Dimensionality Reduction in Inverse Scattering: Applications to Microwave Imaging for Breast Cancer Detection

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Microwave tomography involves illuminating an object with low-power microwaves from an antenna array and measuring the scattered microwave signals for the purpose of estimating the spatial distribution of dielectric properties within the object. The estimated properties are obtained by applying inverse scattering techniques to the scattered signals. Potential applications of microwave tomography are wide-ranging, spanning early-stage breast cancer detection to geophysical prospecting.

Microwave tomography is challenging because of the nonlinear and ill-posed nature of the inverse problem. The difficulties of the problem are compounded by the fact that the properties distribution is usually estimated on a dense regular mesh of voxels. This can result in tens of thousands of unknowns for 3-D imaging, which greatly complicates solution of the inverse problem. Furthermore, the resolution implied by a dense voxel-based grid is generally not attainable, since the maximum resolution is limited by the antenna array geometry and/or by the wavelength of the microwave signals.

We circumvent these obstacles by expanding the properties distribution in a relatively small number of basis functions to greatly reduce the dimension of the inverse problem. The inverse problem then involves solving for a small number of basis function expansion coefficients. This greatly reduces the complexity of the nonlinear inverse problem, while not negatively impacting the imaging performance. But more importantly, the reduced dimension allows non-traditional solution strategies, such as variable selection methods, to be applied to the inverse problem. Such alternative strategies are not computationally feasible in the context of the original voxel-based inverse problem.

We illustrate the effectiveness of our approach in the context of microwave imaging for breast cancer, although the methodology is relevant to other inverse scattering applications. Representative backscattered signals are acquired using computational electromagnetic simulations of antenna arrays surrounding MRI-derived 3-D numerical breast phantoms. Imaging results are compared with those obtained using the original voxel-based formulation, and future research directions are discussed.