Multi-Sensor Measurement Campaign at TNO-FEL Test Lanes in July 2002

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Abstract

In July 2002 a multi-sensor measurement campaign took place at the Test facility for landmine detection systems located at TNO-FEL, The Netherlands. The goal of the campaign was to perform simultaneous data acquisition of GPR and polarimetric IR data under realistic environmental conditions. The data have been collected over the sand and the grass lanes. High quality data sets have been obtained.

1. Introduction

Up to now the metal detector remains the most widely used remote sensing tool during humanitarian demining operations. This sensor suffers from a high false alarm rate, especially when used at former battlefields. Significant efforts have been made to develop other remote tools to assist deminers. Among other potential candidates, Ground Penetrating Radar (GPR) and polarimetric infra-red (IR) camera look like promising technologies, which should be used to solve the problem [1, 2].

First laboratory experiments on landmine detection with GPR have been performed using unmodified commercial GPR systems (one of such systems is Pulse Ekko GPR from Sensor & Software Ltd. (Canada)). More recently, a lot of efforts were put in optimizing GPR technology for landmine detection [2]. The International Research Centre for Telecommunications-transmission and Radar (IRCTR) in the Delft University of Technology is also active in this area. This work has already resulted in a principally new GPR system – a multi-waveform full polarimetric GPR [3].

Similar to GPR, first experiments with IR have been conducted using conventional IR cameras [4]. Later on, it has been understood that polarimetric information is extremely useful for landmine detection, and more sophisticated equipment has been developed [5, 7].

Unfortunately, neither GPR nor IR alone can solve the landmine detection problem. Due to surface clutter, GPR has principal problems with detection of flush buried mines, while IR cameras cannot detect deeply buried mines. However, a combination of both sensors might lead to a drastical improvement in mine detection. To investigate potentials of such sensor combinations and to elaborate sensor fusion techniques a multi-sensor (GPR+IR) measurement campaign has been planned and executed at the TNO-FEL test lanes [5] in July 2002. Three research teams from Delft University of Technology and TNO-FEL took part in this campaign with two GPR sensors and a polarimetric IR sensor. This paper describes this campaign in details. Results of data processing and sensor fusion are presented elsewhere [8].

The test lanes scenario is described in Section 2. The measurement setup for the IRCTR GPR is presented in Section 3, while the setup for another (commercially available) GPR is presented in Section 4. The polarimetric IR measurement setup is described in Section 5. The measurement procedure is described in Section 6. Main conclusions are drawn in Section 7.

2. Scenario Description

The measurements have been performed over two lanes: the sand lane and the grass lane [6]. Both lanes have dimensions of about 3m wide, 10m long and 1.5m deep.

The ground water level is controlled in both lanes. One month before the measurement campaign the sand lane has been covered to create maximal possible homogeneous moisture distribution in the soil.

The sand lane has been measured under two conditions: dry sand (when the soil was dried out for a month, and the ground water level has been decreased to 1.2m below the surface) and wet sand (when the ground water level has been artificially raised up to 30cm below the soil surface and the soil was wetted by rain). Experimentally determined in the frequency range from 0.5GHz up to 3GHz the real part of sand's dielectric permittivity is about 2.5 and the imaginary part of the dielectric permittivity is about 0.02 (Fig. 1). Some spikes on the curves in Fig. 1 are due to internal resonances in the sample holder. The sand surface was relatively flat with RMS height variations of less than 1cm. Beneath a thin layer (about 1cm thick) of an arenaceous (powdery) sand there was a crust with a thickness of 1 to 2cm thickness of highly dense sand. Beneath the crust layer the sand is powdery again.

The wet sand is a very inhomogeneous ground. The showers made the upper 10-15cm of the soil very wet, while beneath that wet layer the sand remained quite dry. Just from visual observation of the sand surface it was clear that water due to showers penetrated in the soil nonhomogeneously, making some places wetter than others. Experimentally determined (in the same frequency band as above mentioned) water content in the sand varies between 10% and 16% (mass percentage). This large water content has increased both the dielectric permittivity and ohmic losses in sand. Experimentally determined dielectric permittivity of the upper layer of wet sand (upper 10-15cm of soil) varies between 7 and 12 for the real part and between 0.3 and 2.4 for the imaginary part.

Using Time Domain Reflectometers (TDR) buried at different places in the lane, variations of sand moisture have been constantly monitored. An example of such data is shown in Fig. 2, where sharp moisture increase due to the rains can be seen.

Soil in the grass lane has a complicated structure. Top level of soil is a typical "polder" soil with grass vegetation on it. The average height of vegetation is estimated as 5cm, and the vegetation layer was not very dense. The "polder" layer is approximately 25cm thick. The ground in it is visually very inhomogeneous due to vegetation roots and other natural reasons. Dielectric permittivity of this layer has been estimated from responses of GPR targets and gave rise to an approximate value of the order of 9. During the measurements the soil in the grass lane was dry so the ohmic losses in the "polder" layer were relatively low. The "polder" layer is lying on a sandy substrate, which looks like a reasonable homogeneous dry soil. Dielectric permittivity of this substrate seems to be lower than the one of the "polder" layer, and indeed in GPR data strong reflections from the "polder"-sand interface have been observed.

Because IR camera detects differences in apparent temperatures of an object and background, the thermodynamic temperature of different simulants and soil has been monitored using thermocouples placed in the simulants and directly in soil. An example of such temperature records of two thermocouples (one was placed on the sand surface and another one was buried 5cm deep in the sand) are presented in Fig. 3. Large temperature differences between day and night periods can be observed. The amplitude decreases with depth.

Each lane has three parts with different scenarios: empty part (in which there are no intentionally buried objects), training part (for which the ground truth is known) and the evaluation part (for which the ground truth is known only to the owners of the test lanes). The training and evaluation parts contain mine simulants and false alarms [6]. The objects in the training parts of the lanes are spaced quite densely, so the distance between two neighboring objects is not larger than 60cm. Such dense spacing of the objects makes some problems for GPR sensors because of essential overlapping of the object responses. Fortunately, the weak scatterers are placed far away from the strong scatterers (except of some particular configurations in the grass lane).

There are 4 different types of anti-personnel mine simulants, which are placed in both lanes (Table 1). We note the mines by the types: C-, B&E, F- and G- mines. The C- type mines are the relatively large plastic objects with medium metal content; B&E and F are small and lightweight with little content of metal; and the G-mines are small but have considerable metal content.

In the testing part of the sand lane the mine simulants are placed at the level of 1cm above the surface, 1cm and 6cm below the surface. The distance is measured from the top of the mine up to local soil level. In the grass lane the simulants are placed 5cm above, 0cm and 5cm deep in the soil. Such shallow burial depths of the mines give a principal opportunity to detect the mines with different sensors, e.g. metal detector, IR camera, GPR, etc.

In addition to the mine simulants, the sand lane contains false alarms (barbed wire with three knots, bricks, stones, plastic bottle, etc.) and calibration targets such as brass sphere 5cm in diameter. All false alarms were buried at the depth of 6cm (from the top of the object till the surface). The false alarms have been buried two months prior to the measurement campaign in order to minimize disturbances of the ground above the objects.

3. IRCTR GPR Measurement Setup

The video impulse radar developed at IRCTR [3] has 2 orthogonal polarized transmit antennas and 4 receive antennas connected to the independent channels correspondingly (Fig. 4). In addition to a vast variety of available transmit/receive antenna configurations the radar performs measurements with 2 impulse generators, which fire impulses with duration of about 0.5 ns and 0.8 ns respectively. While using these generators the radar has an operational bandwidth (on 10dB level) from 260MHz till 2220MHz for the 0.8ns generator and from 790MHz till 3040MHz for the 0.5ns generator.

During the measurement campaign the radar has been mounted on the re-locatable scanner of TU Delft (Fig. 4). The scanner allowed positioning of the payload (with the weight up to 50kg) at any point within a scanning area of 3m by 3m with an accuracy of 0.1mm. Elevation of the payload above the surface can be changed manually within 50cm range. The scanner can be easily wheeled on the measurement position.

During the measurements the heights of the receiving loops over the surfaces were chosen to be 20 cm over the sand and 10 cm over the grass. Different elevation of the receive antennas above the ground is caused by a wooden frame around the sandy lane, which rises above the soil level on approximately 15cm and limits minimal possible elevation of GPR antennas. The grass lane is constructed in a different way, so the wooden frame is slightly below the soil level and the GPR antennas can be set at arbitrary elevation above the highest point on the lane (which in this particular case was a trigger of an anti-tank mine rising roughly 9cm above the averaged soil level).

The radar and the scanner have been controlled by a remote computer with a control software, which made possible automatic measurements on a two dimensional grid. The data acquisition parameters and radar settings are controlled by the same software. The acquired raw data are stored automatically at the remote computer for further processing.

The GPR was running in a continuous mode (with

250kHZ pulse repetition rate) during a single scan along the lane. The length of a scan was 256cm, and 465 A-scans have been acquired within a single B- scan. The separation is space between two neighboring B-scans was 3cm resulting in acquisition of 79 B-scans over the measured area. The measurement campaign finished up with 42 C-scans 2.56m*2.37m acquired with the video impulse radar over 6 different parts of the lanes. The data have been recorded using 10ns time window with 512 time samples. Averaging (stacking) number was 64.

4. Pulse Ekko Measurement Setup

Another radar, which has been used in the measurement campaign, is the commercially available Pulse Ekko system. It has been used with 500MHz antennas. The radar has been mounted on the test facilities measurement bridge [6] during measurements over the sandy lane and on the TU Delft scanner during measurements over the grass lane. Both lanes have been surveyed with scans along the lane. The transmit and the receive antennas of GPR were perpendicular to the scan direction.

The GPR was running in a continuous mode (with 25kHZ pulse repetition rate) during a single scan along the lane. From scan to scan the measurement bridge has been moved manually with a step of 5cm or 10cm. Antenna elevation above the ground was of about 5cm.

5. Polarimetric IR Measurement Setup

The polarimetric infrared setup consists of a rotating wire grid polarisation filter in front of the lens of the IR camera. The filter rotates synchronously with the frame sync of the camera [5]. The frame rate of the camera is set at 100Hz and the integration time is set at 1ms. During a full rotation of the filter 60 images are acquired. The camera is mounted on the measurement platform at a height of 2.0m in a forward-looking direction (Fig. 5). This platform moves with a constant speed of about 0.2m/s along the bridge. The orientation of the camera is 65° off-normal, i.e. looking 25° downwards. The lens used in this experiment is a 50mm lens. This lens gives a field of view of 9.1°. The field of view on the ground has a width between 0.65m at the bottom and 0.91m at the top. The depth of the field of view is 1.83m and it starts at 3.53m from the platform.

The polarimetric system is operated in a free-running mode in which image sequences are acquired continuously. Using a laser distance meter the distance travelled by the platform along the measurement bridge is measured and recorded. Every 3cm the laser distance meter gives a trigger pulse. These trigger pulses are recorded along with the images. The exact position of each image in the sequence is estimated using interpolation of the trigger pulses.

6. Measurement Procedure

The main scientific challenge of the measurement campaign is to perform simultaneous (or quasi-simultaneous) measurements with three different (and not integrated) sensors. The sensors have been mounted on different measurements platforms and replacing these platforms take quit some time. Also the measurement speed of the GPR sensors is considerably lower that that of the polarimetric IR sensor: depending on the measurement grid, it takes at least a day for a GPR sensor to cover the full lane, while the IR sensor measures the full lane in less than a quarter of an hour.

It had been decided that the polarimetric IR measurements would be performed in the morning (at a rising sun) and late in the afternoon. In the time period between these measurements, GPR measurements would be performed on the same lane. Due to a demand for a very dense measurement grid for the IRCTR GPR system (the maximal step size should not be large than 3cm), in a single day only one third of a lane could be measured by that system. As a result, polarimetric IR measurements should be repeated at least 3 times over the sandy lane, at the days when GPR measurements took place.

The measurement campaign has been scheduled for 10 working days during two weeks (including assembling and disassembling the re-locatable scanner). For each soil type (dry sand, wet sand and grass lane) 3 measurement days have been scheduled. The weekend in between the working days has been used for rising the ground water level in the sand lane and moistening the soil. Despite of the very dense measurement plan, no reserve days (for unforeseen circumstances) have been planned in the campaign. At the end of the campaign, it was found that more than 90% of the planned activities have been realized.

During the measurement campaign three different teams (one team per each sensor involved) worked simultaneously at the lanes. Coordination of activities of these teams was a crucial factor to perform the measurements within allocated time frame.

Another important issue related to simultaneous work of the different teams was electromagnetic interference, which might be caused by simultaneously operating equipment. Especially, simultaneous work of two different GPR systems with an overlapping operational bandwidth was an important issue. It has been found that due to different pulse repetition rates of both radars and due to the positioning of Pulse Ekko antennas close to the ground, the interference between these two radars was undetectable while the radars were separated at the distance of 20m. The only observed electromagnetic interference was caused by operational mobile phones, which can be easily detected just on the screen of IRCTR GPR. To prevent such kind of EMI, mobile phones have been switched off in the test area.

7. Conclusions

The joint multi-sensor measurement campaign resulted in acquisition of a unique data set of polarimetric GPR and polarimetric IR data, quasi-simultaneously measured over three different types of ground in a controlled environment. Furthermore, for GPR data three subsets of data are available: two subsets are acquired by IRCTR GPR system using two generators with different pulse durations (resulting in different operational bandwidth) and one subset acquired with commercially available Pulse Ekko GPR system. Due to its quasi-simultaneous acquisition, the data set can be used for sensor (GPR and IR) fusion and for evaluation of sensor performances. The results of this work will be reported elsewhere [8].

Controlled environment gives a very important opportunity to correlate outputs of the sensors with physical parameters of the ground (like dielectric permittivity, moisture, temperature, etc.) and buried objects. The experiment with moisture increase in the sandy lane is a unique experience, which allows physically correct investigation of the influence of the soil moisture on detectability of landmines.

Use of controlled measurement bridges provided not only precise position information, but also allowed to perform measurements on pre-defined grids. The latter considerably improves the quality of the measured data.

From the managerial point of view, the measurement campaign was extremely successful. The measurement plan has been fulfilled on more than 90% despite of very condense time schedule, unforeseen events and absence of the reserved time. Possibility of successful joint work and fruitful cooperation of three research teams (simultaneous working with different non-integrated sensors) has been demonstrated. Due to advance planning and flexibility in plan's realization, negative interference of simultaneous activities of teams was kept on negligible level.

Finally, the lessons learned during this multi-sensor measurement campaign generate important background knowledge for future multi-sensor measurement campaigns. The main lessons are:

- Instead of simultaneous IR and GPR measurements, it is possible to perform IR measurements just before or/and just after GPR measurements (see Section 6).
- To simplify allocation of the images produced by different sensors, it is advisable to put simple targets, which can be detected by all sensors, in different parts of the scanning area.
- Soil temperature, structure and moisture should be monitored during the whole measurement campaign.

Acknowledgment

The work presented in this paper is partly sponsored by the Netherlands Ministry of Defense and partly by the Dutch Technology Foundation STW, the Applied Science Division of NWO and the technology program of the Ministry of Economic Affairs of the Netherlands.

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Code	Mine type	Diameter (mm)	Height (mm)	Weight (g)	Case	Metal content
B**	AP	62	53	90	plastic	non
C**	AP	117	48	669	PVC	medium
E**	AP	62	53	86	plastic	non
F**	AP	55	42	82	ABS	low

Table 1. Description of mine simulants in the lanes.

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EUDEM2-SCOT - 2003

International Conference on Requirements and Technologies for the Detection, Removal and Neutralization of Landmines and UXO

15-18 September 2003 - Vrije Universiteit Brussel, Brussels, Belgium, Proceedings

Volume - 1

SCOT
Society for Counter Ordnance Technology