April 2008

Intelligent Robotic Behaviors for Landmine Detection and Marking

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Landmines are a constant danger to soldiers during combat and to civilians years after conflicts cease, causing thousands of injuries and deaths per year. The undetonated ordnance left in the battlefield is often neglected by the military when planning the return of civilians. The humanitarian mission, however, continues until the last mine is removed. This article discusses experimental results achieved with a robotic countermine system that utilizes autonomous behaviors and a mixed-initiative control scheme to address the challenges of detecting and marking buried landmines. By collaborating with a termite and ground-based robot mapping interface, the termite can perform the search and detection task without the use of accurate global positioning information or continuous communication with the operator. Results show that the system was able to find and mark landmines with a very low level of human involvement. In addition, the data indicates that the robotic system may be able to decrease the time to find mines and increase the detection accuracy and reliability.
occupancy grid map built by the robot. One lesson learned in terms of air-ground teaming was that it may not be possible to automatically generate a performant representation of the world and ground representation especially when error such as positioning inaccuracy and camera skew play a role. Even with geo-referenced imagery, real-world trials showed that the GPS-based correlation technique does not reliably provide the accuracy needed to support the countermine mission.

In most cases, it was obvious to the user how the aerial imagery could be used or rotated to accurately determine the line of sight fusion between the ground robot’s digital map and the air vehicle’s image. To alleviate dependency on GPS, collaborative tasking tools were developed that use common reference points in the environment to correlate disparate internal representations (e.g., aerial imagery and ground-based occupancy grids).

As a result, correlation tools were developed that allow the user to select common reference points within both representations. Examples of these common reference points include the corners of buildings, fence posts or vegetation marking the boundary of roads and intersections. In terms of the need to balance human and robot input, it was clear that this approach required very little effort from the human (a total of four mouse clicks) and yet provided a much more reliable and accurate correlation than an autonomous solution. It is also important to note that the same interface tool that correlates aerial imagery with the ground map can also use satellite imagery or other forms of terrain data.

Once the imagery and the map are integrated, the imagery serves as a backdrop for the operator to task the robot to previously known areas. The representation used for this experiment implements a three-dimensional, computer-game-style representation of the real world constructed on-the-fly. The three-dimensional representation maintains the relative sizes of objects in the environment and illustrates the map built by the robot as it relates to the aerial image and the position of the robot, obstacles, mines, and the path cleared by the robot. Figures 3 and 4 illustrate different perspectives of the interface used for the experiment. This fusion of data from ground and aerial vehicles is more than just a situation-awareness tool. It supports a collaborative positioning framework that exists between air vehicle, ground vehicle and human operators. Each team member contributes to the shared representation and has the ability to make sense of it in terms of its own, unique internal state.

Experiment. To test the proposed system and mission requirements, personnel from the U.S. Army Maneuver and Support Center and the U.S. Army Test and Evaluation Command, both based at Fort Leonard Wood, Missouri, conducted an experiment 20–28 October 2005 at the Idaho National Lab’s UAV airdrome. The U.S. Army TEKO authored the experiment plan, performed the field experiments and collected all data collected. The experiment consisted of repeated trials of a dismounted route-sweeping task, and data collected included measurements of human, robot and overall team performance of the resulting system. Sweeping a dismounted lane required the robot to navigate a path to a target location while physically and digitally marking detected mines and the boundaries of the searched lane. A test lane was prepared on a 30-meter (100-yard) section of an unimproved dirt road near the INL UAV airdrome. Six inert A-15 anti-tank landmines were buried on the road between six and eight inches (15–20 centimeters) deep.12 Sixteen runs were conducted with no obstacles on the lane and 10 runs had various obstacles scattered on the lane such as boxes and crates as well as sagebrush and tumbleweeds.

Procedure. The robot was prepared for operation at the beginning of each trial. Each trial consisted of the operator tasking the robot to the starting point of the lane, initiating a brief mine sensor-calibration behavior, and then initiating the 5-meter (5-foot) lane-sweeping behavior. Altogether, this included a total of three button clicks on the operator control unit. Since the repeated use of colored dye would produce confusion regarding the type of ground, water was used instead of dye throughout the experiment.

In the as-run processed, test personnel followed the robot placed red poker chips at the location of each wet spray mark. These poker chips allowed personnel to accurately measure distance from the center of the dye spray to the center of mine as shown in Figure 5. The water then dried before the next trial. Throughout the experiment, all mine locations reported to the operator control unit were checked and a copy of the data log and screenshots of the recordings from the OCU were saved. A photograph of each mine and its location was taken, and a video of each run was recorded. Data sheets recorded meteorological data, mine

Figure 2: Occupant board pilot platform.

Figure 3: Operator control unit with “sliding view” of strikes and lane.

Figure 4: OCU showing correlation of robot map correlated with an aerial mosaic.

Figure 5: The Arcturus T-15 air vehicle. (Image courtesy of David J. Bruegger.)
lane boundaries were marked in the physical environment. Error was 12.67 centimeters (4.98 inches) for 91 mines and the average marking mark and the center of the mine was measured and recorded. The robot was physically marked on the ground. During the 26 runs executed through the experiment the robot correctly detected 124 out of 131 mines (95 percent). Of the seven mines not detected two were due to a misalignment of the flagger, two were due to a miscalibration of the height sensor, and three were not detected during sharp turns to avoid obstacles. All missed mines were at or near the edge of the proofed lane. Autonomous Robotic Countermine System was successful in all runs in autonomously negotiating the 50-meter (55-yard) course and marking a proofed one-meter lane. This was true even when the lane was covered by a high density of clutter, including brush, boxes and large stones. The 26 runs had an average completion time of 5.75 minutes with a 99 percent confidence interval of +/- 0.31 minutes. The maximum time taken for any run was 6.307 minutes. Another interesting finding is that the average level of human input throughout the counter-mine exercises was less than 2 percent when calculated based on time. The U.S. Army Test and Evaluation Command indicated that the ARCM System achieved “very high levels of collaborative tactical behavior.” When the MANSCEN applied the “autonomy levels for unmanned systems” metric, which includes indices for operator interaction, environmental difficulty and task complexity, to evaluate the overall autonomy of the system, a level of eight to nine was applied out of a possible 10.

Findings

The research reported here indicates that operational success was possible only with a mixed-initiative approach that defined different, complementary responsibilities and roles for the human, air vehicle and ground vehicle. The results of the real-world experiment showed that the autonomous robot counter-mine system accurately marked, both physically and digitally, 124 out of 131 buried mines in an average time of less than six minutes. Comparing the robot to a human performance baseline is difficult and no attempt was made to perform a rigorous comparison. In order to provide a rough juxtaposition, consider that, according to MANSCEN, it would take approximately 25 minutes for a trained deminer to complete the same task accomplished by the robot. In terms of probability of detection, a trained deminer detecting mines on a 50-meter (55-yard) training lane can expect to discover between 60 percent and 90 percent of the mines, depending on experience and the type of landmine to be detected.

Future Work

While the robot’s performance is encouraging, it is important to understand that many challenges remain. One important caveat to the work reported here is that the mines used had a high metallic content. The need to find low-metallic mines will require a more advanced sensor. Ongoing collaboration with the Night Vision and Electronic Sensor Directorate’s Advanced Mine Detection Sensor Program. According to experimentation performed by the NVESD, this sensor has shown the greatest potential to increase probability of detection for low-metallic mines. A new effort under the direction of the Program Manager for Countermining and Explosive Ordinance Disposal at Fort Belvoir, Virginia will test how effectively the ARCM behaviors can be used on the deminer on the 50-meter proofed lane. This will allow the team to gain more understanding of the potential of robotic technologies to support reconfiguration for different counter-mine tasks and environments. The experiment reported here was conducted, the software behavior architecture used has been ported to several different vehicles including the

Figure 6: Example of mine marking.

Figure 7: Mine and lane display on the interface (OCU).

Figure 8: The iRobot Packbot outfitted with the Cyterra AN/PSS-14 mine sensor.

Figure 9: Proofed Lane marking.

Figure 10: The Robot Packbot outfitted with the Cyterra AN/PSS-14 mine sensor.
To reduce the cost of the system, the behaviors 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 behavior to be used for larger areas.

Another consideration for humanitarian demining is the price of the robotic platforms. In particular the authors would like to thank Mark McKay, Matthew Anderson, Jodie Young, Warren Jones and Scott Bauer from the UVG, MUV, UV and MUV from Raytheon, Dr. Jeff McDermott at the National Robotics Engineering Consortium at Carnegie Mellon University, Aaron Munro, Bart Everitt, and Estrellina Thompson at the U.S. Army Test and Evaluation Command, Cliff Hudson and Ellen Purdy Thompson at the U.S. Army Test and Evaluation Command, Chris Dave and Miles Walon from the Idaho National Laboratory for 27 years. Now in the Robotics and Human Systems Group, Nielsen is one of the recipients of a 2008 R&D 100 Award for developing a Robotic Intelligence Kiosk.

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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 ATV can be driven manually. When commuting between the base camp and the minefield, it is preferable to have a pilot driving Gryphon. 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.

The manipulator is named Field Arm and was designed in a protographic configuration, so it is balanced by a counterweight in any position. Very little energy is required when moving the manipulator or when it is still above the minefield. The Field Arm has been developed with carbon-fiber pipes and aluminum joints, and the actuators are located in its base. Experiments have confirmed that Field Arm consumes much less energy than a conventional manipulator even when the base is inclined as is often the case when operating on rough terrain.

For marking possible landmines, there are two different mechanisms. One is based on paint, with a nozzle installed at the tip of the manipulator. When the position of a possible landmine is identified, the manipulator can reach inside the minefield and move an array of sensors above the soil. Whenever a possible landmine is detected, the system can mark the spot and move to the next scanning position. Since it never enters the minefield, the system does not require heavy and expensive armoring. In addition, because it is based on a standard vehicle, it can be less expensive than the other armored solutions proposed.

Part of the mine-detection work can be automated; however, the entire operation is always under surveillance of the operator, as is the data analysis process. The operator performs delicate steps, with remote control, retaining a safe distance from the minefield. This procedure does not exclude the need for armored detonating machines. On the contrary, if the new landmine-detection procedures employed in cooperation with the machines that are already in use, it is balanced that the safety and eventually the speed of mine clearance can be improved.

In the basic configuration, Gryphon is equipped with mine sensors and can be employed for landmine detection only (Stage II) of the tasks performed inside the minefield). With some more research and modifications, it is expected that it could be equipped with other tools, such as rotary cutters and probes, and be used also for vegetation removal (Stage I) and landmine neutralization (Stage III) by digging the soil and placing explosive charges, thus keeping the human operators away from the minefield at all times.

Subsystems

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.

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