Matching Medium for Biomedical Microwave Imaging

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***Abstract* – The choice of matching medium in microwave imaging for biomedical applications is studied. A multi-layer planar human tissue is first used to investigate the amount electromagnetic wave is transmitted through the tissue model using different matching medium. This will give us further insights on wave propagation through human tissue, which assists us to determine to choice of matching medium. Image reconstruction of simplified human breast model with different matching medium using an inverse scattering algorithm will be used to verify our findings.**

***Index Terms* — Microwave Breast Imaging, Matching Medium, Microwave Imaging, Biomedical Application**

I. Introduction

The potential use of microwave imaging for medical diagnosis has been of significant interest over the last two decades. Extensive efforts have been focus on microwave breast imaging aiming to locate tumors from the healthy glandular tissue. There are two different approaches in general, namely the radar-based imaging approach (e.g. [1]-[5]) and the inverse scattering approach (e.g. [6]-[11]). The radar-based imaging approach, first proposed by Hagness et al. [1]-[3], aims to locate strong scatterers due to the significant contrast between the tumor and the healthy glandular tissue. The image reconstruction process involves re-focusing the scattered signal back to the breast volume in the imaging domain and sums coherently, i.e. a coherent-sum process [2]. Numerous studies have been conducted from different research groups and variations of the original radar-based technique, such as microwave imaging via space-time (MIST) beam-forming [4] and tissue sensing adaptive radar (TSAR) [5], have been proposed and received significant attentions over the years. The inverse scattering approach [6]-[11], on the other hand, aims to reconstruct the unknown dielectric profiles of the breast volume. First, multi-static measurement from the breast volume is taken. Then, the entire imaging domain is modelled using full-wave numerical solution of the Maxwell's equations (e.g., finite element method [6], method of moment [7], finite-difference time-domain [8]-[10]) with the same antenna configurations. The corresponding forward problem can thus be computed with an initial guess of the "breast volume". Given the reference data from the "actual" breast volume from measurement and the simulated data from the "assumed" breast volume in the numerical domain, a cost function based on the differences between these two datasets can be defined. The cost function is then minimized in an iterative manner by changing the dielectric properties in the modeling domain using an optimization algorithm. Assuming that the global minima is reached at the end of the optimization, i.e., the simulated data is almost identical to the reference data, the resultant dielectric profiles in the numerical domain is thus the resultant image provide that the global minima is reached.

Compare to many other biomedical applications where the antenna is being implanted inside the patient (e.g.[12]), the antenna system is placed outside human bodies. The radiated field from the antennas travels in air and strikes the skin. Due to the differences of the relative permittivity between the human tissue and air, a large portion of the signal will be reflected from the air-skin interface and only a small portion will be transmitted into the breast, which is not very efficient. To enhance the transmission into the breast volume, the use of matching medium is introduced. Various numerical and experimental studies have been proposed to evaluate the quality of the reconstructed images under different matching medium [11], [13]-[16]. Simplified transmission line models have also been used to determine the optimal matching medium [17]. However, there is not any optimal choice about the permittivity and conductivity of the matching medium.

The objective of this paper is to determine the optimal region of the matching liquid that is suitable for microwave imaging in biomedical applications. Instead of performing a series of inverse scattering problem which is computationally extensive, a simplified, multi-layer planer human tissue model will be used to investigate the transmission and reflection capabilities under different configurations over a range of frequencies. This will give us some insights about electromagnetic propagation in such multi-layer structure, and provide us an idea on the range of permittivity that would be preferred for biomedical applications.

II. Matching Liquid in Microwave Imaging

The use of matching medium in biomedical microwave imaging has been studied by a number of groups [5], [11]-[13]-[16]. Originating from practicality prospective, Meaney et al. [11] and Gilmore et al. [13] aim to identify a suitable background matching medium that is clinically acceptable, readily disposable and relatively inexpensive, with a goal to improve the quality of the reconstructed image using an

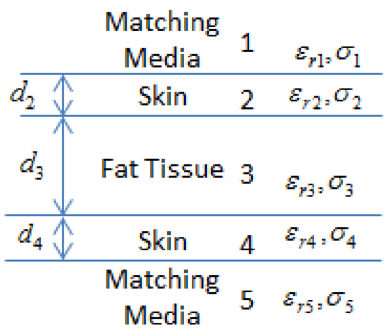

Fig. 1. A simplified 5-layer planar human tissue model

inverse scattering algorithm. Sill and Fear [5] performed numerical study to evaluate the imaging performance of a radar-based imaging algorithm with matching liquids that are similar to skin ($\varepsilon_r = 36$), fatty tissue ($\varepsilon_r = 9$) and oil ($\varepsilon_r = 3$). Angiulli et al. [14] performed a similar numerical study looking at the performance of the reconstruction using an inverse scattering algorithm with different matching background with relative permittivity of 1 to 60.

On the other hand, efforts have also been contributed to investigate the optimal permittivity of the matching medium that results in minima reflection coefficient using a simple one-dimensional-three-layer model (matching medium, skin and fat tissue). Rappaport [15] has numerically determined the optimal material properties of the matching background with small reflection ($|\Gamma| < 0.2$). However, most of these optimal values for relative permittivity and conductivity are impractically high which is not realistic. Similar approach has been adopted in [15] and [16] to evaluate a suitable choice of low loss matching background that results in small reflection from the medium-skin interface. However, there is yet any rule-of-thumb about the choice of matching liquid for microwave imaging in the biomedical context.

III. Multi-Layer Planar Model

Figure 1 shows the multi-layer planar human tissue model used in this study. It is made up of 5 layers, namely the matching media, skin, fat tissue, skin and matching media. To accurately model the electrical properties of the tissues at the frequencies of 0.1 to 10GHz, the numerical values from the Cole-Cole 4 model [18] are used. The matching medium with permittivity of 3 to 80 will be considered. Both Transverse Electric (TE) and Transverse Magnetic (TM) plane wave excitations under different angles of incidence will be considered and the corresponding transmission coefficients through the structure will be computed. With the transmission coefficients, we are able to evaluate the portion of energy that has been transmitted through the tissue model when different matching medium is used.

To numerically determine the transmission coefficients over a wideband of frequencies, recent attempts have also been made to directly compute the wideband the reflection and transmission coefficients in time domain under short pulse illumination [19]-[22]. Here, a frequency domain approach is adopted such that the frequency-dependent nature of the relative permittivity and conductivity of human tissues can be directly used. Details of this frequency domain formulation can be found in [23].

It is clear that in microwave imaging configurations, the antennas are closely surrounding the breast volume in the near-field region and having an "ideal" setting with *TE/TM* polarized plane-wave excitation at a specific incident angle is not feasible. However, the nature of the propagation will give us better insights on how the wave propagates through the tissue. This will give us better idea on the choice of matching medium for microwave imaging in the biomedical context.

IV. Conclusion

The choice of matching liquid in microwave breast imaging has been studied. A multi-layer planar human tissue model is used to evaluate the portion of the energy that has been transmitted through the tissue, which gives us further insights about wave propagation in human tissues. The details of the results and conclusion will be presented in the conference.

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