Automatic Detection of Subsurface Objects with the Impulse GPR of the UGO-1st Robotic Platform

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***Abstract*—This paper discusses a technique for automatic detection of subsurface objects using the impulse UWB radar of the "UGO-1st" robotic platform. The method is programmed as a Web application with capabilities for flexible adjustment of data processing parameters by the user. It provides reliable detection without false alarms and with correct calculation of coordinates for shallow buried subsurface objects.**

***Keywords*—GPR, automatic detection, web application, data processing, subsurface object detection.**

I. INTRODUCTION

Despite the perfect understanding of the deadly danger of minefields, different kinds of new mines are appearing in recent years. An especially dangerous type is minimum-metal plastic mines. While a mine with metal casing can be readily detected with a metal detector, the plastic-cased mine may be undetectable by most of the well-developed methods.

Furthermore, plastic cases are not subject to corrosion. This means that such mines can stay in the ground for a long time and remain dangerous.

Therefore, mine clearance is a large and persistent problem. According to recent estimates, during only five years of war in Donbas (Ukraine), 700,000 hectares of land have been turned into minefields [1]. And other minefields all over the world making large territories useless for living and working.

The demining of such large areas requires new approaches, which must be safe for sappers, and productive (with high detection probability, and low false alarms).

In the last decade, new approaches are developing based on combining sensors of different types. Each sensor reacts to a particular physical property of the mines, and the combination of properties may produce a signature that allows not just detection, but recognition of the type of mine.

II. ROBOTIC PLATFORM UGO-1ST

In the framework of the Project #G5014- "Holographic and Impulse Subsurface Radar for Landmine and IED Detection" [2] of the NATO Science for Peace and Security (SPS) Program a multi-sensor robotic platform for humanitarian demining, called "UGO-1st" (Fig. 1) has been developed. This system includes an impulse ground penetrating radar 1 (GPR) developed at the O.Ya. Usikov IRE NASU, holographic subsurface radar 2 (HSR) and Infrared camera 3, and other auxiliary equipment. According to the project task, the platform is designed for research purposes and testing proposed mine detection methods.

"UGO-1st" is assembled on the Jackal robot platform [3].

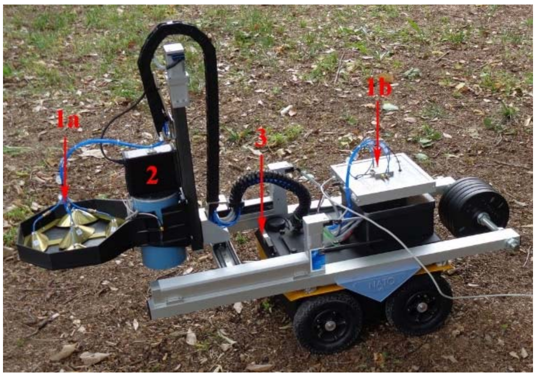


Fig. 1. The "UGO-1st" robotic platform

Impulse GPR is used for rapid detection and coordinate determination for subsurface inhomogeneities in the electrical parameters of soil (i.e., targets or suspicious objects) [4], [6]. After the coordinates of the suspicious object have been determined, the holographic radar starts its sounding. It scans the area where the suspicious object is located. The result of this scanning is a 3D image of the object. The obtained image allows the operator to decide whether the object is a mine and, if so, what possible type. The infrared camera provides additional information about the soil surface condition and the presence of obstacles, tripwires, and other environmental conditions.

The robotic platform can be operated remotely, making demining operations safer for sappers. It does not need time for rest, and the use of approaches of Industry 4.0 allows applying powerful remote computers and experts for mine recognition and classification.

The impulse GPR of UGO-1st consists of the:

1. Antenna system with four receiving antennas located at the corners of the square and one transmitting antenna in the center (located at the intersection of the diagonals of the square).

2. System unit with a pulse generator, receiver, synchronization unit, and a control unit.

The first step of the UGO-1st action is the detection and determination of coordinates for a subsurface object within the lane of investigation. As we consider distant control by UGO-1st, the detection should be done automatically without operator intervention. For this purpose, algorithms for determining the coordinates of objects using the times-of-flight (TOF) of reflected signals [4] and algorithms for the selection of real objects based on the sets of registered positions have been developed [6]. The aim of the paper is to show the technique for automatic detection and positioning of subsurface objects with the impulse GPR of the UGO-1st robotic platform.

For this purpose, we developed a web application "Target Detector", allowing investigation of the reliability of the algorithm and dependence of detection/positioning results on parameters of data processing.

III. Radar Method for the Determination of Coordinates of Shallow Buried Subsurface Objects

To calculate coordinates of objects in soil, TOFs of electromagnetic impulses from the transmitter to the object and back to the receiver are used. For this purpose, it is necessary to know the precise time of radiation of the sounding signal and the time of arrival of the reflected signal at the receiver. Since, along with the "useful" signal, the receiver detects other "interference" noise that overlap the signal and distort its shape, the probability of detection of objects decreases, and in the best case, the error in determining their coordinates increases.

In order to determine the TOFs accurately, it is necessary to extract the reflected signal from interfering noise. To do this, we consider in more detail the radiophysical phenomena that occur in the process of the pulsed sounding of subsurface objects.

The scenario shown schematically in Fig.2 is as follows: The transmitting antenna of the impulse GPR (T) radiates an electromagnetic (EM) pulse that propagates in the soil surface (S) direction. Part of its energy (1) is reflected by the surface and comes back to the receiving antennas (R). Another part (2) penetrates the medium, and part of this field (3) is reflected (scattered) from the object (O). Part of the EM field energy (4) passes through the media boundary and goes to the receiving antennas to be recorded by the GPR receivers. The part of the EM field that came directly from the transmitter (5) (direct coupling) and the part of the field reflected from the platform structure (6) are also recorded. Parts (5) and (6) make a strong "background clutter" for detecting a useful signal and must be filtered out during processing. To do this, a background removal procedure is performed.

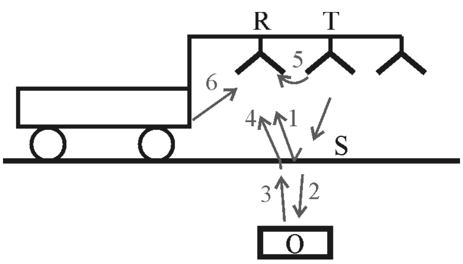


Fig. 2. Paths of EM fields propagation at the impulse subsurface sounding

The signal (1), which is a reflection from the surface, also should be filtered. Unlike the static parts (5) and (6), which do not change or change slightly with time, reflection (1) depends on the property of the soil, distance to the surface (due to vibrations, inclination, changes in the tilt of the antennas while the platform is moving on an uneven surface). Commonly used simple subtracting of averaged signal does not help here.

In the beginning, it is necessary to record "reference" data at the test site at the place where there are definitely no subsurface objects. Then it can be used with additional scaling procedures for processing and data filtering.

IV. Algorithms and Procedures for Automatic Detection

The received data processing flows according to the following algorithm (Fig.3).

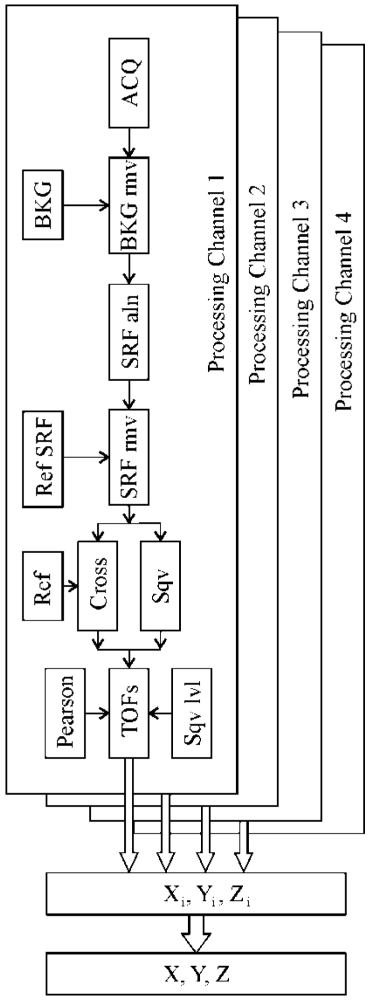


Fig. 3. The data processing algorithm

The algorithm includes:

1. Data acquisition (ACQ);
2. Direct coupling removal (BKG rmv);
3. Signal alignment and scaling by reference reflection from the surface (SRF aln);
4. Reflection from the surface removal (SRF rmv);

5. Calculation of the Pearson coefficients (Cross) for the reference signal (Ref);
6. Calculation of energetic coefficients (Sqv);
7. Selecting of TOFs by the levels of Pearson coefficients (Pearson) [4], [6] and levels of energetic coefficients (Sqv lvl);
8. Calculation of probable object coordinates;
9. Checking the probable object coordinates at the next sounding steps and filtering the coordinates of targets from them.

We used reflection from a metal disc of 10-cm diameter as the reference signal for Pearson correlation. Also, we define the energy coefficient as:

$$Sqv(t) = \frac{1}{E}\int_{0}^{\Delta} u^2(t+\tau)d\tau \ ,$$

where $\boldsymbol{E}$ is the energy of reference signal, Δ is a size of time window in which energy is collected, u is an acquired signal.

The developed web application allows the user

- to download the collected data as sdf files,
- to analyze collected and process data in both B-Scan and A-Scan format,
- to adjust the threshold values of the Pearson coefficients and energetic coefficients,
- to get the coordinates of probable objects in accordance with the settings.

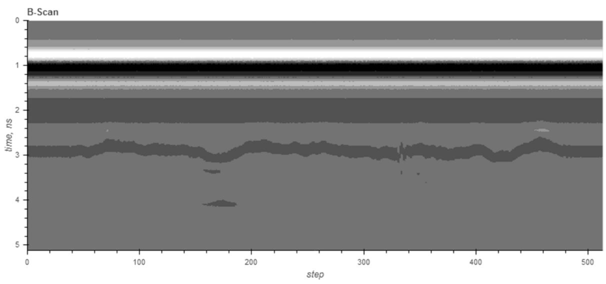
For example, consider the data collected at the test area in the garden of the University of Florence. The GPR data were taken over a 2.6 m long section with buried objects (Fig.4).

a)

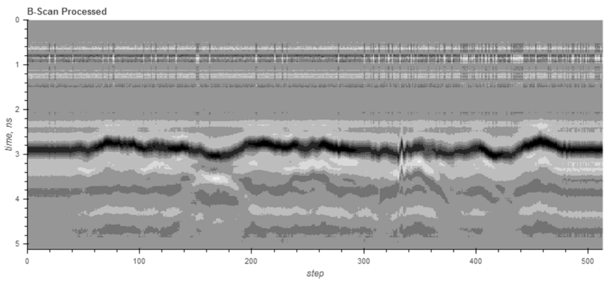
b)

c)

Fig. 4. Buried objects. a) metal tin, b) a simulant of a PMN-4, c) simulant of a PMN-1



a)



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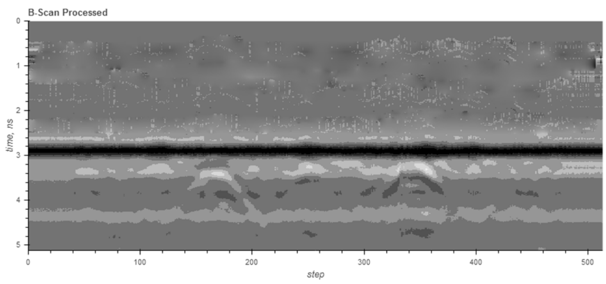

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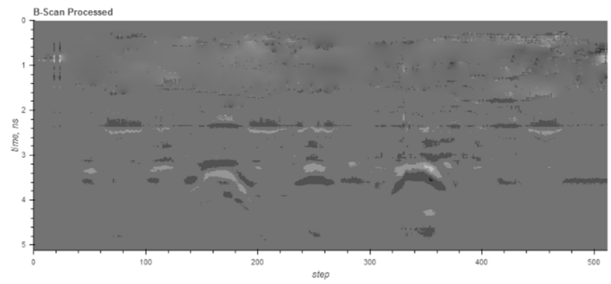
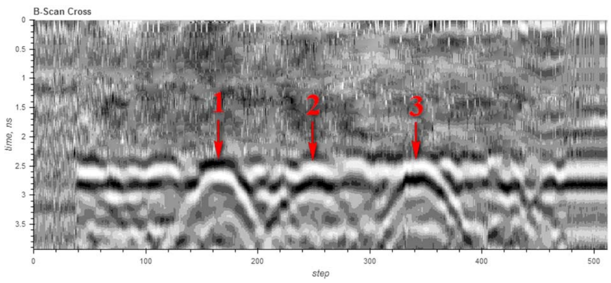
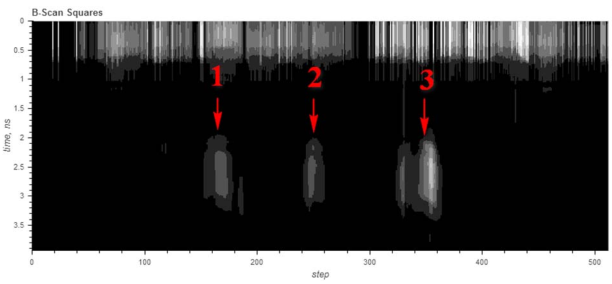


d)

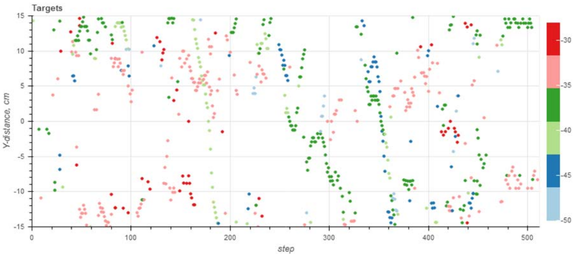


e)

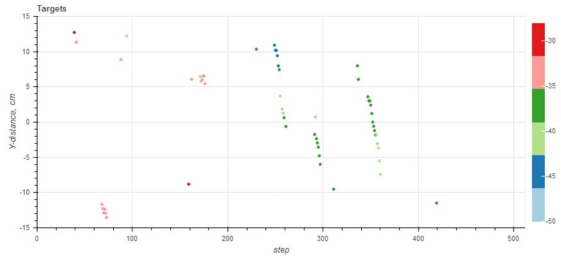


f)

Fig. 5. B-scans examples steps of the data processing. a) raw data, b) background is removed, c) aligned soil surface, d) removed soil surface, e) cross-correlation, f) energetic coefficient.



a)



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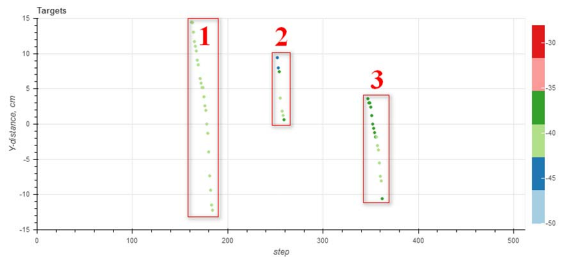

c)

Fig. 6. Object selection and positioning

Fig.5 shows B-Scans of the channel-1 at processing steps. Raw GPR data have strong background signals masking reflection from objects in the bottom half of the B-scan a). After background removal b) reflection becomes a bit better visible, but hyperbolic patterns are masked by reflections from the soil surface (dark horizontal winding line in the middle of the B-scan. It is conditioned by an inclination of the GPR antenna system and moving it up and down at the scanning process during data acquisition. After aligning reflections from the surface Fig.5c, the line from winding becomes straight, and hyperbolic patterns become of correct shapes. Subtraction of reflections by surface gives us B-scan (Fig.5d), where reflections from objects are the most contras. In these conditions, the detection of reflections along the B-scan by using Pearson's correlation algorithm becomes very simple (Fig.5e). In order to be sure that Pearson's correlation provided detection of the real signal is used additional criterion energetic coefficient showing the presence of reflecting energy in the signal (A-scan). It is conditioned by the disadvantage of Pearson's correlation. Sometimes, the correlation coefficient may be significant because the algorithm finds a signal of necessary form in the noise. Selection signals, according to the energetic threshold, allow eliminating phantoms. Fig.5f gives information about the existence (or absence) of the energy of reflections in the B-scan.

The arrows in Fig.5e and f indicate the scans obtained when approaching objects.

For a visual representation of detected objects a map of the Y-coordinates of objects at each sounding step is used. According to the technique described in [5], [6], the origin of the reference system coordinate is in the center of the transmitting antenna. When the platform moves, this coordinate decreases uniformly [4], [5], [6]. This characteristic is used in our application.

Fig.6a shows the Y-coordinates of probable object positions corresponding to a low threshold Pearson coefficient (equal to 0.1) and an energy coefficient (equal to 0.01). It can be seen that at such thresholds, the application shows a lot of spurious positions of detected objects.

Fig.6b shows the effect of the spatial filter on the positions detected in Fig.6a. Although the spatial filter [6] removes some of the marks, the detected objects' positions still remain overloaded by false marks (false alarms). An increase in the threshold of Pearson's coefficient to 0.3 and the energy coefficient to 0.05, together with the use of a spatial filter, gives good results.

Fig.6c shows the Y-coordinates of the three detected objects and an absence of false alarms. The first set of marks (1) shows the Y-coordinates of the detected object obtained asUGO-1st approaches the metal tin. The second set (2) shows the Y-coordinates of PMN-4 as the robot gets closer, and the third shows the approach to the PMN-1.

V. Conclusions

This paper analyzes the technique of automatic detection of subsurface objects using the impulse radar on the "UGO-1st" robotic platform. The steps of the detection algorithm are described. It is shown that special attention should be paid to the TOF calculation and selection of appropriate Pearson's and energetic coefficients. To test the method, we developed the web application "Target Detector", which provides visualization of the detection and positioning for subsurface objects and allows for optimization of the data processing procedures.

Acknowledgment

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