Advances in Ground Penetrating Radar for Humanitarian Demining

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ABSTRACT

In this paper the activities in the Low Countries in the area of development of Ground Penetrating Radars for humanitarian demining are described. These activities include development of electromagnetic theory for simulation of radiation, propagation and scattering of electromagnetic waves in typical GPR scenarios as well as for subsurface imaging and inversion, development of relevant signal processing methods and development of the principally new hardware for detection and classification of detected targets.

INTRODUCTION

Recently considerable efforts are put in development of Ground Penetrating Radar (GPR) systems for detection of surface-laid and shallow buried targets such as antipersonnel landmines. Such application requires principally new (in comparison with conventional GPR) design of the system. Together with essential improvements of such hardware specifications as down- and cross-range resolution, sensitivity, stability, etc., this specific application requires a principally new ability to classify and identify detected targets. Hence, the requirements to the radar system for landmine detection shift the optimal system specifications into another direction compared to conventional GPR applications [1]. Successful detection and identification of landmines requires also much more complicated signal processing. As a result, development of GPR systems dedicated to landmine detection became one of the most advanced and the most dynamic research topic in the fields of radar and wave scattering. In the Low Countries several research groups perform active research in the field of GPR for landmine detection. Results of their activities are summarized in this paper.

HARDWARE DEVELOPMENT

In the area of hardware, development of four new GPR systems should be mentioned because of principally new approaches in the design. A laboratory prototype of compact ultra wideband (UWB) video impulse systems has been built in Royal Military Academy in Brussels [2]. The radar radiates a 0.35ns monocycle pulse (covered bandwidth from 1GHz till 5GHz on 3dB level), which provides sufficient down-range resolution for antipersonnel mine detection. Due to special design of its antenna system this GPR can work in the vicinity of metal detector coils without disturbing the metal detector. Another UWB video impulse system has been developed by TNO-FEL [3]. Pulse spectrum of this system covers frequency band from 200MHz till 3.5GHz on 3dB level. Using IRA antennas [4] and a high power transmitter this system illuminates a limited spot on the ground surface so that the probing field impinges at the air-ground interface at Brewster angle. Such choice of the probing field according to the system designers should improve considerably "surface clutter" to "scattered signal" ratio, which limits detectability of any GPR system. Finally, International Research Centre for Telecommunications-transmission and Radar (IRCTR) at TU Delft came with a new concept of the antenna system for landmine detection GPR [5]. This concept has been realized in two GPR systems (concept demonstrators), one of which is a fully polarimetric GPR system qualified for field work [6,7] (Fig. 1). In all abovementioned systems main attention has been paid to the antenna system design, which is believed to be the most critical part of any GPR for landmine detection. However, in stepped-frequency CW radar (built also in IRCTR) the whole system design is novel. The principal novelty of this system is simultaneous transmission of 8 frequencies achieved via using 8 parallel channels in the transceiver [8]. Such technology allows considerable reduction of data acquisition time (one A-scan is acquired within 1.7msc). In principal multi-frequency technology can provide much more benefits than just reduction of data acquisition time (e.g. signal coding). Full potential of this technology will be exploited in future.

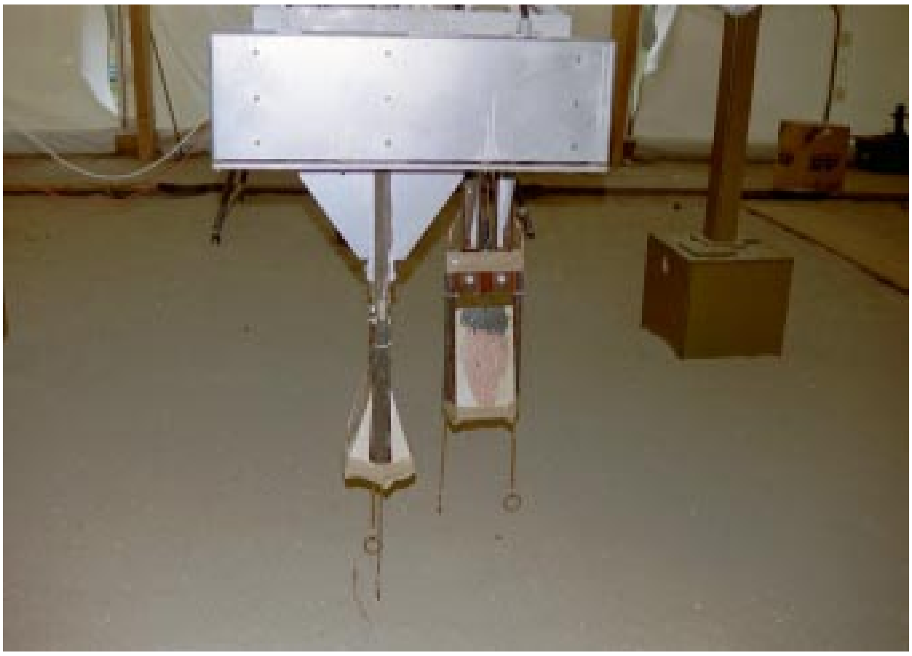

Fig. 1. Fully polarimetric GPR built in IRCTR

SOFTWARE PROCESSING

In the area of signal processing research activities cover a vast area from subsurface imaging till data fusion. Despite of considerable progress in hardware development the acquired data can be further enhanced by means of signal pre-processing (e.g., time drift compensation, system transfer function deconvolution, etc.). New efficient pulse compression technique based on system transfer function deconvolution has been proposed by B.Scheers from RMA [2]. Several effective background removal algorithms have been developed by B.Sai from IRCTR [9]. Substantial progress in imaging algorithms has been achieved as well. While standard migration algorithms deal with probing wave propagation in one medium (ground), in typical landmine detection scenario the probing wave impinges from air, sustains refraction at air-ground interface, propagates and scatters from objects in a second medium (ground). So multi-media environment should be an essential part of imaging algorithm for landmine detection. Several such algorithms have been developed independently in RMA and TU Delft [10, 11]. Next logical step in signal processing is primary detection of objects. Here we would like to mention advanced algorithms for hyperbola detection and for area localization developed in RMA [12]. Another interesting results concerned primary object detection including improvement of signal to clutter ratio in raw data have been obtained in Vrije Universiteit Brussel [13, 14]. Identification and classification of detected objects is thought to be done based in feature space. So feature extraction becomes one of key elements in the whole signal processing chain. To this end a novel approach of effective inversion developed by N. Budko from TU Delft [15] is of high importance because it allows to estimate dielectric permittivity of detected objects. Links between different signal features and physical properties of target has been studied in [16]. Large library of UWB responses of different antipersonnel mines and false alarms has been collected by TNO-FEL by means of their GPR system [3]. And finally at the top of the signal processing chain data a decision-making algorithm is placed. Majority of such algorithms are based on different data fusion schemes (with fusion at levels of data, features, decisions etc.). Often GPR is only one from several sensors used in a mine-detection system. Decision-making algorithms for such sensor suites have been developed and analyzed by TNO-FEL and RMA [17, 18].

ELECTROMAGNETIC MODELING

Both system design and object identification tasks require substantial developments in electromagnetic theory, namely in forward modeling and inverse scattering. The group headed by Prof. P.v.d.Berg from TU Delft achieved a number of new results in inverse scattering theory developing the filtered version of the time-domain backpropagation algorithm, the time-domain version of the contrast source inversion (CSI) method, multi-frequency inversion algorithms and effective inversion method [19-21, 15]. An accurate and efficient forward modeling method was developed and extensively used to get a thorough understanding of GPR. Recently developed reduced-order modeling technique allows to model a realistic three-dimensional configuration [22]. Significant progress has been achieved by application of FDTD algorithms to simulation and optimization of transient antennas [23]. Modeling of surface clutter has shown a principal possibility to reconstruct surface profile from phase measurements of the scattered field [24].

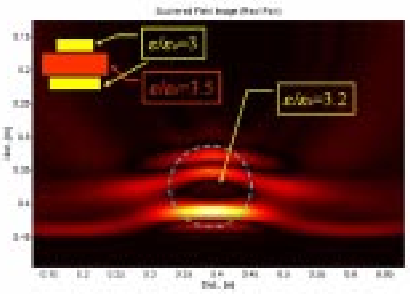

Fig. 2. Illustration of the effective inversion method. Theoretical model of a mine is shown in top left corner, while its simulated SAR image is shown in the center. The dashed circle represents an effective model of the mine with estimated dielectric permittivity. Courtesy of Dr. N. Budlo (EM lab, TU Delft)

ELECTRICAL PROPERTIES OF THE GROUND

Finally, problem of landmines detection raised again an issue of electrical properties of the ground. Any GPR system can detect ultimately just spatial variations of ground's dielectric permittivity. So advance study of ground dielectric properties in UWB frequency range becomes of principal importance. Characterization of wet soils in the 2GHz-18GHz frequency range has been performed in UCL [25]. Spatial variations of soil dielectric permittivity are the subject of a research project held at IRCTR [26].

CONCLUSION

Concluding this overview of recent advances in development of GPR for humanitarian demining, it is reasonable to say that abovementioned challenging application has stimulated considerable developments of electromagnetic theory (both forward and inverse scattering problems), antenna theory and practice, system design and signal processing methods.

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