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Review Article of Microwave Imaging Techniques and Dielectric Properties for Lung Tumor Detection

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Abstract. This article presents the microwave imaging techniques in order to detect early lung cancer with dielectric properties of normal and cancerous tissues which affect the propagation of the microwave signal. Identifying the contrast of dielectric properties of normal and cancerous lung tissues is significant in microwave imaging because it is used in reconstructing the image either in radar-based or tomographic imaging techniques. In microwave imaging measurement from past researchers are highlighted in order to identify the optimum distance of the antenna from the human thorax and the significant size of the tumour that can be detectable.

INTRODUCTION

Lung cancer has a higher mortality rate because it is frequently discovered too late. According to the World Health Organization statistic in 2015, lung cancer was listed as the most devastating and high priority which almost 1.70 million patients are diagnosed for every year [1]. While in Malaysia, on the report of Malaysia Study on Cancer Survival 2018, the survival rate for lung cancer across all stages is 11% within five year, which the median time of survival after being identified is only 6.8 months [2]. The lack of variability in survival rate from lung cancer clearly raises a concern about possible solutions. Experts recommend that the top defence against lung cancer is between early detection and treatment.

One of the most favoured imaging routine in current lung cancer diagnosis is computed tomography (CT). However, the CT is high-risk radiation vulnerability, costly, high false positive rate and cannot work on a routine basis [3]. Additionally, the radiations cause from CT increase the possibility of cancer mostly in children due to the sensitivity of radiation-induced carcinogenesis [3]. Another technology, magnetic resonance imaging (MRI), is a substantial tool for lung imaging without ionizing radiation, but not advocated for regular lung screening because it gives inadequate anatomic information, time-consuming and expensive [4]. Recently, microwave imaging has been widely explored for early lung cancer detection for its safety, low cost and dissimilarity [5].

Microwave imaging is a technique use nonionizing radiation, developing radiological images of the internal tissues of the human body and low health risk method. Microwaves are identified in the electromagnetic (EM) spectrum between frequencies 300 MHz and 30 GHz which the high frequency of the wave can easily spread through of the human body and pass through different interfaces of the human body [6]. Moreover, the microwave imaging equipment consists of a microwave source, a receiver, an antenna array for transmitting the signals and a radio frequency switch to switch between different antenna elements in the antenna array [7]. This implies two approaches for producing microwave images which are tomography and radar-based technology.

The detection of lung cancer with microwave imaging is based on the dissimilarity in dielectric properties of cancerous tissues compared to normal tissues at microwave frequencies [8]. Different tissues have different dielectric properties that are characterized by relative permittivity and conductivity. Attributable to the difference between normal and cancerous tissues, the interchange of the EM signals will be different for different tissues [9]. Hence, the detection of tumour is performed through the microwave imaging technique with a comparison of dielectric properties for normal and cancerous tissues.

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DIELECTRIC PROPERTIES FOR CANCEROUS AND NORMAL LUNG TISSUES

The important element of microwave imaging technique is the measurement of dielectric properties of normal and cancerous lung tissues which influence the propagation of the microwave signal. The different dielectric properties are characterized by conductivity and permittivity. In general, the conductivity is defined as the free path length and speed of the electron inside the material while the permittivity is associated as the molecule dipole moment per volume [10]. Besides that, when the lung tissues are affected by the disease and temperature, there has a variation in the dielectric properties with respect to healthy tissue. By monitoring these variations, the anomalies of normal and cancerous tissues can be treated and identified.

Generally, when the frequency increases, the conductivity increases and permittivity decreases. A mathemathical model to parameterize values of conductivity and permittivity with their frequency dependence is the Debye's model, given as [11−13].

$$\varepsilon_r^* = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 - j\omega\tau} - \frac{j\sigma_o}{\omega\varepsilon_o} \quad [1]$$

$$\sigma^* = \sigma_\infty + \frac{\sigma_o - \sigma_\infty}{1 - j\omega\tau} \quad [2]$$

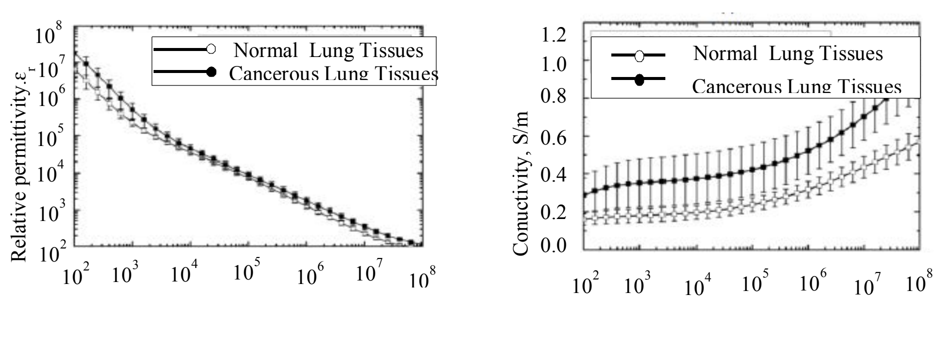
The debye's model has some limitations in expressing all dispersion complexities. Therefore, the Cole-Cole's model used; given as

$$\varepsilon_r^* = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 - (j\omega\tau)^\alpha} - \frac{j\sigma_o}{\omega\varepsilon_o} \quad [3]$$

$$\sigma^* = \sigma_\infty + \frac{\sigma_o - \sigma_\infty}{1 - (j\omega\tau)^\alpha} \quad [4]$$

Where the parameter is depending on the nature of the material [11].

By exploring the experimental study of dielectric properties of human lung tissues in vitro by J. Wang, B. Sun, and H. Wang [14], the comparison of dielectric properties of cancerous and normal tissues in human lungs is presented. From operation patients with lung cancer, the specimens obtained was impedance spectra from 100 Hz to 100 MHz [14]. The mean and standard deviation of the relative permittivity and conductivity of cancerous and normal tissues were presented. Figure 1(a) shows the relative permittivity mean value with two types of tissues decrease with increasing frequency, *f.* The relative permittivity shows a slow drop and the contrast between cancerous and normal tissues drop off with frequency range from 1 kHz to 1 MHz. Hence, as a result, the relative permittivity of cancerous tissues is 1.2 – 3 times larger than normal tissues [14]. Whereas in Fig. 2(b), the conductivity of the two types of tissues increasing *f* is shown. Nevertheless, the conductivity varies slightly at low frequencies. Based on that result, one can conclude the conductivity of cancerous tissues (0.28 – 0.96 S/m) is higher than normal lung tissue (0.16 – 0.57 S/m) [14].



(a) (b)

FIGURE 1. Dielectric spectrum properties of cancerous and normal tissues (a) Relative permittivity, (b) Conductivity [14]

The dielectric properties are establish on healthy lung tissues for identical frequencies. Stuchly and Stuchly[15] report stated the similar conductivity range from 0.62 to 0.72 S/m with the permittivity values of human lungs in vitro at body temperature between 200 and 500 MHz. While, Durney et al [16] as well as Foster and Schwan [17] give conductivity 0.53-0.73 S/m of human ex vivo lung tissues at room temperature from 200 MHz to 1 GHz with 35 value of relative permittivity. In Joines et al [18] the conductivity of malignant tissues was establish higher than the normal lung tissues : the conductivity of normal lungs increased from 0.64 S/m to 1.16 S/m (respectively from 0.84 S /m to 1.24 S/m) and the permittivity of normal (respectively malignant) lungs was establish to decrease from 65.0 to 60.3 (respectively from 61.0 to 54.0) between 200 MHz and 900 MHz.

MICROWAVE IMAGING TECHNIQUES

The basis for microwave imaging lies in the notable dissimilarity in the dielectric properties between the cancerous and normal tissues at microwave frequencies. The microwave travelling through the chest, tend to scatter due to the changes in the electrical properties. At the receivers and transmitter the noticed energy the will be alters. Then, the images are created from the particulars of detected energies shown in Fig. 2. This implies in two screening imaging that approaches in microwave imaging screening which is tomography and Ultra Wide Band (UWB) radar imaging.

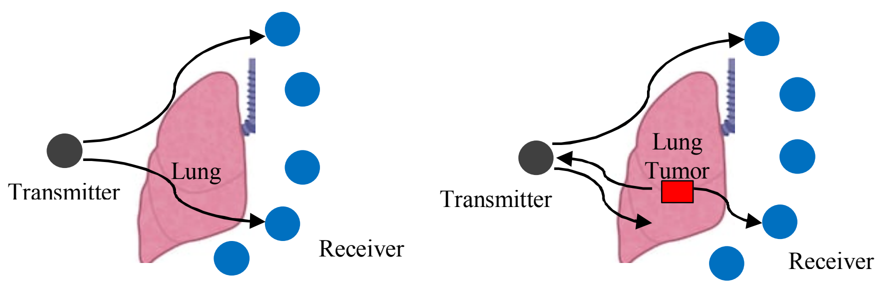


FIGURE 2. Signal transmission of lung cancer detection

In microwave tomography, the transmitter and receiver antennas will be surround the object that under consideration. In the quantifications method, the combination antennas are created by each antenna that worked as a transmitter and receiver [19]. The system used UWB radar imaging from reflected waves of the objects and rebuilds the image. The reflection that appears due to differences in the dielectric properties of normal and cancerous tissues are used. A major advantage of this technique over microwave tomography is avoided the inverse scattering problem and measure the backscattered signals [20].

MICROWAVE IMAGING MEASUREMENT SETUP

Based on the experiment by [21] and [22], they had identified the optimum distance of the antenna from the human thorax and the significant size of the tumour that can be detectable. The frequency band that was the suggested by [23] from 3 GHz to 5 GHz; for effective and safe penetration of microwave signal to the human lung the low frequency are recommended,. Referring to Fig. 3, the sliced section of the thoracic wall covering dimensions of 60 mm x 60 mm is cubically illustrated to represent the human thorax model. The thickness of every tissues layer displayed is originated from the work of Cavagnaro et al [24].

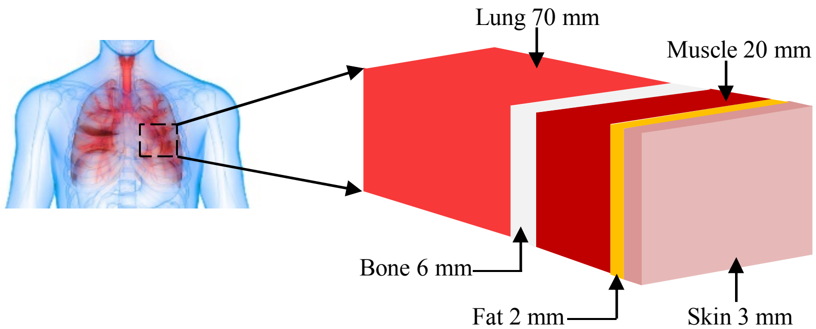


FIGURE 3. Multilayer of thoracic tissues [16]

In [21], the simulation measurement setup was performed by using the UWB antenna as shown in Fig. 4 in order to detect the lung tumour and Fig. 5 shows the side view of the thorax model [22]. Hence, the optimum distance, d between the antenna and the human thorax had identified. It can be seen in Fig. 6 and Table 1, the distance with 10 mm is the lowest return loss that the reflection coefficient represents. It shows the antenna works best at a distance 10 mm on the frequency of 3.67 GHz which matched the research result in [22].

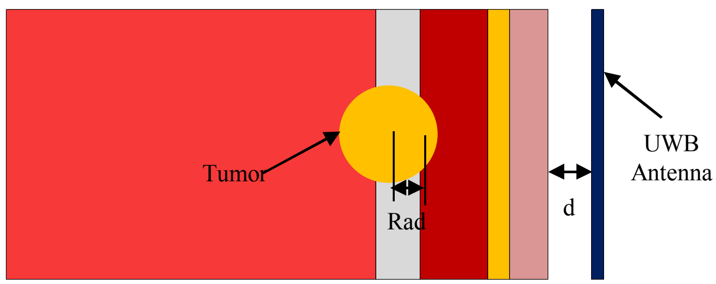


FIGURE 4. Parameter of antenna distance in the measurement setup [21]

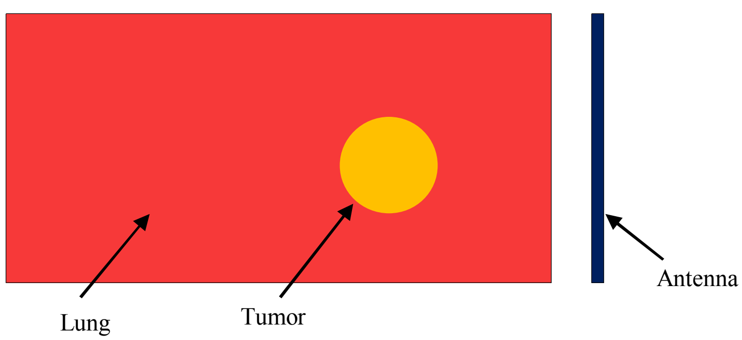


FIGURE 5. Side view of the lung model showing tumour (muscle sphere) and antenna [22]

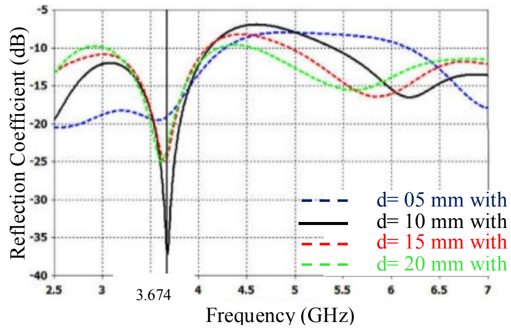


FIGURE 6. Simulated return loss with different values of *d* [21]

TABLE 1. Reflection coefficient at different antenna distance [21]

Antenna distance. *d* (mm)	Reflection Coefficient (dB)
5	-20.45
10	-37.21
15	-24.99
20	-24.93

According to [25] and [26], the approximate tumour size of early-stage lung cancer detected using Computed Tomography (CT) scanning is typically 15 mm in diameter or less. Then, in Fig. 7 shows the tumour with 4 mm radius in size is the most significant size the tumour can be detectable and it's same also with the size of the tumour above than that. While the simulation result of tumour with radius from 3 mm and below shows there is no frequency shifting and non effective to detect the tumour inside the lung. Hence, UWB microwave imaging is capable to differentiate between normal and cancerous tissues with economical alternative among non-invasive methods in order to avoid exposure to any harmful radiation.

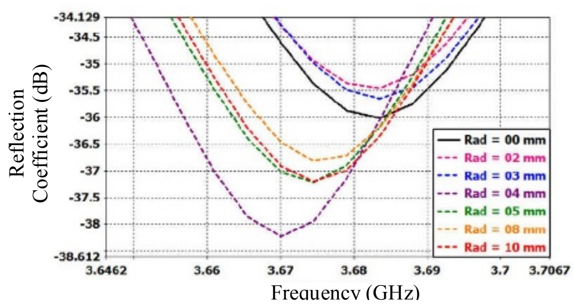
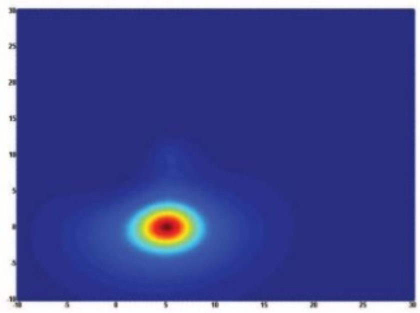
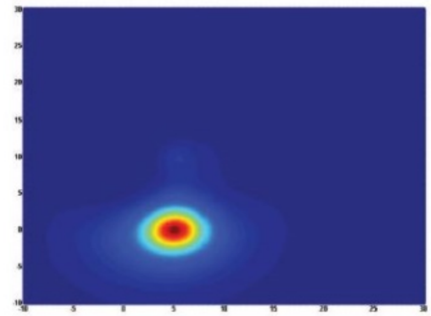


FIGURE 7. Magnified view of simulated return loss with different values of *Rad* [21]

Based on [27], they try to motivate researchers into adapting some of the succesfull imaging techniques for lung imaging as much research in microwave imaging had been devoted to the breast. Hence, it is possible to detect lung tumour using microwave and the contrast in the dielectric properties of normal and cancerous lung tissues, which serves as the basis for microwave imaging. There have two models of lung tumour were considered with the antenna was distanced 10 mm from the surface of thorax which given by Camacho and Wang model. The simulation for both model was performed in CST Microwave Studio and it shows in Fig. 8 (a) and (b). It is found that both tumour can be detected as given in the 'radargram' image results.



(a)



(b)

FIGURE 8. Simulation result of a 10 mm lung tumour from (a) Camacho model and (b) Wang model inserted into the human thorax [27]

CONCLUSION

This paper discussed the experiments related to the microwave imaging techniques and dielectric properties of lung tissues to detect early lung cancer in biomedical application. The current methods used to detect and treat the lung cancer are, CT scan and MRI. However, these methods have several disadvantages such as unsafe radiation exposure, expensive, high false positive rate, insufficient anatomic information and time-consuming. By using microwave imaging techniques, it can avoid any harmful radiation, safe and low-cost.

From the findings, it tells the importance of identifying the information related to the conductivity and relative permittivity of cancerous and normal lung tissues. According to the in vitro experiment, the conductivity of cancerous tissues is 1.6 – 2 times larger than the normal tissues. While relative permittivity of cancerous tissues is 1.2 -3 times larger than normal tissues. Hence, from the information of contrast in dielectric properties can provide important functional information about health and reconstruct the images in microwave imaging.

Last but not least, from the experiment that has been conducted by the past researchers, the optimum distance of the antenna from the human thorax and the significant size of the tumour that can be detected had been identified. Therefore, by using this information it can be applied in microwave imaging.

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