Simulation of TRT-Configured Ground-Penetrating Radars Over Heterogeneous Grounds

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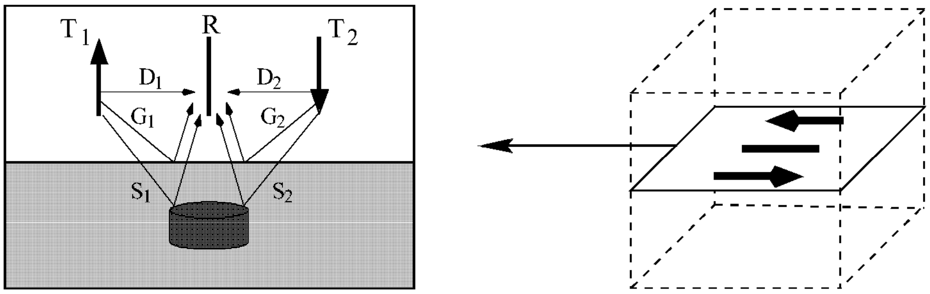
1 Introduction

The finite-difference time-domain (FDTD) method, along with the perfectly-matched layer (PML) absorbing boundary conditions (ABCs), has been used extensively to simulate ground-penetrating-radar (GPR) scenarios. The main difficulty in both practical and numerical GPR problems is the domination of the received signals by the direct coupling from the transmitter. Various practical [1] and numerical [2] methods have been devised to degrade this coupling and enhance the detectability of the buried target.

The transmitter-receiver-transmitter (TRT) configuration [3, 4] is an attempt to design GPR models with identically zero coupling at the receiver. In this configuration, the receiving antenna is located in the middle of the two identical transmitters, which are fed 180° out of phase. The TRT configuration, illustrated in Fig. 1(a), implies the existence of a symmetry plane in the middle two transmitters and the cancellation of the direct signals (D_1 and D_2) coupled from the transmitters at the receiver location. Moreover, if the ground is homogeneous and the ground-air interface is uniform, the two reflected signals (G_1 and G_2) also cancel out at the receiver. The TRT configuration is an efficient and powerful way to enhance the detection of buried targets by removing or decreasing the amplitudes of large undesired signals.

Although different alignment and polarizations of TRT-configured GPR models yield a variety of results on a fixed scenario [4], in this paper, a single configuration, which is depicted in Fig. 1(b), is used. This GPR model consists of three horizontally-polarized antennas aligned parallel to the path of the radar unit.



(a)

(b)

Figure 1: (a) Basic TRT configuration of the radar unit and the definition of the direct (D_1, and D_2), reflected (G_1, and G_2), and scattered (S_1, and S_2) signals. (b) The TRT configuration used in this paper.

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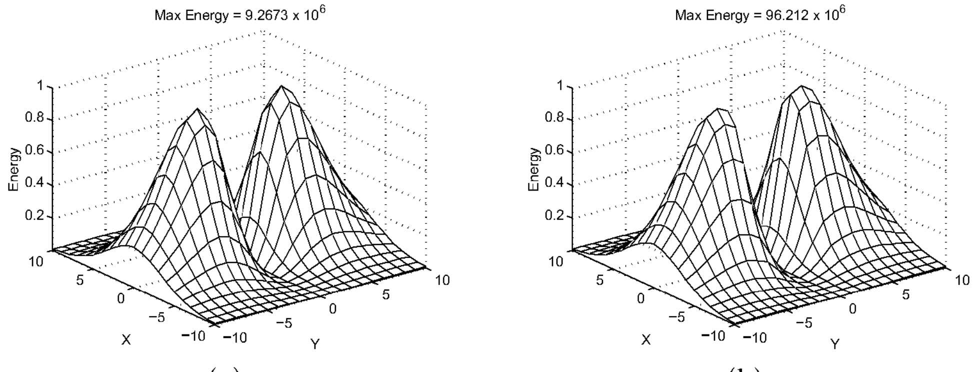
2 Optimization of the Antenna Separation

For the GPR configuration in Fig. 1(b), changing the distance between the transmitting and receiving antennas affects the amount of scattered energy observed at the receiver. Figure 2 displays two C-scan results of a conducting disk, with 2.5 cm radius, 4 cm height, and buried 5 cm under the ground. These two results are obtained with GPR models of 1-cm and 4-cm transmitter-receiver (T-R) separations. Figures 2(a) and (b) reveal that larger amounts of scattered energy is observed on the receiver while the T-R separation increases.



(a) (b)

Figure 2: The C-scan results of a conducting disk, buried 5 cm under the ground. The T-R separation is (a) 1 cm and (b) 4 cm.

Although the received energy seemed to increase with the separation of the antennas in Fig. 2, the received scattered energy is likely to decrease to zero as the separation approaches infinity. Therefore, an optimum value should be encountered while the transmitters and the receiver are taken apart. In order to demonstrate the existence of this optimum distance and find its value, a number of simulations are carried out with the TRT-configured GPR model. In the referred simulations, the T-R separation of the GPR model is changed from 1 cm to 16 cm in one-cm steps. With each of the 16 GPR models, a B-scan measurement is performed and the maximum received energy is recorded. Figure 3 displays these energy figures with respect to the T-R separation value and demonstrates that the optimum T-R separation value is between 6 cm and 7 cm.

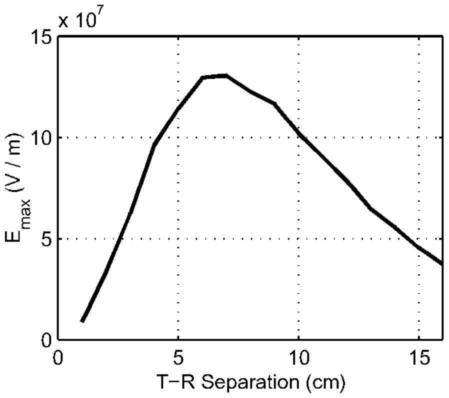


Figure 3: The maximum received energy vs. the T-R separation.

3 B-Scan Results with Heterogeneous Ground Model

In this section, the performance of the TRT-configured GPR model is investigated when operating on heterogeneous ground models. Above a homogeneous ground model, the signal observed at the receiver is solely due to the buried target. However, this is not a realistic situation and the effects of ground inhomogeneities, especially surface disorder, should be studied in order to firmly comment on the overall performance of the TRT configuration. For this reason, a simulation setup governing a heterogeneous ground model, which is displayed in Fig. 4, and a TRT-configured GPR model is designed. The ground model has a permittivity of $8\epsilon_0$ and a conductivity of 0.01 S/m. There are 40 holes on the ground-air interface, modeling the surface disorder. Moreover, there are 40 highly conducting small objects in the middle level of the ground and 80 other small scatterers in the lower level of the ground. The sizes, locations, permittivities, and conductivities of these objects are randomly selected.

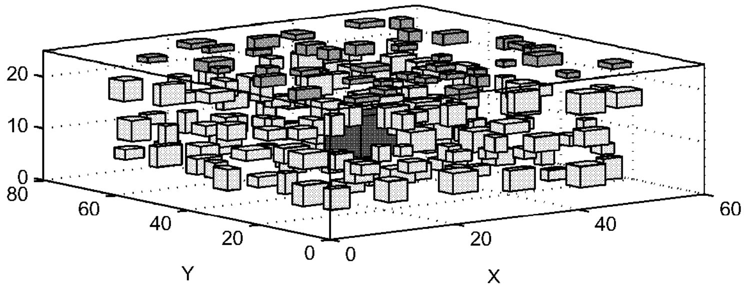


Figure 4: The heterogeneous ground model.

First, the simulation results of the same dielectric disk, buried in a homogeneous ground, is displayed in Fig. 5 in order to provide a comparison with the heterogeneous-ground simulation results. The radar unit travels on a linear path and stops at a point whose projection is on the center of the dielectric disk. The scattered-field image demonstrates that the buried target is easily detected when buried in a homogeneous ground. In Fig. 5, two extra energy plots are given, which display the scattered energy values with respect to the radar position and time-step value.

Figure 6(a), which presents the simulation results of the dielectric disk with the heterogeneous ground model, demonstrates that the signals scattered from the disk are still visible, although a large noise is observed at the early time steps of the B-scan. This noise is absent in the B-scan results obtained with the homogeneous ground, in Fig. 5. In order to investigate the characteristics of this noise, the heterogeneous ground model is altered and another simulation is performed. In this new ground model, the surface holes in the previous model are moved one cell into the ground, and therefore, the ground-air interface is regularized. The simulation results of this ground model are displayed in Fig. 6(b). Comparison of Fig. 6(a) and 6(b) reveals that the large early-time noise in the results of heterogeneous ground with surface disorder are degraded in the results of the heterogeneous ground with regular ground-air interface. Therefore, it is possible conclude that the TRT-configured GPR is sensitive to surface roughness and the main source of noise is these detoriorations in the ground-air interface.

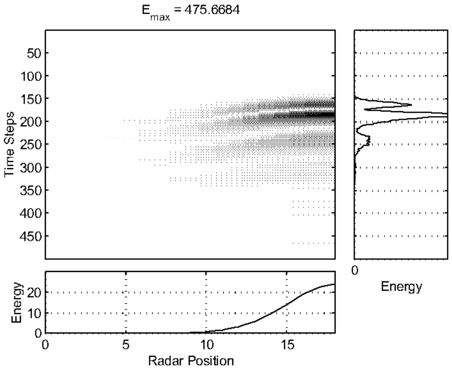
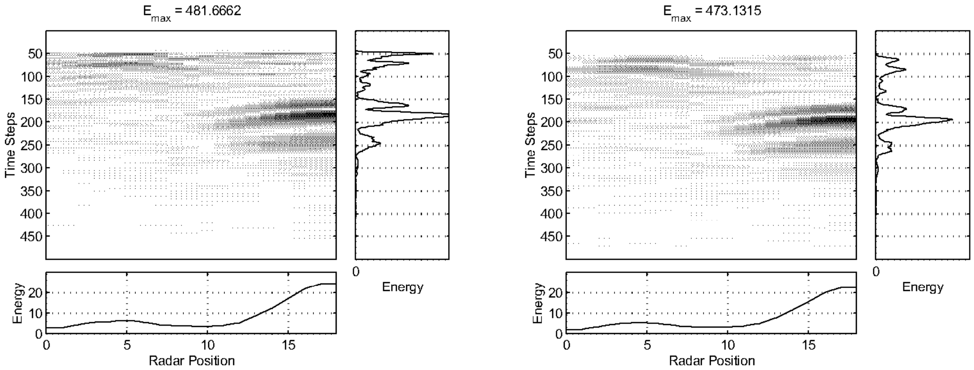


Figure 5: The simulation results of a dielectric disk obtained with a homogeneous ground model.



(a) (b)

Figure 6: The simulation results of a dielectric disk obtained with a heterogeneous ground model that contains (a) surface disorder and (b) no surface disorder.

4 Concluding Remarks

The TRT configuration of the GPR is a powerful tool to degrade the large undesired signals that dominate the total-received signal. Ground inhomogeneities, especially the ones in the surface of the ground, influence the measurements. However, the signals scattered from the target are still observed at the receiver.

References

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