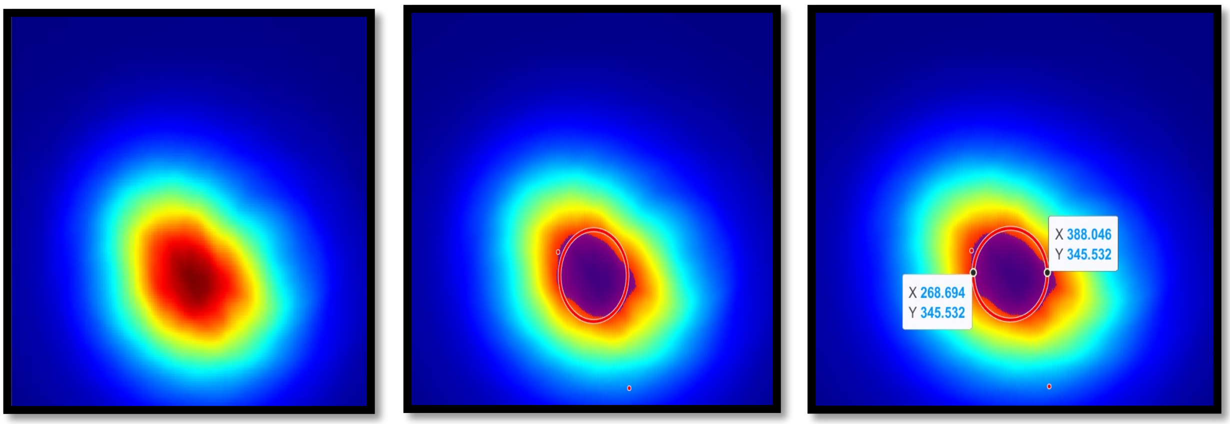


Fig. 7 Pattern for the antenna movement



(a) (b) (c)

Fig. 8. (a) Image generated from the intensities of scattered signals (b) Red outlined circle generated on tumor detected (c) Coordinates for the red outlined circle

Table 4
Size calculation

Circle calculation	Pixel	Millimeter
Diameter	Calculated diameter, 388.046 – 268.694 = 119.352 Right (x-axis) = 388.046 Left (x-axis) = 268.694	Calculated diameter, 102.670504 – 71.091954 = 31.57855 Right (x-axis) = 102.670504 Left (x-axis) = 71.091954
Radius	$\frac{119.352}{2} = 59.676$ Radius = Diameter / 2	$\frac{31.57855}{2} = 15.782$ Radius = Diameter / 2

3. Conclusions

In conclusion, this work has yielded a variety of results across multiple aspects. The simulation of the rectangular microstrip patch antenna provided valuable data on key antenna parameters, such as the reflection coefficient and operating frequency. Ensuring that the antenna meets the specified simulation requirements is essential to achieve better resolution and accuracy. The addition of the vertical slots and other slots in the antenna design significantly improved the reflection coefficient and operating frequency, leading to a better-performing antenna. The optimized patch antenna demonstrated improved matching impedance and reduced reflection coefficient, indicating enhanced performance. Moreover, the antenna was successfully applied to brain imaging applications. The SAR assessment conducted within a human head phantom confirmed the antenna's safety, with SAR values well below the permissible limit. The antenna scanned the human head phantom at different locations to generate tumor images, accomplishing the goal of producing tumor images. By comparing the reflected signals from the head phantom with and without a tumor, the unique reflected signals associated with the tumor were detected. These signals were distinct due to the tumor's different dielectric properties, allowing for effective tumor detection. Additionally, the project successfully obtained tumor size estimations based on the generated images. MATLAB software and image processing techniques were employed to achieve this objective. While the accuracy of the size estimations reached 63% compared to the actual tumor size.

Acknowledgement
This project is financially supported by the Malaysian Ministry of Higher Education (grant no: RACER/1/2019/TK04/ UMS//1) and Universiti Malaysia Sabah under the SPLB schemes (grant no: SLB2204). Special thanks to High Voltage Power Energy Research (HiPER) for the support.

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