A Lossy Half-space Green's Function Forward Model and Inversion Method for Geophysics Problem

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Sensing and detection of dense non-aqueous phase liquids (DNAPLs) in soil is very significant and beneficiary for geo-environmental engineering, but challenging due to uncertain and hard to determine wave characteristics through soil media. The detection task may be possible by discriminating dielectric property contrast between DNAPL pools and saturated soil background. Despite least invasiveness of ground penetration radar (GPR), but due to its depth limitations, other alternatives should be implemented to detect DNAPLs. Sensing the subsurface volume between boreholes using cross-well radar (CWR) is an innovative and non-invasive technique, which is effective for deep investigations.

In this work, an analytical model is developed to approximate CWR sensing in infinite half-space lossy media in the frequency domain. Half-space dyadic Green's function in integral form for a vertical polarized dipole source is derived. Integration for angles goes far into evanescent range. To analyze the reflection behavior of a spherical wave onto a planar interface at oblique angle, plane wave decomposition technique is used to replace the spherical wave with a collection of all modes of plane waves. Fresnel reflection theory is utilized to investigate each plane wave reflection due to the planer inter- face. The Born approximation is employed as a linear model for a shape-based inversion, developed to localize the object. This localization is possible assuming the contrast between the clutter and lossy background as a priori information.

The forward model is validated via CWR experiment. Soil parameters (relative dielectric constant, and loss tangent) variance with frequency is approximated with a quadratic polynomial. Calibration of soil parameters is conducted comparing the results with experimental CWR data, using an iterative low-order parameterized optimization technique that involves both magnitude and phase information. Forward model and CWR experimentation results agree well over broad frequency range. Localization and reconstruction of the object is implemented using non-linear least square optimization by minimizing a cost function that calculates the misfit between the predicted numerical simulation and experimental observation. The proposed inversion method generates satisfying preliminary results, which are validated by numerical experiments.