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Electromagnetic scattering by underground targets using the cylindrical-wave approach

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The electromagnetic detection of buried cylindrical targets, as structures encountered in the inspection of archaeological sites, or pipes, conduits, and tunnels, has been recently addressed in several works. The development of techniques for investigating cylindrical inhomogeneities embedded in a dielectric medium, is a challenging topic also in several other applications, including non-destructive evaluation and testing in civil engineering, and medical imaging.

Ground-penetrating radars (GPRs) are extremely useful in probing subsurface targets through electromagnetic waves. These tools solve an inverse problem, to estimate the electromagnetic properties of a target from field measurements. Different algorithms are employed to post-process the collected experimental data: most of them need a fast and accurate forward solver, to perform repeated evaluations of the scattered field due to known targets, and to be used in combination with some optimization techniques.

In this paper, we present an efficient spectral-domain method that we developed for the solution of the two-dimensional electromagnetic plane-wave forward scattering by a finite set of perfectly-conducting or dielectric cylinders, buried in a dielectric half-space or in a finite-thickness slab.

The technique is called Cylindrical-Wave Approach (CWA), because the field scattered by the targets is represented in terms of a superposition of cylindrical waves. Use is made of the plane-wave spectrum to take into account the interaction of such waves with the planar interfaces. Suitable reflected and transmitted cylindrical functions are defined; adaptive integration procedures of Gaussian type, together with acceleration algorithms, are employed for the numerical solution of the relevant spectral integrals. All the multiple-reflection phenomena are taken into account.

The method may deal with both TM and TE polarization fields; it can be applied for arbitrary values of permittivity, radius, and depth, of the buried targets. Obstacles of general shape can be simulated, by means of a suitable set of circular-section cylinders. The technique can be employed to study the scattering of an incident pulsed plane wave, with a rather general time-domain shape. Since the CWA is implemented in the frequency domain, dispersive soils can be modelled.

The CWA can be used for the characterization of suitable scenarios in the context of GPR applications, which usually employ purely-numerical finite-difference techniques. The method developed by us is very fast, therefore it can be exploited in iterative algorithms for the solution of inverse problems, and is effective for the sensing of cylindrical inhomogeneities buried in the earth.

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