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Lessons Learned from Field Tests in Croatia and Cambodia

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In addition to the planned final experiment at Fort Leonard Wood, the AR2 effort will include experiments to evaluate rigorously the performance benefits associated with the use of a prior terrain map and the use of live aerial imagery from a UAV.

The research presented here can be adapted from the military arena for relevancy to the challenges of humanitarian demining. It is important to note that humanitarian demining is significantly different from military demining. Anti-Tan and Baz point out that “The military needs to breach a narrow path for human intervention to be feasible and with acceptable losses due to missed mines. On the other hand, humanitarian demining requires 100 percent detection and removal of all mines on a large area.”

To address the challenges of humanitarian demining, a multi-robot approach is being developed which will use multiple, inexpensive platforms that can provide peer validation to increase the probability of detection. The multi-robot strategy will also allow the behaviors to be used for large areas.

Another consideration for humanitarian demining is the price of the robots platforms. To reduce the cost of the system, the behaviors presented in this article have now been ported to a commercial four-wheeled robot manufactured by Segway that costs less than a third of the fielded military systems under consideration. As different robots and sensors become available, the portability and reconfigurability of the behavior will allow them to be used across a variety of tasks and environments.

This work could not have been successful without the help of many individuals and organizations. In particular, the authors wish to thank Mark McKay, Matthew Anderson, Jade Boyle, Warren Jones and Scott Bauer from the JMU. U.S. Army Peacetime Programs, Herman and Jeff McMahill at the National Robotics Engineering Consortium at Carnegie Mellon University, Aaron Burnmester, Bart Everett, and Estrella Pats at the Space and Naval Warfare Systems Center in San Diego, Dr. Kornogit and Or Regui Vincent at Stanford Research Institute, David Kendrick, David Comella, Nadine Dickerman, Major Roger Owen, and Master Sergeant Workman at the MANSICN Factory Center, Clay Thompson at the U.S. Army Test and Evaluation Command, Clayton Holman and Ellen Purdy at the Joint Ground Robotics Enterprise, Colonel Jerry Griffin at the Robotics Systems Joint Program Office, Elaine Luna at the Night Vision and Electronic Sensors Directorate, Lieutenant Colonel Raymond “Butch” Boyd and John Hegle at the U.S. Army Engineer School.

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Mike Walton has been a Control Systems Software Engineer at the Idaho National Laboratory for 7 years. Now in the Robotics and Human Systems group, Walton is one of the recipients of a 2008 R&D 100 Award for developing a Robust Intelligence Kernel (IRKI) and the IRKI Automatismi (IRKI-A). His expertise includes experiments to evaluate rigorously the performance benefits associated with the use of a prior terrain map and the use of live aerial imagery from a UAV. The platform is based on a commercial all-terrain vehicle. In order to control the ATV remotely, radio-controlled mechanisms have been installed for steering, throttle, braking and gear-changing. The ATV is equipped with a gasoline engine (79cc, 4-stroke) that powers an onboard generator and produces electric energy for all automation mechanisms, as well as for the sensors installed in the manipulator. The platform can operate, therefore, without interruption for one entire day, functioning as a portable source of electricity in the field.

In addition, the vehicle can be driven manually. When commuting between the base camp and the minefield, it is preferable to have a pilot driving the ATV. In this way, no additional vehicles for transporting the machine are required. Once Gryphon reaches the border of the minefield, it can be switched to remote-driving mode.

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Simplified SOP

The standard operating procedure described below applies to Stage II (landmine detection).

Position ATV. A typical operation starts with the positioning of the ATV along the border of the minefield (see Figure 2a). The ATV may be driven by a pilot along the minefield, but ideally it should be controlled remotely.

Acquire images. Once the ATV is in place, the stereovision camera will acquire images of the minefield and generate a three-dimensional model of the terrain (see Figure 2b) so that rocks, bumps and ditches can be recognized. At the same time, a scanning path will be generated automatically, taking into account all obstacles present in the three-dimensional model.

Scan area. In the next step, the manipulator will scan the area automatically, following the trajectory on the three-dimensional model of the terrain (see Figure 2c). The operator does not need to control the manipulator. Because of the automatic control, the distance between scanning lines and the scanning speed are always kept constant, contributing to the reliability of the process.

Display data. Once the scanning is over (it takes between two and 12 minutes to scan an effective area of 2 square meters [21.5 square feet]), depending on the sensors used, the data acquired by the sensor(s) are displayed for the operator in a remote controller (see Figure 2d). It is then up to the operator to decide what signals correspond to possible landmines. To assist this delicate task, several techniques can be employed, such as adjusting the contrast of images or combining data from different sensors in the same image.

Mark mines. When the possible landmines are identified, the operator chooses their positions on the display of the remote controller. Then the manipulator moves automatically to the selected spots to mark them (see Figure 2e), either with paint or with a disc plate. The operator may then move the ATV to the next scanning position and repeat the process.

Experiments in Croatia

The Croatian Mine Action Centre has been employing great efforts to clear its remaining minefields. CROMAC’s Center for Testing, Development and Training is testing new technologies, and Gryphon was selected for detailed tests of sensors and locomotion.

Description of the tests

The tests were performed in one of the CROMAC training sites in Pakrac and consisted of eight lanes (16m by 1m) with objects buried at previously undisclosed positions. Each lane was made of different types of soil: uncooperative and heterogeneous, uncooperative and homogeneous, and cooperative and homogeneous.

During these tests, one Gryphon unit was employed, with a metal detector and GPR set as the sensor payload (see Figure 3). In addition, at that time the GPS and other marking systems had not been implemented yet, so every time a possible landmine was identified in the data from the sensors, it was necessary to measure its coordinates and then manually place a disc plate on the test lane. The operation of Gryphon and the analysis of the data acquired with the sensors were performed by members of our team, with limited interaction with local deminers. However, operating in conditions close to those of a real minefield provided the authors with feedback and insights that are often missed when developing machines in the controlled environment of a laboratory or factory.

Results. During the tests, each team was asked to employ the data from the GPR to determine if the metallic target detected by the metal detector was a landmine, a metallic fragment or just noise. The official results of the tests were compiled based on these instructions. The operators, therefore, were supposed to mark any positive signal from the MD as a metallic fragment if the GPR did not show clearly the shape of a landmine. If the target actually was a landmine, the final result would be considered a false negative (i.e., a missed landmine), even though the MD identified the presence of a metallic object.

Ground-penetrating radar is a new technology that is still undergoing adjustments and improvements. To bring Gryphon closer to real minefield conditions where only MDs are employed as sensors, the authors have made a new evaluation of the results, considering only the data from the MD assembled on the manipulator of Gryphon.

Gryphon performed well scans for each type of soil (namely, cooperative homogeneous in Lane 1, uncooperative homogeneous in Lane 3, and uncooperative heterogeneous in Lane 7). Table 1 (next page) presents the results of the tests after the new evaluation by the authors, plotted against the best-performance set by two human deminers working with standard handheld MD. As one can see, the Gryphon-mounted MD performed better than the standard. In addition, Gryphon presented a higher rate of false positives per square meter in Lanes 1 and 3 than the standard values.

Note that neither handheld nor Gryphon methods achieved a 100-percent detection ratio. This is normal for a test setup, where a relative comparison of the results of the tests with many different sensors is necessary. The performance of any sensor should not be degraded by integrating it into Gryphon. In the worst-case scenario, the sensors assembled on Gryphon should perform as well as the standard, handheld sensor. This was true only in Lane 1. Among the reasons for an apparent decrease in the performance of the Gryphon-mounted MD, there may be problems in the calibration of the MD, in the analysis of the data and in the positioning/marking on the terrain. The latter was especially repetitive, time-consuming and prone to errors. The author strongly believes that the performance of the MD assembled on Gryphon was not decreased and that the results in Lanes 3 and 7 inferior to the standard are due mostly to the reasons mentioned above. Later experiment results from tests in Cambodia (2006, presented next) and a different set of tests in Croatia (2007) demonstrate that, in fact, Gryphon is able to achieve better than handheld scanning. Official results of the CROMAC test should be available in 2008.
In spite of the problems, the local deminers praised some of the features of Gryphon. One of them was the visualization of MD data on a display. Instead of identifying buried metal only by sound from the MD, with Gryphon it is possible to store the data from the MD and then display it as a color graphic. Because the motion of the manipulator is kept at a constant speed with regular intervals between the scanning lines, the visual interpretation of data can be considered to be reliable, something that would be very difficult to achieve with a handheld MD.

The automatic three-dimensional terrain model generation capability with the stereovision camera performed as expected and allowed Gryphon to scan irregular soil, keeping the sensor head always a constant distance from the ground. This feature is an important one, since the operator can focus his or her attention on the supervision of the system.

Experiments in Cambodia

The Cambodian Mine Action Centre has been working to remove landmines remaining from conflicts 30 years ago in what, at first sight, may seem to be an overwhelming task. According to a senior manager of CMAC, approximately 75 percent of the country remains to be cleared of landmines in a verifiable way. CMAC has been focusing its efforts on high-priority areas such as roads, villages, water reservoirs and fields suitable for agriculture. The consequences of these efforts can be seen in villages flourishing again, schools being rebuilt and infrastructure being slowly, but steadily, restored.

The most important lessons learned during those experiments were:

- Automatic positioning and marking systems should be integrated to reduce the operating time while scanning a minefield.
- Analyzing and displaying data should be done in a faster and more intuitive way, since one cannot afford to work on a desk inside a room in a minefield.
- The most basic and repetitive tasks, such as acquiring images for the three-dimensional terrain model and copying sensor data from Gryphon to the portable control unit, should be automated, so that the operator can focus his or her attention on the supervision of the system.
- Automatic three-dimensional terrain model generation capability with the stereovision camera performed as expected and allowed Gryphon to scan irregular soil, keeping the sensor head always a constant distance from the ground. This feature is an important one, since some landmines with low metal contents may be missed if the MD is too far from the soil.
- The greatest change in the Gryphon system during the tests in Croatia and Cambodia was perhaps in the user interface. In order to make it easy to operate for local deminers (many of whom had no previous experience using a computer), the interface was greatly simplified with fewer buttons and switches, and an intuitive graphic interface based on colors was added.
- Local deminers operated the system and the authors were prohibited from entering the test lanes. Only access to the calibration boxes was granted, where the deminers were instructed in the operation of the system for approximately two weeks. After the initial period of training, the local deminers were able to operate both vehicles without any support from the authors and solve some simple problems that happened during the operation. The analysis of acquired data from MD and GPR was also performed by the deminers in the field.

<table>
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<tr>
<th>Table 1: Results of scanning tests in Croatia.</th>
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<tbody>
<tr>
<td>Lane 1</td>
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<tr>
<td>Detection Ratio</td>
</tr>
<tr>
<td>79.8%</td>
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<tr>
<td>Lane 3</td>
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<tr>
<td>92.9%</td>
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<tr>
<td>Lane 7</td>
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<td>75.0%</td>
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<th>Table 2: Data for each lane of the test site for Gryphon equipped with MD. Data from lane 4 were not available at the time of publication.</th>
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<tr>
<td>Lane 1</td>
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<tr>
<td>Detection Ratio</td>
</tr>
<tr>
<td>98.0%</td>
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<tr>
<td>Lane 2</td>
</tr>
<tr>
<td>72.0%</td>
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<tr>
<td>Lane 3</td>
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<tr>
<td>92.0%</td>
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<tr>
<td>Lane 4</td>
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<tr>
<td>84.0%</td>
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<td>Lane 6</td>
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<td>96.0%</td>
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<td>Lane 7</td>
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<td>52.8%</td>
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The targets missed by Gryphon were also missed by the standard MD, which means they were buried in positions that were too deep or too difficult to detect by the standard handheld MD. Lane 7 was composed of three different sections of dry sand, dry clay and dry laterite. In addition, the targets consisted of Type 72 anti-personnel mines and Type 40 anti-tank mines, buried close to each other. This layout was devised to test the limitations of the sensor devices. In fact, the MD data often showed only one target when an anti-tank mine was buried beside anti-personnel mines. Therefore, the detection ratio in Lane 7 was considerably lower than in all other lanes. Even then, the results obtained with Gryphon match the standard.

These results are closely tied to the type of mine sensor used. Obviously, they are also affected by the capability of Gryphon to move the sensor close to the ground, while keeping the arraying spacing uniform between the scan lines. The other features of Gryphon (safety of operation, simplicity of operation, visualization of scanned data and comfort to the user) were evaluated with feedback from the local deminers.

It is clear, therefore, that the weakest points of Gryphon were in its relatively complex assembly, insufficient documents and manuals for operation and maintenance, and the ruggedness of the portable display against the strong sunlight in Cambodia. Equipment that requires maintenance by local deminers has been placed in easily reachable places. Additionally, the authors are working to improve the technical documentation of Gryphon, including a video showing the standard operating procedures that can be used in training. Finally, the display of the portable control unit must be covered by a portable shade (which can be folded inside the control unit) and placed, wherever possible, against the sunlight.

Comfort to the operator, safety, and ease of understanding the graphical interface and audio tones were ranked highly by the deminers. The controls and the operation sequence still can be improved to meet the SOPs of CMAC. The feedback from the local deminers about the vehicle-mounted approach is very encouraging and suggests that if Gryphon is employed in combination with other sensors, it may reach a detection ratio higher than the standard.

Future Works

From the reevaluation of 2006 field tests in Croatia and Cambodia, it can be concluded that the performance of landmine detection with Gryphon has reached a satisfactory level. Vegetation removal (see Figure 7) has been studied to some extent, but there is a lot of research required before its implementation. With the use of rotary tools connected to the end-effector of Field Arm, it would be possible to cut vegetation prior to performing landmine detection, while keeping the sensors away from the minefield.

Another task that would benefit from the use of a remote-operated tool is landmine neutralization. To perform landmine neutralization with Gryphon, prodders and other digging tools could be attached to the end-effector of Field Arm. To perform landmine neutralization with the minefield conditions and requirements.

Furthermore, the experiences in Croatia and Cambodia proved that the vibration generated by the gasoline engine of Gryphon, the compliance of the suspension of the vehicle and the motion of Field Arm do not negatively affect the performance of the sensors used. There were also no interferences with the electronics of the sensors employed. Instead, with the controlled motion of Field Arm, it was possible to acquire data in a regular domain, something that is very difficult to achieve by moving the sensors manually.

It is a regular pattern that allowed the visual analysis of data on a screen, greatly enhancing the evaluation process. The Gryphon system performed exceptionally well in Croatia and Cambodia. Although there are still details to be improved, the authors are testing other sensing technologies and hope to deploy the system in minefields for landmine detection in the near future.

Figure 7: Vegetation removal and landmine de- tection performed in a minefield in Cambodia. The detection of landmines on the spot could be achieved with another tool connected to the end-effector of Field Arm. For this purpose, a common interface between the various tools must be designed and implemented, so that the same platform (Gryphon and Field Arm) can be employed for all demining stages of the works performed inside a minefield.

Conclusions

The Gryphon system for remote detection has seen steady progress in recent years, mainly due to the field experiments performed in Japan and other countries. By testing the machines in close-to-real-world conditions and operating them with local deminers, it is possible to learn much about their requirements, not only in terms of environmental resistance (extreme temperatures, rain, sand, etc.) but also with respect to operational procedures and human-machine interface. Any system or tool developed in laboratories of faculty to assist humanitarian landmine clearance should be tested in the field as soon as possible, ideally in the presence of deminers, so that they can be adjusted to the local conditions and needs.

It is important to note that Gryphon is a mobile platform for remote operation in minefields. The results of tests described in this paper and the rate of landmine identification performance in minefields have been employed. The authors designed this system so that it can easily be adapted to operate with different kinds of sensors, according to the minefield conditions and requirements.

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