Model-Based Inverse Scattering for Microwave Breast Imaging: An Analysis of Tissue Feature Sensitivity versus Model Error Sensitivity

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Quantitative microwave imaging based on inverse scattering shows promise for breast cancer risk assessment, detection, and treatment monitoring due to its low cost, non-ionizing nature, and fully three-dimensional imaging potential. Solving for the unknown tissue dielectric properties distribution is commonly achieved using iterative model-based inverse scattering algorithms. These algorithms function by comparing measured scattered fields to scattered fields calculated from a forward simulation. The underlying assumption is that the best match between simulated and measured signals will occur when the simulated model of the object, i.e. the breast, has the same dielectric properties as the true object, and that differences between the measured and simulated signals are dominated by differences between the actual and estimated properties of the object. For any array, uncertainty in the material properties of the "known" environment outside the object represents an additional source of signal discrepancy, and thus it is of interest to evaluate the desired sensitivity to breast tissue features relative to undesired sensitivity to uncertainty in the properties of the environment.

We define the "feature signal" as the difference between the simulated array measurements in the presence of the true target (S_{true}) and the simulated array measurements in the presence of a baseline version of the object which lacks the key feature of interest (S_{base}). We define the "error signal" as the difference between S_{true} and the simulated array measurements of the true object with perturbed environmental material properties (S_{pert}). The "sensitivity ratio" is defined as the ratio of the feature signal, $|S_{\text{true}} - S_{\text{base}}|^2$, to the error signal, $|S_{\text{true}} - S_{\text{pert}}|^2$. This ratio serves as a quantitative metric for evaluating potential array designs based on their sensitivity to features of interest and their robustness in the presence of material properties uncertainty and for gaining insight about the precision needed in dielectric properties characterizations of the "known" array environment (e.g. immersion media, substrates, etc.).

In this work we investigate this sensitivity ratio for breast imaging using FDTD simulations of an array of miniaturized patch antennas (Burfeindt *et al., IEEE Antennas Wireless Propagat. Lett.,* vol. 11, pp. 1626-1629, 2012) surrounding MRI-derived numerical breast phantoms (`http://uwcem.ece.wisc.edu/MRIdatabase/index.html`). We evaluate the impact of varying environmental material properties uncertainty and the performance of different array designs (varying antenna-to-object distance, and varying degrees of breast compression) in the presence of fixed environmental material properties uncertainty.