Imaging of Underground Anomalies using RF Tomography and Lateral Waves

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I - Motivation

Recently, the problem of underground complex (UGC) detection has become a critical topic for protection of national borders, sensitive areas as well as civil applications, such as mining safety, search and rescue, environmental engineering, exploration geophysics, archaeology and speleology. Presently, underground imaging is best accomplished by ground penetrating radars (GPR). However, common GPRs still face many challenges, such as high attenuation losses, frequency dispersion, expensive wideband systems, low SNR, and limited views. Improvements have been achieved by applying tomography in the framework of GPR [1]-[6], but: 1) multi-monostatic configuration is used, thus limited view is still present; 2) systems are still wideband, 3) no system can operate in areas inaccessible to an operator.

II - Radio Frequency Tomography

We introduced a new approach based on a *multiview* and *multistatic* configuration where the *view* (associated with the distributed transmitters) and the *observation* (associated with the multiple receivers) diversities allow us to acquire more information about the scene. Using view and observation diversity, the spectral content of the waveform illuminating the targets is significantly reduced. In principle, even when a monochromatic waveform is employed, highly resolved outputs are obtainable. This RF tomography based methodology operates using a set of low-cost randomly deployed earth penetrating transponders. Using the principles of inverse scattering or diffraction tomography, we developed a scheme for imaging underground anomalies, thus revealing, locating and tracing concealed objects.

III - Theoretical Background

The task of imaging the underground can be formulated as an inverse scattering problem where the objective is to determine the dielectric and conductivity anomalies of the region under investigation. The first expedient is to construct a linear model of the electromagnetic wave propagation into the ground, by selecting suitable dyadic Green's functions and making approximations on the scattered electric field [7]-[11]. This linear model can be represented as an operator applied to the dielectric anomalies that return the values of the scattered electric field. Discretization of the linear operator results in formulating the inverse scattering problem as a matrix inversion. The next step involves deriving image reconstruction methods based on the peculiar characteristics of the ground and the geometry: 1) Levenberg – Marquardt based method 2) Truncated Singular Value Decomposition 3) Back-Propagation 4) 3D Fourier Transform. The first two methods are very efficient, reliable, and robust to noise; however, they may be computationally intensive when the area to be investigated is large. The other two methods are exceptionally fast and simple, but they are extremely sensitive to noise and clutter.

IV – Current Challenges

Our effort has been to implement new strategies to accurately perform image reconstruction. We outline three main challenges that need to be addressed: 1) Transponders are affected by external, thermal, and quantization noise, clutter, and nonlinearities due to the saturation of amplifiers or ferrite cores. These factors can be modeled as a perturbation on the actual scattered electric field, and the signal processing for the image reconstruction must be designed robust with respect to these variations. 2) The number of available transponders is limited, and some units may not properly sample the electric field. An efficient image reconstruction method should provide comprehensible outputs even when the number of views and observations are deficient. 3) Prior studies in RF tomography have considered the wave propagation to be inside an unbounded homogeneous medium. In reality, sensors are deployed above the ground; therefore the propagation occurs in proximity to adjacent planar media (i.e. air and earth) and an accurate description of the wave propagation involves *lateral waves*.

V - Proposed Solutions

To overcome these issues, we are pursuing the following strategies: 1) Development of a Tikhonov based regularized solution of the inverse tomographic problem. 2) Accurately weighting the sampled data according to the SNR values at the receiver, and include this information in the algorithm. 3) Accelerate the computation of the regularized solution by invoking the Spectral Lanczos Decomposition. 4) Application of the Truncated Singular Value Decomposition method, and proper selection of the threshold based on the SNR. 5) Formalization of the concept of "resolution" for Rf Tomography. 6) Derivation of suitable Green's Functions formulations that account for the air-earth discontinuity. Detailed results will be shown at the time of the conference.

VI - References

[1] G. A. Ellis, and I. C. Peden, "Cross-Borehole Sensing: Identification and Localization of Underground Tunnels in the Presence of a Horizontal Stratification," *IEEE Trans. Geosci. Remote Sens.*, Vol GRS-35, No.3, pp 756-761, May 1997.

[2] A. J. Witten, J. E. Molyneux, and J. E. Nyquist, "Ground Penetrating Radar Tomography: Algorithms and Case Studies," *IEEE Trans. on Geosci. Remote Sens.*, Vol. GRS-32, No. 2, pp. 461-467, Mar 1994.

[3] T. J. Cui, and W. C. Chew, "Diffraction Tomographic Algorithm for the Detection of Three-Dimensional Objects Buried in a Lossy Half-Space," *IEEE Trans. Antennas Propag.,* Vol. AP-50, No. 1, pp. 42-49, Jan. 2002.

[4] T. B. Hansen, and P. M. Johansen, "Inversion Scheme for Ground Penetrating Radar that Takes Into Account the Planar Air-Soil Interface," *IEEE Trans. Geosci. Remote Sens.,* Vol. GRS-38, No. 1, pp. 496-506, Jan. 2000.

[5] P. Meincke, "Linear GPR Inversion for Lossy Soil and a Planar Air-Soil Interface," *IEEE Trans. on Geosci. and Remote Sens.,* Vol. GRS-39, No. 12, pp. 2713-2721, Dec. 2001.

[6] G. A. Tsihrintzis, P. Meincke, and A. J. Devaney, "Buried Object Detection and Location Estimation from Electromagnetic Field Measurements," *IEEE Trans. Antennas Propag.*, Vol. AP-47, No. 11, pp. 1742-1744, Nov. 1999.

[7] M. C. Wicks, "RF Tomography with Application to Ground Penetrating Radars," *IEEE Proc. 41st Asilomar Conference 2007*, pp. 2017-2022, Nov. 4-7, 2007.

[8] G. Leone, and F. Soldovieri, "Analysis of the Distorted Born Approximation for Subsurface Reconstruction: Truncation and Uncertainities Effect," *IEEE Trans. on Geosci. and Remote Sens.,* Vol. GRS-41, No. 1, pp. 66-74, Jan. 2003.

[9] R. Persico, R. Bernini, and F. Soldovieri, "The Role of the Measurement Configuration in Inverse Scattering from Buried Objects under the Born Approximation," *IEEE Trans. Antennas and Propag.,* Vol. AP-53, No. 6, pp. 1875-1887, Jun 2005.

[10] L. Lo Monte, and D. Erricolo, "Distributed RF Tomography for Voids Detection," *Proc. 2008 Meeting for the Military Sensing Symposia (MSS), Specialty on Battlespace Acoustic and Seismic Sensing, Magnetic and Electric Field Sensors,* Laurel, MD, USA, Aug. 19-21, 2008.

[11] F. Soldovieri, J. Hugenschmidt, R. Persico, and G. Leone, "A Linear Inverse Scattering Algorithm for Realistic GPR Applications," *Near Surface Geophysics*, Vol. 5, No. 1, pp. 29-42, Feb. 2007.