GPR Landmine Imaging: 2D Migration and 3D Inverse Scattering in Layered Media

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Abstract. We present two methods for ground penetrating radar (GPR) imaging of landmines: 1) The migration technique has been successfully applied to processing field data collected at a test site and is shown to be a useful real-time imaging method; 2) A full 3D nonlinear inverse scattering algorithm has been developed in multilayered media and is demonstrated to reconstruct high-contrast buried objects in high-resolution.

INTRODUCTION

Ground penetrating radar (GPR) is an important tool in detecting subsurface buried objects such as landmines and unexploded ordinance. In particular, for demining purpose, one is interested in distinguishing between the signatures of landmines from those of clutters (such as rocks and tree roots). Currently, the most popular schemes for processing GPR landmine data are based on signal processing methods, as demonstrated in [2]. In this work, we alternatively apply and develop wave-based imaging methods: (a) a two-dimensional migration technique for GPR data, and (b) a 3-D nonlinear inverse scattering method based on the contrast source inversion and the dyadic Green’s function for a layered medium. The 2-D migration is suitable for the current measurement setup where the data is collected in the cross range direction. For potentially new GPR systems, one may be able to collect the data using a 2-D antenna array, thus enabling the 3-D image reconstruction of buried objects.

DATA AND MIGRATION APPLICATION

The GPR data processed in this work was collected for the detection of landmines by Niitek, Inc. at a U.S. government testing ground. A linear 24-sensor array of 1.2m is positioned along the crosstrack direction. The sensor array is moved at a constant interval (5 cm) in the downtrack direction until the whole interested area is scanned. The number of time sampling points is 416 per trace.

We apply the phase-shift migration technique [4] to processing the GPR data. Shown in the left panel of Figure is the raw data for the GPR array on top of a anti-tank metallic landmine. The circular landmine is 216 mm high and 230 mm in diameter, and is buried 3 inches deep. It is observed that there is a strong horizontal reflection event due to the ground bounce, which is “clipped” in order to show the weaker signal from the landmine. More interestingly, a diffraction hyperbola appears in this section. The hyperbola is not symmetric, possibly due to the tilt of the landmine. The right panel of Figure shows the migrated result. Clearly, the diffraction hyperbola in the raw data now collapses into the correct shape approximately. This example, as well as other examples not shown here for metallic and plastic landmines, shows that the image of landmine was significantly improved after migration. Thus, any focusing effects the migration technique can be in principle very useful in landmine detection and discrimination.
3D NONLINEAR INVERSE SCATTERING IN LAYERED MEDIA

Now we turn to inverse scattering methods which aim to provide quantitative estimate of the electrical properties of the scatterer, which is not available in migration methods. Note that such GPR inverse scattering problem is both nonlinear and highly ill-posed and the presence of the ground surface and possibly subsurface layers makes this problem even more challenging.

For planarly multilayered background media extending to infinity in $x$ and $y$ directions, the 3D GPR inverse scattering problem is to reconstruct the complex permittivity $\epsilon$ of inhomogeneous objects embedded in layer $i$ where a $D$ domain is defined, given the GPR measurements in layer 1 (air), where $S$ domain is defined. The scattered electric field measured in the air can be symbolically written as $E_{sc}^1(r) = G_S[w](r)$, $r \in S$ and the object equation for the contrast source $w(r) = \chi(r)E(r)$ can be written as $w(r) = \chi(r)E^{inc}(r) + \chi(r)G_D[w](r)$, $r \in D$, where the contrast function $\chi(r) = \frac{\epsilon(r)}{\epsilon_i} - 1$ and $\epsilon_i$ is the complex permittivity of layer $i$ and $E(r)$ is total field. Note that the operations $G_{S,D}$ are now involving the dyadic Green’s function for the magnetic vector potential in a layered medium, rather than a scalar Green’s function in a homogeneous background. The complex contrast function $\chi$ is inverted by minimizing a cost functional consisting of the misfits in the data and object equations [1, 3].

Here we present the results for the two-layer case. In the lower half space of $D$ domain whose dimension is $9.2 \times 9.2 \times 9.2 \text{ cm}^3$, there are two buried objects with the electrical parameters $\epsilon_r = 4.0$ and $\sigma = 0.16 \text{ S/m}$. The background is characterized by $\epsilon_{r1} = 1.0$, $\sigma_1 = 0 \text{ S/m}$; $\epsilon_{r2} = 2.0$, $\sigma_2 = 0.02 \text{ S/m}$. Note that the permeability for background and the objects is all equal to $\mu_0$ in free space. Domain $D$ is divided into $15 \times 15 \times 15$ voxels. A $z$-directed electrical dipole source is operated at the frequency of 2 GHz. We assume a 2-D planar array with 64 sources and 64 receivers uniformly distributed, with an aperture dimension of $60 \times 60 \text{ cm}^2$ and 3 cm high. Thus we have complex data of 4096 using one component $E_z$ of the scattered data in the reconstruction.

Figures (a) and (c) show the ground-truth of permittivity and conductivity profiles of two buried objects on three orthogonal cross sections. By comparison, we observe that the permittivity profile at iteration 500 in Figure (b) is well inverted in the spatial distribution and permittivity level. The inverted conductivity profiles of Figure (d) also exhibit a fashion similar to the case of permittivity. It is demonstrated that the convergence of our algorithm is fairly stable for this problem. In fact, this point is illustrated clearly in error curves versus the iteration number. Due to the space limit, more results will be presented in the meeting.

CONCLUDING REMARKS

For processing the GPR measurements in landmine detection and discrimination, a) We employed the migration technique that appears to be an effective method to focus the diffraction hyperbola onto the landmine targets in real time; b) we developed the 3-D nonlinear inverse scattering method in a layered medium which is demonstrated to provide quantitative estimate about the physical properties of buried object.

Figure 1: The raw GPR data (left) and the migrated profile (right) for a metallic landmine.
Figure 2: The ground truth (a) and inverted profiles (b) for permittivity; The ground truth (c) and inverted profiles for conductivity.

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References


