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Advances in Inverse-Profiling of Subsurface Targets Using Machine-Learning Techniques

Maryam Hajebi[(1)] and Ahmad Hoorfar*[(2)]
(1) University of Hormozgan, Bandar Abbas, Iran; email: m.hajebi@hormozgan.ac.ir
(2) Villanova University, Villanova, PA, USA; e-mail: ahoorfar@villanova.edu

The Subsurface inverse profiling focuses on reconstructing the dielectric composition, shape, and geometrical properties of buried objects based on the scattered fields received by multiple antenna elements. These fields are collected when the medium is illuminated by strategically positioned transmit antennas (Figure 1). This technique is widely applied in medical imaging, remote sensing, ground-penetrating radar, intra-wall or through-wall imaging, and nondestructive testing.

Subsurface imaging of high-contrast dielectric objects is typically formulated as an inverse-scattering (IS) problem, which is inherently challenging due to its ill-posedness, non-uniqueness, and non-linearity. The ill-posedness and non-uniqueness stem from the limited independent data that can be collected [1].

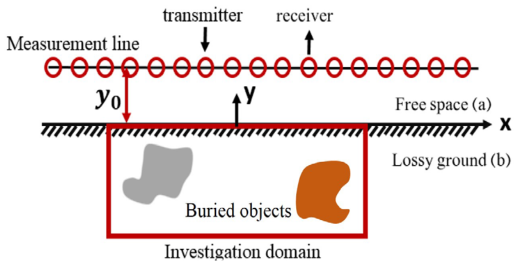

Figure 1. Configuration of subsurface inverse problem

To partially address these challenges, various regularization methods have been developed. The increased computational power of modern CPUs has also driven a growing interest in solving IS problems using global stochastic optimization techniques. While these methods are highly accurate, they remain computationally intensive, even when combined with fast low-resolution initializers [2]. More recently, artificial intelligence (AI) and machine learning (ML) techniques have emerged as powerful tools for addressing inverse scattering and radar imaging challenges.

In this review presentation, we will discuss recent advancements in utilizing Convolutional Neural Networks (CNNs) to efficiently address subsurface inverse problems. Our approach relies solely on amplitude measurements collected at receiving antennas, bypassing the complexity and cost associated with acquiring both amplitude and phase data. Specifically, we explore the hybridization of CNN-based methods for profiling dielectric objects by parameterizing their shapes using general elliptical functions. This approach enables the reconstruction of high-contrast, buried homogeneous objects with varying cross-sections—from full elliptical to wedge-like shapes using a maximum of only eight optimization parameters. Additionally, we present the integration of CNNs with cubic spline expansion (CSE) for contour modeling of scatterers with arbitrary curvilinear shapes, significantly reducing the number of unknowns in densely populated target scenes [3]. We will also discuss the use of fast, low-resolution diffraction tomography images as inputs to carefully designed neural networks for high-resolution imaging and inverse profiling of subsurface dielectric objects. Numerical results for various subsurface inverse-profiling scenarios will be presented.

References

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[2] M. Hajebi and A. Hoorfar, "Subsurface Inverse Profiling and Imaging Using Stochastic Optimization Techniques," in Signal and Image Processing for Remote Sensing, CRC Press, 2024.

[3] M. Hajebi and A. Hoorfar, "Integration of CNNs and Spline Expansion for Subsurface Profiling of Arbitrary Shape Objects," IEEE AP-S Symposium, Florence, Italy, 2024.