Detection of targets from radar tracks of the UWB-GPR "1Tx + 4Rx" on the mobile platform "UGO 1st"

Luca Bossi, Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Firenze, 50139, Italy
Pierluigi Falorni, Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Firenze, 50139, Italy
Gennadiy Pochanin, IRE NASU (O.Ya.Usikov Institute for Radiophysics and Electronics of NAS of Ukraine), Kharkiv, 61085, Ukraine
Vadym Ruban, IRE NASU (O.Ya.Usikov Institute for Radiophysics and Electronics of NAS of Ukraine), Kharkiv, 61085, Ukraine
Tetiana Ogurtsova, IRE NASU (O.Ya.Usikov Institute for Radiophysics and Electronics of NAS of Ukraine), Kharkiv, 61085, Ukraine
Fronefield Crawford, Depts. of Earth & Environment and Physics & Astronomy Franklin & Marshall College Lancaster, USA
Timothy Bechtel, Depts. of Earth & Environment and Physics & Astronomy Franklin & Marshall College Lancaster, USA
Lorenzo Capineri, Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Firenze, 50139, Italy

Summary
In humanitarian demining, it is of primary importance to ensure personnel safety while minimizing search and detection times [1]. Furthermore, traditional detection techniques based on electromagnetic induction are primarily manual and thus are not easily adapted to an automated detection system. In this article, we show a specially-designed UWB-GPR radar and a dedicated algorithm able to analyze radar data and automatically detect the position of landmines buried in soil at shallow depth [2]. We compare the automated detection capability to that of experienced humans visually analyzing radar data.

Introduction
The UWB "1Tx + 4Rx" radar mounted on the "UGO 1st" robotic platform (developed within NATO project G-5014) [3] [4], was used to record tracks or B-Scans during the movement of the cart along a lane in the landmine test field at the faculty of engineering of the University of Florence (Italy). The GPR "1Tx + 4Rx" radar transmits UWB short pulses of about 2 GHz bandwidth and center frequency [5] and reflections are recorded by four separate receivers (Figure 1), allowing automated processing to obtain all 3 Cartesian coordinates of a detected object. The main idea is to use it in real-time however at this stage we checked the reliability of the developed algorithm using radar data previously acquired by the GPR.
The use of an automatic detection algorithm installed in the GPR on the robotic platform allows more reliable detection, making field detection operations faster, more efficient and safer for the operators. To verify the reliability of the automatic detection algorithm, we conducted an experiment in the garden of the School of Engineering of the University of Florence.

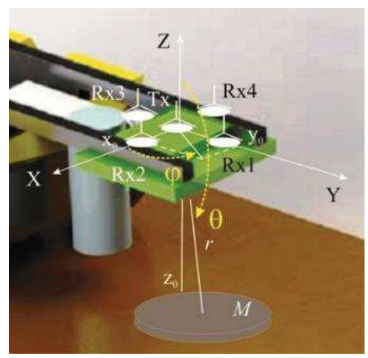


Figure 1. Schematic representation of the UWB GPR "1Tx + 4Rx" antenna system.

We set up a lane with three anti-personnel mine simulants (Figure 2). The simulants were buried over six months before the experiment in order to allow the soil to equilibrate around them. All three mine simulants were covered by approximately 3 cm of soil. After the acquisition, the automatic detection algorithm was applied, and the results are shown. For comparison, another test field with different, smaller devices was exploited: the test field set up at the European Commission's Joint Research Center (JRC) at Ispra (Varese province, Italy) [6]. The results obtained are shown and compared with the previous ones.

Automatic Detection Algorithm description

The automatic detection algorithm is described in a previous paper [7]; it includes the following steps:

1. Subtraction of background signals due to direct coupling, cart reflections and air-soil interface.

2. Calculation of the TOFs of the sounding signal from the Tx antenna to the subsurface object and back to each of the 4 Rx antennas by using the Pearson's correlation algorithm.
3. Obtained TOFs allow calculation of all 3 Cartesian coordinates of the detected objects [2, 5] in the reference system integral with the antenna system (Figure 1).
4. Spatial filtering [8] selects coordinates compatible with subsurface objects, excluding phantom positions appearing at the previous step.

After detection, the GPR generates the "ALARM" signal and sends it along with calculated coordinates to the Robotic Operating System (ROS) controlling the system to stop it and initiate scanning with holographic radar.

Experiment description
The UWB "1TX + 4 RX" GPR was mounted on the "Ugo 1st" robotic platform and connected wirelessly with the dedicated software for acquisition of B-Scans. The first experiment was conducted on a lane created in the garden of the University of Florence. This soil is mainly clayey and contains many clutter elements such as stones, metal particles and roots. There are three target objects: a 10 cm diameter metal box, a PMN4 type mine simulant and a PMN1 type mine simulant. The objects are arranged as in Figure 2 and the lane measures 4 m in length.
Environment conditions:

- Weather: cloudy
- Wind: slight
- Temperature: 24°C

The simulants are arranged at about 1 m from each other. The lane has characteristics of uneven dry ground with presence of sparse leaves. For this study, the track recording takes place without interruption, with the robot moving at constant speed under remote control and using dedicated radar software. The results are described below.

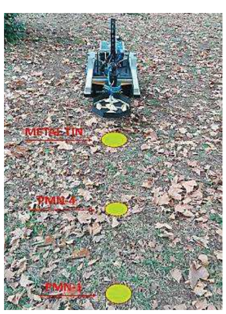


Figure 2. Lane setup of the test field at University of Florence in the garden of School of Engineering.

The second experiment was conducted in a terrain with similar characteristics but without clutter and with smaller anti-personnel mine simulants and in similar environmental conditions. In this way we could check the reliability of the algorithm even in slightly more difficult conditions (smaller targets).
This second experiment was conducted at the test site of the JRC (Figure 3).

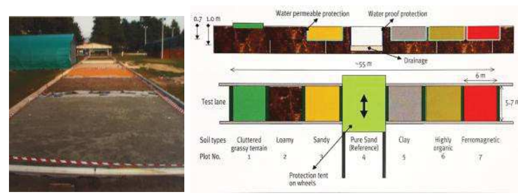


Figure 3. (Left) Test field at JRC. (Right) Configuration of entire test lane with different soils scenarios (courtesy of [6]).

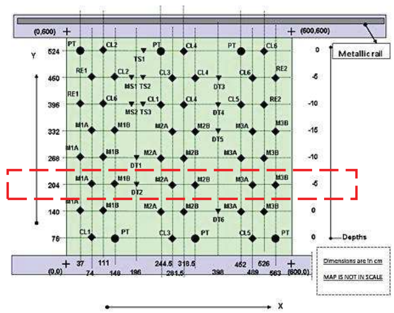
The test field is located at the JRC Outdoor Test Facility [6], a flat grassy area with excellent drainage capacity (Figure 5). The test lane is formed by a strip of ground separated from the surrounding terrain by two concrete walls of about 50 cm in width and 70 cm in depth. The use of steel reinforcement in the walls was avoided to minimize a potential interference on the measurements. The complete test lane measure about 55 m and contains seven soil scenarios. For the test we use the scenario number 2 (Loamy) - Figure 3.

Figure 5. Robot "Ugo 1st" on landmine testfield at JRC – Ispra. The wooden arrows placed on the soil indicates the targets positions.

The test field environment is characterized by these conditions:

- Atmospheric moisture: 54%
- Soil moisture: 8.4%
- Temperature environment: 29 °C

The chosen lane has characteristically uneven relief. The targets have been buried for five years, the vegetation is compatible with flat ground in mid-September (grass of about 10 cm height) and the composition of the soil is loamy. Several anti-personnel mine simulants are buried in the ground at a depth of 5 cm there, as shown on the map in Figure 5. Track recording takes place without interruption, remote controlling the robot at constant speed with dedicated radar software. At the beginning and at the end of the lane there are two concrete sleepers buried in the ground which are included in the scan for their characteristic reflected signal that can be used as references for the beginning and end of the lane.



Legend

M1A Low metal surrogate 50 mm ,Ø **M1B** medium metal surrogate 50 mm Ø
M2A Low metal surrogate 80 mm Ø, **M2B** medium metal surrogate 80 mm Ø
M3A Low metal surrogate 110 mm Ø, M3B medium metal surrogate 110 mm Ø
PT positioning target, RE1 calibration sphere, RE2 calibration block/sphere
CL1 stone, **CL2** barbed wire, **CL3** drink can, **CL4**, plastic box, **CL5** wooden cylinder, **CL6** spent cartridge
TS Temperature sensor, **MS TRIME** Moisture sensor, **DT Delta T** Moisture sensor (NOTE DT6 is at 5cm depth)

Figure 5. Targets position in the area. Red dashed line indicate the lane traveled by robot (for courtesy of [6]).

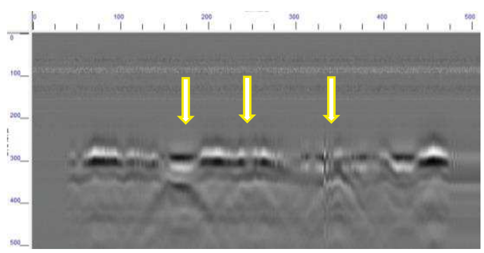


Figure 6. Radar track recording (B-SCAN of channel one of four recordered at JRC).

Four tracks are recorded simultaneously, one for each receiving antenna (Figure 6) and are processed through the automatic detection algorithm. The results are described below. To highlight the difficulty in the detection, four international teams from the NATO SPS project mentioned above were also asked to try to detect the position of the devices based on the visual analysis of the radar tracks (B-SCAN). The results of this experiment are also shown, confirming the difficulty in identifying small buried plastic objects based solely on visually examining the radar records.

Results

The application of the detection algorithm at the lane in the University garden (Figure 2) is shown in Figure 7. The detection algorithm is developed as a web application that allows selection of parameters for the optimization of the detection as a function of the environment and terrain conditions. In Figure 7, the horizontal scale shows the position of the GPR as the signal ordinal number (it is similar to usual B-scan in time lapse mode). The vertical coordinate means the Y coordinate of the detected position for the reference system (Figure 1). Detected objects are marked by color points. Every point represents a detection. Colors indicate the height of the center of the antenna system over the detected object (Z coordinates).

There are three chains of colored points. Each chain means that, while the cart moves, the Y coordinate of the detected object changes. For the first object, the metal tin, Y coordinate spread from +12.5 cm (signal #162) to -14 cm (signal #190) while the height of the antenna system is between 30 cm and 35 cm. Thus, the metal tin is reliably detectable in the route of sounding. For the mine simulants, the ranges along Y direction at which we got reliable detection are a bit less (13.8 cm and 14.5 cm, respectively). There are no false alarms in the results of this experiment due to the well-matched parameters of data processing.

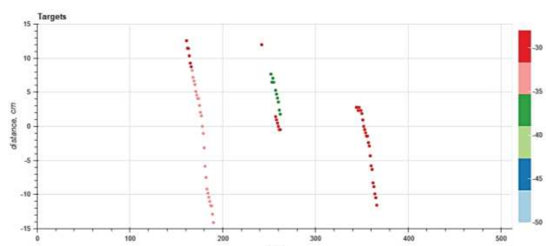


Figure 7. Results of application of the automatic detection algorithm in the garden of School of Engineer of University of Florence.

Below are the results of the test at the Joint Research Centre of the European Commission – Figure 8; In this case, GPR detected several objects but only seven of them are characterized by a chain of marks which we expect to see as reflections from an extended object. With the hypothesis that the chains of marks at steps 90 and 820 are due to the edges of the testbed, we suppose that not all objects are detected. Other positions are characterized by fewer numbers of points and cannot be reliably interpreted as detected objects. Furthermore, there is a high number of false alarms.

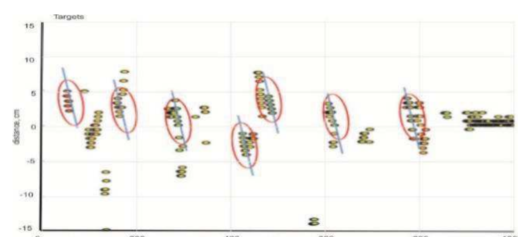


Figure 8. Results of test at Joint Research Centre of European Commission.

Table 1. Probability of Detection (PD) / Probability of False Alarm (FA).

	CH1 [%]	CH2 [%]	CH3 [%]	CH4 [%]
Unifi Operator #1	16.7 83.3	16.7/ 66.7	50/ 33.3	33.3/ 83.3
Unifi Operator #2	16.7/ 83.3	33.3/ 66.7	16.7/ 83.3	16.7/ 66.7
F&M Operator #3	16.7/ 83.3	16.7/ ND	0/ ND	16.7/ ND
Usikov Operator #4	16.7/ 83.3	ND/ ND	ND/ ND	ND/ ND

Table 1 show the results of the tests carried out by sending a recorded track of channel 1 (see Figure 6) to people trained to interpret this type of radargram for the identification of buried objects. These persons were unaware of the number and position of buried simulants, they were asked to identify their position on the diagram – see Figure 9 for an example of this procedure. The table shows the probability of correct detection and the probability of false alarms.

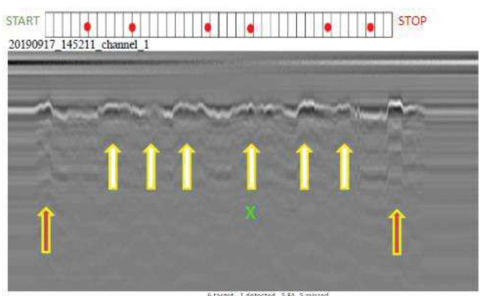


Figure 9. Example of manual analysis of B-SCAN track to identify the potential targets. Red dots are the correct positions of real targets (that operator didn't know) and the yellow arrows are the presume detected for the operator. The green cross, in this case is the only correct detection.

Conclusions

In order to verify the reliability of the proposed automatic anti-personnel mine detection algorithm, two experiments were conducted at different sites. The first test, carried out in the garden of the School of Engineering of the University of Florence, provided a correct automatic detection of three out of three buried objects. The algorithm also calculated the correct buried object position and antenna height from the ground surface. A similar experiment was conducted on the test field of the Joint Research Centre of the European Commission. The data collected with this second experiment are more critical. The target detection done by the research group member with a blind test, did not provide a high detection rate with respect to false alarms (see Table 1). The application of the automatic detection algorithm also confirmed the difficulty of detection. This result is partially justifiable with the different nature of the soils of the two experiments and by size and depth of the mines. In the test field at JRC the plastic land mine simulant was deeper and smaller than the targets in the first experiment. Other elements may have contributed to differentiate the quality of the radar trace and the consequent degradation of the algorithm's performance and suggests further investigations both of the adopted physical model and also the revision of the signal processing to account for different characteristics of the soil.

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