A Fast 2D GPR Forward Solver for Convex Objects Based on a Deep Learning Technique

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The forward modeling of ground-penetrating radar (GPR) is of paramount importance to facilitate the understanding and interpretation of GPR data. It also plays a key role in generating large GPR data sets to develop inversion and machine learning-based frameworks. The classical full-wave forward solvers, such as the ones based on finite-difference time-domain (FDTD) (C. Warren et al., *Comput. Phys. Commun.*, 209, 163-170, 2016), require excessive computational time and resources, especially when their repetitive execution is required to generate a large data set for a specific GPR scenario. To tackle this issue, a deep learning-based forward solver has recently been developed to predict the 1D A-scans for a specific subsurface scenario (I. Giannakis et al., *IEEE Trans. Geosci. Remote Sens.*, 57(7), 4417-4426, 2019). However, 1D signals only provide limited information about the subsurface objects. Furthermore, various 2D deep learning-based forward solvers have recently been proposed to obtain the field distributions from the given input data for specific scattering, lithography, and biomedical applications (S. Qi et al., *IEEE J. Multiscale Multiphys. Comput. Tech.*, 5, 83-88, 2020) (Y. Mao et al., *IEEE Trans. Antennas Propag.*, 69(5), 2921-2928, 2021) (T. Yokota et al., *Brain Stimul.*, 12(6), 1500-1507, 2019). These studies demonstrated high efficiency and satisfactory accuracy of 2D deep neural networks to characterize the electromagnetic phenomenon for certain scenarios.

In this study, a 2D GPR forward solver leveraging a deep learning technique is proposed for characterizing radar signatures of subsurface convex objects. In particular, a U-shaped convolutional neural network, called U-Net (R. Olaf et al., *Int. Conf. Med. Image Comp. Comp Ass. Interv.*, 234-241, 2015), is used to obtain GPR B-scans for given 2D subsurface permittivity maps. The network consists of an encoder and a decoder with skip connections between them to avoid information loss. For training and testing of the network, a large data set, including the permittivity maps and their corresponding B-scans, is generated using an open-source 2D FDTD solver for various convex objects. A loss function that combines the mean square error and the mean absolute error is used to optimize the weights in the network. Numerical results verify the capability of the proposed solver in the accurate and efficient prediction of the B-scans for given permittivity maps of subsurface scenarios with random convex objects. The normalized mean absolute percentage error and structural similarity on the testing data are 0.1030% and 0.9992, respectively. Furthermore, the computational time required to obtain one B-scan for a given permittivity map is only 8 ms, making the proposed forward solver at least 33,000 times faster than the conventional FDTD solver, which requires about 4.5 mins to obtain each B-scan. These results demonstrate the high accuracy and ultra-high efficiency of the proposed deep learning-based 2D GPR forward solver for convex objects. The comparison between the B-scans obtained by the proposed solver and the FDTD solver will be presented in the talk. Furthermore, the generalization ability of the proposed solver for other GPR applications will be discussed.