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An Investigation of Microwave Tomography Technique to Detect Brain Tumour Through Cross-Section Imaging at Frequency 0.5 GHz to 1.5 GHz

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Abstract: The growing significance of cancerous tissue including brain tumour requires a fast and efficient technology detection. The most current technologies being applied for brain imaging system are Computed Tomography (CT) scan and Magnetic Resonance Imaging (MRI). Whilst these two detection applications are very well established, both systems are expensive, time and space consuming, and raise safety issues to patients due to the radiation and strong magnetic effects. This research aims to assess the feasibility and potential performance of microwave tomography (MWT) for brain imaging with a particular focus on brain tumour detection. The study was conducted using Finite Element Model software, COMSOL Multiphysics to develop a 2D modelling of an antenna array and measure the scattered electric field by solving forward problem. MATLAB software will be used as an inverse problem solver to reconstruct 2D images of the tumour by using Linear Back Projection (LBP) algorithm.

Keywords: Microwave tomography, brain tumour, finite element model, linear back projection

1. Introduction

Brain tumour is known as the most fatal types of cancers that can cause disabilities and death. Every year more than 9,000 people in the United Kingdom (UK) were diagnosed with primary brain tumours of which half are cancerous. Meanwhile, an estimated 700,000 people in the United States are suspected of having brain tumours of whom 86,000 were diagnosed in 2019. As to how much it affects the people in the UK and US, an increased trend occurrence of the brain tumours is also demonstrated in Malaysia, therefore it is currently mandatory for the expansion of research in investigation and treatment of brain tumours. A.Wright [1], has demonstrated the recent technologies of brain scanning techniques including Computerized tomography (CT), Magnetic resonance imaging (MRI), Functional magnetic resonance imaging (fMRI), Positron emission tomography (PET), Single-photon emission computed tomography (SPECT), Diffusion tensor imaging (DTI) and Diffuse optical tomography (DOT) and they all have limitations. CT and MRI are currently the most commonly used diagnostic tools for brain tumour detection. Whilst these two detection methods are very well established, both systems require expensive treatment, time and space consumption, and may cause safety issues to patients due to radiation and strong magnetic effects. Research had been done by [2], [3] and [4] to establish results relating to the ability of dielectric properties that contributes in distinguishing property in human head phantom demonstrated via either fabrication of an anatomy or realistic head

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phantom. Based on [3] and [4], the range of frequency for operation of the head phantom is between 0.5 to 4 GHz. The result of image reconstruction has also been successfully obtained by other research [2] through the frequency range of 0.5 GHz to 2GHz by using a circular object which represents the head.

In such a framework, the feasibility of MWT for neuroimaging and evaluation of perfusion-related injuries within the brain has been demonstrated in the detection of brain stroke injury [5],[6],[7],[8],[9]. MWT has a potential application for fast imaging technique and its development is fast gaining popularity, due to its capability as non-invasive real-time, safe, portable, and cost-efficient tissue viability monitoring. For detecting brain tumour via application of MWT, it requires a calculation technique which consists of forward scattering and inverse scattering problem. The finite Element Method (FEM) is preferred as the best numerical method to solve forward problem model in the frequency domain among several numerical methods [10]. The study highlighted the possibility of employing future head imaging development through an efficient image reconstruction algorithm that depends on the scattered electric field data obtained from a 2D simulation setup. The MWT showed the feasibility as a new imaging technique for brain disease such as brain stroke [5],[6],[11],[12],[13],[14], and brain injury detection [1],[15]. Thus, this presentation of MWT feasibility towards brain disease presents an opportunity for brain tumour detection which harness as tumour tissue characteristic. The major advantage of microwave-based tomography is that they can give good contrast between higher and lower permittivity substance other than being non-intrusive, non-invasive, non-radiation and low cost.

This research proposes a microwave tomography system based on the electromagnetic inverse scattering method measuring at microwave frequency, as an alternative to CT and MRI. This study aims to investigate the feasibility of microwave tomography to determine complex permittivity distribution from the scattered electromagnetic field around the periphery of the substance at different angles, thus creating multiple views of the brain tumours A range of frequencies spanning from 0.5 GHz to 1.5 GHz will be used to determine the best frequency that constructs the best image quality that represents the real phantom. This study will apply the software COMSOL Multiphysics to develop a 2D modelling of an antenna array and measure the scattered electric field by solving forward problem. MATLAB software will be used as a platform to reconstruct 2D images by using Linear Back Projection (LBP) algorithm.

2. Materials and Methodology

This research work begins with the literature review to find gaps and as well as to understand previous work and currently available technologies. From the literature review, the best potential specifications were determined to make it works on the application. The modelling of the sensor will be developed in the COMSOL Multiphysics to resolve the forward problem. MATLAB will be used to run the Linear Back Projection Algorithm for image reconstruction. Obtained images will be analysed and compared with the real phantom. Optimisation will be carried out if the obtained images do not meet the desired result.

2.1 Study on Substance

A preliminary analysis of the substance in human brain concerning their behaviour is mandatory before modelling is carried out. The brain plays a role as the most complex organ in the human body [16]. The MWT result is regulated by the properties of dielectric properties for each material. This research comprises of many types of substance including different type of solid and liquid which have different types of dielectric properties. As for that, it required identification of each behaviour of substance according to its permittivity and conductivity. The high water content in tumour tissues produces a high value of permittivity in comparison to normal tissues [16]. The permittivity value of tumours tissue has approximately 14% higher value compared to those of normal tissues. In this study, the 2D brain phantom with tumour was constructed with different layers of relative permittivity. The equation 1 given below shows the relative complex permittivity of a lossy material which depends on the frequency of radiation [10].

$$\grave{\varepsilon}_r = \varepsilon_r + \frac{\sigma}{j\omega\varepsilon_0} \quad (1)$$

The relative permittivity is defined by $\grave{\varepsilon}_r$, followed by ε_r, real relative permittivity, σ is the conductivity, ω is the angular frequency, and ε_0 is the free space permittivity.

2.2 MWT Modelling in COMSOL Multiphysics

By referring to [10], a head phantom is constructed according to different thickness of the tissues. According to the Zubal head phantom slide 36 [9], the brain size is approximately 150mm x 200mm. The average diameter for tumour size are in range of 40mm, with a study of an elliptically shaped of tumour in range of 32mm x 40mm [16]-[20]. In the process of evaluating the sensitivity of the system, it is required to study different location of the tumour. Since the tumour has the possibility to grow and spread at any places, the position is set at a different part of the brain. Whilst the frequency plays a critical role in wave penetration, the simulation of frequency is applied at range of 0.5 GHz to 1.5 GHz as to figure out the suitable frequency for the desired result [21]-[26]. As for the radiation and thermal safety [12],[24], the transmission power is applied at certain limited value which at maximum 1mW or 0dBm. For high sensitivity and fast computation, the system is implemented with a minimum of eight rectangular patch electrode. The Table 1 presents the simulation parameter while the values of permittivity and conductivity for normal brain tissue and tumour tissue at 1 GHz is showed in Table 2.

Table 1 - List of parameters

Tissue	Thickness (mm)	Relative permittivity, ε_r	Conductivity, σ (S/m)
Skin	5	41	0.89977
Skull	7	12	0.15566
Cerebral Spinal Fluid (CSF)	3	68	2.4552
Grey Matter	-	52	0.98541
Tumour	-	62.8	1.24

Table 2 - Dielectric properties of substance

	Parameter	Values
1	Number of electrodes	8
2	Power applied at electrodes	1mW [14]
3	Frequency	0.5 GHz to 1.5 GHz
4	Brain size	150mm x 200 mm [9]
5	Size of tumours	Range of 32 mm x 40mm
6	Size of electrode (*l x w)*	40 mm x 10 mm
7	Position of tumours	Left, Right, Center, Top, Bottom
8	Software simulation	COMSOL Multiphysics

2.3 Modelling of the Sensor Array

The system will be constructed using 8 measurement channels with one of the electrodes functioning as a transmitting antenna and the other seven as the receiving antennas [25]. Example of the modelling is shown in Fig. 1. The performance of microwave tomography is obtained through simulating the 2D brain phantom by turning on each antenna port accordingly. Each simulation requires only one transmitting antenna port to be powered on and the rest of seven antenna ports will act as the receiving ports. Thus, there are eight simulations are required to be performed in order to obtain the dataset of tumour inside 2D brain phantom. The position of tumour is constructed at different positions inside the brain phantom as shown in Fig. 2. The value of scattered electric field received by the receiving antenna port will be computed using Finite Element Method (FEM), the forward problem solver [10]. The interface of COMSOL is as per Appendix B.

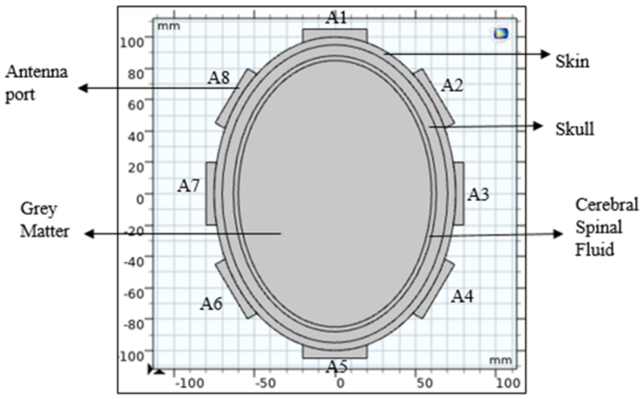


Fig. 1 - Modelling in COMSOL

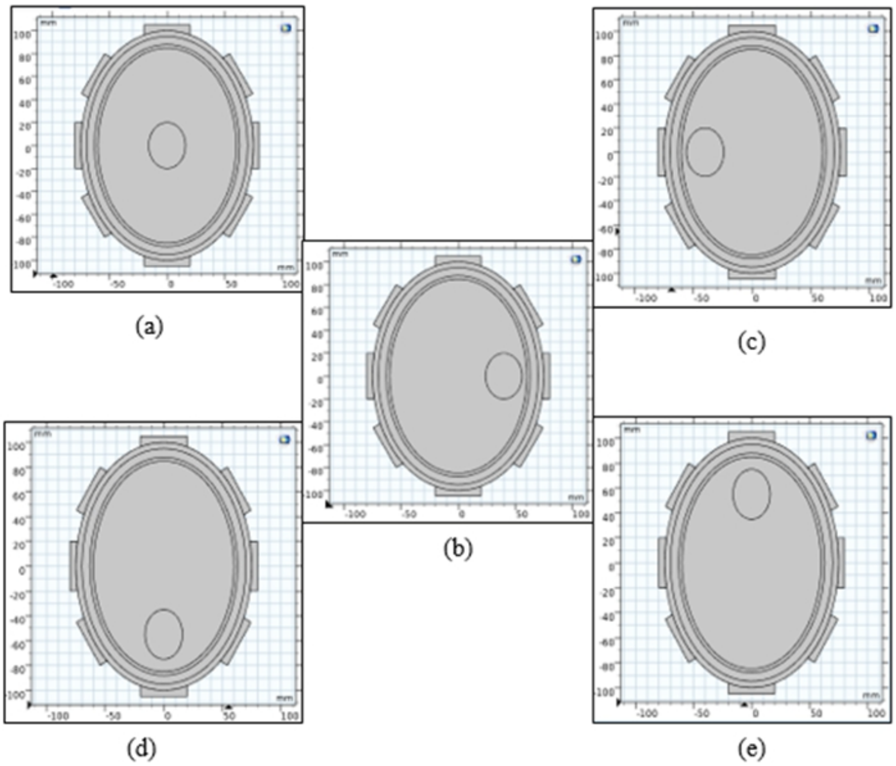


Fig. 2 - Position of the tumour, (a) Center; (b) Right; (c) Left; (d) Bottom; (e) Top

2.4 Image Reconstruction in MATLAB

The major output of the forward problem solver will be used to reconstruct the image in MATLAB. The value of scattered electric field obtained from the simulation of 2D brain phantom in COMSOL will be used in image reconstruction via MATLAB. The Linear Back projection (LBP) algorithm [22], is used to perform the image reconstruction process of the 2D brain phantom. The LBP algorithm is based on the computation of the sensitivity maps for every path projection [22],[23]. The pixel locations of the 2D brain phantom are defined for performing the process of sensitivity maps for every path projection. All the elements of scattered electric data from 2D brain phantom are added up in sensitivity map. The result will be divided by the pixel location of the sensitivity map. Next, the multiplication process are performed between the previous result with the sensory loss and the maximum number of color pixels used. The concentration profile of 2D brain phantom is obtained from a combination of scattered electric field data projection for each antenna port with its computed sensitivity map [22]. The image of 2D brain phantom is reconstructed based on the result of multiplication process.

3. Results and Discussions

The ranges of frequencies were studied to choose the best frequency in image reconstruction for brain tumour detection. The Fig. 3 below observe the electric field scattered gather by each of the receiving antenna port and compute the electric field strength obtained at receiving antenna port according to different frequency. Fig. 3 illustrates the electric field for tumour placed at center side of the brain with different frequencies. The graph trend describe the decrease pattern of electric field strength received by each receiving antenna port as the higher frequency were applied. It is observed that the same trend allocates for all the tumour location including tumour placed at left, right, bottom and top of the brain. The value of electric field strength received by the receiving antenna port were computed from the electric field scattered through brain material. When frequency arises, its emit the higher energy to be absorbed by the microwave and produced the higher attenuation within the material in the brain. Thus, the amount of electric field accepted by the receiving antenna port will be reduced and perhaps the low image quality were generated. The frequency of 0.5 GHz indicates the highest electric field strength followed by 1.0 GHz and 1.5 GHz. Since the value of 1.5 GHz almost equal to zero, the range of 0.5 GHz to 1 GHz can be conclude as the optimal value for brain imaging [7]. In order to reconstruct the best image quality of brain tumour, 1 GHz is chosen as this frequency can resolve the bigger objects [14].

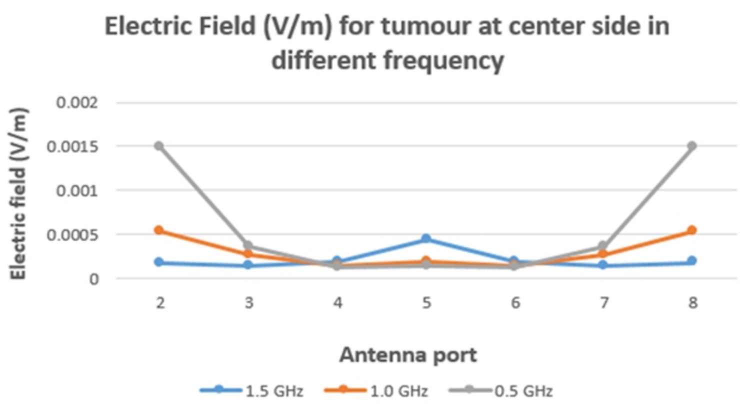


Fig. 3 - Electric field (V/m) for tumour at center side in different frequency

Based on Fig. 4, each tumour at a different position shows the different value of electric field strength received by the receiving antenna port perspectively. The tumour at bottom and center side of the brain contribute the lowest and the highest electric field strength received by each antenna port. The electric field strength value for the other tumour placed at left, right, and top of the brain are in the medium range value. It shows that the amount of scattered electric field propagates through antenna port were distinct at different tumour position. Hence, the result shows that microwave tomography has the potentiality in determining the complex permittivity distribution of brain tumour from the scattered electromagnetic field substance at a different position.

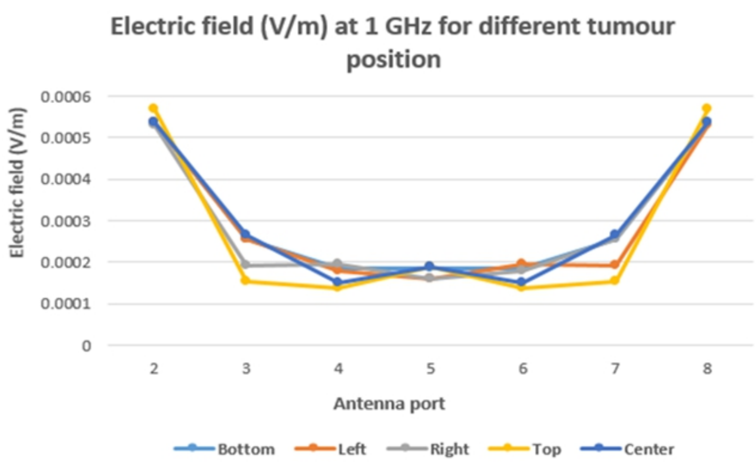
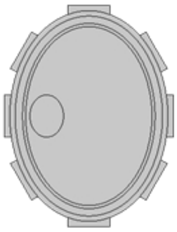
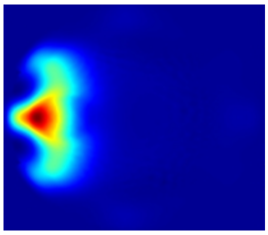
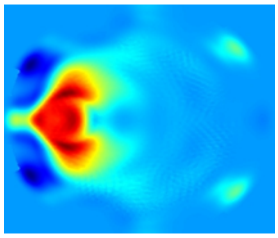
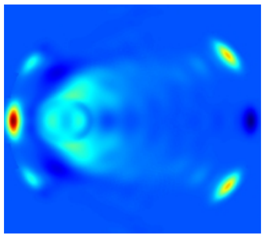
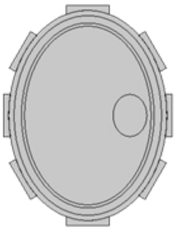
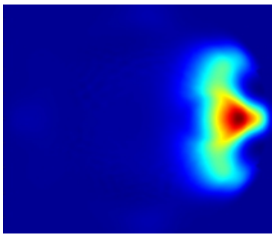
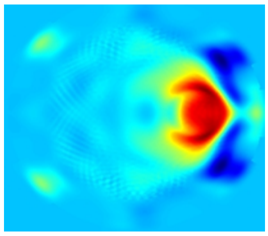
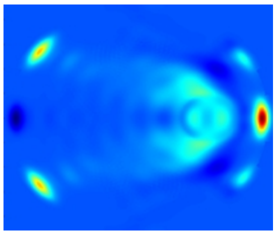
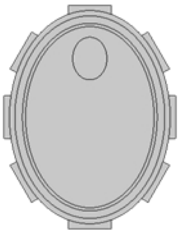
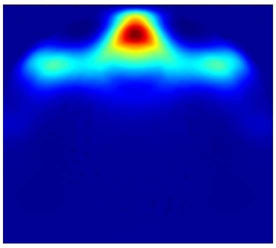
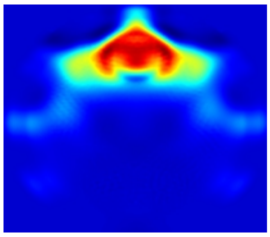
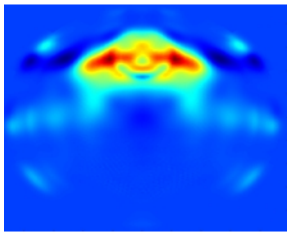
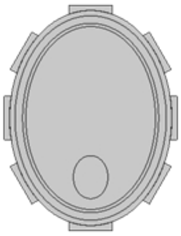
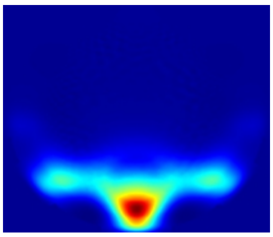
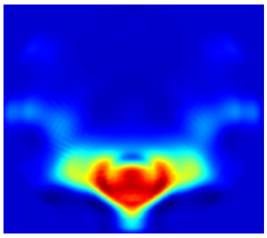
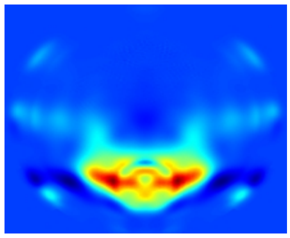
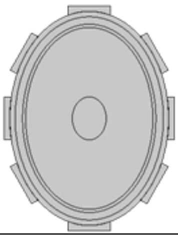
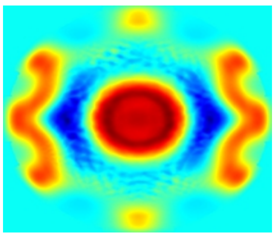
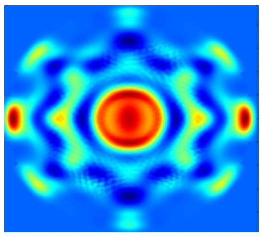
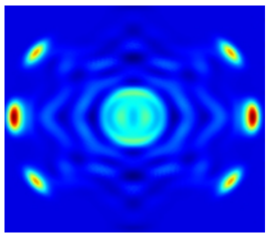


Fig. 4 - Electric field (V/m) at 1 GHz for different tumour position

Table 3 shows the reconstructed images for different tumour positions with three different frequencies covering 0.5 GHz, 1.0 GHz, and 1.5 GHz. It can be seen that the permittivity difference can be detected at 0.5 GHz and 1.0 GHz. However, at 1.0 GHz, the tumour at the boundary i.e. top, bottom, left and right are more prominent in size in comparison to 0.5 GHz. However, it is observed that there is a slight difference in size between the four tumour at the boundary due to the inconsistent location of the tumour during the design stage in COMSOL. The distance between the tumour and electrodes determines the amount of penetration depth of the electric field through the material. The image reconstruction at the center produces good images at 0.5 GHz and 1.0 GHz. However, at 1.0 GHz, the image of the brain tumour at the centre is found to be more accurate to the real phantom in size. The results were obtained as such because when the frequency increases, the interaction between microwaves and the tissues in the brain become stronger due to higher energy absorption. These phenomena lead to the strong scattering presentation within brain tissue and allow electromagnetic waves to perform strong tumour detection. The reconstructed images at 1.5 GHz are the least acceptable at all locations perhaps due to the high attenuation occurred through brain tissue which produces least signal to be captured by the electrodes. Thus, the result of image reconstructed from 1.5 GHz were produced in poor quality. The result in overall significantly shows that 1.0 GHz is the best frequency to be applied for the image reconstruction of the brain tumour to obtain the images closest to the real phantom.

Table 3 - Image reconstruction for brain tumour at 0.5 GHz, 1.0 GHz, and 1.5 GHz

Real Phantom (Tumour position)	Frequency (GHz) 0.5	1.0	1.5
Left 			
Right 			
Top 			
Bottom 			
Center 			

4. Conclusion

The microwave tomography (MWT) technique is proven feasible to be used as early detection of brain tumour through the determination of complex permittivity distribution. The 8-antenna MWT system was designed and simulated in COMSOL Multiphysics and has solved the forward problem. At the backend, the LBP algorithm is used on MATLAB for image reconstruction. The results shows most promising images at 1.0 GHz for all locations of tumour i.e. left, right, centre, top and bottom in the human head phantom, in comparison to 0.5 GHz and 1.5 GHz. The major contribution of this work is that the results can be used as early detection for further treatment to increase the survival rate of patients who have brain tumour. Additionally, this new system is foreseen to be inexpensive and portable that would highly benefit people with low income and those living in rural areas.

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References

[1] Van der Geer, J., Hanraads, J. A. J., & Lupton, R. A. (2000). The art of writing a scientific article. Journal of Science Communication, 163, 51–59
[2] Strunk, W., Jr., & White, E. B. (1979). The elements of style (3rd ed.). New York: MacMillan
[3] Mettam, G. R., & Adams, L. B. (1999). How to prepare an electronic version of your article. In B. S. Jones & R. Z. Smith (Eds.), Introduction to the electronic age (pp. 281–304). New York: E-Publishing Inc
[4] Fachinger, J., den Exter, M., Grambow, B., Holgerson, S., Landesmann, C., Titov, M., et al. (2004). Behavior of spent HTR fuel elements in aquatic phases of repository host rock formations, 2nd International Topical Meeting on High Temperature Reactor Technology. Beijing, China, paper #B08
[5] Fachinger, J. (2006). Behavior of HTR fuel elements in aquatic phases of repository host rock formations. Nuclear Engineering & Design, 236, 54
[1] Wright, A. (2010). Brain scanning techniques (CT, MRI, fMRI, PET, SPECT, DTI, 57 DOT). Cerebra Positively Different, 1089812, 1–14
[2] Collier, T. J., Kynor, D. B., Bieszczad, J., Audette, W. E., Kobylarz, E. J., & Diamond, S. G. (2012). Creation of a human head phantom for testing of electroencephalography equipment and techniques. IEEE transactions on Biomedical Engineering, 59(9), 2628-2634
[3] Mobashsher, A. T., & Abbosh, A. M. (2014). Three-dimensional human head phantom with realistic electrical properties and anatomy. IEEE Antennas and Wireless Propagation Letters, 13, 1401-1404
[4] Giacometti, V., Guatelli, S., Bazalova-Carter, M., Rosenfeld, A. B., & Schulte, R. W. (2017). Development of a high resolution voxelised head phantom for medical physics applications. Physica Medica, 33, 182-188
[5] Scapaticci, R., Bucci, O. M., Catapano, I., & Crocco, L. (2014). Differential microwave imaging for brain stroke followup. International Journal of Antennas and Propagation, 2014
[6] Mohammed, B., Abbosh, A., & Ireland, D. (2012). Directive wideband antenna for microwave imaging system for brain stroke detection. In 2012 Asia Pacific Microwave Conference Proceedings, 3, 640-642
[7] Semenov, S. Y., & Corfield, D. R. (2008). Microwave tomography for brain imaging: Feasibility assessment for stroke detection. International Journal of Antennas and Propagation, 2008
[8] Petrović, N. (2014). Measurement system for microwave imaging towards a biomedical application. Doctoral dissertation, Mälardalen University
[9] Munawar Qureshi, A., Mustansar, Z., & Maqsood, A. (2016). Analysis of microwave scattering from a realistic human head model for brain stroke detection using electromagnetic impedance tomography. Progress In Electromagnetics Research, 52, 45-56
[10] Priyadarshini, N., & Rajkumar, E. R. (2013, July). Finite Element Modeling of scattered electromagnetic waves for stroke analysis. In 2013 35th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 1, 2404-2407)
[11] Hill, C. I., Nixon, C. S., Ruehmeier, J. L., & Wolf, L. M. (2002). Brain tumors. Physical Therapy, 82(5), 496-502.
[12] Mobashsher, A. T., & Abbosh, A. M. (2015). Developments of tomography and radar-based head imaging systems. In 2015 International Symposium on Antennas and Propagation (ISAP), 1-3
[13] Semenov, S. (2009). Microwave tomography: review of the progress towards clinical applications. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 367(1900), 3021-3042
[14] Gabriel, S., Lau, R. W., & Gabriel, C. (1996). The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz. Physics in Medicine & Biology, 41(11), 2251
[15] Yiu, E. M., Laughlin, S., Verhey, L. H., Banwell, B. L., & Canadian Pediatric Demyelinating Disease Network. (2014). Clinical and magnetic resonance imaging (MRI) distinctions between tumefactive demyelination and brain tumors in children. Journal of Child Neurology, 29(5), 654-665
[16] Lancaster, M. A., Renner, M., Martin, C. A., Wenzel, D., Bicknell, L. S., Hurles, M. E., Homfray, T., Penninger, J. M., Jackson, A. P. & Knoblich, J. A. (2013). Cerebral organoids model human brain development and microcephaly. Nature, 501(7467), 373-379
[17] Pastorino, M. (2010). Microwave imaging (vol 208). John Wiley & Sons
[18] Joachimowicz, N., Vasquez, J. T., Turvani, G., Dassano, G., Casu, M. R., Vipiana, F., Duchêne, B., Scapaticci, R., & Crocco, L. (2018). Head phantoms for a microwave imaging system dedicated to cerebrovascular disease monitorin. In 2018 IEEE Conference on Atenna Measurements & Applications (CAMA), 1-3
[19] Türkkan, G., V. Yürüt-Çaloglu, V., Caloglu, M., Uzunoglu, S., Kilic¸-Durankus, N., & Cakir-Nurlu, D. (2015). The most important prognostic factor in elderly patients with glioblastoma multiforme: Diameter of residual tumor. Radiotherapy and Oncology, 115, S691

[20] Yoo, D. S. (2004). The dielectric properties of cancerous tissues in a nude mouse xenograft model. Bioelectromagnetics: Journal of the Bioelectromagnetics Society, The Society for Physical Regulation in Biology and Medicine, The European Bioelectromagnetics Association, 25(7), 492-497

[21] Health Canada. (2015). Radio Standards Specification - Radio Frequency (RF) Exposure Compliance of Radiocommunication Apparatus (All Frequency Bands). Standard No. 4. https://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf01904.html

[22] Podari, N., Muji, S. Z. M., Jabbar, M. H., & Rahim, R. A. (2014). Design and modeling of linear back projection (LBP) algorithm for field programmable gate array (FPGA). ARPN Journal of Engineering and Applied Sciences, 11(24), 14075-14077

[23] Amirulah, R., Muji, S. Z. M., Jabbar, M. H., Syaib, M. F. A., Rahim, R. A., & Mahmood, M. N. (2015). Fixed-point sensitivity maps for image reconstruction in tomography. Jurnal Teknologi, 73(6)

[24] Mobashsher, A. T., Bialkowski, K. S., Abbosh, A. M., & Crozier, S. (2016). Design and experimental evaluation of a non-invasive microwave head imaging system for intracranial haemorrhage detection. Plos one, 11(4), e0152351

[25] San, S. S. S., Rahiman, M. H. F., Zakaria, Z., Talib, M. T. M., Pusppanathan, J., & Jamaludin, J. (2018). Simulation study of microwave imaging for brain disease diagnostic. Journal of Telecommunication, Electronic and Computer Engineering, 10(1-16), 21-26

[26] Gabriel, S., Lau, R. W., & Gabriel, C. (1996). The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues. Physics in Medicine & Biology, 41(11), 2271-2293