Inverse Scattering Analysis Applied to Breast Cancer Detection

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Breast cancer still remains a leading cause of cancer death among women worldwide. Early detection is an important issue for effective treatments. Although positive clinical results have been shown for imaging modalities such as magnetic resonance imaging (MRI) and ultrasound, microwave-based imaging techniques have been gaining increasing attention. The large contrast in the microwave properties of normal and malignant breast tissue, low-cost of microwave equipment, non-ionizing radiation, and successful preliminary studies are all reasons suggesting that microwave-based imaging has the potential to detect small tumors. In such framework, the approach based on inverse scattering techniques can estimate not only the location and size but also the shape and electrical properties of a scattering object existing in normal breast tissues, leading to the identification of malignant tumors from measurements of the scattered fields.

In summary, there is enough preliminary data in the literature to conclude that the contrast between malignant and normal breast tissue at microwave frequencies is significantly greater than the small (few percent) contrast exploited by more conventional breast imaging modalities like X-ray mammography and ultrasound. This research investigates the possibilities of using microwaves and microwave tomography to detect changes in electrical properties of various tissues. The work contains both theoretical modeling and construction of such a scanning system for early breast cancer detection. The goal of this project is to develop a safety and low-cost microwave scanning system of screening for breast cancer which is able not only to detect the presence of a suspicious area but also to identify its malignancy. Towards this goal, the project will involve as follows:

(i) Development of a microwave image reconstruction algorithm
(ii) Development of scanning and data collection software
(iii) Computational electromagnetic modeling
(iv) Design of suitable antennas for emitting and collecting a microwave pulse

This report is organized into seven chapters in the following manner. Chapter 1 describes typical active microwave imaging system and provides a brief description about the rationale of implementing the project.

Chapter 2 presents the mathematical basis of the FDTD method. The Yee cell structure in the FDTD algorithm is introduced and the numerical approximations to the Maxwell curl equations suitable for program implementation are presented. Since all problems considered in this thesis are unbound, Convolution Perfectly Matched Layer

(CPML) as an absorbing boundary condition is required to truncate the solution space. It also capable to treat dispersive and nonlinear medium.

Chapter 3 introduces an approach to microwave imaging used in this thesis which is known as Forward-Backward Time-Stepping (FBTS) inverse scattering technique, formulated in the time-domain utilizing FDTD to reconstruct the dielectric properties of the scatterer. This section also shows the formulation of parallel algorithm in FBTS in order to minimize the computational time. A standard dipole antenna model in the 3-D FBTS algorithm, represented by the FDTD method, is derived and implemented. A simulated parametric study of an Antipodal Vivaldi antenna for emitting and collecting a microwave pulse has been carried out. It can be used to possess a wide input bandwidth and radiation pattern for future development of the FBTS inverse scattering technique.

Chapter 4 demonstrates the efficacy of two-dimensional (2-D) FBTS simulation to generate images that provide useful quantitative information about the internal composition of the MRI-derived breast model. For preliminary study, the breast model is assumed to be immersed in a lossless coupling liquid as a background medium, which is chosen with a permittivity that roughly matches breast fat tissue. Further research works utilizing the numerical breast model in a free space instead of coupling liquid to detect more than one tumor embedded in the breast. The aim of using a free space as the background medium in this study is for the microwave mammography equipment easier to be maintained than using coupling liquids.

Chapter 5 covers several simulations and experimental works in this thesis. A simple dielectric "phantom" (breast-like) model is designed to have a configuration similar to breast tissues. This model consists of a section of polyvinyl chloride (PVC) pipe to represent skin, styrofoam to represent fat and glass object to represent tumor. The three-dimension (3-D) MRI-derived breast model is analyzed utilizing four illumination schemes, which depending on the different microwave transmitter/receiver positions. The differences in image quality among the four illumination schemes is examined in the numerical study provide some significant insight into the choice of measurement points for scattering characterization of the breast. To analyze the efficacy of the parallel computing applied to FBTS method, a cluster of 8 Personal Computers (PCs) is constructed and parallel processing is realized using Message Passing Interface (MPI). A 3-D reconstruction of wooden hollow cylinder from the experimental data is examined by parallel FBTS algorithm.

Chapter 6 offers a Linear Relation approach to treat dispersive MRI-derived breast model. In this concept, Debye's relations are commonly used in FDTD formulations to describe the frequency dependence of the permittivity of a material. Thus, this approach can approximate a nonlinear relationship explicitly by manipulating the relationship between the relative permittivity and conductivity.

Chapter 7 draws conclusions of the work presented in this thesis and suggestions are made for future research work.