Adjoint Field and Level Set Methods for Tomographic Imaging

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Goals

- Development of novel methods for non-linear inverse scattering problems
- Combine imaging-based techniques with object detection approaches
- Synthesis of adjoint field methods for imaging and level set methods for multiple object characterization with application to limited view, 3D inverse problems in inhomogeneous media

Significance

- Environmental monitoring and remediation
- Characterization of pollution plumes using crosswell radar or electrical impedance data

Technical Approach

The propagation of electromagnetic fields in 2D is modeled by the inhomogeneous Helmholtz equation

\[ \Delta u + k_m^2(x) u = q_n(x) \quad \text{in } R^2 \]

\[ k_m^2(x) = \frac{\omega_m^2 \mu_0 \epsilon_0}{\sigma(x) / \omega_m \epsilon_0} \]

Data are gathered for a finite number of point sources \( q_n, n = 1, \ldots, N \) distributed in two boreholes, and a small number of frequencies \( \omega_m, m = 1, \ldots, M \). Finitely many receivers are located in the two boreholes.

The goal: Recover the distribution of the dielectric permittivity \( \epsilon(x) \) given the gathered data.

Two step approach:

Step 1: Construct a first guess for locations and contrasts of the unknown inclusions using adjoint-field based Source Type Adjoint Field (STAF) method

Step 2. Recover the shapes of the inclusions using a level set representation whose structure is based on the results of Step 1

Relation to ERC

- Barriers
  - Barrier 2: New, reduced order methods for processing sparse and cluttered data.
  - Barrier 5: Must deal with efficient implementation to move from 2D to 3D

- Beds
  - SoilBED: methods initially intended for environmental applications. Will be validated on data from NU facility as well as data provided by INEEL and LLNL collaborators
  - MedBED: plan to migrate method from environmental to medical imaging application, specifically diffuse optical tomography and microwave imaging
Current Status
• Initial version of adjoint field method has been implemented
• Initial results for crosswell problem look encouraging and for full-view tomographic imaging look even better
• Level set methods under development

Other Connections
• Project funded by Dept. of Energy, Idaho National Energy and Environmental Laboratory
• Anticipate close collaboration in near future with
  ➢ INEEL
  ➢ LLNL Vadose Zone Observatory
  ➢ Boise Hydrogeophysical Research Site (BHRS) at Boise State University (outreach)
• Techniques developed here are directly applicable to a wide range of CenSSIS problems
  ➢ Diffuse wave medical imaging
  ➢ Mine detection
  ➢ Non-destructive testing

Plans and Project Evolution
➢ In the next year:
  ➢ Initial level set implementation
  ➢ Merging of level set techniques with multiscale reduced order adaptive modeling for background estimation
➢ In a few years
  ➢ Full 3D implementation of forward model and inversion routine on
  ➢ Validation on crosswell GPR data from LLNL as well as BHRS
➢ Within the decade
  ➢ Fusion with full suite of environmental sensors: impedance imaging, seismic, hydrological
  ➢ Rapid assessment and continual monitoring:
    ➢ Continuously monitoring by downhole sensors
    ➢ Telemeter data to processing facility
    ➢ Implementation for real time updating (tracking) of subsurface state.

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