

A Two-Stage Deep Neural Network for Ground-Penetrating Radar Data Inversion under Heterogeneous Soil Conditions

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Ground-penetrating radar (GPR) has been widely used for the non-destructive inspection of subsurface structures. In the GPR inverse problem, the conversion from the recorded GPR data to subsurface object-related information is of great importance for mapping the subsurface utilities as well as detecting, recognizing, and monitoring the subsurface objects. The reconstruction of subsurface permittivity maps from B-scans allows obtaining the size, shape, location, and permittivity information of the objects. Traditional reconstruction algorithms developed for this purpose, such as full-waveform inversion (Q. Ren, *J. Appl. Geophys.*, 151, 186-193, 2018), suffer from high computational cost and low accuracy when applied to complex scenarios. To tackle these issues, deep learning-based methods have recently been developed to characterize the mapping from the B-scan to the permittivity map (J. K. Alvarez et al., *13th IEEE Conf. ICIEA*, pp. 611-616, 2018) (B. Liu et al., *IEEE Trans. Geosci. and Remote Sens.*, pp. 1-21, 2021). However, these methods only consider the ideal homogeneous soil environments and neglect the noise and clutter due to heterogeneity of the subsurface environment, which can severely interfere with the objects' signatures in the B-scans and lower the accuracy of reconstructed permittivity maps.

In this study, we propose a two-stage deep neural network for reconstructing permittivity maps from B-scans obtained under heterogeneous soil conditions. In the first stage of the network, a 2D U-Net (R. Olaf et al., *Int. Conf. Med. Image Comp. Comp Ass. Interv.*, 234-241, 2015) is employed to extract the main hyperbolic signatures of the objects and remove the noise and clutter due to heterogeneous soil. In the U-Net, convolutional layers with multiple receptive fields are utilized to extract multi-scale features from the B-scan. In the second stage, the denoised B-scan from the first stage and the original noisy B-scan are provided to the two input channels of the second U-Net. Then the second U-Net builds the mapping relationship between the B-scans and the permittivity map. To train and test the proposed network, a large data set consisting of the noisy B-scans, the denoised B-scans, and their corresponding permittivity maps is generated using an open-source 2D finite-difference time-domain simulator. The end-to-end training of the network is performed using a loss function combining the mean square errors (MSE) obtained in two stages. Our preliminary results show that the normalized MSE, mean absolute error, mean pixel relative error, and structural similarity are 0.0004, 0.0011, 0.1642%, and 0.9912, respectively. The testing results demonstrate that our proposed methodology allows accurate reconstruction of permittivity maps from B-scans obtained under heterogeneous soil conditions. In the talk, we will present the comparison results with existing deep learning-based methods and the generalization ability of the proposed two-stage network.