March 2008

Experimenting with New Technologies for Technical Survey in Humanitarian Demining

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of humanitarian-demining equipment from Canada and Sweden, has led to a considerable reduction in ITEP mechanical testing equipment trials.

The only non-U.S. activity during 2007 was the performance and survivability trial of the Mini MineWolf carried out by the German Test Center for Weapons and Munitions with support from Canada. 13 The Mini MineWolf full and trials were evaluated according to the Workgroup Agreements on Test and Evaluation of Demining Machines (CWA 15044:2004) in August-September 2007 and the final test report 14 was released in January 2008. 15

The U.S. HD R&D Program carried out several tests of adopted commercial off-the-shelf shovels and rock crusher, as well as of the Nemesi M3 mechanical clearance and area preparation tool. The final reports of the latter two trials are available at the U.S. HD Program Publications Web site. 9

Sweden has executed several mechanical equipment trials in the course of 2008 at the SWEDIC Yorra riffle test facility. In May and September 2008 they ran performance and survivability trials of the DOK-MG MV10 double drum (full and half-scale) Digger D2 full and tiler 16 respectively. Furthermore, the Freeland 5000 Flail, a Swedish mechanical ground clearance prototype, was evaluated in August 2008. 17 All trials were carried out following the CEN Workshop Agreement 15044:2008 test guidelines. Test reports for the MV10-17 and the Freeland 5000 Flail have already been released and are available via the ITEP Web site. The MVA full, the new Rovera-5 and the Scannjack with full and tiler are currently under consider-

ation by SWEDIC for testing according to the CWA 15044:2004 in 2009.

Personal Protection 18

Upon request of the United Nations Mine Action Service, Sweden performed two series of tests on new personal protective equipment (PPE) in November 2007 and November 2008 respectively. These tests were limited to blast trials executed according to the CEN Workgroup Agreement on test and evaluation of Personal Protective Equipment (CWA 15766:2007). 19 The final test reports are available on the ITEP Web site. The main objective of the Swedish PPE trials was to experimentally validate the CWA 15766:2007 (test and evaluation of personal protective equipment). The publication of a fourth CEN Workgroup Agreement on soil characterization for metal detectors and ground-penetrating radar is expected at the end of 2008. Work on the latter CWA 15545 was produced in November 2006 to produce a second part for the CEN on test and evaluation of metal detectors, providing a methodology for the classification and measurement of soil properties relevant for demining operations using metal detectors and ground-penetrating radar and/or dual-sensor detectors.

Franciska Barry has been working for the International Technical Test and Evaluation Program for Humanitarian Demining since June 2002. Her main tasks are to provide advice, assistance and coordination services to the ITEP executive Committee. She is a technical consultant regarding to the CWA 15756:2007 development and the CEN Workshop Agreement 15756:2007 (test and evaluation of personal protective equipment). The ITEP is instrumental in determining priorities about the actions to be taken in order to increase the effectiveness of humanitarian demining, to improve the performance and safety. The objective of making the world free from anti-personnel mines by 2020 has proven overly optimistic, after the initial emotional effect of the Ottawa Convention signing. Lack of adequate funding for mine action is one of the causes, but the difficulties of dealing with vastly heterogeneous objects (anti-personnel mines, UXO, anti-tank mines and other improvised explosive devices) were probably underestimated.

What is desirable is instrumentation capable of yielding a “tomography” of the underground that not only gives the position, size, and form possibilities of hidden objects, but also labels them according to their nature. 20 Of course, just as in the case of medical equipment, the instrument should help the operator but not hide sensitive decisions from him/her, principally because they strongly affect safety. Therefore, signal processing should be based on techniques of proven reliability and yield information about the uncertainty of the result. Information given to the final operator (usually the clearing operator) is often quite significant to many sensing schemes. As sensors based on different physical principles (electromagnetic induction, dielectric properties, thermal properties, stiffness, even atoms/molecular properties) respond differently to each characteristic of the ERW (mass, size, explosive, bulk, air gap, etc.), the combination of sensed “signatures” could be used to discriminate between possible ERW and confounders (e.g., stone, empty metal container). What is desirable is instrumentation capable of yielding a “tomography” of the underground that not only gives the position, size, and form possibilities of hidden objects, and also labels them according to their nature. 20

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Published by JMU Scholarly Commons, 2008
12.1 winter 2008/09 | the journal of ERW and mine action | research and development | 101
**Activities and Goals**

The Humanitarian Demining Laboratory located in Castenas di Latina (near Rome, Italy), was set up in 2005 by researchers of Università La Sapienza di Roma in order to experiment on mine-detection techniques. The first task was to realize and test a prototype of an active thermal detection system, based on localized heating and sensing, first proposed by one of the authors in 2003 and up to then developed only as a feasibility study through simulations.10,11,12

The goal of the laboratory is prototyping and testing a multisensory platform for low-metal content ERW detection, employing diverse techniques with special attention to the operational requirements described in the previous section, and applying state-of-the-art data fusion and decision techniques for target classification.

*Facilities of the laboratory include an indoor sandbox of about 2.3 cubic meters, fitted with a monowheel cart controlled by an on-board microcontroller communicating by radio link with a personal computer. The cart can scan such instruments of the sandbox at controlled velocity. It currently holds infrared heaters and sensors for the thermal system described above.*

A laser doppler vibrometer is also available for vibrometry/acoustic experiments, and acquisition of detectors with GPR is foreseen, while in the meantime simulations are underway. Small autonomous and semi-autonomous cooperating robots are also being designed as a prospective solution for scanning light instrumentation on the ground. An outdoor sandbox similar to the above has recently been realized. It will be used after weathering and grass growing, and will be extended in the future. Use of heater and controlled field is also foreseen in the near future.

In this way, the authors plan to move gradually from a very “friendly” environment (dry sand), to increasingly realistic settings. Some types of instrumentation are being only, or mainly, considered for the research and validation phase because they are expensive and require care, handling and signal processing (e.g., infrared camera, laser doppler vibrometer), and simultaneously more rugged solutions are being considered for operational systems (e.g., contactless thermometers, microphone arrays).

**Active Thermal Detection of Mines**

A conceptual rendering of the thermal system proposed in 2003 and currently under experimental validation at the Humanitarian Demining Laboratory is shown in Figure 1 on the next page.

A theoretical heater is scanned over the surface, so as to deliver a strong heat pulse that gradually diffuses in a depth of about 10 centimeters. After the heating phase, cooling takes place through the ground, and surface temperature is recorded at one or several time lags using a contactless thermometer (pyrometer). Heating and cooling dynamics are affected by thermal properties of the bulk under the surface (assuming that the latter is reasonably uniform). When an object is buried under the soil, it modifies such dynamics. In particular, explosive materials have lower heat diffusivity than most soils, and heat is absorbed or stored (extremely low diffusivity). Therefore, diffusion of heat downwards is prevented during heating, and cooling may be slowed by release of heat accumulated in high-capacity material. As heating is fast, it mostly depends on surface properties, rather than mass properties, so that we may assume that basically the same amount of energy is transferred to fine soil as over a buried object. The dynamic phenomena described cause a temperature anomaly to appear on the surface that registers warmer than where no objects are buried.

**Dynamical thermal mechanisms have been used by several authors using natural or wide-area artificial heating and infrared camera sensing.**12,13,14 In one approach, heat transfer is more rapid, so that blurring by diffusion in all directions is reduced; moreover, power necessary for heating is reasonably limited, and area scanning can be faster. The instrumentation used is rugged and inexpensive, yet quite accurate.

Methods based on microwave heating were also proposed.15 The main difference of such an approach is that heating takes place directly within the mass and is influenced by dielectric and electromagnetic properties of soil (especially water content) and target materials. A comparison of effectiveness of the two methods under similar conditions (in particular power used and speed of area scanning) has not been tried yet.

**Detailed simulation of the system under study has been reported in previous papers,**16,17 proving its feasibility for shallowly buried objects, down to 0.5 cm depending on soil conditions. This conclusion is consistent with results obtained in other applications of thermography that indicate the ratio of depth to characteristic dimension of discontinuities easily exceeds 10.18 Therefore, the proposed system appears to be a good complement to techniques that do not work well near the surface due to clutter (e.g., GPR, acoustic). Exploration of parameter space also allows preliminary optimization for prototype design.

In the current setup, the authors employ a fan infrared heater of approximately 0.03 m², working at 2 kW (about 700°C/m², compared with a maximum of 1 kW/sq m solar radiation), at least 80 percent of which we may assume is actually absorbed. The heater is scanned over the ground at a speed on the order of 0.1 m/s, so that about 3 MJ/m² are transferred on a stripe of surface about 12 m² wide, covering more than 2 kg m². The limit to total scanning speed is the warming speed because sensing can be obtained much faster. As the heater is very simple and inexpensive, scanning speed ends up being directly proportional to available power (ultimately to generator fuel supply), so that these figures are only an indication of such a ratio (i.e., scanning speed to power supply) based on current settings.

Optimal delay for measurement (pyrometer scanning) depends mostly on the depth of the object, so it is appropriate to take multiple measurements during the first several minutes after heating occurs, and up to one hour after, for deep objects.

The current setup is obviously impractical for field deployment but useful for accurate characterization under controlled conditions. The system envisaged for operation purposes can be based on different actuation strategies according to available practical scenarios. In general, the system applies to scanning small robots (or eventually unmanned aerial vehicles) to move relatively fast about the area under examination, of small size and lower power consumption than a light autonomous vehicle. Therefore, we expect to mount it on a robotic arm, stretching out from a safe area and providing power through a cable from a portable generator.

The sensors are instead very small and light, and require little power. With the optimal setup, the surface more densely than with the heater and to take measurements at several time lapses. For this reason, we are considering use of very small robots for eventually unmanned aerial vehicles (UAVs) to move relatively fast about the area under examination, with accurate positioning based on remote video and/or radio (differential global positioning system) localization. In any case, actual implementation of the system should be adapted to diverse operating scenarios.

Experimental activity is aimed at validating simulation results. The first results, published recently,19 and new experiments currently underway are quite encouraging, basically confirming simulations. Besides optimizing operational parameters, we are currently engaged in evaluating signal-processing strategies for contrast enhancement.
For this reason, we applied to the raw data a wavelet analysis, removing components of the signal that correspond to spatial frequencies, which represent variations that are too fast (spatial frequency > 10 cm⁻¹) or too slow (< 10 cm⁻¹) to correspond to the reasonable size of a mine. In this way, the black plot of Figure 2 is obtained, showing positions of the true objects clearly.

The result of a scan over soil containing a surrogate mine buried 3-cm deep is shown in Figure 3 along with filtered signal. In this case, the delay time is in fact a difference in (heating and) cooling speed, rather than a pure exponential over a point versus time during cooling. We may assume that cooling is essentially exponential over bare soil and that a combination of exponential versus position on a scanning line, passing over the center of a surrogate mine. A very clear hump is visible, denoting presence of the buried object.

**Discussion of Results, Conclusions and Perspectives**

The active thermal system discussed in the previous section of the article is being developed as a means of detecting shallowly buried low-metal content ERW. Preliminary results prove that it is a promising technique, consistent with operational requirements, as was previously stated during our discussion on the importance of monitoring at the Technical Survey earlier in the article. However, the technique is still not mature for practical application.

In the next few months, we expect to obtain extensive characterization of performance, in particular concerning feasible depth of detection, in the sandbox. Within the same time frame, we will use robots to carry heaters and instruments, in order to perform outdoor experiments in more realistic settings. In one year, we expect to complete a feasibility study for a practical system and be ready for prototyping. Experiments with vibrothermal techniques are already under way, so that within the same year we should be able to take scans with the LDV and GPR alongside the thermal system and start evaluating the combination of information from the different sensing schemes (data fusion).

The issue of depth appears to be an intrinsic limitation for thermal systems that are basically limited by the ratio of depth to size of the object, so that a 5-cm depth is probably the limit for detection of an 8-cm diameter mine (while it is in fact known that larger anti-tank mines are visible at larger depths even from aerial imaging). In our opinion, the thermal system will not be sufficient alone but is a good complement to systems that perform well near the surface, and it works for totally metal-free objects.

Another significant issue still to be addressed in vegetation. In fact, wherever the surface is not visible, the system is easily blinded. While a light cover of grass might only add more clutter to measurements, any significant vegetation needs to be removed before scanning. It is to be noted, however, that pyrometers are very small and light, so that they can be scanned through grass very close to the surface, while X-ray cameras would suffer stronger limitations. See Endnotes, page 114.

This research was partly supported by the Italian Administration of Città di Latina, Italy, and by the nonprofit organization Tecnologie Solidali, Rome, Italy.