Short-term scientific missions on forward and inverse electromagnetic-scattering techniques for ground penetrating radar

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Short-Term Scientific Missions on forward and inverse electromagnetic-scattering techniques for Ground Penetrating Radar

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***Abstract*—This work aims at offering an overview on the scientific results stemming from a selection of three Short-Term Scientific Missions (STSMs) carried out in 2016 and funded by the COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar." The research activities focused on the development and use of electromagnetic modelling and inversion techniques for Ground Penetrating Radar applications. In a STSM, a scientist has the possibility to visit a colleague abroad, in order to undertake joint research and share experience, techniques, equipment and infrastructures that may not be available in the home institution. This is a powerful networking tool that allows developing linkages and scientific collaborations between institutions involved in a COST Action.**

Keywords——Ground Penetrating Radar; electromagnetic scattering; inversion techniques

I. INTRODUCTION

The main objective of COST (European Cooperation in Science and Technology) Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" [1] (April 2013 – October 2017) is to exchange and increase scientific and technical knowledge and experience on Ground-Penetrating Radar (GPR) techniques in civil engineering, while promoting a wider and more effective use of this safe and non-destructive technique. The Action involves participants from 28 COST Countries (Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Macedonia, Germany, Greece, Ireland, Italy, Latvia, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom), 1 Cooperating State (Israel), 6 Near Neighbour Countries (Albania, Armenia, Egypt, Jordan, Russia, Ukraine), and 6 International Partner Countries (Australia, Colombia, Hong Kong, Philippines, Rwanda, United States of America). The scientific structure of the Action includes 4 Working Groups (WGs). WG1 focuses on the design of novel GPR equipment. WG2 deals with the development of guidelines for GPR surveying of transport infrastructures, buildings and construction materials, and for sensing of underground utilities and voids. WG3 develops forward and inverse electromagnetic techniques for the solution of near-field scattering problems, and data-processing techniques. WG4 studies the use of GPR outside from the civil engineering area and its integration with other non-destructive testing techniques.

Short-Term Scientific Missions (STSMs) are important means to develop collaborations between institutions involved in a COST Action. Scientists have the opportunity to visit colleagues abroad, in order to undertake joint research and share ideas, experience, techniques, equipment and other facilities. This paper aims at presenting scientific results stemming from a selection of TU1208 short missions carried out in 2016. The research activities dealt with the development and use of electromagnetic-modelling (Section II) and inversion (Section III) methods for GPR. Previous STSMs on these topics were presented in [2].

II. STSMS ON ELECTROMAGNETIC MODELLING FOR GPR

In April 2016, Alessio Ventura (Italy) visited Antonis Giannopoulos and Craig Warren (United Kingdom). The activities focused on developing accurate models of GPR antennas with two different approaches, namely the Finite-Difference Time-Domain (FDTD) method and the Finite-Integration Technique (FIT). This study started in remote cooperation before the mission and involved also Lara Pajewski (Italy). High-frequency commercial GPR antennas were simulated in free space and over a lossy dielectric. The employed FDTD solver was gprMax, an open-source simulator [3], whereas the commercial software CST Microwave Studio was used for simulations with the FIT. Very good agreement between FDTD and FIT was observed. The comparisons highlighted the importance of understanding how features such as material dispersion and antenna feeding are modelled. This is especially relevant for GPR applications, where antennas operate in the near field and their interaction with the surveyed ground/structure and targets has important effects on the recorded radargrams. An example of cross-talk results obtained for a 1.5 GHz shielded bow-tie antenna is given in Fig. 1.

In April-May 2016, Alexei Popov (Russia) visited Marian Marciniak (Poland). They continued a study started by Igor Prokopovich (Russia) during a previous mission and involving Lara Pajewski (Italy) as well. A semi-analytical solution was developed, to solve the forward back-scattering problem of a pulsed field emitted by a dipole in the presence of a non-uniform dielectric half-space. A new coupled-wave version of the Wentzel–Kramers–Brillouin (WKB) approximation was proposed, obtained by extending the Bremmer-Brekhovskikh [4] approach to the time domain. Numerical results were obtained and compared with gprMax results, with very good agreement: see Fig. 2. To demonstrate the applicability of the approach to real scenarios, the technique was successfully employed for the post-processing and interpretation of GPR radargrams collected on the Lake Chebarkul, in Russia.

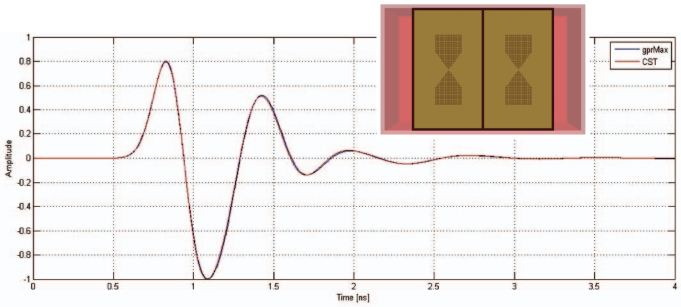


Fig. 1. Cross-talk results obtained for a 1.5 GHz antenna.

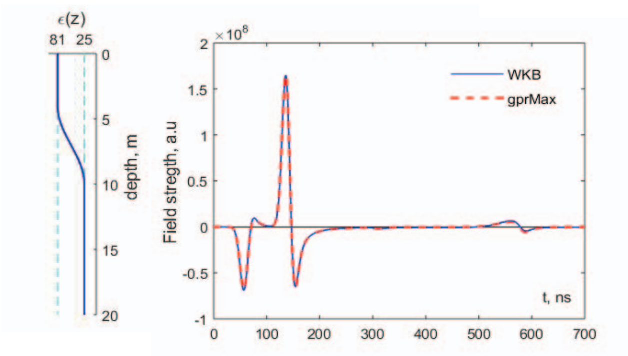
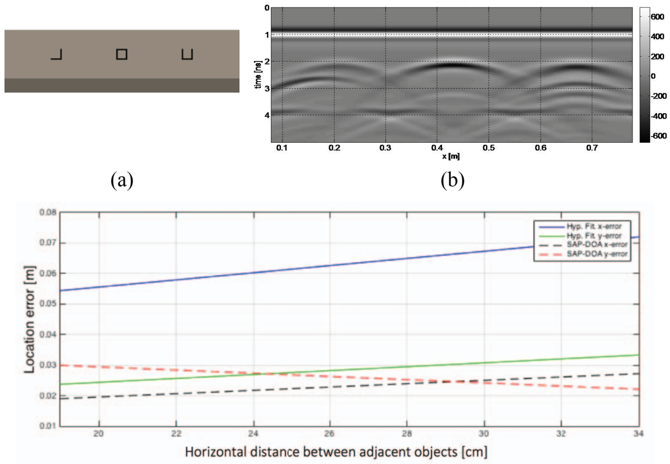


Fig. 2. Profile of half-space dielectric permittivity and simulated A-Scan.

III. STSMs on Inversion Techniques for GPR

In January 2016, Simone Meschino (Germany) visited Lara Pajewski (Italy). Aim of the mission was to continue a study started during a previous STSM, where a method based on Sub-Array Processing (SAP) and Direction of Arrival (DoA) algorithms was developed and applied to GPR data [5]. New tests were performed on synthetic radargrams calculated by using gprMax and involving concrete cells with circular-section steel rods of different radii and positions, dielectric rods, and other reinforcing elements. The SAP-DoA accuracy was compared to that of the standard time-domain hyperbola approach. As expected, both methods give better results when the distance between the sought reinforcing elements is longer. The hyperbolic interpolation method is more accurate than SAP-DoA for circular-section objects; nevertheless, in the case of targets with different shape, the hyperbola approach cannot be employed whereas the SAP-DOA method can still provide interesting results: see Fig. 3.



(a) (b) (c)

Fig. 3. (a) Geometry of the problem, (b) Synthetic B-Scan calculated with gprMax, (c) Results of SAP-DoA and hyperbola methods.

IV. Conclusions

This paper presents results obtained during three COST Short-Term Scientific Missions (STSM), dealing with the development of modelling and inversion techniques for Ground Penetrating Radar (GPR) applications. STSMs are flexible bottom-up networking tools, encouraging and supporting researchers to work together, start new international collaborations or strengthen existing ones. Most visits yield interesting scientific results in a short period of time.

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