Demining Robots: Overview and Mission Strategy for Landmine Identification in the Field

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***Abstract*—We present an overview of a system under development, with NATO funding, wherein a team of robots uses multiple sensors to identify and characterize buried landmines or other explosive threats. Two of these sensors are ground penetrating radars (GPRs). One is an ultra-wideband impulse radar and the other is a continuous wave holographic subsurface imaging radar. In an earlier phase of the project, these sensors were successfully tested using a prototype robot on which both GPRs were mounted. The separate robots are connected via a central unit with shared data and communication. We describe the planned strategy using these two key sensors and others to automatically navigate and efficiently survey a minefield. With this novel approach, and with tripwire detection enabled on the first robot, the complex task of threat detection will be automatic and rendered completely safe for the operator. The risk of unexpected blasts from undetected tripwires or triggered pressure plates will also be mitigated.**

***Index Terms*—landmine, ground penetrating radar, holographic radar,demining, detection, humanitarian demining, cooperative robots**

I. Introduction and Motivation

The identification and removal of landmines is a critical humanitarian task that can leverage technology such as ground penetrating radars (GPRs) and other sensors to increase efficiency in the demining process, decrease the demining cost, and prevent demining casualties.

According to the latest Landmine Monitor report[1], in 2019 there were an estimated 60 states and other areas with buried landmines and other ordnance, and more than 5500 landmine casualties were reported that year. Roughly 80% of these casualties were civilians, of which 43% were children. 2019 was the fifth year in a row with high numbers of landmine casualties.

GPRs have been used in various contexts for landmine identification (see [1] for a review). We are developing a landmine identification system based upon GPRs and auxiliary instruments in order to reliably and quickly detect buried mines and discriminate them from ubiquitous conflict zone clutter. Our specific application is in the Donbass conflict region of eastern Ukraine which has experienced recent landmine contamination, but the methods can be applied in other countries affected by the landmine problem.

Goals of this project include producing inexpensive components for the system and using a shared database of sensor data to make decisions on whether detected objects are likely to be landmines or clutter. This builds upon Industry 4.0 concepts [2] [3] and will ultimately make our system easily reproducible and relatively inexpensive.

II. The UGO 1st Prototype

A prototype robotic system was developed as part of NATO Science for Peace and Security Programme project G5014.[2] The primary sensors in this system were two GPRs, an ultra-wideband impulse radar [4] [5] and a continuous wave holographic subsurface radar (HSR) [6]. Both GPRs were mounted on an adaption of a commercial platform, the Jackal unmanned ground vehicle, available from Clearpath Robotics.[3]. We are

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[1] http://www.the-monitor.org

[2] http://www.nato-sfps-landmines.eu

[3] https://clearpathrobotics.com

using this same Jackal platform for the expanded development described below.

This prototype system, dubbed UGO 1st, was successfully demonstrated to NATO at the Advanced Workshop on Explosives Detection in Oct 2018 in a test field with buried landmine simulants [7]. Fig. 1 shows this prototype with the impulse GPR, HSR, and auxiliary sensors and instruments indicated. See [8] for a review and summary of the UGO 1st prototype system.

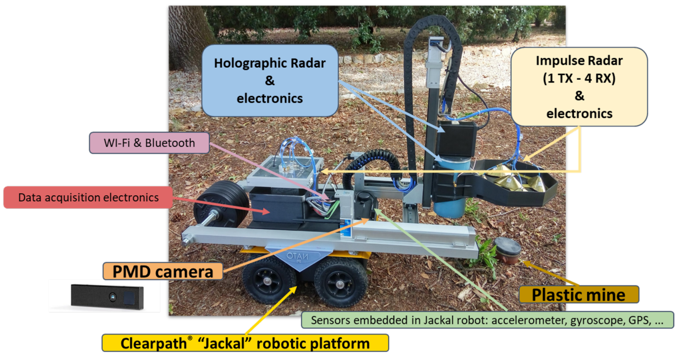

Fig. 1. The UGO 1st prototype robot from NATO SPS project G5014.

III. Demining Robots Expanded Concept and Mission Strategy

The NATO Science for Peace and Security Programme has funded a continuation of this project (now G5731), titled *Multi-sensor Cooperative Robots for Shallow Buried Explosive Threat Detection*, or *Demining Robots* for short.[4] This expands upon the UGO 1st concept to develop multiple robots carrying more sensors. This team of three robots (UGO 1st through UGO 3rd) will act in concert to inspect a minefield and will send sensor data from each robot to a central unit with a common shared database.

Fig. 2 shows a schematic of the three robots with the different sensors on each. The two GPRs are now mounted on separate robots, and a metal detector (MD) has been added to a third robot as an auxiliary sensor. The three robots are referred to as (1) the GPR robot, (2) the MD robot, and (3) the HSR robot. Each robot has high precision position and heading accuracy which allows the target under investigation to be sequentially re-occupied with high precision.

The GPS antenna is at the center of each robotic platform. Thus, the coordinates of the Jackal are coordinates determined for the center of the platform. However, as seen in Fig. 3, which uses the first GPR robot as an example, the coordinates of the target are in the reference system $X0Y$, which is offset from the center of the robotic platform. In order to obtain the object coordinates in the absolute (GPS) coordinate system, we must measure the angle α between the GPR offset direction and the GPS-determined North direction, and we must know the precise distance between the GPS and the origin of the

[4]http://www.natospsdeminingrobots.com/

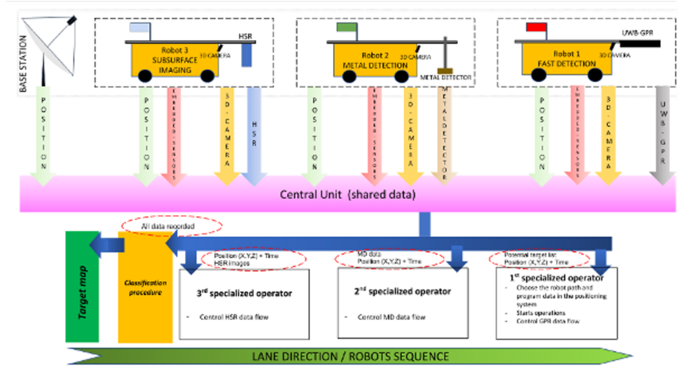

Fig. 2. Schematic of the three-robot configuration showing individual sensors and components and the central unit used for communication and storage. The robots are sequenced 1, 2, 3 going from right to left in the figure.

$X0Y$ coordinate system (the orange arrow in Fig. 3.). This same concept applies to the MD and HSR robots, which also have instruments that are offset from the GPS.

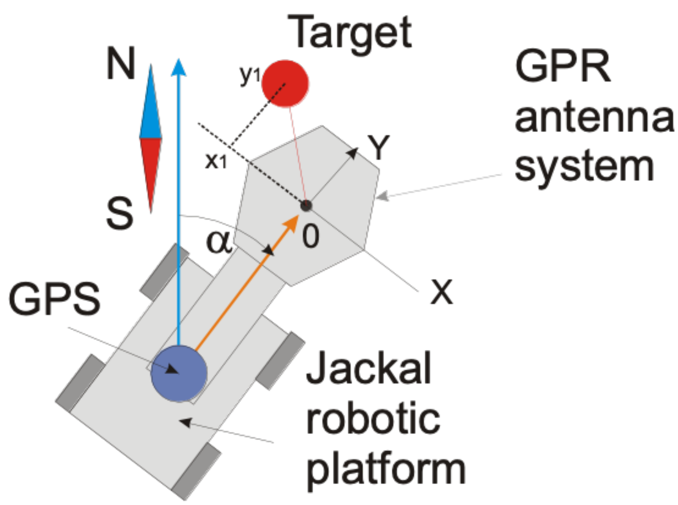

Fig. 3. The jackal platform with the ultra-wideband impulse GPR mounted in front of the robot. Heading information (angle α) and the position offset between the GPR and GPS (located at the center of the platform) are used to determine the position of the buried target in GPS coordinates.

In addition, we plan to implement real-time tripwire detection on the first robot to avoid accidental destruction in a real minefield. We have investigated the feasibility of tripwire detection in hyperspectral images, and our success has been reported in [9].

In our mission strategy, the three robots move sequentially through the field along a pre-defined "Greek line" path. This motion is automated and navigation is programmed in advance using GPS waypoints (WPs) to which each robot has access. Fig 4 illustrates the concept. The three robots are parked next to the field. WPs in the field are defined as GPS coordinates, and the robots visit these WPs sequentially. After the last WP is reached, the robot returns the the parking area. This is detailed further below.

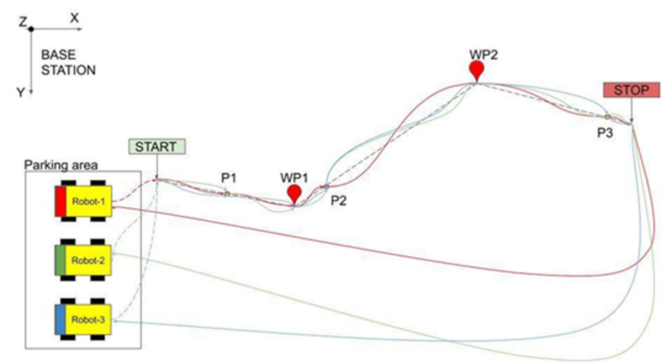

Fig. 4. Illustration of the configuration prior to field investigation. Three robots sequentially follow GPS-defined WPs, with each robot having different sensors mounted.

For the survey, we first mark the area to be investigated in the field and in the software (for example, in Fig. 5 this would be the four flags indicated in red at the corners of the rectangular box). Into this area we put all of the WPs (blue circles in Fig. 5) which define the trajectory that covers the survey area. We implement a Greek line trajectory that is characterized by (1) $2N$ WPs where N is the number of lines (for example, the blue lines shown in Fig. 5), and (2) a length and width of the rectangular field. The lane width is then calculated from these numbers and lies in the range 0.3 to 0.5 m, the width within which objects can be reliably detected with our sensors (as reported in [10]). An additional WP is defined as both the starting and ending position for the robot (note that this WP is not in the Greek line configuration). This WP could be a spot in the parking zone, for example, where the robots reside when not actively probing the field.

The first (GPR) robot proceeds along the trajectory defined by the WPs, (the blue path in Fig. 5). During movement, the GPR detects objects (red stars in Fig. 5). For example, it would detect $n = 1 \ldots N$ objects with coordinates $(x_n,\, y_n)$. These coordinates are sent to the central unit along with the angle α relative to North as shown in Fig. 3. Note that each sensor will send additional information to the central unit as well.

Detection of objects by the first GPR in real time is not strictly necessary since the second robot can follow anytime after the first robot finishes. This flexibility allows us to use the set of collected data from the first GPR robot to create B-scans of buried objects along the path. A Hough transform can be applied to the hyperbolic patterns in the B-scans (see [11] for details), and together with local position information, we can create a log of objects for further investigation with the HSR radar (on robot 3).

At a later time (after the first GPR robot has finished its mission), the second robot with the MD is sent along the same trajectory as the first robot. Following this same trajectory is convenient since all WPs are already defined. Note that if the width of the lane of detection for the MD is different from that of the GPR, we can set other WPs specifically for the second MD robot. During its movement, the MD robot detects objects (illustrated by green stars in Fig. 5). For example, it would detect $m = 1 \ldots M$ objects with coordinates $(x_m,\, y_m)$. These coordinates are sent to the central unit along with the heading angle (and with raw and aggregated data for later use), just as was the case for the first (impulse GPR) robot.

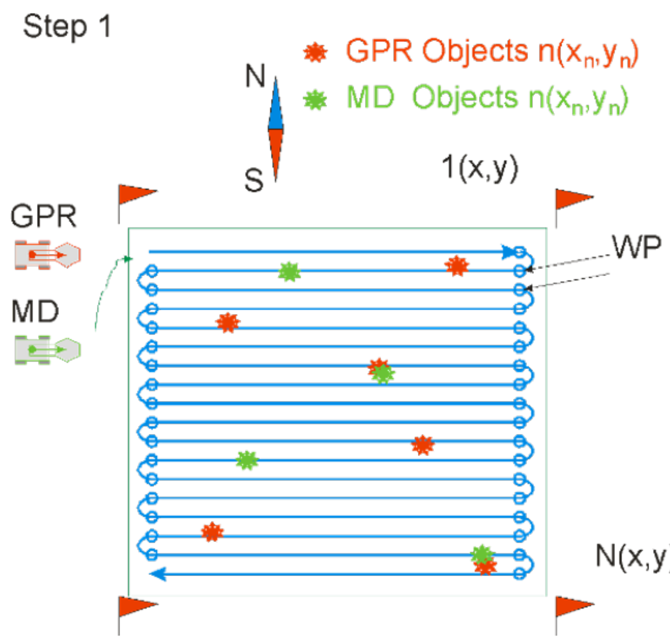

Fig. 5. Greek line trajectory followed by the first two robots for complete rectangular field coverage. The first robot has a mounted impulse GPR (red) and the second robot has a mounted MD (green). The objects identified in the field by each of these sensors are indicated by the same colors as the robots.

After the MD robot has completed its scan, there will be two sets of coordinates with auxiliary information for each. Specifically, there will be one set of coordinates and angles from the first GPR robot and one set from the MD robot. All sensors also send data to the central unit, such as GPR elaborated information from the values measured and the raw data that was used to make detections.

For the next step, we rotate the Greek line pattern by 90 degrees with new WPs (see Fig. 6) and survey the field again using the first two robots (impulse GPR and MD). This can reveal buried objects that were not detected in the first pass. A detection occurring in only the second pass might result from irradiation of the object by the GPR or MD from another angle (owing to the different approach angle to the object) and from other signal reflections. After this second pass has finished, any additional detected objects are added to the list of identified targets (with coordinates and auxiliary information). This information is sent to the central unit and saved there.

In the final step, all of the detected object positions from the first two robots become the set of WPs for the third (HSR) robot (Fig. 7). This robot then takes an an optimized route through the field using these WPs and scans the identified objects to produce high-resolution plan-view images. This trajectory is shown in Fig. 7. Note that the third robot takes the longest amount of time to investigate each object since

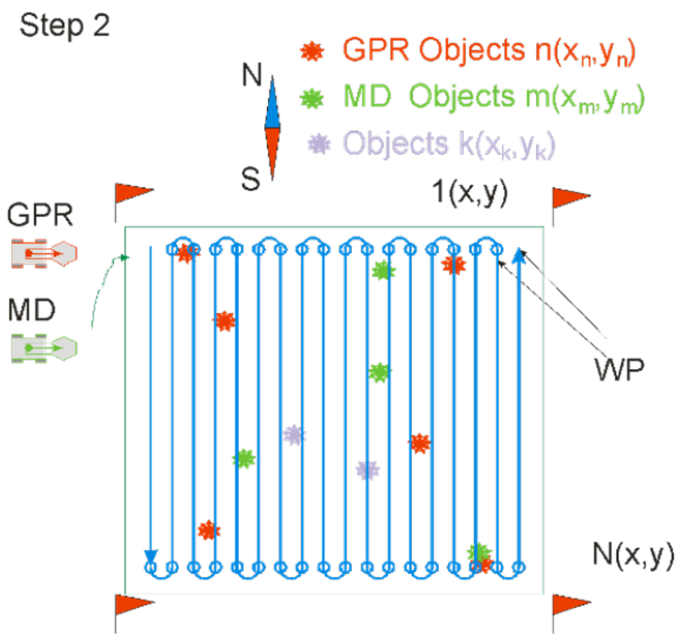

Fig. 6. Greek line configuration for the second pass of the first two robots through the field. The Greek lines are now rotated 90 degrees from the original configuration, and a new set of WPs has been defined. Color coding is the same as in Fig. 5.

it uses an electromechanical scanner to produce a hologram of the target, which takes a few minutes per object. Thus the optimized path is important for this third robot to use.

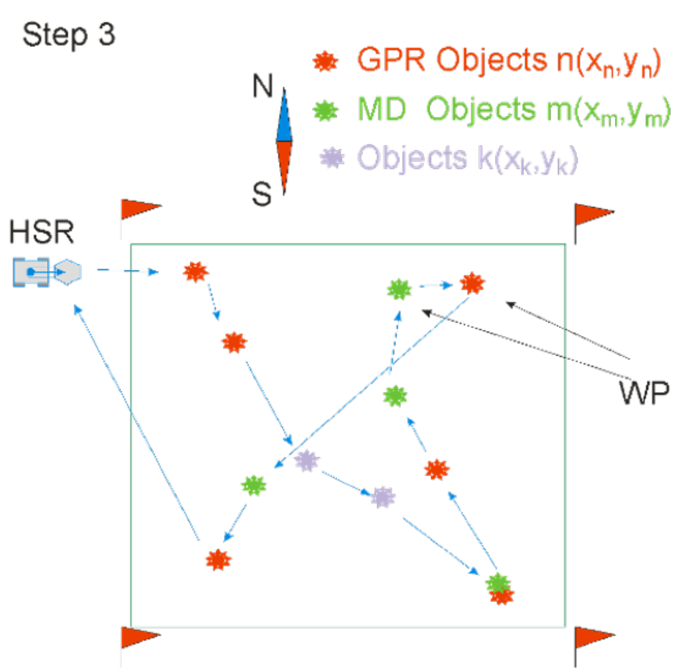

Fig. 7. Trajectory of the third robot with a HSR radar mounted on the robot. The robot uses the set of target positions identified by the GPR and MD robots as GPS-defined WPs for its path.

After the data have been collected by the various sensors on the three robots and saved in the central database, fusion of the information can then be performed in order to determine whether a buried object is likely to be a landmine or clutter.

IV. Summary

Using our UGO 1st sensor platform as a prototype, we are developing an expanded multisensor system that uses two different GPRs as key sensors along with several auxiliary sensors for buried landmine detection. The system employs three robots that move sequentially through a minefield in an automated fashion using GPS positioning to collect data on buried objects. These data are used to determine if a buried object is a landmine or harmless clutter. We are implementing tripwire detection for the first robot to avoid destruction in the field. With this novel approach, the complex task of threat detection will be automatic and rendered completely safe for the operator. The risk of destroying the robot from unexpected blasts from undetected tripwires or triggered pressure plates from the weight of the instrument will also be mitigated.

Acknowledgment

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