Field and Contrast Eigenfunction Expansions and their Application to Microwave Imaging Algorithms

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Microwave imaging (MWI) is an imaging modality that seeks a quantitative reconstruction of the permittivity and conductivity of an object-of-interest (OI) from data collected via electromagnetic interrogation. MWI has shown potential in biomedical applications as it uses non-ionizing, low-power radiation. For biomedical imaging a matching fluid is commonly used to ensure that sufficient energy couples to biological OIs while reducing reflections from the interface between the matching fluid and the external environment. Containing the matching fluid inside a metallic chamber reduces modeling error as the fluid/metal interface is well approximated by a perfect electric conductor (PEC).

In this work we exploit the presence of a PEC boundary and formulate the forward electromagnetic problem using eigenfunction expansions for the scattered-fields, incident-fields and complex contrast function, all of which are assumed to be zero-valued on the boundary of the problem domain. We focus on the two-dimensional transverse magnetic case for simplicity. Using eigenfunction expansions it is possible to maintain the dependence between scattered-field coefficients and contrast coefficients. From the resulting expressions it is straightforward to compute both the first and second derivatives of the scattered-field coefficients with respect to the contrast coefficients.

The relationship obtained when the scattered-field, incident-field and contrast are all expanded using eigenfunctions is applied to MWI algorithms. First, we use the first derivatives of the scattered-field coefficients with respect to the contrast coefficients to formulate Gauss-Newton inversion algorithms. Next, we investigate the effects of the second derivatives when computing the full Hessian matrix for Newton method inversion algorithms. Last, we exploit the fact that when the coefficients of contrast-sources are known the solution to the forward problem requires only the inverse of a diagonal matrix, a fact that is advantageous in the context of contrast-source inversion (CSI).

The performance of MWI algorithms using the eigenfunction formulation is evaluated using both synthetic data and experimental data collected in the Electromagnetic Imaging Lab (EIL) at the University of Manitoba.