PROBING MATTER WITH ELECTROMAGNETIC WAVES

Enhancing GPR Microwave Imaging through Innovative Information Acquisition Techniques

Giacomo Oliveri*, Marco Salucci**, Lorenza Tenuti*, and A. Massa(*,**)

* *ELEDIA Research Center @ DISI, University of Trento, Trento, Italy, {giacomo.oliveri, lorenza.tenuti}@unitn.it*
** *Laboratoire des Signaux et Systèmes, CNRS-CentraleSupélec-Univ. Paris Sud, Gif-sur-Yvette Cedex, France {marco.salucci, andrea.massa}@l2s.centralesupelec.fr*

Abstract

Ground Penetrating Radar (*GPR*) is worldwide recognized as an efficient, other than effective, prospecting instrument for performing subsurface investigations [1],[2]. Its main applications involve both civil engineering and geophysical studies, as well as archaeology and military domains. Despite the remarkable plethora of available techniques developed by the scientific community in the last decades, many efforts are still needed to improve microwave imaging approaches applied to half-space scenarios. It is in fact well known that *ill-posedness* and *non-linearity*, characterizing free-space inverse problems [3], become even more relevant when dealing with subsurface configurations, given (*i*) the higher complexity of the scattering model, due to the presence of the (possibly rough) interface, and (*ii*) the limited amount of collectable information, mainly caused by the availability of strongly aspect-limited measurements. In order to partially mitigate the aforementioned problems several regularization techniques have been proposed, and the use of approximations aimed at linearizing the scattering equations has been widely considered for *GPR* imaging [1]. As a matter of fact, all these approaches are based on the availability of specific *a-priori* information on the unknown scenario at hand (such as, for example, the presence or not of weak scatterers), to effectively tackle the loss of information characterizing the inversion problem.

In this framework, Bayesian Compressive Sensing (*BCS*) [4]-[7] seems to the authors an excellent candidate to deal with *GPR* microwave imaging whereas the sparsity constraint of the buried objects with respect to a properly chosen representation basis is verified. Following such an approach, the contrast source-based inversion procedure can be re-formulated within the Bayesian probabilistic framework and the retrieval of the unknown equivalent current *J* is accomplished by solving a *MAP* problem through a fast Relevance Vector Machine (*RVM*) [4]. Moreover, multi-task (*MT*) variants of the classical *BCS* formulation can be successfully employed as information acquisition techniques in order to exploit the correlation existing between different views and/or frequencies [5]. Some preliminary numerical results have shown the potentialities of these techniques, which allow the retrieval of the dielectric distributions of multiple sparse buried objects, even in the presence of a significant noise component on the measured data.

Multi-resolution strategies, such as the Iterative Multi-Scaling Approach (*IMSA*) [8]-[10] represent another fundamental tool to mitigate the occurrence of false solutions (i.e., local minima in the cost function to be minimized) as well as to regularize the inversion process. As a matter of fact, these approaches allow to reduce the ratio between the number of unknowns and the amount of informative data, leading on the one hand to an increased resolution within the identified regions of interest and on the other hand to a significant reduction of the computational costs.

In addition to all the above mentioned techniques, it is important to highline the intrinsic wideband nature of *GPR* measurements, opening the door to a vast use of multi-frequency imaging methods. In such a context, the authors developed in [9] a Frequency Hopping (*FH*) multi-scaling integrated scheme based on a conjugate gradient (*CG*) deterministic approach for the solution of subsurface problems, which is able to effectively exploit the information coming from the frequency diversity of the measured *GPR* radargram. Moreover, the joint exploitation of the *FH* strategy and the *IMSA* allows not only to favorably compare with other state-of-the-art imaging techniques, but also to overcome the single-resolution (*BARE*) implementation, both in terms of accuracy and in terms of computational efficiency, as

denoted by both successful numerical and experimental validations [9]. In order to provide some insights on the potentialities of the proposed technique, Fig. 1 presents a numerical result concerning the retrieval of an "*O-shaped*" homogeneous cylinder buried inside a lossy homogeneous non-magnetic soil with relative permittivity $\varepsilon_{rs} = 4.0$ and conductivity $\sigma_s = 10^{-3}$ S/m. The investigation domain is supposed to be successively illuminated by $V = 20$ e.m. sources placed above the interface (which is located at $y = 0$ m), while the scattered radiation is collected by $M = 19$ probes, co-located with the sources. The buried scatterer is characterized by relative permittivity $\varepsilon_{ro} = 5.0$ and conductivity $\sigma_o = 10^{-3}$ S/m, respectively. Moreover, $Q = 5$ frequency components are extracted from the transformed *GPR* radargram within the $[200, 600]$ MHz range and are considered by the *FH*-based inversion procedure, with a uniform step of $\Delta f = 100$ MHz. Fig. 1(*a*) shows the actual contrast function within the imaged domain, defined at position $\mathbf{r} = (x, y)$ and frequency f as $\tau(\mathbf{r}) = [\varepsilon_r(\mathbf{r}) - \varepsilon_{rs}] + j[\sigma_s - \sigma(\mathbf{r})]/2\pi f \varepsilon_0$. Fig. 1(*b*) shows the retrieved contrast by the single-resolution technique (*FH-BARE-CG*), while Fig. 1(*c*) depicts the retrieved contrast by the multi-resolution technique (*FH-IMSA-CG*), when assuming a Signal-to-Noise ratio equal to $SNR = 40$ dB on the time-domain total field. As it can be seen, both techniques are able to correctly detect the presence and the location of the object. However, the *FH-IMSA-CG* is able to provide a better estimation of both the shape and the contrast [Fig. 1(*c*)] of the target, as well as a suppression of the artifacts characterizing the background region of the *FH-BARE-CG* reconstruction [Fig. 1(*b*)].
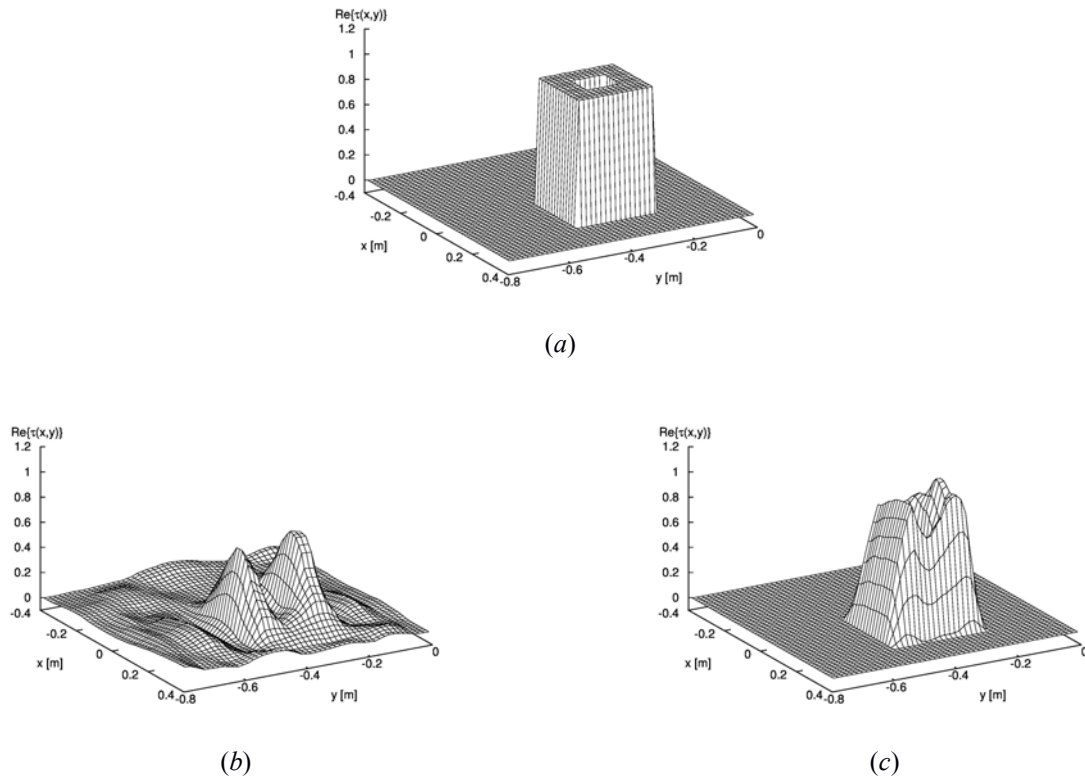

(*a*)

(*b*)   (*c*)

Fig. 1. *Homogeneous "O-shaped" Target* - (*a*) Actual contrast and retrieved contrast by (*b*) *FH-BARE-CG* and (*c*) *FH-IMSA-CG* for $SNR = 40$ [dB].

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Citations

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