ANATOMICALLY REALISTIC FDTD MODELING OF MICROWAVE INTERACTIONS WITH THE HUMAN BREAST

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Abstract: We have developed anatomically realistic FDTD breast models for investigating and developing innovative methods of breast cancer diagnosis and treatment using electromagnetic waves at RF or microwave frequencies. The geometry of the breast model is derived using high-resolution MRI breast scans. The frequency-dependent dielectric-property parameters assigned to different breast tissues are incorporated using Debye models for our most recent dielectric spectroscopy measurements conducted on freshly excised breast tissues. We illustrate the use of these breast models by presenting highlights of our recent investigations of microwave imaging via space-time beamforming for early stage breast cancer detection.

The critical need for new technologies to improve detection, diagnosis, and treatment of breast cancer is widely recognized [1]. A number of innovative diagnostic and therapeutic technologies employing radio waves or microwaves are under investigation for this purpose. Recent examples include active [2]-[5], passive [6], and hybrid [7]-[8] microwave imaging technologies for detection and diagnosis as well as adaptive microwave phased array systems [9] for hyperthermia treatment. Finite-difference-time-domain (FDTD) simulations based on anatomically realistic breast models can provide a virtual lab bench for exploring the feasibility of new technologies and improving design concepts. In this paper, we review recent progress in the development and application of FDTD breast models for investigating new microwave technologies for breast cancer detection and treatment.

Anatomically realistic FDTD breast models are developed from MRI data sets obtained during routine clinical procedures at the University of Wisconsin Hospital and Clinics. The highest image resolution is achieved when the patient is lying in the prone position with a special MRI coil encircling the pendulous breast. However, to permit a variety of breast models to be created, MRI scans are taken with the same patient in both prone and supine positions. Using the low-resolution MRI images of the naturally flattened breast of the supine patient as a guide, we vertically compress and laterally expand the high-resolution images so that the overall shape the breast follows that of the supine patient. In this manner, we achieve high resolution images of both patient orientations that have been proposed in conjunction with microwave breast cancer management technologies.

A linear interpolation scheme is applied to change the MRI pixel resolution to the desired FDTD grid cell size. We use a simple segmentation approach to remove from the image the skin region which is contaminated by imaging artifacts. Then we artificially re-introduce an artifact-free skin layer. Malignant breast tumors of various sizes are also artificially introduced into the model at different locations. Finally, each grid cell is assigned the appropriate dielectric properties in a manner which preserves the natural heterogeneity of the breast. The frequency dependence of the dielectric properties is incorporated in the FDTD model using an auxiliary differential equation approach for first-order Debye dispersions. Debye curves are constructed from empirical fits to our most recent dielectric spectroscopy measurements of freshly excised breast biopsy and breast reduction specimens. Breasts with different average densities including radiographically dense breast and breasts with different heterogeneity levels are also modeled by varying the assumed Debye parameters for normal breast tissues.

We illustrate the use of these FDTD breast models in an application to breast cancer detection. We have recently proposed a method of microwave imaging via space-time (MIST) beamforming for detecting and localizing backscattered energy from small malignant breast tumors. In our system configuration, an antenna array is placed on the surface of the naturally flattened breast of a subject lying in the supine position. Each element in the array sequentially transmits an ultrawideband microwave pulse into the breast and receives the backscatter. Robust space-time beamforming algorithms are applied to the recorded backscatter signals to generate a reconstructed image showing backscattered energy as a function of location. In this paper, we demonstrate the performance of this MIST beamforming technique by applying our latest space-time beamformer designs to simulated backscatter data obtained from FDTD breast models.

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