URSI-RCRS 2024, ARIES/GEHU, Bhimtal, India, 22 - 25 October, 2024

Tomographic Ground Penetrating Radar: Comparison of Various Image Configurations

Mallikarjun Erramshetty[(1)]
(1) Department of Electronics and Communication Engineering, National Institute of Technology Goa, Goa, India, emallikarjuna@nitgoa.ac.in

Abstract

This paper presents tomographic detection of dielectric and conducting objects buried beneath earth subsurface. Three tomographic image configurations are considered: Bistatic, Singleview-multistatic, Multiview-multistatic configurations. The reconstruction capabilities of each are studied by considering numerical examples. The effect of erroneous assumption on the background medium is investigated. Truncated singular value decomposition (TSVD) is used for the inverse solution. The study also show the effect of truncation number in TSVD on output result.
Index Terms - conductors, dielectrics, detection, singular value decomposition, tomographic detection, image configuration.

1. Introduction

Ground-Penetrating Radar (GPR) is the topic of interest for many researchers as it is having numerous applications in the field of military, civil, archaeology survey, and so on [1]. In classical GPR works, a modulated electromagnetic pulse is transmitted into the ground and the strength of reflected echo signal is measured. By changing the position of the antenna and determining the echo delay time, a two dimensional (2-D) graph can be obtained (radargram) and the object location is inferred. It does not give information about the object's electrical properties or geometric features and become difficult in a complicated scenario. In recent works, tomographic ground-penetrating radar has been developed as an alternative approach to overcome such difficulties [2, 3]. Wherein scattered field integral equations are solved. However, these problems are highly non-linear and are not suitable for real-time applications. As a result, Born Approximation (BA) is adopted for a linear inverse solution [4].

The effectiveness of the tomographic GPR system depends on both hardware set-up and data processing. In this framework, the present work investigates the effect of background medium on target's estimation. In general, targets' properties are estimated with known, mostly, uniform background medium. However, the exact electrical properties of background soil space difficult to know as it varies with location. The erroneous assumption does have a significant effect on the inverse solution. Hence, the present work is focused in this direction. Here, three image configurations are considered: Bistatic (BS), single-view multistatic (SVMS) and multiview-multistatic(MVMS). For the inverse solution, truncated singular value decomposition (TSVD) is used. In TSVD, the quality of output depends on threshold number. Hence, the paper also studies effect of this threshold number on output image.

2. Problem Formulation

For simplicity, two-dimensional (2D) scalar scenario is considered and it is made of two homogeneous half spaces separated by a plane of $y = 0$. The upper half is free space, whereas the lower one has complex permittivity of ϵ_b and the target objects are buried within. The object dimensions along z-axis is infinite. If the target objects are illuminated by a transmitting antenna (Tx) from upper half space, and the incident field is polarized along z-axis, then, Born's approximated scattering equations for this problem, can be written synthetically as [6]

$$\boldsymbol{G}[\chi] = \boldsymbol{f} \qquad (1)$$

where $\boldsymbol{f}$ indicates scattered electric fields, respectively, $\boldsymbol{G}$ is a mapping function from object's domain to scattered field domain, and χ is the object's contrast function that can be expressed as $\chi = \left(\frac{\epsilon_r}{\epsilon_b} - 1\right)$, where ϵ_r and ϵ_b are the relative permittivities of the target and the background medium, respectively. Eq. 1 is a linear inverse problem and can be solved by truncated singular value decomposition (TSVD), and final form of solution can be represented by [7]

$$\chi = \sum_{i=1}^{T} \frac{1}{\sigma_i} \langle \boldsymbol{f}, u_i \rangle v_i \qquad (2)$$

wherein $\{u_i, \sigma_i, v_i\}$ denotes the SVD of $\boldsymbol{G}$. Truncation number (T) is to be selected to filter out the insignificant singular values

3. Image Configurations

In BS configuration, two antennas are used. One is transmitting antenna (Tx) and the other one is receiving antenna (Rx). Both antennas are kept near to the air-soil interface. At a given location, the buried targets are illuminated with Tx at various frequencies and the resulted scattered fields are measured at the receiver end. Next, both antennas are moved together along the observation line (along the x-axis) with a fixed offset between them and the measurement process is repeated for other required measurements. If M number of measurements is performed for F number of frequencies then the total number of measurements is $(M \times F)$. The advantages of this setup are: It is a simple design from a hardware point of view (Only two antennas are required). The inverse solution is easy since it has a few number of measurements. However, this configuration does not suitable for accurate estimation. In SVMT, a total of N antennas are located over observation line. At a given time, one antenna works as a transmitter while others are used as receivers. Hence, total number of measurements is $(N-1) \times F$. It is a complex design but signal acquisition time is faster. This configuration also does not suitable for accurate estimation. MVMT is similar to SVMT but the illumination process is repeated for each transmitting antenna. Hence, total number of measurements are $N \times (N-1) \times F$. Here, best-estimated results can be achieved through this design. However, at the cost of complex hardware design.

4. Preliminary Numerical Results

A dielectric square cylinder of dimensions $0.6m \times 0.6m$ is considered and located at a depth of 1 m as shown in Fig. 1 (a). It has the relative permittivity $\epsilon_r = 3$ with respect to background medium. The permittivity of background soil is $4 - 0.036i$ assumed. The frequency range 200 MHz to 700 MHz with span of 25 MHz is considered. A total of 21 Antennas are placed over the half-space region for SVMT and MVMT configurations. The scattered field data is corrupted with noise level of 20 dB. The results from SVMS, BS, and MVMS are shown in Fig. 1(b), Fig. 1(c), and Fig. 1(d), respectively. The value of T in Eq. 2 is selected at which singular values drop below -20 dB. It can be seen that SVMS can able to show target's signature but unable to give accurate target's location and geometry features. BS configuration able to provide target location and rough estimates. However unwanted images appear nearby object. Good estimates are observed with MVMS. The erroneous assumption about background medium and the effect of truncation number in TSVD will be presented in the full paper.

5. Conclusions

In this short paper, reconstruction results of the dielectric object using three different configurations are presented. It is shown that the best possible estimations can be achieved through the multiview-multistatic configuration (MVMS). The singular value threshold and the complex permittivity of the background medium significantly impact the imaging accuracy. MVMS outperformed both SVMS and BS configurations in providing accurate target localization and geometry. Further analysis of background medium assumptions and TSVD effects will be detailed in the full paper.

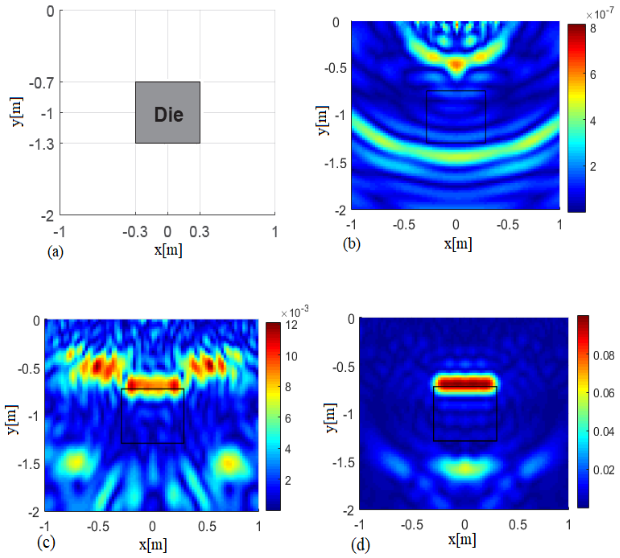

Figure 1. Tomographic reconstruction of square dielectric cylinder: (a) Reference profile. (b) Single-view case. (c) Bistatic case. (d) Multistatic case.

6. Acknowledgements

The research work carried out in this paper is supported by the Core Research Grant, SERB, India, File no. CRG/2020/004127.

7. References

1. Harry M. Jol, Ground Penetrating Radar: Theory and Applications. Amsterdam, The Netherlands: Elsevier, 2009.

2. M. Ambrosanio, M. T. Bevacqua, T. Isernia and V. Pascazio, "he Tomographic Approach to Ground-Penetrating Radar for Underground Exploration and Monitoring: A More User-Friendly and Unconventional Method for Subsurface Investigation," *IEEE Signal Processing Magazine* , **36**, 4, July 2019, pp. 62-73. doi**:** 10.1109/MSP.2019.2909433

3. M. Ambrosanio, M. T. Bevacqua, T. Isernia and V. Pascazio, "Performance Analysis of Tomographic Methods Against Experimental Contactless Multistatic Ground Penetrating Radar," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, **14**, 2021, pp. 1171-1183.
doi: 10.1109/JSTARS.2020.3034996

4. 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 Propagat.,* **53**, 6, 2005, pp. 1875–1887. doi**:** 10.1109/TAP.2005.848468

5. A. Giannopoulos, “Modelling ground penetrating radar by GprMax,” *Construction Building Mater*., **19,** 10, 2005, pp. 755–762.

6. J. Munk, “An equivalent source inversion method for imaging complex structures,” Ph.D dissertation, Ohio State University, USA, 1999.

7. D. Comite, A. Galli, I. Catapano, and F. Soldovieri, “The role of the antenna radiation pattern in the performance of a microwave tomographic approach for GPR imaging,” *IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens.*, **10**, 10, 2017, pp. 4337–4347. doi**:** 10.1109/JSTARS.2016.2636833