A model for wave propagation in biological tissues is developed and tested for stability using the Yee's Difference Time Domain (FDTD) method. For a lossy, dispersive (frequency-dependent) tissue, it is important to model the behavior of electromagnetic waves in the time-domain for applications such as breast cancer detection. In order to apply FDTD techniques, discretized conductivity models are necessary. The Four Zeros Conductivity Model provides a single pole, rational function of the 2-transform variable well-suited for this application. A real average dielectric constant for the tissue is used with the modeled conductivity to calculate theoretical propagation constant to be compared with propagation constant calculated from measured conductivity and permittivity. This comparison shows good agreement between measured and theoretical attenuation rates and phase constants for high fat breast tissue. The stability condition equation, derived using von Neumann analysis, is examined in the frequency domain. Stability in the time domain is then tested for the model parameters using 10 FDTD with a modulated Gaussian wave excited in breast fat tissue. For this type of tissue, simulated electromagnetic transmission obtained shows expected attenuation and forward propagation of the wave.

State of the Art

The Four Zeros Conductivity model is better suited to application in time domain modeling than the traditional Cole-Cole expression. This model significantly reduces the number of model parameters.

Time domain modeling of wave propagation in complex realistic media can be used to develop imaging systems for uses such as breast cancer detection, classifying the work as a S3 system level project.

This work is classified under R1 and R2 research thrusts because it involves computational modeling and develops a model that can be used in various applications.

Developing the Model

Measured data for conductivity and permittivity are fit to the Four Zeros Conductivity model by solving simultaneous equations for $b_1$, $b_2$, $b_3$, and $b_4$ and making an initial estimate for $a_0$.

A final value of $a_0$ is selected in the stability analysis and the propagation constant is calculated for the measured data and modeled conductivity and average dielectric constant.

Stability Analysis

The four roots are calculated and the maximum magnitude of the roots at each for each combination of $a_0$ and $d_0$ is plotted. Values of $a_0$, $b_1$, $b_2$, and $b_3$ are selected at uniformly spaced discrete points around an initial estimate of $a_0$, and between $d_0$ min and $d_0$ max.

Future Work

• The FDTD simulation can be adapted for time reversal. In this case artificial loss must be added to maintain convergence and then removed to obtain true initial state.

• This technique has been tested in the stability analysis of the model developed above.

• Model parameters can be derived for various lossy, dispersive media.

• An automated approach to obtaining model parameters can be developed.

References


Figure 1: The mnej and imaginary parts of the propagation constant calculated from the conductivity model[modified] and from images measurement[modified].

Figure 2: Normalized error plots for the mnej and imaginary parts of the propagation constant.

Figure 3: The mnej and imaginary parts of the propagation constant calculated from the conductivity model[modified] and from images measurement[modified].

Figure 4: The mnej and imaginary parts of the propagation constant calculated from the conductivity model[modified] and from images measurement[modified].

Figure 5: The mnej and imaginary parts of the propagation constant calculated from the conductivity model[modified] and from images measurement[modified].

Figure 6: The mnej and imaginary parts of the propagation constant calculated from the conductivity model[modified] and from images measurement[modified].

Figure 7: Example of the excitation applied to the model in FDTD simulation and model parameters.

Figure 8: Electric field component of Gaussian excitation wave in high fat breast tissue at five time steps.

Figure 9: Magnetic field component of Gaussian excitation wave in high fat breast tissue at five time steps.

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