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Three-Dimensional Characterization of Buried Metallic Targets via a Tomographic Algorithm Applied to GPR Synthetic Data

Davide Comite (1), Alessandro Galli (1), Ilaria Catapano (2), Francesco Soldovieri (2), and Elena Pettinelli (3)

(1) DIET, Department of Information Engineering, Electronics and Telecommunications – 'Sapienza' University of Rome, Rome, Italy, (2) IREA, Istituto per il Rilevamento Elettromagnetico dell'Ambiente – C.N.R., Naples, Italy, (3) Department of Physics "E. Amaldi" – Roma Tre University, Rome, Italy

This work is focused on the three-dimensional (3-D) imaging of buried metallic targets achievable by processing GPR (ground penetrating radar) simulation data via a tomographic inversion algorithm.
The direct scattering problem has been analysed by means of a recently-developed numerical setup based on an electromagnetic time-domain CAD tool (CST Microwave Studio), which enables us to efficiently explore different GPR scenarios of interest [1]. The investigated 3D domain considers here two media, representing, e.g., an air/soil environment in which variously-shaped metallic (PEC) scatterers can be buried. The GPR system is simulated with Tx/Rx antennas placed in a bistatic configuration at the soil interface. In the implementation, the characteristics of the antennas may suitably be chosen in terms of topology, offset, radiative features, frequency ranges, etc. Arbitrary time-domain waveforms can be used as the input GPR signal (e.g., a Gaussian-like pulse having the frequency spectrum in the microwave range). The gathered signal at the output port includes the backscattered wave from the objects to be reconstructed, and the relevant data may be displayed in canonical radargram forms [1]. The GPR system sweeps along one main rectilinear direction, and the scanning process is here repeated along different close parallel lines to acquire data for a full 3-D analysis.
Starting from the processing of the synthetic GPR data, a microwave tomographic approach is used to tackle the imaging, which is based on the Kirchhoff approximation to linearize the inverse scattering problem [2]. The target reconstruction is given in terms of the amplitude of the 'object function' (normalized with respect to its maximum inside the 3-D investigation domain). The data of the scattered field are collected considering a multi-frequency step process inside the fixed range of the signal spectrum, under a multi-bistatic configuration where the Tx and Rx antennas are separated by an offset distance and move at the interface over rectilinear observation domains.
Analyses have been performed for some canonical scatterer shapes (e.g., sphere and cylinder, cube and parallelepiped, cone and wedge) in order to specifically highlight the influence of all the three dimensions (length, depth, and width) in the reconstruction of the targets. The roles of both size and location of the objects are also addressed in terms of the probing signal wavelengths and of the antenna offset.
The results show to what extent it is possible to achieve a correct spatial localization of the targets, in conjunction with a generally satisfactory prediction of their 3-D size and shape. It should anyway be noted that the tomographic reconstructions here manage challenging cases of non-penetrable objects with data gathered under a reflection configuration, hence most of the information achievable is expected relating to the upper illuminated parts of the reflectors that give rise to the main scattering effects. The limits in the identification of fine geometrical details are discussed further in connection with the critical aspects of GPR operation, which include the adopted detection configuration and the frequency spectrum of the employed signals.

[1] G. Valerio, A. Galli, P. M. Barone, S. E. Lauro, E. Mattei, and E. Pettinelli, "GPR detectability of rocks in a Martian-like shallow subsoil: a numerical approach," Planet. Space Sci., Vol. 62, pp. 31-40, 2012.
[2] R. Solimene, A. Buonanno, F. Soldovieri, and R. Pierri, "Physical optics imaging of 3D PEC objects: vector and multipolarized approaches," IEEE Trans. Geosci. Remote Sens., Vol. 48, pp. 1799-1808, Apr. 2010.