

HUMANITARIAN DEMINING ROBOT GRYPHON

– CURRENT STATUS AND AN OBJECTIVE EVALUATION –

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Abstract- Mechanical systems or robots to assist landmine detection are expected to greatly improve quality of humanitarian demining tasks. These new systems could provide: i) safer operation; ii) advanced methods for automatic target recognition and discrimination; iii) consistent performance with less influence of “human-factors”; iv) better detection performance, i.e., higher probability of detection (POD) and lower false alarm rate (FAR); among others. However, despite many research/development efforts around the world, no practical landmine detection robot has yet achieved maturity for practical use. Nonetheless, the humanitarian demining robot Gryphon, which current status of development is described in detail, is close to meet the requirements for practical use. This paper analyses the results from latest on-site tests underwent by Gryphon in Croatia (2006, 2007) and Cambodia (2006), to make a critical and objective evaluation of its validity, and clarify the points that still require further development in order to realize a practical humanitarian demining robot.

Index terms: All terrain Vehicle (ATV), buggy vehicle, robotic manipulator, metal detector (MD), ground penetrating radar (GPR), global positioning system (GPS), target discrimination.

I. INTRODUCTION

Anti-personnel landmines and explosive remnants of war do not lose their explosive force even long after war or conflicts are over, and even now, they still remain a real threat for many populations around the world. The goal of humanitarian demining is to remove these remnants of war and assure a cleared and safe land that can be used without fears. This differs from the military demining (also called breaching), which basically focus in clearing paths for military purposes.

sensors, record data and present the resulting sensor images to the operator who then can mark suspect spots. Additionally, a novel algorithm based uniquely on the acquired data from an MD has been tested, and shows promising results in extracting more than just the position of buried metallic objects; next to identifying the depth at which a metallic object is buried, it allows also performing discrimination. The developed robot was tested in several field trials on test minefields in Croatia and Cambodia.

II. GRYPHON PROJECT- AN OVERVIEW

During the period of October 2002 to October 2007, the Japan Science and Technology Agency (JST), having received designation from the MEXT (the Ministry of Education Culture, Sports, Science and Technology) has funded research and development in two areas: i) advanced sensing technology; and ii) access-and-control technology, with objective to offer new solutions for the worldwide humanitarian demining problem. Our group in the Tokyo Institute of Technology focused in the latter area, access-and-control technology, and succeeded in the development of a new teleoperated robotic system called “Gryphon” that can effectively and reliably carry and control many mine detection sensors developed by other groups, as well as other commercial sensors.

As shown in Figure 1, Gryphon is based on a commercially available All Terrain Vehicle (ATV) to which a custom long-reach robotic manipulator carrying a mine detector is mounted. The robotic manipulator is automatically controlled to scan the terrain, without intervention of a human operator. This is achieved by acquiring three-dimensional topographical information of the area to be scanned, by using a stereo vision camera. The recorded mine detector data is then presented to the operator who, after careful inspection and evaluation, can indicate suspect spots that will be marked directly onto the minefield with an onboard paint- or plate-marking system. Additionally an optional RTK-GPS localization system records the location of the acquired data and marked spots, within a few centimeter precision.

- *The Manipulator*

The manipulator consists of counter-balanced pantographic arm with 3 degrees of freedom [9]. This configuration allows taking advantage of a reduced power consumption and improved insensitivity towards the ATV's suspension (the ATV's inclination when the arm reaches far out is drastically reduced). The arm is completed with a 2 degree of freedom wrist mechanism that allows positioning most mine detectors over the terrain in the best-possible way, following the curvature of the ground. Taking into account the possibility of using a metal detector as mine detector, the front part of the manipulator is entirely free of metallic parts to avoid reducing sensing sensitivity or influencing data reading; the wrist mechanism is mainly made of polyoxymethylene, while the front link is made of glass fiber reinforced plastic (GFRP). Wrist actuators are remotely located and linked through two rods.

An alternative 3 degrees of freedom wrist mechanism can also be attached to the manipulator and is meant to be used when carrying heavier mine detectors (capacity of about 10 Kg).

- *The Stereo Vision Camera*

In order to compute the trajectory of the mine detector over the terrain, a model of the terrain to scan is constructed by make usage of a stereo vision camera. The camera is located on the first link of the manipulator and allows, by taking several depth maps of the terrain surrounding the ATV, to build a model of the latter upon which all trajectory calculations will be based. See [10] and [11] for further details.

- *The Mine Detector*

Currently, the default configuration of the mine detector is based on commercial hand-held MDs. Two types are available and have been thoroughly tested: the CEIA MIL-D1 and the Minelab F3. Both are statically operating MDs, they however differ from their generated signals and how their respective image interpretation should be performed. Figure 2 shows the sensor images of two scan passes performed with Gryphon equipped successively with the two MD types over the same 2 m² area. One can see that the output of the MIL-D1 (double-coil configuration) has a typical 2-lobe pattern centered over the metallic objects, while the single-coil type F3 produces a simple circle. Still, both are easy and intuitive to interpret even for novice operator/deminer who should identify the landmine/metal fragment.

- *The Marking Systems*

Once Gryphon scanned a portion of terrain, mine detector data will be shown to the operator who can then decide to mark suspected mine locations. This allows decoupling the mine detection and prodding procedure. Two different marking systems have been developed for Gryphon. The first one, based on water-soluble color paint, has a nozzle attached to the mine detector and allows not only marking suspect spots, but also to write additional information on the terrain. The second marking system operates by having the manipulator fetch a marking plate from a marking plate dispenser and dropping it onto the correct position.



Figure 4: Paint marker and marking plate dispenser.

Both marking alternatives operate fully automatically and require only the operator to indicate the appropriate spot by a click on the control box screen. An optional marking system based on *Real-Time Kinematics GPS* (RTK GPS), if present, will additionally record marked spots with a precision of 4-5 cm.

The plate marking system was developed mainly to have versatile marking systems on test sites; indeed, often one given requirement is to leave the terrain unmodified so as to allow additional blind tests on the same day. The system is however inappropriate to use on real minefields since the plates can be shifted from their original position accidentally or by natural cause (e.g. wind). The paint marker on the other hand is much more robust to such influences, but the best is to use it in conjunction with the RTK-GPS for additional safety and conserve recorded data validity over a longer period.

1) The ATV is driven into position (through manned or unmanned operation). Since Gryphon operates along the minefield borderline, the vehicle is positioned so as to be able to scan on its left or right side.

2) The surrounding terrain is geometrically modeled by acquiring several depth maps with the stereo vision camera.

3) Autonomous scanning is executed, detector data processed and visualized in the control box.

4) After evaluation of acquired data, suspected mine locations are marked using one of the two onboard marking systems.

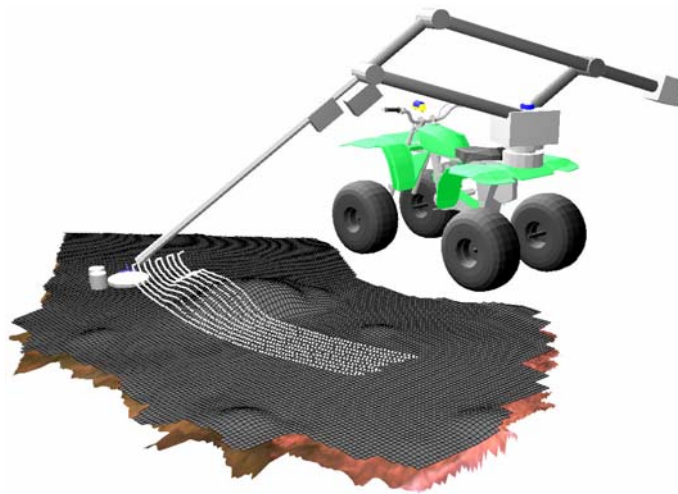


Figure. 7. Control software display image with model of terrain.

Gryphon operates by scanning a 1 meter wide lane, 2 square meters at each ATV position. The approach direction is always from the cleared side, the vehicle staying in safe zone. MD and GPR sensing can be performed simultaneously and recorded data are presented as a series of images, which can be evaluated separately by the operator.

Individual Gryphon machines can also be used conjointly, where each entity would be in charge of a specific detection/discrimination task. Three Gryphon robots successively scanning the same area, once with an MD, then with an array-GPR, and finally with an NQR sensor for instance, is a scenario that becomes possible. This modularity allows for a very flexible detector configuration with distributed detection characteristics. Data overlap between individual machines is guaranteed by the RTK-GPS localization systems.

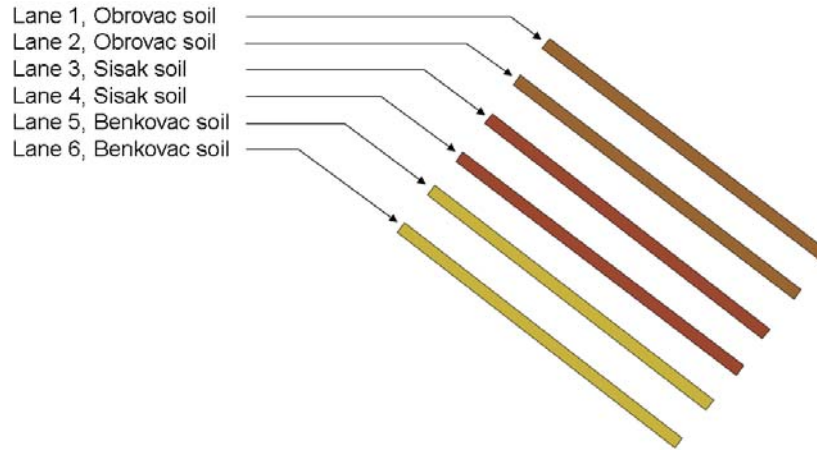


Figure 8. Layout of the test site as acquired by the RTK-GPS.

B. The mine detector

Two Gryphon machines, one equipped with an F3, the other one with an array-type GPR (cf. Figure 9), were used in a dual-sensor configuration. While the first machine scans for and marks only metallic targets, the second machine inspects the spots marked by the first machine and decides whether it is a landmine. And so the mine detection task is divided into detection (with the MD) and discrimination (with the GPR). Recorded data overlap between MD and GPR is guaranteed by the RTK-GPS.

Scanning is performed 2 m^2 at a time, starting with the MD-Gryphon. Distance between individual scan passes is 4 cm and the scanning speed is 50 cm/s. Upon completion of the MD-Gryphon's scan which takes approx. 3 minutes, the GPR-Gryphon moves into the same position previously held by the MD-Gryphon and scans the same surface at a speed of 7 cm/s. Distance between individual scan passes is 45 cm in that case (the array-type GPR scans a width of more than 45 cm at a time) and task completion requires less than 2 minutes.

signal in the GPR images would allow discriminating targets. Once the entire lane was scanned and evaluated, a *total station* would acquire marked spots. This allowed evaluating the performance of the Gryphon dual-sensor system by matching Gryphon-identified target coordinates with the real target coordinates. At the same time overall performance of the dual-sensor Gryphon system doesn't say much about the effect of automation; when looking at MD results only, is Gryphon able to attain the same performance than the handheld version in terms of probability of detection or false alarm rate?

To answer this question, data recorded with the MD-Gryphon during the trials was reprocessed with improved algorithms and re-evaluated, taking into account only clearly visible signals. Target locations were then compared against real target locations and performance evaluated for all 6 lanes. Table 1 summarizes results for the MD-Gryphon.

TABLE I
PROBABILITY OF DETECTION AND FALSE ALARM RATE FOR MD-GRYPHON

	Probability of detection (POD)	False alarm rate [m⁻²] (FAR)
Lane 1	76%	0.11
Lane 2	86%	0.07
Lane 3	93%	0.04
Lane 4	86%	0.04
Lane 5	93%	0.07
Lane 6	90%	0.04

Above results were obtained by using an F3 as sensor payload on Gryphon. The MIL-D1 was also tested on lane 5 (POD of 45% and FAR of 0.21/m²). This performance discrepancy between the F3 and MIL-D1 doesn't necessarily tell anything about each MD's overall performance and could be linked directly to the soil type on that lane (some MDs perform better or worse depending on the soil type).

Worth noting, details about the number of targets, type or their burial depth or position were not

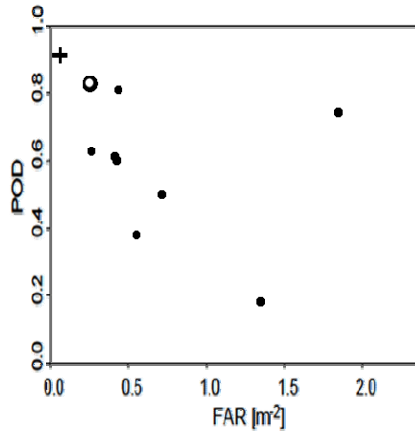


Figure 11. FAR vs POD diagrams for lanes 1-6. “+” indicates performance of Gryphon equipped with an F3, “O” indicates performance of a hand-held F3, and “•” indicate performances of other hand-held MDs tested during the STEMMD trial 2006.

From above diagrams, it can be seen that the vehicle-mounted F3 systematically performs better than its hand-held version in terms of false alarm rate. The probability of detection is also improved except on the Sisak soil, where results are slightly inferior. The generally very good result of Gryphon illustrates the strength obtained from data visualization. Performance could even be further improved by optimizing image processing algorithms or by scanning at closer distance to the ground. These tests confirm previous tests’ good repeatability and good data consistency, coming from a reduced human factor effect.

IV. MD-BASED LANDMINE DISCRIMINATION

Having the ability with Gryphon to easily generating precise sensor images, a method was developed that is able to discriminate for a certain landmine-type, based uniquely on an MD. The algorithm takes advantage of an MD’s sensitivity profile that is precisely measured for a searched landmine type. This *landmine fingerprint* is then matched against data from a blind scan, which, if unsuccessful, allows discriminating the target. Best results were obtained by using the MIL-D1. Figure 12 shows the MIL-D1’s sensitivity profile for a PMA-2 landmine simulant.

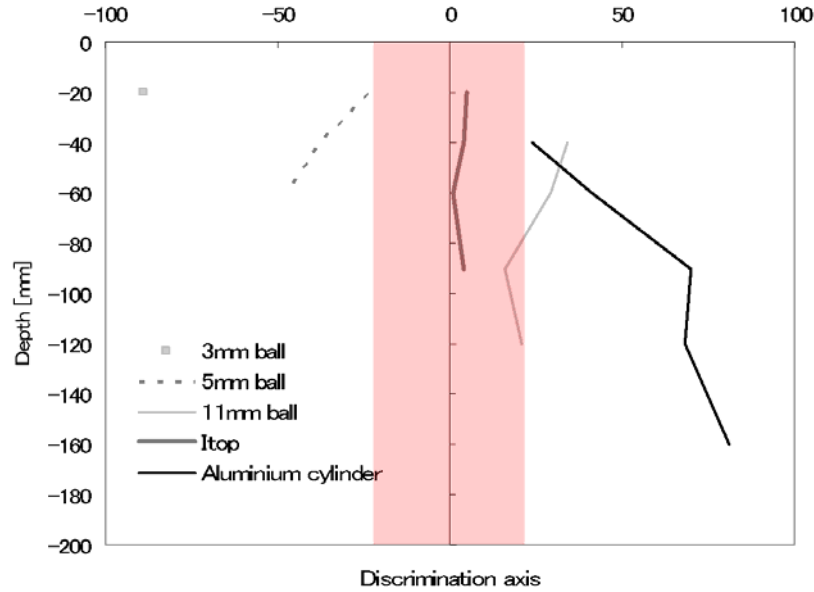


Figure 14. Discrimination experiment result for in-sand buried targets.

The shaded area indicates that the target has higher similarities with the searched object (e.g. itop), and should therefore be handled like a landmine (not discriminated).

V. CONCLUSIONS

A machine for semi-automatic scanning operation with a large variety of landmine sensors was developed. It can assist a human deminer by guaranteeing his safety through remote operation, and by generating precise sensor images. The device has been thoroughly tested in several field trials and results indicate that its imaging capability can improve the probability of detection and reduce the false alarm rate. In case of metal detectors, soil compensation procedures become less crucial and can potentially be performed afterwards, in a more effective way.

Additional image processing methods can extract more specific information about a target and allows for MD-based discrimination. The developed method shows good potential but still needs confirmation in further tests and trials.

The Gryphon system is proposed to be used as a complement to traditional metal detectors. A portable version of Gryphon's manipulator has also been developed, and is ideally suited as a sensor testing platform, reducing the *human factor* during comparative tests to a minimum.

The effectiveness of Gryphon as an access-and-control vehicle is already confirmed, and advanced

- [10]M. Freese, S. P. N. Singh, E. F. Fukushima, S. Hirose, Bias-Tolerant Terrain Following Method for a Field Deployed Manipulator, Proc. IEEE Int. Conf. on Robotics and Automation, Orlando, FL, 2006, pp. 175-180.
- [11]M. Freese, E. F. Fukushima, S. Hirose, W. Singhose, Endpoint Vibration Control of a Mobile Mine-Detecting Robotic Manipulator, Proc. Americ. Control Conf., New York, NY, 2007.
- [12]K. Takahashi, F. Xuan, T. Kobayashi, Q. Lu and M. Sato, Field Evaluation of Handheld Landmine Detection GPR System in Croatia, Proc. 8th SEGJ International Symposium, Kyoto, Japan, 2006, pp. 177-181.
- [13]J. Ishikawa, M. Kiyota and K. Furuta, Evaluation of Test Results of GPR-based Anti-personnel Landmine Detection Systems Mounted on Robotic Vehicles, Proc. of the IARP Int. Workshop on Robotics and Mechanical Assistance in Humanitarian Demining, Tokyo, Japan, 2005, pp. 34-44.
- [14]J. Ishikawa, M. Kiyota, N. Pavkovic and K. Furuta, Test and Evaluation of Japanese GPR-EMI Dual Sensor Systems at Benkovac Test Site in Croatia, technical report JST-TECH-MINE06-002, Japan Science and Technology Agency, 2006.
- [15]The Project for Research and Development of Mine Clearance Related Equipment in Cambodia by ODA (official development assistance), Lastupdate:13.04.2008,
Available at <http://www.jst.go.jp/kisoken/jirai/en/event/event061121/index.html>
- [16]Nikola Pavkovic, Jun Ishikawa, Katsuhisa Furuta, Kazunori Takahashi, Mate Gaal, Dieter Guelle, "Test and Evaluation of Japanese GPR-EMI Dual Sensor Systems at Benkovac Test Site in Croatia", HCR-CTRO_TECH_GPR 08-001, March, 2008.
Available at http://www.itep.ws/pdf/TestDualSensorJST_CTRO2007.pdf
- [17]D. Guelle, M. Gaal, M. Bertovic, C. Mueller, M. Scharmach, M. Pavlovic, "SOUTH-EAST EUROPE INTERIM REPORT FIELD TRIAL CROATIA, (Continuation of the ITEP-Project Systematic Test and Evaluation of Metal Detectors - STEMMD), 25 September – 18 October 2006", Berlin, March 2007. Available at http://www.itep.ws/pdf/STEMMD_Interim_Croatia_final.pdf
- [18]Yvan Baudoin, et Al, Mobile Robotic Systems Facing the Humanitarian Demining Problem State of the Art (SOTA) December 2007 ITEP 3.1.4 Task, The 7th IARP International WS HUDEM'2008, AUC, Cairo, March 28-30, 2008, pp. 1-31.