Inverse Scattering for Site Characterization

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Non-invasive reconstruction of subsurface heterogeneities using stress waves is a long-standing problem in mechanics owing to its relevance in seismology, material characterization, and medical diagnosis. In the context of three-dimensional (3D) tomography the supporting inverse scattering solutions, derived from a variety of simulation platforms, commonly bear a prohibitive computational cost that is compounded by the need for prior information. To address the problem, this study deals with the development of a suite of imaging methodologies that jointly show a promise of rendering 3D identification and characterization of subterranean objects from (visco-) elastic waveforms tractable in everyday engineering and diagnostic situations.

In a first attempt to tackle the inverse scattering problem a prototype, boundary-only reconstruction technique is developed that revolves around the concept of shape sensitivity and the use of singular solutions for the reference background solid. The key advantage of this approach, that renders only the outline of subsurface heterogeneities, is that it avoids costly volume discretization often associated with wave-based imaging. Given its roots in non-linear minimization, however, this technique is not equipped to deal with the non-convexity of cost functionals that is customary in waveform tomography. To mitigate the problem, a preliminary imaging tool that altogether voids optimization and thus the need for prior information (manifest in the so-called initial ``guess'') was recently established building upon the concept of Topological Sensitivity; a method conceived for the shape optimization of mechanical structures. Physically, the Topological Sensitivity furnishes an information about the variation of a cost functional when an infinitesimal defect is nucleated at a sampling (i.e. trial) point inside the reference solid. For the featured class of inverse scattering problems, this quantity permits an explicit representation that is responsible for its computational efficiency. Recent analyses suggest that both topology, geometry and material characteristics of underground objects can be approximately identified from the subsurface distribution of topological sensitivity and its embedded (or ``nucleating'') elastic parameters. As an alternative to the latter approach the so-called Linear Sampling method, rooted in far-field sonar and radar imaging, is generalized to permit a full-waveform 3D tomography in elastic and viscoelastic background profiles with various degrees of complexity. In a philosophical departure from the earlier reconstruction methodologies, both topological sensitivity and linear sampling operators serve as ``LED'' indicators that light up for trial, i.e. sampling points striking the subsurface defects. Accordingly they are minimization-free, computationally-effective, and operate without the need for initial ``guess''. Beyond their intrinsic potential for seismic prospecting and engineering geophysics, the proposed developments may find use in medical diagnosis where an information about the spatial distribution of (visco-) elastic tissue properties shows a promise of exposing early malignant lesions that are indiscernible in (anatomic) x-ray, magnetic resonance, and ultrasound images.