HUMAN HEAD PHANTOM MATERIAL CHARACTERIZATION FOR MICROWAVE IMAGING SYSTEM

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Dedicated to my beloved family, mother and father

and

To my honourable supervisor, Dr Norhudah Binti Seman

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ABSTRAK

Barah payudara dan otak tersenarai sebagai barah yang menjadi penyebab utama kematian di seluruh dunia. Baru-baru ini, pengimejan gelombang mikro telah dicadangkan untuk pengimejan dan diagnosis barah payudara, dan boleh diteruskan untuk pengimejan barah otak. Walau bagaimanapun, tisu dan sel kepala manusia berbeza daripada tisu dan sel payudara manusia terutama daripada sifat-sifat dielektrik justeru itu penghasilan fantom kepala yang sesuai diperlukan. Fantom yang perlu bagi sistem pengesanan barah otak mesti mempunyai spesifikasi tertentu untuk menjadikannya sesuai dengan sistem pengimejan. Tesis ini membentangkan siasatan terhadap sifat-sifat dielektrik bahan fantom kepala manusia untuk sistem pengimejan gelombang mikro. Dalam penyiasatan, sampel-sampel fantom dibuat menggunakan air dan gelatin dalam menghasilkan fantom yang kos efektif. Skop penyiasatan adalah pada sifat air, tisu fantom, faktor perubahan dielektrik, pengawetan fantom dan jangka hayat fantom. Siasatan ini memberi tumpuan kepada sifat dielektrik yang terdiri daripada ketelusan relatif dan kekonduksian di seluruh frekuensi gelombang mikro daripada 1-6 GHz. Semua ukuran diperoleh menggunakan Rangkaian Penganalisis Vektor dengan prob dielektrik untuk mendapatkan ketelusan kompleks. Siasatan ke atas ciri-ciri air menunjukkan bahawa sebarang jenis air putih mempunyai sifat dielektrik yang hampir sama. Lima komposisi bahan berasaskan gelatin dibentangkan dalam siasatan ini menunjukkan ia mempunyai sifat dielektrik hampir sama dengan lima tisu kepala manusia iaitu perkara kelabu (komposisi 5g gelatin, 20g air dan 0.5 gula), perkara putih (komposisi 5g gelatin dan 14g air), cecair tulang belakang serebrum (komposisi 10g gelatin dan 50g air), darah (komposisi 10g gelatin dan 30g air) dan kulit (komposisi 10g gelatin dan 20g air). Selain nisbah antara air dan gelatin, tiga faktor-faktor lain iaitu suhu, garam dan gula mampu mengubah sifat dielektrik bahan. Pengawetan bahan berasaskan gelatin telah dicadangkan menggunakan cuka dan ia mampu memanjangkan jangka hayat fantom. Hasil dalam tesis ini berguna dalam meningkatkan pengetahuan mengenai sifat dielektrik bahan yang digunakan dalam fantom kepala manusia yang mana penting apabila menghasilkan, memperbaiki dan mengawal sifat dielektrik fantom.

ABSTRACT

Breast and brain cancers are stated as the most common causes of cancer-related deaths around the world. Recently, microwave imaging has been proposed for breast cancer imaging and diagnosis, and can be extended for brain cancer imaging. However, tissues and cells for human head are different from human breast especially in terms of dielectric properties thus requiring the development of an appropriate head phantom. The required phantom for brain cancer detection system must have particular specification to make it compatible with the imaging system. This thesis presents an investigation on dielectric properties of materials of human head phantom for microwave imaging system. In the investigation, samples of phantoms are made using water and gelatin in producing a cost effective phantom. The scopes of investigation are on the characteristics of water, tissues of phantom, dielectric variation factors, preservation of phantom and lifespan of phantom. This study focuses on dielectric properties consisting of relative permittivity and conductivity across microwave frequency from 1 to 6 GHz. All measurements are obtained using Vector Network Analyzer with a dielectric probe to obtain complex permittivity. Investigation on water characteristics indicate that almost any type of plain water has similar dielectric characteristics. Five compositions of gelatin-based materials presented in this investigation showed to have similar dielectric properties with five human head tissues, which are grey matter (composition of 5g gelatin, 20g water and 0.5g sugar), white matter (composition of 5g gelatin and 14g water), cerebral spinal fluid (composition of 10g gelatin and 50g water), blood (composition of 10g gelatin and 30g water), and skin (composition of 10g gelatin and 20g water). Besides the ratio between water and gelatin, three other factors of temperature, salt and sugar are discovered to be able to change the dielectric properties of the materials in the investigation. The preservation of gelatin-based material is proposed using vinegar and is able to prolong the lifespan of phantom. The outcome in this thesis is useful in gaining knowledge on dielectric characteristics of material used in human head phantom which is important in the stage of developing, tuning and controlling the dielectric properties of the phantom.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

At the beginning of this research, two most important terms which required to be understood are ‘Microwave Imaging’ and ‘Human Head Phantom’. Referring to the title of this research, the properties of materials used in human head phantom are investigated for the purpose to be used in modelling of phantom for microwave imaging.

Microwave imaging can be defined as a system, which occupied to sketch the internal structure of an object, so by that the internal structure of that object can be observed. This system operates by illuminating the object with an antenna that generates electromagnetic energy at microwave frequencies. This frequency is depending to the specification of the system. There are two techniques normally used in microwave imaging, the first one is using antenna at transmitting and receiving side which the object is illuminated by microwave signal from antenna at transmitting side, then the signal propagate through the object and collected by receiving antenna at the other side. While, the second is using reflection technique, which transmitted microwave signal will be reflected by the object then collected by the same antenna.

In the development of microwave imaging system, modeling of realistic human phantom is also required. The word of phantom sometimes confusing people who does not has basic knowledge in this area. Human phantom basically is a model of human body parts including its cells and tissues, which mimic cells and tissues of real human. In microwave imaging system, phantom is used to simulate the interaction of electromagnetic wave with biological tissues [1].

Microwave imaging has been mainly proposed for breast cancer detection, but some recent reports have also speculated the use of microwave in extremities imaging, diagnostics of lung cancer, brain imaging and cardiac imaging [2-8].In previous past decade, microwave imaging attracts attention among researcher, which breast cancer imaging is frequently focused on[2-5]. Then, microwave imaging start to focus on brain imaging as reported in [12-18, 78-80], where x-rays mammography, computed tomography (CT) and magnetic resonance imaging (MRI) system act as main scanning system to overcome the complexity of brain imaging especially on brain stroke an others brain cancer diagnosis. But the lack of using these scanning systems because they do not offer safe, fast, cost effective and portable screening tools [16]. X-rays generally can kill living tissue due to ionizing radiation that exposes during screening process that harmful to human body over a prolonged period of time while MRI is very accurate screening tool but it is costly, time consuming and not widely available and also not accessible at rural medical clinics or carried by first response paramedical teams [16, 19].Where, the first response is important to increase the survival rates. While, the microwave has potential for imaging can supplement current diagnostic methods as it may provide fast, cost effective and portable detection systems [6].

Compared to the other medical imaging techniques, microwave imaging is still in its infancy. One historical reason for this might due to the fact that most microwave systems-devices originated in military applications, radar being an obvious example [9-10]. In recent years however, due to the mobile/wireless revolution, unprecedented progress in high performance microwave hardware have been witnessed. This opens up a unique opportunity for development of microwave imaging systems.

In order to carry out a research in this area, multi-disciplinary effort is required. In the case of measurement, the physical human phantom can be developed and then illuminated by an antenna or array of antennas operating over the desired microwave frequency band. The reflected and transmitted signals collected by antennas can be stored for further processing. Depending on the processing technique chosen, this data can be efficiently used to produce map of dielectric constant in image body, such a work done on breast phantom is reported in [11].

1.2 Problem Statement

Other than breast cancer, brain cancer also has been noted as the most common cause of cancer-related deaths around the world. Currently, (MRI) is mostly used for the screening process. But this MRI is too costly and not widely available [19] especially in rural medical centre. Early cancer diagnosis and detection are very important to increase cancer survival rates. Nowadays, microwave imaging has gain attention among researcher due its potential in breast cancer detection. These scenarios then lead to the motivation for development of microwave imaging with the purpose for brain cancer detection, which also causes the study on new phantom for human head is also required. Although there are availability of phantom in the market, but it is costly and not specifically meet the requirements of the system especially in term of operating frequency. Apart from that, the reported study on phantom of human head for microwave imaging application is very limited. The previous study on breast phantom also does not provide explanation on the characteristic and behaviour of material in the phantom. Researcher usually made the recipe of their phantom without provide the information on the relation of their recipe with the dielectric properties of the phantom. These reasons motivate for the investigation on the material of the head phantom.

In fact, high microwave frequency for example 3-11 GHz which is used in ultra-wideband breast cancer detection offers high resolution. However, the use of high frequency might lower penetration of required signal into the brain. At frequencies lower than 3 GHz, it would allow for a higher penetration but would be insensitive to small regions of dielectric changes [15]. Brain imaging is classified as high difficulty application which mainly due to the complexity as well as the structural, functional and electrical in homogeneity of the human brain [18]. Therefore, it is important to determine the optimal spectrum in order to couple electromagnetic energy into the brain matter since the brain is surrounded by a high contrast dielectric shield comprising of the skin, skull and cerebral spinal fluid (CSF).

In electrical form, every tissue in human body as well as in human head can be represented by the electrical properties or also known as dielectric properties. As reported in [39], there are two properties that define the electrical properties of human tissue, which are the relative permittivity (ε_r) and conductivity (σ). These properties represent as the propagation, reflection, attenuation, and other behavior of electromagnetic fields in the human body. The relative permeability (μ_r) of human body can be assumed as 1, which shows the human body is weakly magnetic [39]. Therefore, the characterization study in this research is focuses only in form of permittivity and conductivity.

In this research, the characterization of a human head phantom is conducted based on the study of its electrical properties across 1 to 6 GHz using simple and common material such as jelly powder, gelatin, water and sugar. This wideband frequency range is chosen in order to have good trade off between resolution and penetration in human head imaging since the lower frequency will provide good penetration and good resolution can be provided by higher microwave frequency [26-28]. The electrical properties in term of permittivity and conductivity of the chosen mixtures of materials are obtained through measurement conducted in laboratory using special dielectric probe connected to a vector network analyser (VNA). The characteristics of each measured sample are observed through its analyzed data on relative permittivity and conductivity.

1.3 Objective of the research

The objective of the research is to conduct the following theoretical and experimental investigations through the development of human head phantom which divided as follows:

1) To study and investigate the characteristic of electrical properties on several material used in the human head phantom.
2) To specify the simple composition of material that mimic dielectric of head tissues for microwave imaging system.
3) To improve the lifespan of phantom material by the proposed preservation.

1.4 Research Contribution

Based on the objective in this research, the experimental study performed in this thesis provides following contributions.

1) The characteristics of materials used in head phantom are obtained through the investigation based on electrical properties.

   i. The investigation on water samples has been conducted, which provides useful knowledge on the electrical characteristic of water.
   ii. The investigation on dielectric variation factors has been conducted, which provides useful knowledge to tune and control the dielectric properties using basic material.

2) Compositions of sample material to prepare phantom with similar dielectric properties for five head tissues which are grey matter, white matter, cerebral

spinal fluid (CSF), blood and skin are acquired via the conducted experimental study.

3) The lifespan of phantom material has been investigated thoroughly that lead to the finding of the suitable amount of vinegar that can be used in preservation. Through this proposed preservation, the lifespan of the phantom can be improved.

1.5 Scope of Study

The scope of study basically represents the boundary of work, which must be conducted to ensure the effectiveness in achieving each objective of this research. The scope of study in this research is divided as illustrated in Figure 1.1.

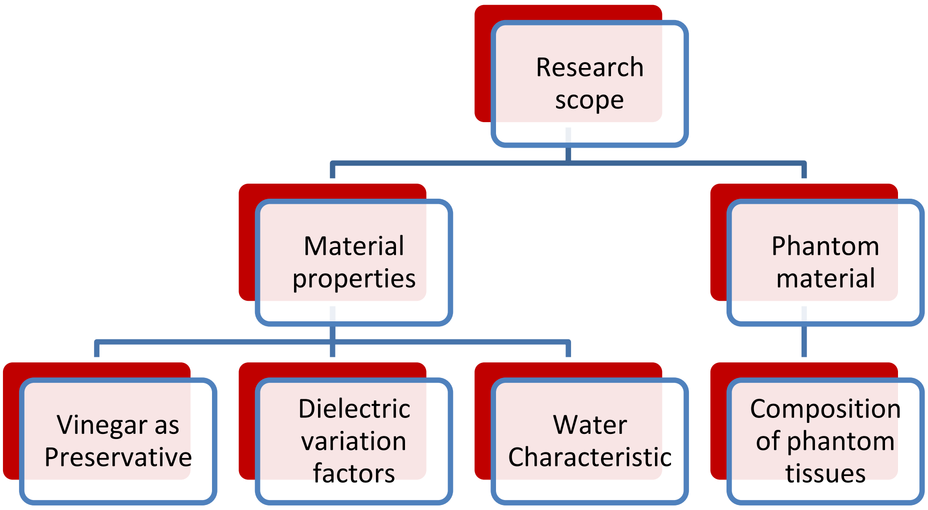

Figure 1.1: Overview on the scope of research.

Based on Figure 1.1, the main scope of this research is divided into two scopes which are on the phantom material study and material properties study. The study under material properties then divided more to three scopes which are the study on water characteristic, dielectric variation factors and preservation. The detailed scopes of study in this research are as follows:

1) Investigation on the electrical characteristic of water used in material for head phantom tissues.

   i. In properties study of tap waters taken from different locations, several samples of tap water are measured to observe dielectric difference due to location of tap water source.
   ii. In properties study of waters that taken from different sources, samples of water from different sources, which are tap water, distilled water, mineral(underground) water, filtered water and reverse osmosis water are investigated in term of their dielectric properties.

2) Investigation on dielectric variation factors on materials for head phantom tissues.

   i. Experimental study is divided into four parts, which to study the properties of tap waters taken from different locations, the properties of waters that taken from different sources, the effects of temperature and the addition of sugar to dielectric measurements.
   ii. Other factors which are temperature and addition of sugar or salt is investigated towards its effects on dielectric properties.

3) Investigation on vinegar as preservative in materials for head phantom tissues.

   i. The experimental study is divided into four parts, which are to study the properties of vinegar that taken from different manufacturers, the effects of vinegar with temperature and the properties of vinegar in the variation of water and the effect of vinegar toward phantom life span.
   ii. Vinegars from several manufactures are investigated on its dielectric properties, which might have dissimilarity.

iii. In others part, vinegar is investigated towards its dielectric changes due to temperature. The mixture of vinegar and water in different compositions are investigated in term of dielectric properties and physical observation.
iv. Furthermore, the investigation on phantom preservation by using vinegar is performed for a few certain of different periods.

4) Experimental study on phantom material to specify the composition of material for head phantom tissues.

i. Firstly, the electrical properties of human head tissues and cells data are collected from database website dielectric properties of body tissues.
ii. In the experimental study, simple and low cost material which is gelatin is used as main phantom material. Various samples of material with different compositions are prepared and measured using Vector Network Analyzer (VNA).Then obtained data is analyzed in term of relative permittivity and conductivity. This relative permittivity and conductivity data are then compared with relative permittivity and conductivity of tissues and cells in real human head. This procedure is conducted continuously until sample of material which most similar to real human head obtained.
iii. Sample of phantom material which is mimicking each tissues and cells of real human head is selected to be used as head phantom tissues.

1.6 Thesis outline

This thesis is divided to six chapters, which are the introduction, literature review, research methodology, phantom experimental result and discussion, dielectric variation factors and preservation of phantom and the last chapter is conclusion and recommendation. In the introduction, brief information is given in introducing microwave imaging and its phantom. In addition, Chapter 1 also consists of the information that significant to this research, which are problem statement, objectives, research contributions and scope. In Chapter 2, research background and literature reviews is provided, which related to ultra wideband microwave imaging system, human phantom, tissues composition in human head and electric properties of material. Important equations for dielectric analysis also described in this chapter.

While, in Chapter 3 provides the methodology of this research. This chapter focusing more on the experimental study in this research starting with the setup of experiment and then the calibration and precision test for the VNA. Then, this chapter presents the methodology of the investigation on phantom material, dielectric variation factors and preservation of material using vinegar. Section of phantom material discusses the experimental study to find compositions of materials that have similar properties with head tissues and cells for the development of human head phantom. While, in section of dielectric variation factors discusses the experimental study on the factors that cause dielectric changes on material and in the preservation of material discuss the experimental study about suitability vinegar as preservative in phantom material.

Chapter 4 in this thesis presents the characteristic for different types of plain water based on their electrical properties. This chapter also presents the composition of materials that have similar electrical properties with real head tissues that could be used as head phantom. The investigation on electrical properties is observed based on the relative permittivity and conductivity that conducted through the measurement in the laboratory. Meanwhile, Chapter 5 discusses the results of the investigation on dielectric variation factors and preservation of phantom. This chapter presents the factors that able to vary the dielectric properties of material. In this chapter also, the results on effectiveness of vinegar that proposed as preservation material is presented

Chapter 6, which is the last chapter of this thesis, concerns the conclusion of the works that have been done in this thesis and provide future recommendation related to this research works.

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