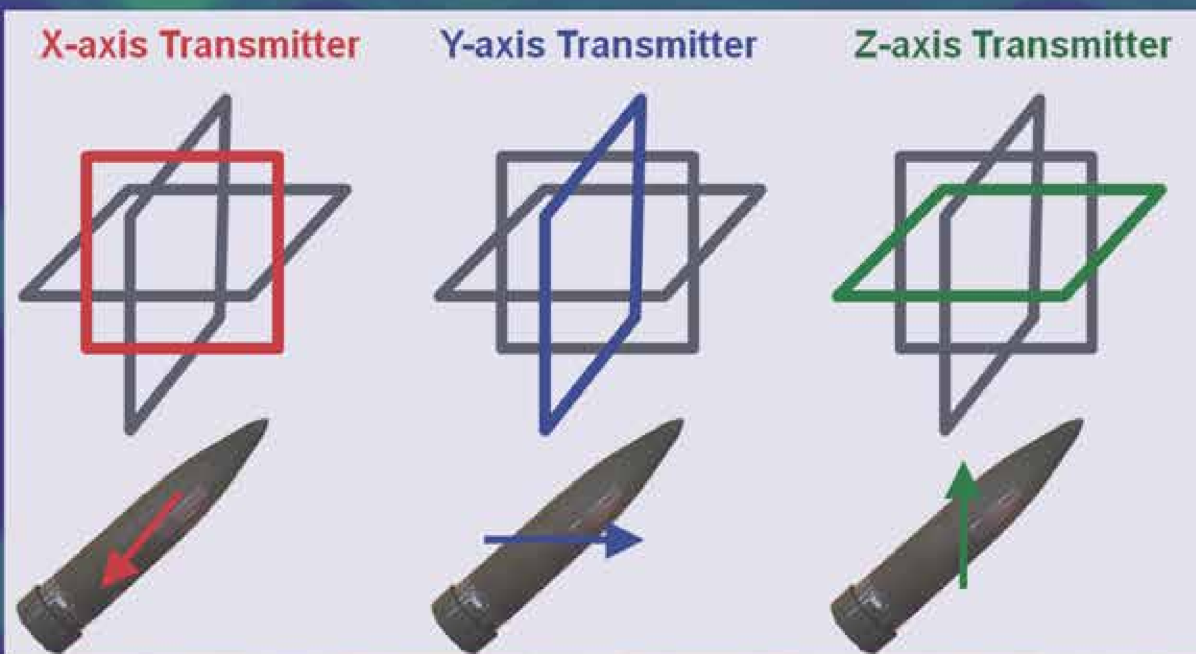
FastTIMES

UXO Geophysics:

Detection and Mapping of UXOs by Electromagnetic Induction Sensor and Self-Tracking Total Station

Case Study: Classification of MEC Targets Using Advanced TDEM Instruments and Analysis

A Man Portable EMI System for Detection and Classification of Unexploded Ordnance in Challenging Environments



Dynamic UXO Classification Sensors: Advanced Digital Geophysical Mapping for Munitions Response Sites

Higher-Resolution Mapping for UXO Including Detection of 20mm Projectiles at Depth

Advanced Classification: What We've Learned and Where We're Heading

September 2014
Volume 19, Number 3

In this special issue of *Fast*TIMES, there are six articles focused on the use of near-surface geophysical methods to locate and map unexploded ordinance (UXO).

Contents

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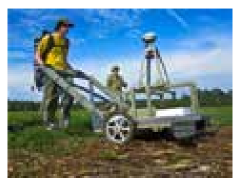

Articles

*Fast*TIMES

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ABOUT EEGS

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"To promote the science of geophysics especially as it is applied to environmental and engineering problems; to foster common scientific interests of geophysicists and their colleagues in other related sciences and engineering; to maintain a high professional standing among its members; and to promote fellowship and cooperation among persons interested in the science."

We strive to accomplish our mission in many ways, including (1) holding the annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP); (2) publishing the Journal of Environmental & Engineering Geophysics (JEEG), a peer-reviewed journal devoted to near-surface geophysics; (3) publishing *Fast*TIMES, a magazine for the near-surface community, and (4) maintaining relationships with other professional societies relevant to near-surface geophysics.

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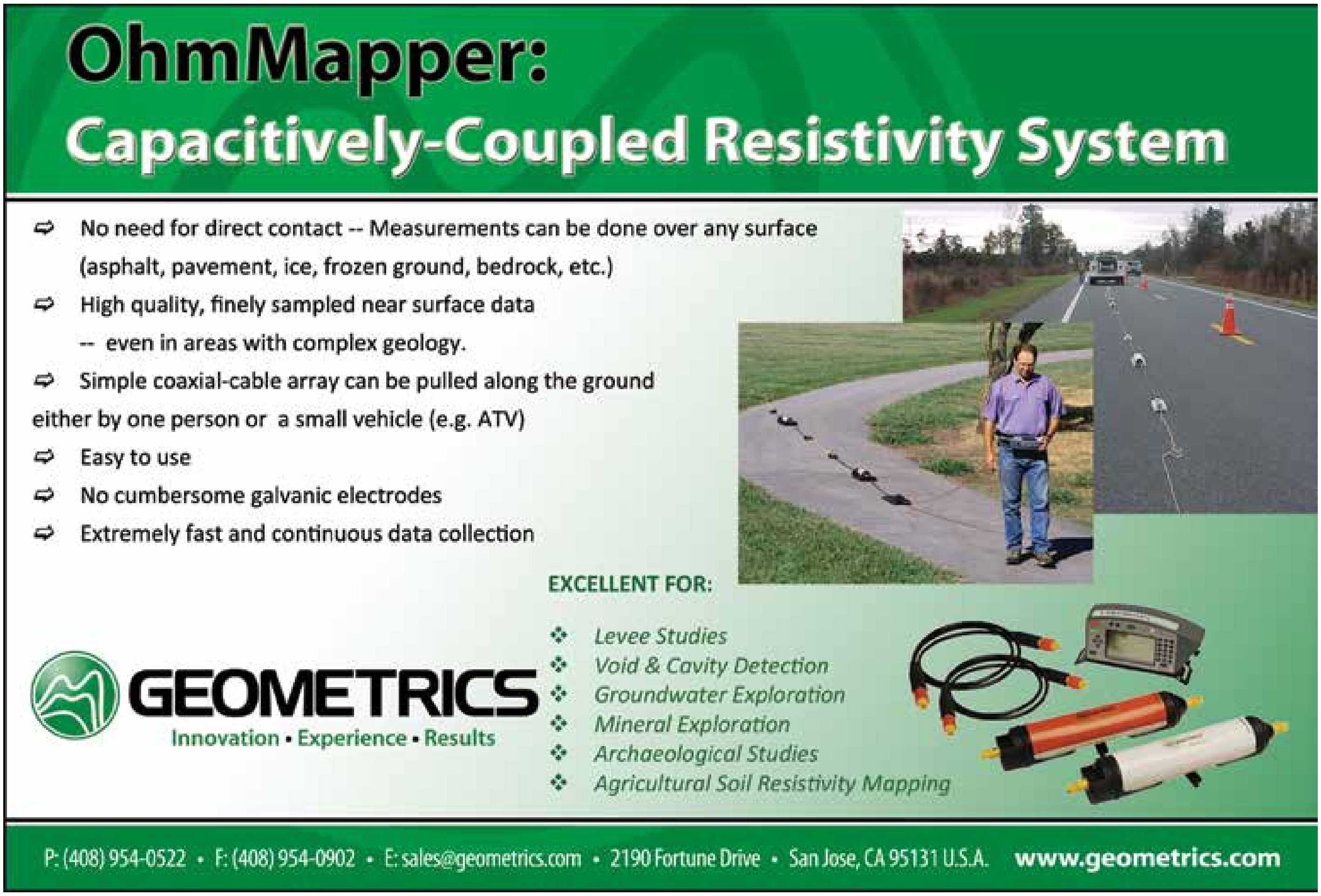
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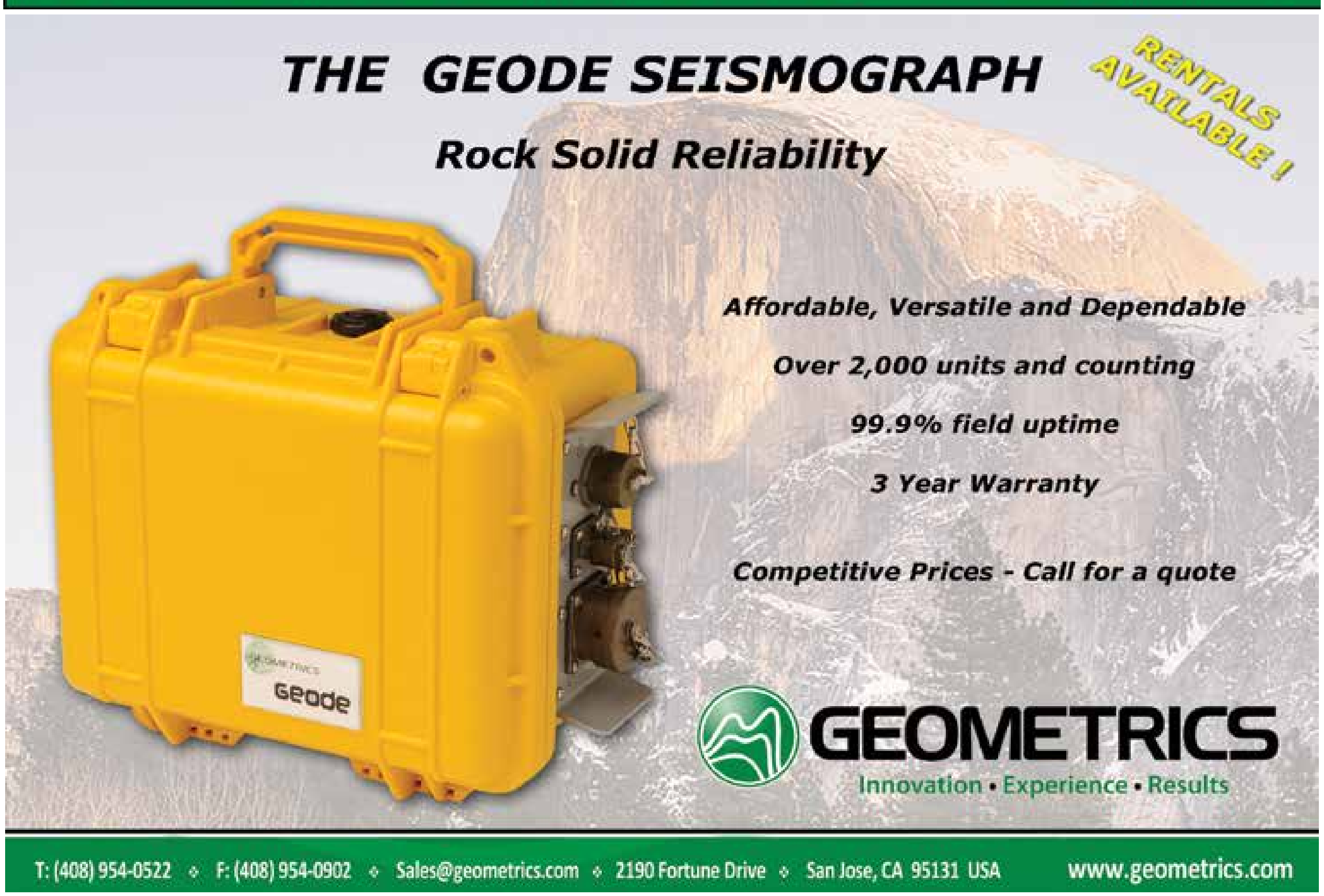
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http://www.seg.org

November 6-7 Multichannel Analysis of Surface Wave (MASW) Workshop
Lawrence, Kansas, USA
http://www.kgs.ku.edu/software/surfseis/workshops.html

December 3 - 4 1st Society of Exploration Geophysicists - Sociedade Brasileira de Geofísica Workshop on Near Surface Geophysics
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December 15 - 19 American Geophysical Union Fall Meeting
San Francisco, California, USA
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2015

February 15 - 18 Australian Society of Exploration Geophysics and Petroleum Exploration Society of Australia - 24th International Geophysics Conference and Exhibition
Perth, Australia
http://www.conference.aseg.org.au
(Note: See page 60 for additional information.)

March 22 - 26 Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP)
Austin, Texas, USA
http://www.eegs.org/Annual-Meeting-SAGEEP/SAGEEP-2015
(Note: See page 59 for additional information.)

October 5 - 9 14th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst
Rochester, Minnesota, USA
http://www.sinkholeconference.com/

Please send event listings, corrections or omitted events to any member of the *Fast*TIMES editorial team.

NOTES FROM EEGS

PRESIDENT'S MESSAGE

Moe Momayez, President
(mmomayez@email.arizona.edu)

IMPACTING THE PROFESSION AND THE PUBLIC

For over 15 years, the American Geosciences Institute has organized Earth Science Week, an international event to foster a better understanding of geosciences and to encourage the careful management and sustainable development of our planet's resources. This year's event will take place from October 12 to 18. Since its inception, EEGS has promoted the science of geophysics as it is applied to environmental and engineering problems. The near-surface community is expected to grow for the foreseeable future, and EEGS will continue its efforts to promote fellowship and cooperation among near-surface geophysics practioners around the world.

As the premier Society championing the development and diligent use of near-surface geophysical techniques, EEGS will expand its reach by forging partnerships with other societies and actively contribute to the field by providing specialized services to its membership and beyond. This is especially important considering that the 4D and 5D characterization of the near surface media and man-made infrastructure have become an integral component of any environmental and engineering project. For example, all mine development projects today call for a closure plan that would involve the development of an integrated system that includes networked geophysical, hydrological, and self-calibrating general chemical sensors to monitor leakage and fluid flow in the subsurface in and around the mine property. Geophysical monitoring can help manage risks and mitigate the engineering costs of mine closure. Similar examples where geophysics can play an integral part and provide substantial cost saving measures in the civil, geotechnical, environmental and other engineering fields abound. EEGS is uniquely positioned to connect the application of near-surface geophysical technologies with societal needs related to environmental stewardship, hazard detection, and sustainable resource development.

The EEGS review of internal processes and future direction will continue over the next few weeks. The Board of Directors is interested in your views of the Society and how we can improve our services. If you haven't contacted us, go ahead and write to me personally, or drop a note via email or anonymous letter to the EEGS staff.

Preparations for the SAGEEP 2015 is in full swing. The online abstract submission site opens on September 5 and the deadline for the initial short abstracts and optional extended abstracts submission is October 17. SAGEEP 2015 is shaping up to be one of the most exciting conference EEGS has ever organized. As a reminder, the SAGEEP hotel special rate will include 3 days prior to SAGEEP to let you take advantage of the South by Southwest festival. I look forward to welcome all of you in Austin.

Moe Momayez, EEGS President

EEGS Foundation makes great strides in its first years.

Since the launch of the EEGS Foundation, there are numerous accomplishments for which we can all be proud: Establishing and organizing a structure that serves the needs of EEGS; underwriting the legal process, achieving tax-exempt status; and soliciting and receiving support for SAGEEP. In addition, the Foundation helped underwrite the SAGEEP conference held this spring in Keystone.

These are only a few of the tangible results your donations to the Foundation have enabled. We would therefore like to recognize and gratefully thank the following individuals and companies for their generous contributions:

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Sponsorship Opportunities

There are always sponsorship opportunities available for government agencies, corporations, and individuals who wish to help support EEGS's activities. Specific opportunities include development and maintenance of an online system for accessing SAGEEP papers from the EEGS web site and support for our next SAGEEP. Make this the year your company gets involved! Contact Moe Momayez (mmomayez@email.arizona.edu) for more information.

From the *Fast*TIMES Editorial Team

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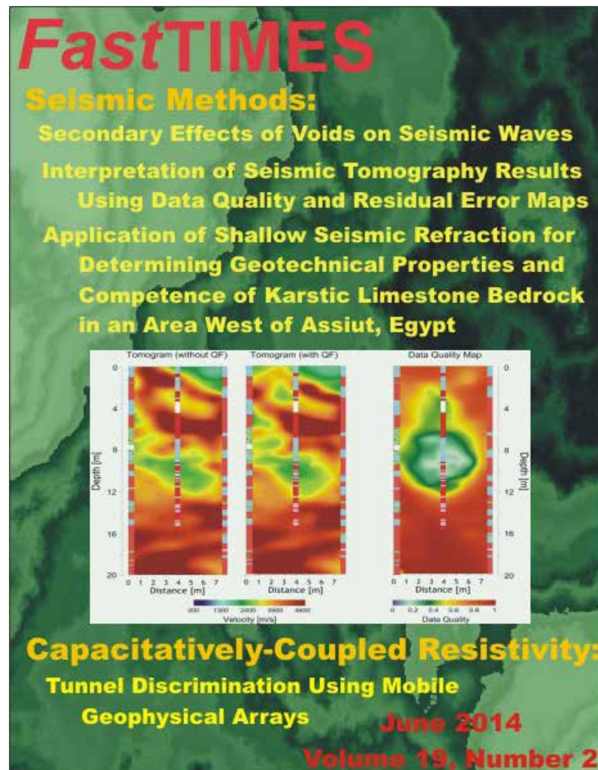
To keep the content of *Fast*TIMES fresh, the editorial team strongly encourages submissions from researchers, instrument makers, software designers, practitioners, researchers, and consumers of geophysics—in short, everyone with an interest in near-surface geophysics, whether you are an EEGS member or not. We welcome short research articles or descriptions of geophysical successes and challenges, summaries of recent conferences, notices of upcoming events, descriptions of new hardware or software developments, professional opportunities, problems needing solutions, and advertisements for hardware, software, or staff positions.

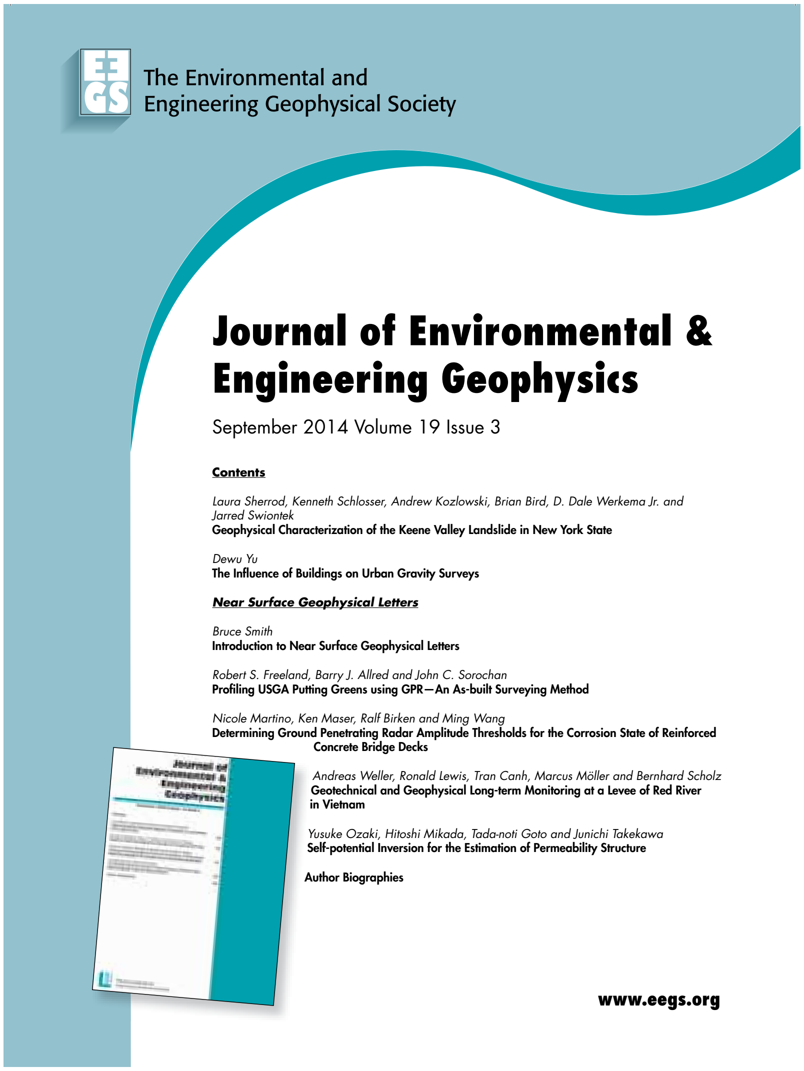
The *Fast*TIMES presence on the EEGS web site has been redesigned. At http://www.eegs.org/Publications-Merchandise/FASTTIMES you'll now find calls for articles, author guidelines, current and past issues, and advertising information.



Submissions

The *Fast*TIMES editorial team welcomes contributions of any subject touching upon geophysics. *Fast*TIMES also accepts photographs and brief non-commercial descriptions of new instruments with possible environmental or engineering applications, news from geophysical or earth-science societies, conference notices, and brief reports from recent conferences. Please submit your items to a member of the *Fast*TIMES editorial team by November 15 to ensure inclusion in the next issue. We look forward to seeing your work in our pages. Note: The December *Fast*TIMES issue will highlight EEGS student chapters. *Fast*TIMES is also looking for guest editors who are interested in organizing a *Fast*TIMES issue around a special topic within the guest editor's area of expertise. Please contact Barry Allred (Barry.Allred@ars.usda.gov) if you would like more information on being a *Fast*TIMES guest editor.

The Journal of Environmental & Engineering Geophysics (JEEG), published four times each year, is the EEGS peer-reviewed and Science Citation Index (SCI®)-listed journal dedicated to near-surface geophysics. It is available in print by subscription, and is one of a select group of journals available through GeoScienceWorld (www.geoscienceworld.org). JEEG is one of the major benefits of an EEGS membership. Information regarding preparing and submitting JEEG articles is available at http://jeeg.allentrack.net.



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Editor's Note

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SUCCESS WITH GEOPHYSICS

*Fast*TIMES welcomes short articles on applications of geophysics to the near surface in many disciplines, including engineering and environmental problems, geology, hydrology, agriculture, archaeology, and astronomy. In this special issue of *Fast*TIMES, there are six articles focused on the use of near-surface geophysical methods to locate and map unexploded ordinance (UXO).

DETECTION AND MAPPING OF UXOS BY ELECTROMAGNETIC INDUCTION SENSOR AND SELF-TRACKING TOTAL STATION

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Introduction

Currently, a metal detector based on electromagnetic induction is the most common detection sensor used in clearance operations of UXOs. This type of sensor has been used a long time and their reliability has been well documented. Electromagnetic induction sensors used in clearance operations for UXO output audible signals when a metallic object is detected, in contrast to those used by geophysical exploration experts, which output values of induced voltage or magnetic field strength. The audible output makes the onsite interpretation simple and straightforward, and thus, easily used by local deminers who are not familiar with the working principles of electromagnetic induction. This might be good enough for the simple detection/excavation/disarming workflow. However, in addition to the audible output, detection mapping capability provides additional benefits such as the improvement of detection performance and documenting survey results. We have been developing a landmine detector with a similar idea – to provide images of a buried target for identification by using ground-penetrating radar combined with a metal detector (Takahashi and Sato, 2008). The system "ALIS" is being deployed by Cambodian Mine Action Centre (CMAC) and tested in real mine fields. Testing has demonstrated the usefulness of imaging (Sato et al., 2012; Sato and Takahashi, 2013). Since 2009, two sets of ALIS tests have detected more than 80 antipersonnel mines.

A system that is capable of mapping metal detector output was developed and evaluated in a field test. In order for mapping to be carried out, the position of the sensor must be logged together with the sensor output. In our system, a self-tracking total station is used to obtain the position of the metal detector. Total station has been successfully combined with other geophysical methods such as ground penetrating radar (e.g., Böniger and Tronicke, 2010; Takahashi and Sato, 2013). The advantages of using a total station are discussed in the next section. The test demonstrated that the system works very well in the field environment.

Keywords: UXO, Metal Detector, Electromagnetic Induction, Total Station.

Metal Detector System

The metal detector used in our system is MIL-D1 DS (CEIA S.p.A, Italy), which has been used in clearance operations of UXOs. The detector is usually operated with audible signals in the field; however, it is also capable to output values of induced voltage. A self-tracking total station is combined to collect the position of the detector. The total station used in our system is QS3A (TOPCON, Japan), which features 20 Hz position acquisition rate and 3 arcseconds accuracy. Once the total station locks a target, it automatically tracks the movement up to a velocity of 15 degrees per second. A 360-degree prism is attached at the handle of the metal detector as a target for the total station to track. A computer is connected to the metal detector and the total station to record metal responses and coordinates. In order for the metal detector to move freely, the communication between the computer and the total station is via Bluetooth, i.e., it is cable free. Figure 1 shows the system. The metal detector data are shown on the computer display during the survey as a map, so that the operator can see where he is scanning and how strong the metal responses on that spot in real-time. In addition, the detector also outputs audible signals.

Figure 1: UXO detection system combining MIL-D1 DS and a total station. The sensor part also contains data acquisition computer and prism. The communication between the computer and total station is wireless using a Bluetooth transmitter.

The conventional UXO detectors usually give audible signals as an indication of buried metal. In UXO clearance operations, the location where the detector beeps needs to be marked immediately so that the spot can be located later for disarming. Our system can also be used in exactly the same way. In addition, it provides a map of metal responses by combining detector output and positions of the sensor. The mapping is considered to have the following advantages over the conventional method with audible signals only.

- **Higher Detection Performance** - In order to make the detector meet the performance requirement in the UXO clearance operation, the sensitivity needs to be set appropriately. The sensitivity setting is like a threshold that determines the intensity of the metal response at which the detector begins emitting audio "beeps". There could be a case that the sensor detected a response from an UXO, but did not beep, due to an inappropriate sensitivity setting, and consequently, the target was missed. Since mapping uses the direct metal response output from the sensor, there is no need for the sensitivity setting. Even very small responses can be recorded and recognized by adjusting color scales after the survey, while still keeping original data. This function improves the detection performance.
- **Easy Interpretation -** Since the output is a map, the interpretation is easy – it shows the intensity of the metal response and one can easily find metal objects. Smaller metal responses produced by smaller UXOs and/or ones buried deeper can easily be found by adjusting the contrast of the map after data acquisition.

A scenario where mapping is particularly preferred may be QA/QC operations. Currently, the audible output is not recorded. Even if it is recorded, it is useless without the position of sensor indicating where the data (strengths of audible signals) are collected. The results of survey, as a map of sensor output, provides the direct proof of clearance operations. The system employs a self-tracking total station to obtain positions of the sensor, which is supposed to move randomly. Positions of a moving sensor can also collected by using GPS or similar devices, however, a self-tracking total station has the following advantages.

(1) Ordinary GPS typically has 3 – 5 m positional accuracy and it is not sufficient for mapping at a few hundreds square meter area scale. A total station usually has enough accuracy to pinpoint a target, which is typically a few arcseconds.

(2) RTK-GPS may have enough positional accuracy. However, it typically costs more than double the price of a self-tracking total station. Moreover, demining and related organizations regularly conduct surveys and they may already have total stations. These existing total stations can easily be combined with metal detectors with a little software development. Or, newly purchased total stations can be used also for surveys. Furthermore, personnel for surveying are already familiar with the use of total station.

Field Test and Results

The UXO detection system was tested at the Cambodian Mine Action Centre (CMAC) in Kampong Chhnang, Cambodia. In a test area, there were 26 buried UXOs of different types at different depths. The UXO locations, types, and burial depths are shown in Figure 2. The entire test area shown in Figure 2 was surveyed to demonstrate detection performance of the system. The test was divided into four smaller areas to scan. The detector scanned in the y-direction for all areas. The total station was set at about (x, y) = (25, -3) m. Figure 3 shows how the survey was carried out.

Survey results are shown in Figure 4. Higher responses (red-colored pixels) are clustered around the locations of targets (blue crosses). There are some scattered high responses, which are considered to be a response from the soil. However, clustered high responses from UXOs are easily distinguishable due to their distributions. These results illustrate the advantage of the system with respect to visualization - easy interpretation.

The sensitivity was set at the nominal level at all times during this test. With this sensitivity setting, we could hear audible "beeps" at only a few locations during the survey. This means that, if MIL-D1 DS was used in the conventional way with audible signals, and with the sensitivity setting used in this field test, more than 20 targets would have been missed. However, with mapping, all the targets can be detected as shown in Figure 4. The only target that might be difficult to be detected from the survey result is a 82 mm mortar at (x, y) = (17, 9) m and 70 cm depth. Still, the results show better detection performance than with audible signals alone, even using the same sensor, which illustrates an advantage in higher detection performance.

It is clear that the detected locations are very accurate for some targets, in particular targets close to the total station. Inaccurate positioning may have two possible explanations: inaccurately planted targets and the accuracy degradation of the total station due to long-range distance. The positions of the targets shown in Figures 2 and 4 as crosses are planned positions (i.e., not measured positions of buried targets) and tape measures may have been used when the site was setup, thus the positions may contain errors. The position accuracy looks worse when the distance to the total station becomes larger. In this case, the error must be random, however, the detected positions look systematically deviated from the planned positions although they are not simple shift and rotation. Inaccurate positioning could be due to both explanations; however, more thorough experiments are required to find the exact reason and solve the positioning problem.

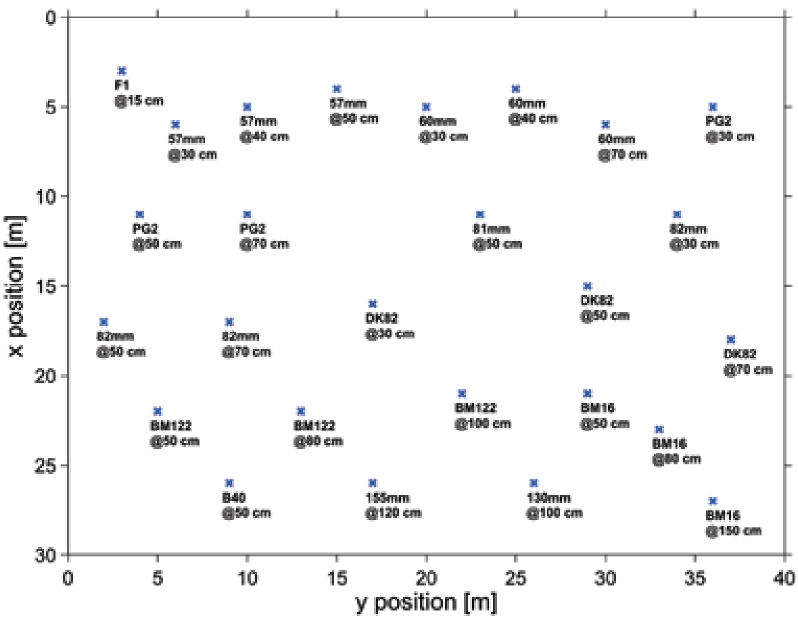

Figure 2: Positions, types, and burial depths of the targets planted in the test area.

Figure 3: Operation of the UXO detection system.

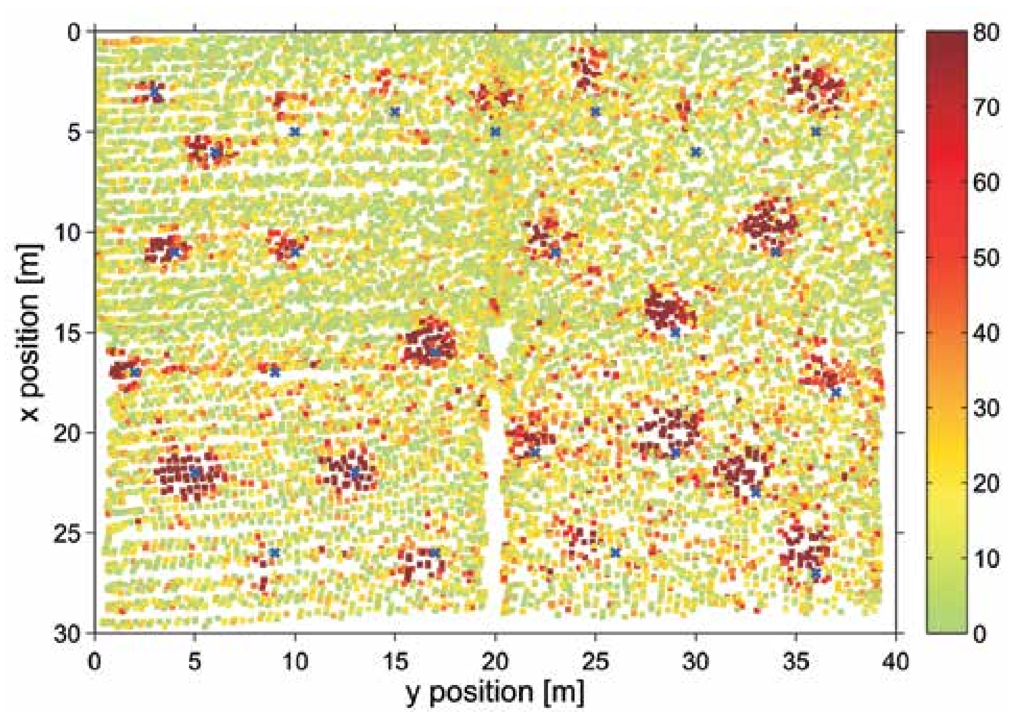

Figure 4: Survey results from the test area. Blue crosses indicate the positions of targets. (Data values are proportional to induced voltage output of detector.)

Conclusions

The test of the UXO detection system with mapping demonstrated the advantages in detectability, data interpretation, and usefulness of data recording. The system can be configured only with off-the-shelf devices, which UXO demining organizations may have already been using. Thus, it also has an advantage in cost over other mapping systems.

The survey results shown in Figure 4 do not depict the shape and/or orientation of targets. However, such conditions must be reflected in the data, and they can be extracted by further data processing, such as inversion (e.g., Lhomme et al., 2008). That information is particularly valuable in real clearance operations, because more exact and safer disarming procedures can be taken by identifying target type, mechanisms, and location of the fuse. The system can provide enough position accuracy and data for inversion processing.

Acknowledgements

The authors would like to thank Cambodian Mine Action Centre (CMAC) for supporting the field test and providing necessary resources. This work was supported in part by the Japan Society for the Promotion of Science (JSPS) under Grant-in-Aid for Scientific Research (A) 26249058 and (C) 24612001.

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CASE STUDY: CLASSIFICATION OF MEC TARGETS USING ADVANCED TDEM INSTRUMENTS AND ANALYSIS

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Introduction

The location and removal of munitions and explosives of concern (MEC) has been an ongoing mission for the Department of Defense (DoD) with hundreds of thousands of acres having already been remediated and an equal or greater amount still awaiting remediation throughout the US and around the world. During the past 15-20 years, digital geophysical mapping (DGM) has become one of the most commonly used tools for the detection of MEC. DGM has consistently shown significant advantages over more traditional analog techniques (mag and flag) both by providing a permanent digital record of subsurface conditions and by significantly reducing the number of target locations that require intrusive investigation. However, even with the use of DGM, it has been estimated that 90% or more of the intrusive investigations result from the presence of non-hazardous and/or non-MEC related materials. The process known as target classification attempts to remedy this by utilizing DGM data to gather more information about an object before removing it from the ground.

A new generation of advanced time-domain electromagnetic (TDEM) sensors and associated data analysis techniques developed in the last several years has, for the first time, made target classification for MEC a realistic goal. The defining characteristic of these systems is their fixed multi-transmitter and tri-axial receivers which illuminate a source from multiple directions and then record the transient decay. This configuration allows for the collection of more information on the response characteristics of a given subsurface object. Software and processing techniques developed to take advantage of this new data has led to the ability to classify MEC targets with greater accuracy than ever before. Several government agencies, primarily the Environmental Security Technology Certification Program (ESTCP) and the U.S. Naval Research Laboratory (NRL), have sponsored demonstrations around the country to allow contractors the opportunity

Keywords: Time-Domain Electromagnetic (TDEM), Digital Geophysical Mapping (DGM), Munitions and Explosives of Concern (MEC), Targets of Interest (TOI).

to test these new methods and to refine the data collection and data processing techniques. NAEVA has participated in 12 such demonstrations and/or remediation projects to date, producing results that significantly reduce the number of targets requiring intrusive investigation while still finding the actual targets of interest (TOI). At the former Southwestern Proving Ground (SWPG) demonstration, conducted in May 2013, NAEVA was able to achieve a greater than 85% reduction in the total number of targets without missing any TOI.

SWPG Demonstration Overview

The demonstration at SWPG was performed as one of a series of ESTCP demonstrations of classification technologies for munitions response. It was designed to evaluate classification methodology at a site with a range of munitions sizes (20mm to 155mm projectiles). The TEMTADS 2x2 person-portable cart was demonstrated in dynamic and cued modes. Dynamic mode involves collecting geophysical data while the instrument is in motion, typically along a series of closely-spaced parallel traverses designed to provide full coverage of given area. Cued data is collected with the instrument stationary and is intended to provide a detailed dataset over a specific point, usually a known subsurface anomaly.

Test Design

There were three key objectives for the SWPG demonstration: collection of high-quality geophysical data and principled selection of anomalous regions in those data; analysis of the selected anomalies using physics-based models to extract target parameters such as size, shape, and materials properties; and the use of those parameters to construct a ranked anomaly list. Each of these components was addressed as a separate step over the course of the demonstration. At a live site such as this, it is expected that only a small number of TOI may be found; far from enough to determine classification performance with acceptable statistical confidence bounds. To avoid this problem, the site was seeded with enough TOI to ensure reasonable statistics with the goal of correctly classifying 100% of the seeded TOI. Performance objectives for the demonstration provided a basis for evaluating the effectiveness and cost of the demonstrated technology. Since this was a detection and classification demonstration, the performance objectives focused on the detection and targeting of all TOI during the dynamic survey and their correct classification during the cued survey.

Site Description

The former SWPG is located in Hempstead County in southwest Arkansas. The demonstration was performed in Recovery Field 15 (RF 15), an area consisting of open farmland with even grade across the site. The 3-acre site was divided into several test areas as shown in Figure 1.

The conceptual site model included the following expected munitions at the demonstration site:

- **20mm**, 37mm, **40mm**, **57mm**, 75mm, **76mm**, **90mm**, 120mm, 105mm, 155mm projectiles, and
- 81mm mortars.

The bolded items identify munitions types recovered during previous investigations. The non-bolded items were recovered at nearby locations and could be reasonably anticipated at RF 15. Note the presence of 20mm projectiles as one of the expected munitions. This is one of the smallest items that can be reliably detected by DGM methods and therefore has a low signal-to-noise ratio (SNR).

After emplacing inert munitions, the demonstration area was mapped using dynamic detection surveys, classification data were collected using cued surveys, and then selected anomalies were excavated to evaluate technology performance. Demonstrators generated ranked anomaly lists which were scored based on the ability to correctly eliminate nonhazardous items while retaining all detected TOI above a stop dig point.

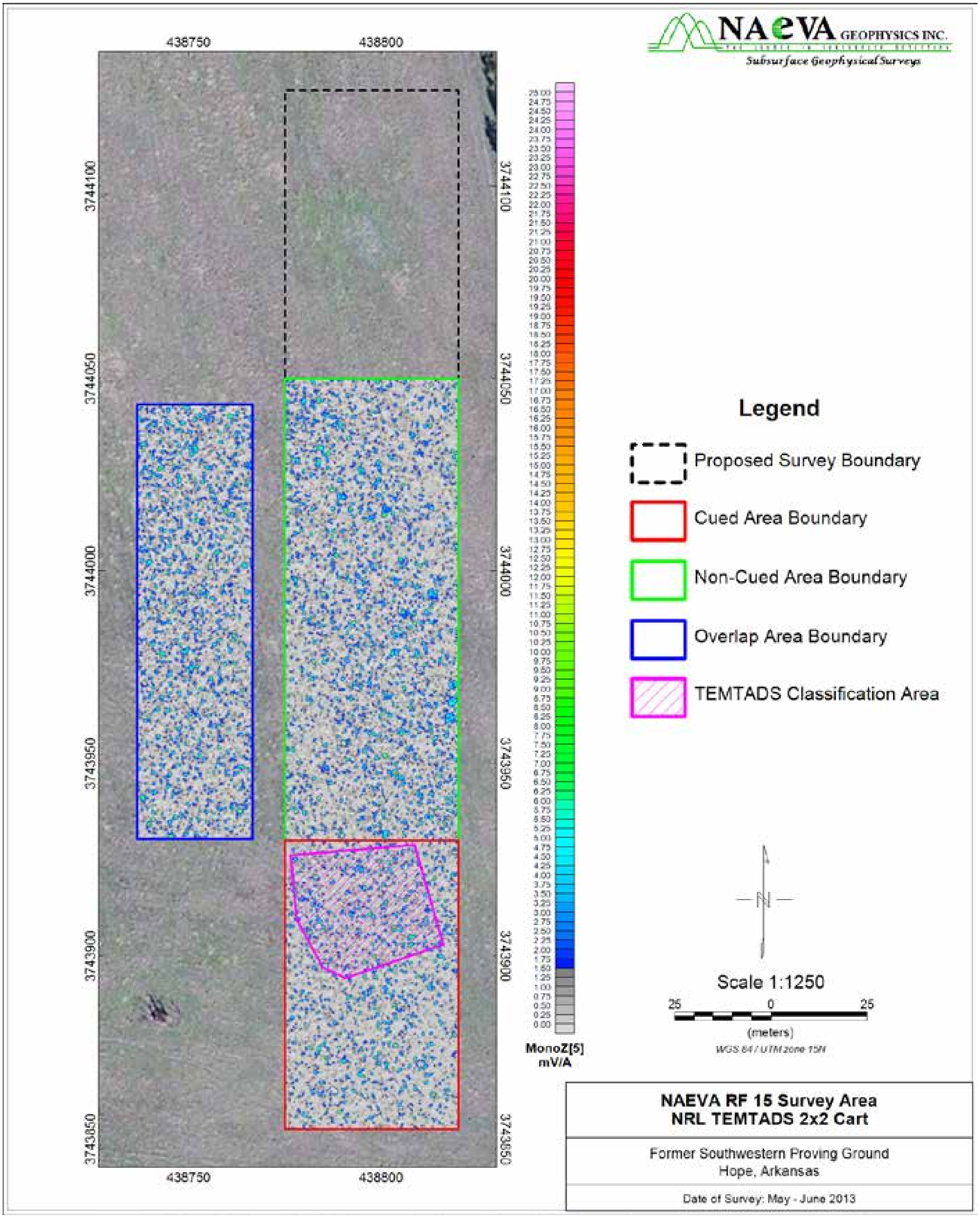

Figure 1: NAEVA dynamic and cued TEMTADS collection areas.

NAEVA collected 3 acres of dynamic data at RF 15 with the TEMTADS 2x2 and selected 1,539 targets for cued interrogation based on anomaly selection thresholds derived from on-site instrument response test data. Static cued measurements were collected over all of the target locations and 500 of these underwent advanced classification. The areas within RF 15 where the cued portion of the demonstration was performed are shown in Figure 2. The classification boundary was selected to encompass an area with the number of anomalies needed for the classification phase of the demonstration.

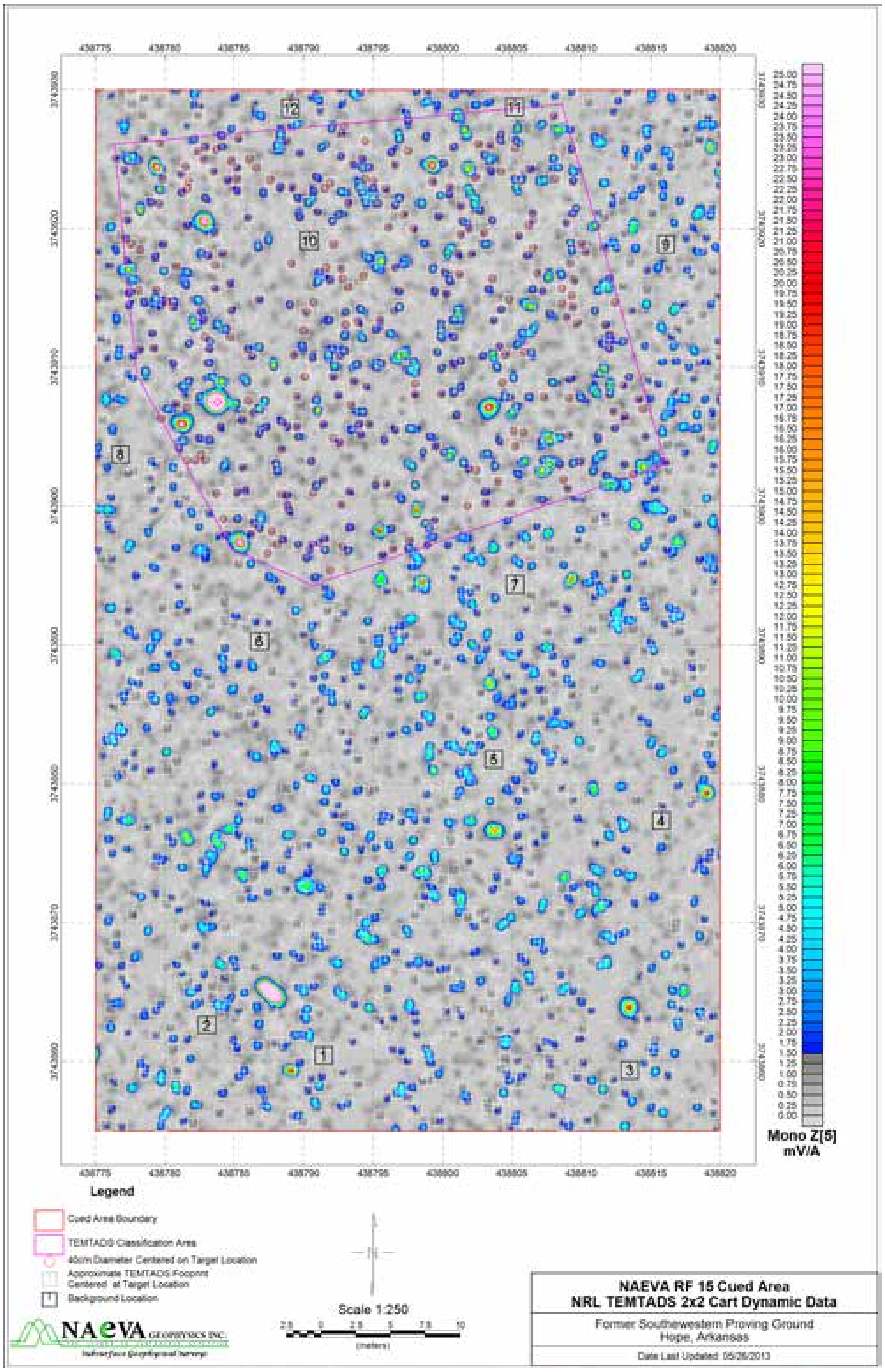

Figure 2: NAEVA cued and classification areas with dynamic data and target selection locations.

Technology Description

TEMTADS/3D EMI Sensors

The TEMTADS 2x2 is an advanced EMI sensor based on NRL's TEMTADS system (Figure 3). The TEMTADS 2x2 consists of four 40-cm transmit coils with four 8-cm tri-axial receiver cubes. For use at SWPG, the system was configured on a wheel-mounted cart measuring approximately 80cm per side with integrated real-time kinematic global positioning system (RTK GPS) equipment and an inertial measurement unit (IMU) used for accurate positioning and orientation measurements. Decay data are collected with a 500 kHz sample rate until 25 ms after turn off of the excitation pulse. These raw decay measurements are grouped into 122 logarithmically-spaced "gates" with center times ranging from 25 Qs to 24.35 ms with 5% widths.

Figure 3: Data collection with the TEMTADS 2x2 cart at SWPG.

Geosoft Oasis Montaj UX-Analyze Module

On behalf of DoD and with support from ESTCP, Leidos, Inc. and Geosoft, Inc. are developing the UX-Analyze Advanced module which provides a comprehensive set of tools for processing, analyzing, and classifying targets from advanced TDEM systems. Raw sensor data is imported into the Oasis Montaj environment where corrections and data quality checks are performed. Inversion modeling functions are used to extract target parameters from cued data followed by the use of library matching tools to rank targets based on the likelihood that they represent TOI. This comprehensive software package is currently the industry standard for MEC data processing and the UX-Analyze module is the only commercially distributed software available for analysis of advanced TDEM data.

Advantages and Limitations of the Technology

The major advantage of the advanced EMI sensors and UX-Analyze software is that combined, they provide a greatly enhanced ability to classify anomalies as being either TOI or non-TOI as compared to conventional DGM sensors (e.g., EM61-MK2). The TEMTADS 2x2 was designed to offer similar cued-mode production rates and classification-grade data quality as seen for larger, towed advanced EMI sensors while operating in rough terrain and treed areas that the larger systems cannot access.

One of the limiting factors in target classification is the ability to accurately resolve individual target parameters when influences from multiple sources are recorded by the sensor. Small sensors were chosen for the TEMTADS 2X2, which helps mitigate this problem but cannot eliminate it completely. Recent developments, including solvers designed for classification in multiple-object scenarios, are being evaluated for their effectiveness in cluttered environments.

Detection Survey

Collection

For each transmit pulse, the responses at all four sensor elements are recorded. The GPS, IMU and EM data are all logged sequentially into a single data file and stored in a binary TEM format. Dynamic collection parameters were set to record the response decay at 19 time gates with center times ranging from 25 Qs to 2500 Qs. The designed survey lane spacing was 0.4m and average down line station separation was approximately 0.1 m.

Processing and Quality Control

Data conversion software, ConvertTEMTADS v2.2, was used to convert and position the data in an ASCII format for preprocessing and target selection. The raw data is formatted with positional data interpolated for the array platform location and raw TEM data for all transmitter/receiver (Tx/Rx) combinations across the 19 time gates. Quality control (QC) checks are performed on the raw data to ensure proper instrument function and data location prior to locating the individual Tx/Rx readings. A smoothing filter is applied to each of the four transmitter currents and data statistics are reviewed to ensure the variation and range is acceptable for each transmitter. The IMU data is also smoothed due to inherent noise and the chance for spurious readings from the IMU which would not accurately represent actual movement of the system. Time progression checks are performed on the CPU and GPS time to ensure data is being logged continuously, and any suspect data is flagged and disregarded in later steps.

Filtering and Drift Correction

A located and normalized dataset is created by positioning the individual Tx and Rx units based on the corrected GPS and IMU data, then normalizing the response according to the transmitter current. EM response filtering is performed to correct for drift and to remove background effects. Monostatic Z channels are created for several of the time gates and the data are converted from negative to positive values. For this demonstration we elected to evaluate the sum of gates 5 through 12, gate 5, gate 12, and gate 16. Target selection was performed on corrected monostatic Z gate 5 data along with decay and signal strength above background evaluations of multiple gates. A windowed statistical leveling filter that removed the median background value from the data was used to apply a leveling correction. To compensate for a small directional positional offset, a small latency correction was applied.

Anomaly Selection

Anomalies were selected using a target selection threshold based on the expected minimum response of a 20mm at 15cm below ground surface (1.50mV/Amp). A grid peak picking algorithm was used to generate automated initial target selections. The gridded data was displayed on a map and evaluated along with profiles of the four selected monostatic Z channels during target refinement. Using a search radius of 40cm, duplicate targets were removed and anomalies above threshold that were not selected with the automated picking routine were added.

Cued Survey

Collection

For the collection of static cued data measurements, a plastic pin flag was placed over each anomaly selected for investigation. The TEMTADS 2x2 was then positioned over the target flag and the transmitter for each array sensor was fired in sequence and decay data were collected from all twelve receiver coils for each transmitter pulse. These data were then stored electronically on the data acquisition computer.

In the field, the operator had access to a series of monostatic decay plots to allow for on-the-fly data QC prior to moving to the next target. In addition, a single-source inversion could be performed to verify the inverted signal location was within the defined QC radius. After collection, additional QC checks were performed by a data analyst using UX-Analyze and any data set deemed unsatisfactory was returned to the field team for recollection.

Preprocessing

The objective of the preprocessing stage is to prepare the cued data for the inversion process. Preprocessing includes metadata verification, background analysis and review, and the identification of questionable or unusable channels. After the data was imported into Oasis Montaj, the initial checks were performed to identify any measurements with poor GPS quality or IMU malfunction.

Data were evaluated from 0.077 ms, corresponding to the 14th recorded time gate, to the end of the time spectrum. Background measurements were reviewed for variability and to identify outliers using statistical tools included in the UX-Analyze module and by the visual analysis of the transient decays. Any background measurements exhibiting poor characteristics, including noise in the early times or influence from nearby metal, were not considered for use as background correction samples. Survey data was corrected using the background samples and data quality checks were then performed on the background corrected targets. Measurements demonstrating a coherent signal separable from noise and no other data quality issues were retained for classification processing.

Parameter Estimation

The raw signature data from the TEMTADS sensors reflect details of the sensor/target geometry as well as the inherent EMI response characteristics of the targets themselves. The principal axis polarizabilities (β_1, β_2, β_3) intrinsic to the target were separated from the sensor/target geometry effects using a standard induced dipole response model. The location and orientation information recorded from the GPS and IMU were then used to locate the fit results in three-dimensional space.

All cued data were inverted using the single source and multi object solver algorithms contained in the UX-Analyze module. Extrinsic properties, including the location, depth, and orientation were reviewed along with the inverted polarizabilities for each target. Inverted results exhibiting large offsets between inverted and recorded sensor locations or unrealistic model depths were deemed unreliable for classification and were either recollected or remodeled. Additionally, parameters such as signal amplitude, dipole fit error, noise levels, and calculated offsets were evaluated.

Classification

Data for each target location was classified using the “Classify and Rank” routine contained in the UX-Analyze module. This routine combines library matching with rule-based decision making. The library used consisted of the measurements contained in the standard TEMTADS library distributed with UX-Analyze and test pit measurements collected at the start of the demonstration. The library was also supplemented with ground truth information requested from the ESTCP Program Office for a representative number of targets selected from target clusters identified during the initial analysis.

All ranked fit results were evaluated by the processors and targets were re-ranked and/or re-classified at processor discretion. This included the substitution of alternate fit results, the reclassification of targets with a good visual match not fully captured by the combined confidence metric, or the reclassification of targets based on their location in Size-Decay parameter space. Data review by the analyst includes evaluating the components of the data displayed in the example decision plot shown in Figure 4 (with the exception of the recovered item photograph). Thresholds were assigned for several parameters as part of the classification process. Threshold values were applied using the “Set thresholds and prioritize” tool contained in the “Classify and Rank” routine. The TOI threshold was determined based on a substantial drop-off in the visual similarity between the extracted polarizabilities and library TOI, training data ground truth, and intrusive results from the top ranked targets on the dig list.

Using the parameters outlined above, NAEVA produced ranked lists classifying each target from the processed data set. The first items on the initial ranked anomaly list were those targets for which ground truth had been requested. Following this, anomalies for which reliable parameters could not be extracted and therefore must be dug were listed. Next was the item deemed most likely a TOI followed by all items that are possibly TOI. Finally, all those items that the demonstrator was confident are Non-TOI were ranked by their confidence (least likely Non-TOI at the top, most likely Non-TOI at the bottom.) In addition, NAEVA provided an expected diameter range for the source (less than 50mm, between 50mm and 100mm, and greater than 100mm).

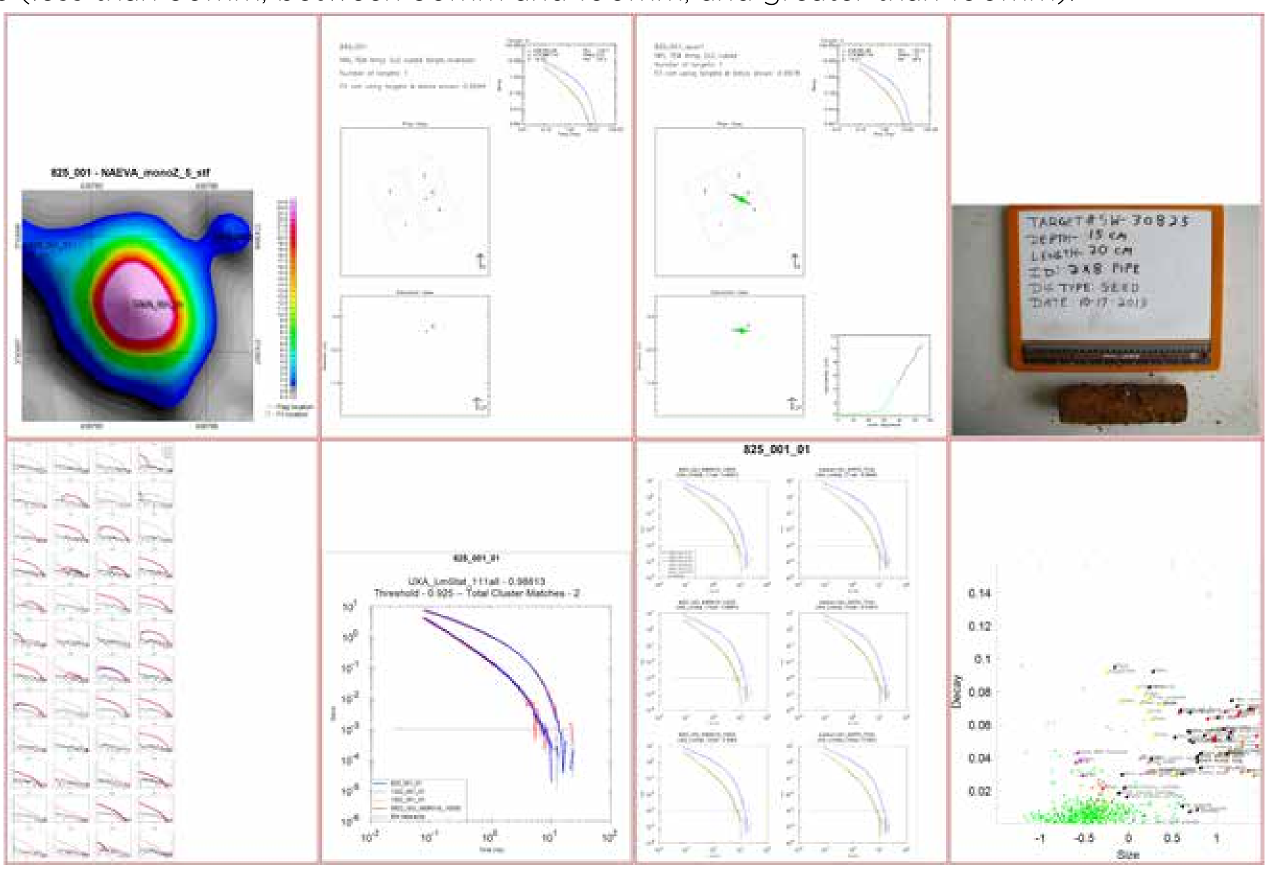

Figure 4: Decision plot for a cued target displaying (clockwise from upper left) dynamic TEMTADS detection survey data with target and fit locations, single source inversion result, multi source inversion result, photo of recovered item, transient decay traces, cluster polarizablity plot, library match polarizbility plot, and size/decay plot.

Performance Assessment – 20mm

NAEVA's ranked anomaly list was scored against the emplaced and recovered targets and was also analyzed to confirm that all QC seeds had been classified correctly. No TOI were missed and the receiver operating characteristic (ROC) curve is shown in Figure 5, with the areas of interest for the analysis described below.

The key regions to interpret the curves used in this program are:

- Origin to Point A: Targets for which ground truth was provide to aid in classification.
- Point A to Point B: Targets requiring intrusive investigation because they cannot be classified.
- Point C: Location of the lowest ranked TOI on the dig list.
- Point D: NAEVA's stop dig point, the threshold for the dividing point between targets classified as potential TOI and Non-TOI. No TOI were missed and 31 Non-TOI items remained above the dig line meaning that 437 Non-TOI did not have to be dug.
- Point D to Point E: Targets that were below the stop dig point representing the reduction in intrusive effort gained through classification. For successful classification, all targets of interest will fall to the left of Point D and the majority of non-TOI will be located to the right of point D.

The primary performance metric is the point at which the curve reaches 100% identification of TOI. The number of non-TOI correctly classified is a measure of the savings possible through classification.

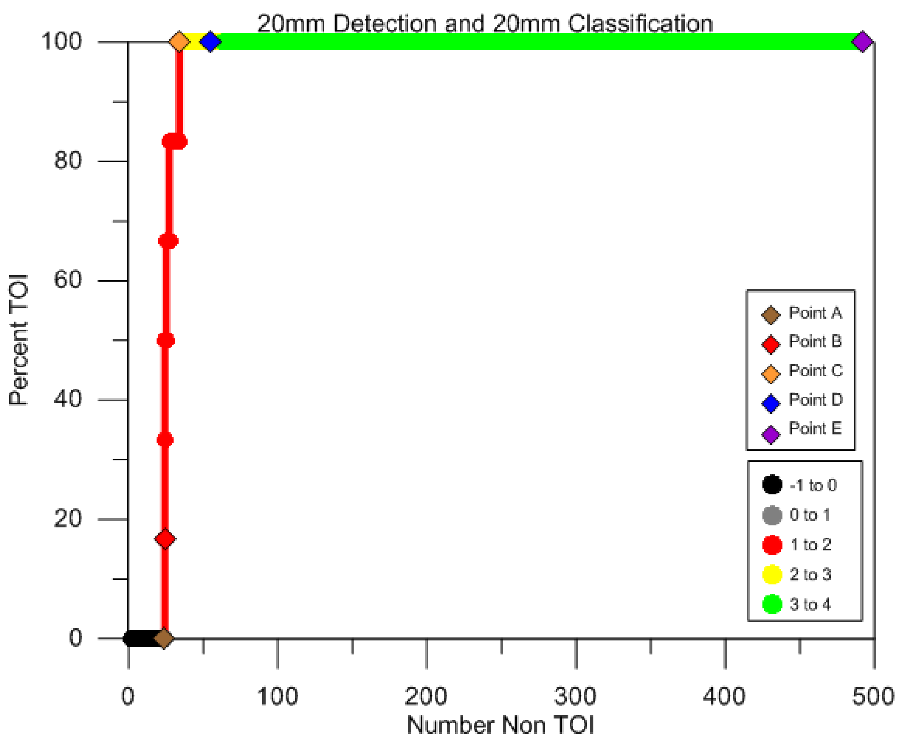

Figure 5: NAEVA's ROC curve from initial demonstration with goal of detecting and classifying 20mm to a depth of 15cm. Key regions (A, B, C, D and E) are indicated.

Performance Assessment – 37mm

The demonstration was designed based on the presence of 20mm projectiles (Figure 6). However, the smallest TOI encountered within the TEMTADS demonstration area was a 37mm at less than 15cm depth (Figure 6). On-site dynamic testing over a 37mm projectile 20cm below ground surface (to center of item) produced a significantly higher threshold (3.00mV/Amp) than that used for detection of a 20mm and would have resulted in a corresponding change in the number of targets selected and classification performance.

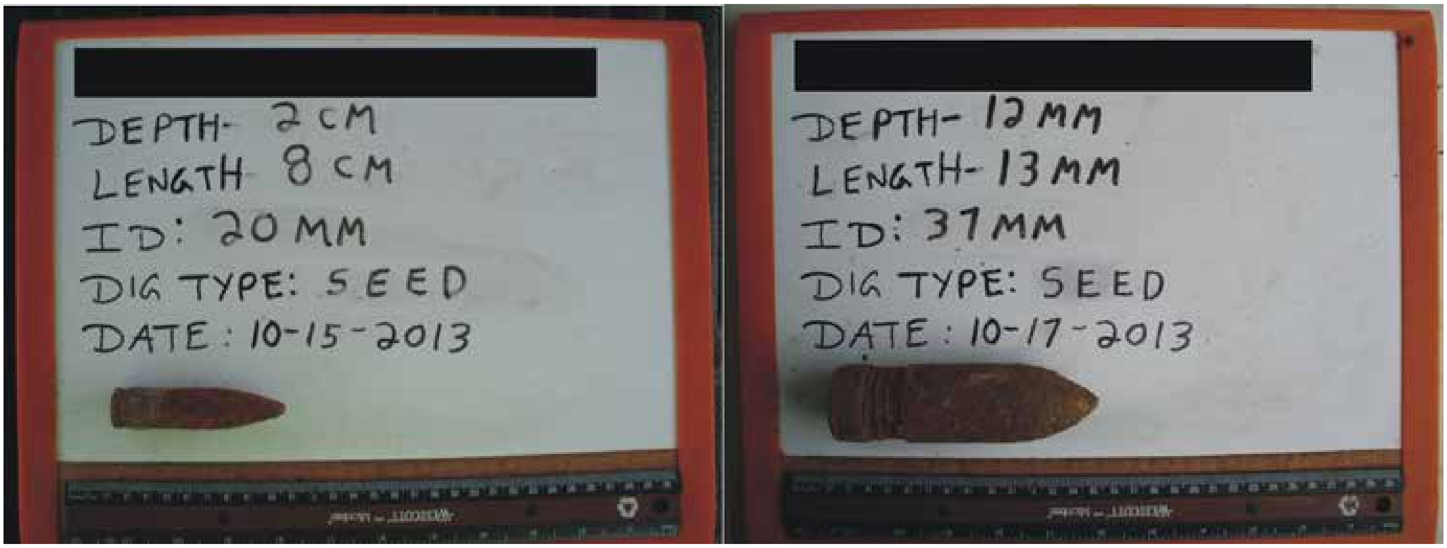

Figure 6: Examples of 20mm projectile (left) and 37mm projectile (right) recovered at SWPG.

The following offers a brief survey of the site activities that are impacted by the number of selected targets to analyze and investigate:
(1) detection survey and target selection to generate an initial target list,
(2) target reacquisition (may be optional on some sites),
(3) cued data collection to be performed at all locations on the initial target list,
(4) classification to be performed on all cued data collected, and
(5) intrusive investigation performed on all targets above stop dig point on the ranked target list.
The threshold used in step 1 will impact reacquisition and cued classification level of effort. For this demonstration there would be a 37% decrease in the number of targets on the initial list if the smallest TOI was changed from a 20mm to a 37mm. The time required to analyze and classify the data would also be reduced. Smaller low signal targets are more difficult to extract classification parameters from and as a result are more difficult to differentiate from similar sized clutter. Re-analyzing the data based on the actual smallest TOI produces the following results (Table 1 and Figure 7).

Table 1: UXO Detection Results.

Classification Stats	20mm Targeting and 20mm Classification	20mm Targeting 37mm Classification	37mm Targeting 37mm Classification
Total Number of Targets	500	500	316
Total Number of TOI	6	6	6
Total Number of Clutter	494	494	310
Dig/Above Stop Dig Point	61	33	23
Do Not Dig/Below Stop Dig Point	439	467	293
Total TOI Above Stop Dig Point	6	6	6
Clutter Above Stop Dig Point	55	27	17
% TOI Recovered	100.0%	100.0%	100.0%
% clutter dug	11.1%	5.5%	5.5%
% Targets Left in Ground	87.8%	93.4%	92.7%

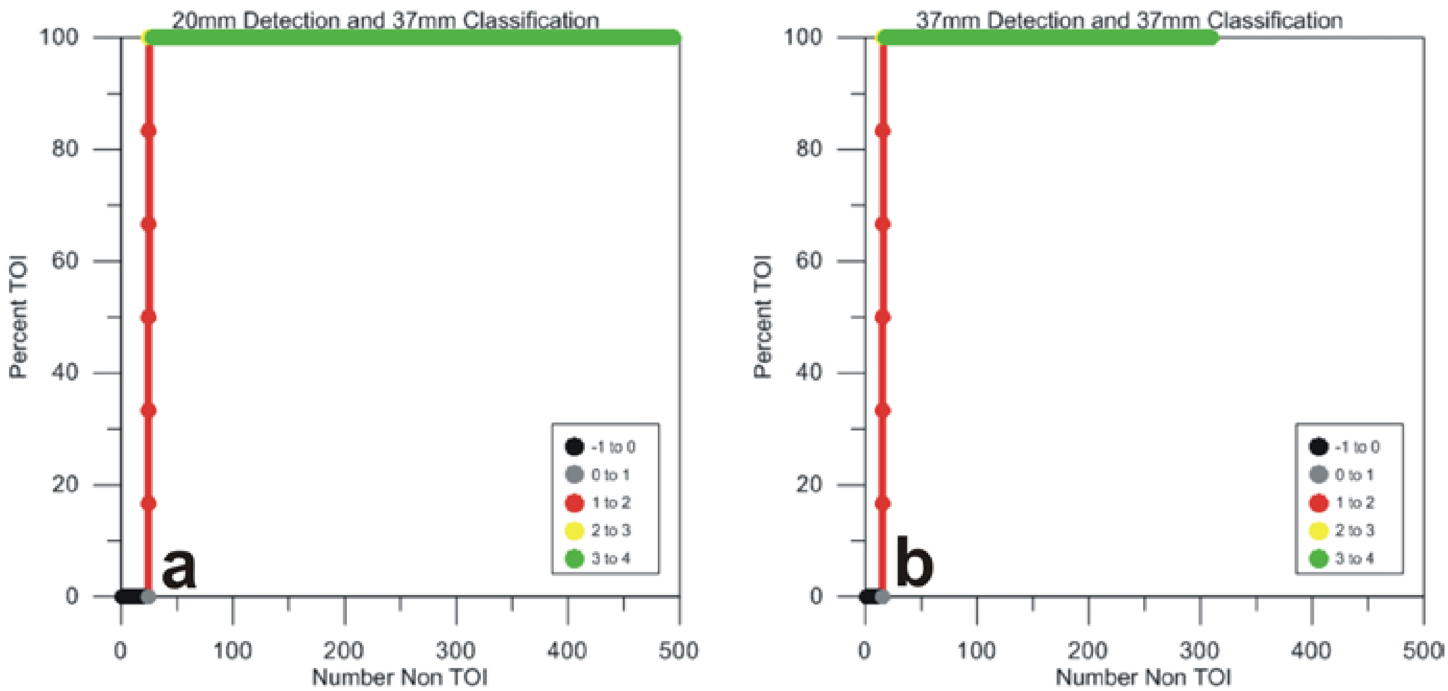

Figure 7: (**a**) ROC curve of reclassified data with the goal of detecting 20mm to a depth of 15cm and classifying 37mm or larger TOI. (**b**) ROC curve of reclassified data with goal of detecting and classifying 37mm to a depth of 15cm.

Summary

NAEVA utilized the latest generation of advanced TDEM sensors to successfully perform a dynamic survey for TOI detection and a cued investigation for TOI classification. While dynamic detection results were similar to traditional DGM techniques, the use of classification processing eliminated nearly 90% of the non-TOI from the intrusive investigation list. Under the current remediation model at MEC sites, the majority of the cost goes toward digging up and removing metal from the site, most of which is not hazardous to the public. The introduction of classification techniques suggests that a modest increase in data collection and analysis costs should lead to a significant decrease in the field effort, the duration, and therefore the overall cost of a given project.

The nature of the expected and recovered munitions types at SWPG illustrates the impact of small munitions on a remediation project. Small diameter projectiles are the most difficult to detect and the most difficult to classify. They are also the most similar to the metallic fragments that make up the majority of the contamination at MEC sites. The more accurate the information is regarding the expected TOI, the more accurately the detection and classification processes can be tailored to the site, and the more overall costs can be reduced (Figure 8).

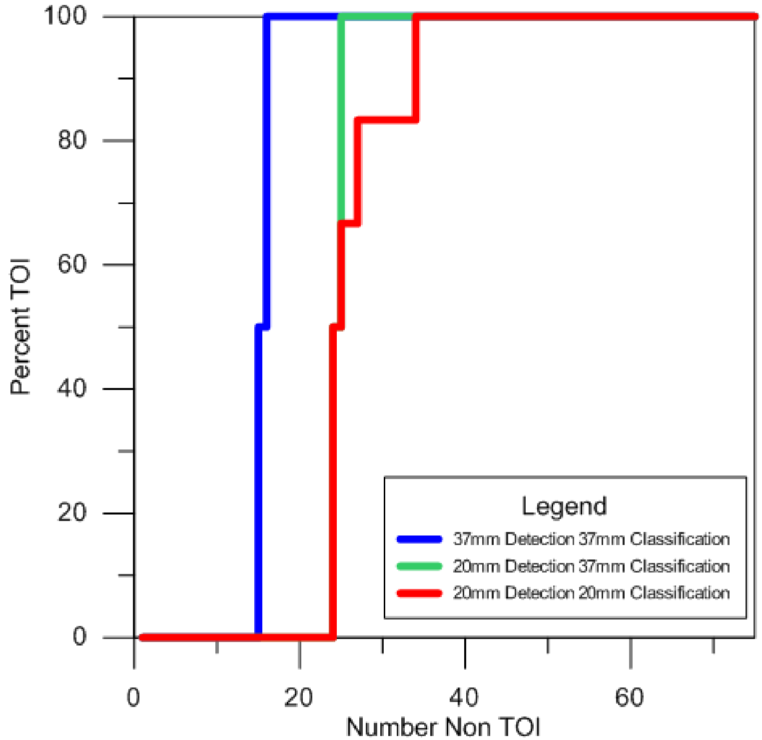

Figure 8: Detail overlay of ROC curves of top 80 targets on the ranked dig list for the three detection and classification thresholds presented.

Acknowledgements

We want to thank Dr. Herb Nelson of ESTCP/NRL, Andy Schwartz from the U.S. Army Corps of Engineers, Dean Keiswetter and Tom Furuya of Leidos, Dan Steinhurst from NOVA Research/NRL, and Nick Valleau and Darren Mortimer from Geosoft Inc. for their involvement in the development of classification techniques and in this demonstration in particular. At NAEVA, the success of this program was dependent on the contributions of Cora Blits, Karen Lemley, Jon Guillard, Ben Dameron, and Peter Jump.

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A MAN PORTABLE EMI SYSTEM FOR DETECTION AND CLASSIFICATION OF UNEXPLODED ORDNANCE IN CHALLENGING ENVIRONMENTS

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Introduction

Efficient and reliable detection and identification of unexploded ordnance (UXO) is one of the most pressing environmental problems at former military sites (Delaney and Etter, 2003). Electromagnetic induction (EMI) sensors have been shown to be a promising technology for detecting UXO (Prouty et al, 2010; Steinhurst et al, 2011). These sensors detect the metal in buried UXO as well as in nonhazardous items. Since hundreds or even thousands of non-hazardous items are often excavated for each UXO, research over the past few years has been focused on classification of buried targets using advanced EMI sensors and data processing algorithms (e.g. Pasion and Oldenburg, 2001; Barrowes et al, 2007) . Detected targets classified as non-UXO can either be left in place or excavated by inexpensive means. This approach can thereby substantially reduce clean-up costs, and has been extensively tested under the ESTCP live sites demonstration program (see www.serdp-estcp.org).

Advanced EMI systems illuminate targets with magnetic fields at three or more orientations and observe the resultant secondary field using multiple receivers. Each receiver measures the magnitude, orientation, and time-decay characteristics of the secondary field at its position. These measurements can subsequently be used to infer the location, orientation and physical properties of buried targets (Pasion and Oldenburg, 2001; Bell et al, 2001; Shubitidze et al, 2011). In particular, classification relies on time -dependent principal polarizabilities estimated for each target (Bell et al, 2001). The estimated polarizabilities can be matched against a predefined library of ordnance polarizabilities to identify targets that are likely UXO.

Keywords: Unexploded Ordnance (UXO), Electromagnetic Induction (EMI), Man Portable Vector (MPV) Sensor, Targets of Interest (TOI), Polarizability.

The EMI systems in use are rather large and are vehicle-mounted or cart-mounted (see Figure 1). Neither of these form factors are conducive to working in challenging terrains (steep slopes, uneven surface, or heavily treed areas). These challenges have motivated the development of a man-portable system, dubbed the Man Portable Vector (MPV) sensor (Barrowes et al, 2007), see Figure 2.

This article describes the MPV system and discusses three examples of its deployment in challenging environments where vehicular or cart-based systems are difficult or impossible to deploy. The three sites are:

- Camp George West, CO, a site with steep terrains,
- New Boston Air Force Station, NH, a site with dense woods, and
- Waikoloa, HI, a site with large boulders and magnetic soils.

The MPV described in this article is a second-generation system yet it is still a prototype and is not commercially available. The existing system is deployed by two crew members. A smaller and lighter data acquisition system has recently been developed and is just now becoming commercially available. Plans are being made to substantially ruggedize the measurement head assembly and to make that commercially available as well. The smaller and lighter data acquisition system should allow one-person deployment but it is unlikely that the system will ever be as small or light as conventional metal detectors.

Navigation and positioning of any of the advanced classification systems is always an issue. Use of RTK GPS is traditionally the solution but in challenging terrain, especially heavily treed areas, GPS signals are unavailable or unreliable. The MPV system includes an optional beacon component so cued-classification data can be collected in environments where GPS is unsuitable. Furthermore, the MPV system includes an optional 3D transmitter coil arrangement (MPV3D, see left panel of Figure 3) so cued-classification data can be collected over pre-flagged locations with a single measurement.

Figure 1: Advanced EMI sensors designed for UXO Classification. The system on the left is the MetalMapper which uses three orthogonal-axis transmitter coils and seven 3-dimensional (3D) receiver sensors called cubes. The system on the right is the TEMTADS 2x2x3D, which uses four vertical-axis transmitter coils with 4 3D receiver cubes.

Figure 2: MPV detection surveys at Camp George West, CO (left), New Boston AFS , NH (middle), and Waikoloa, HI (right).

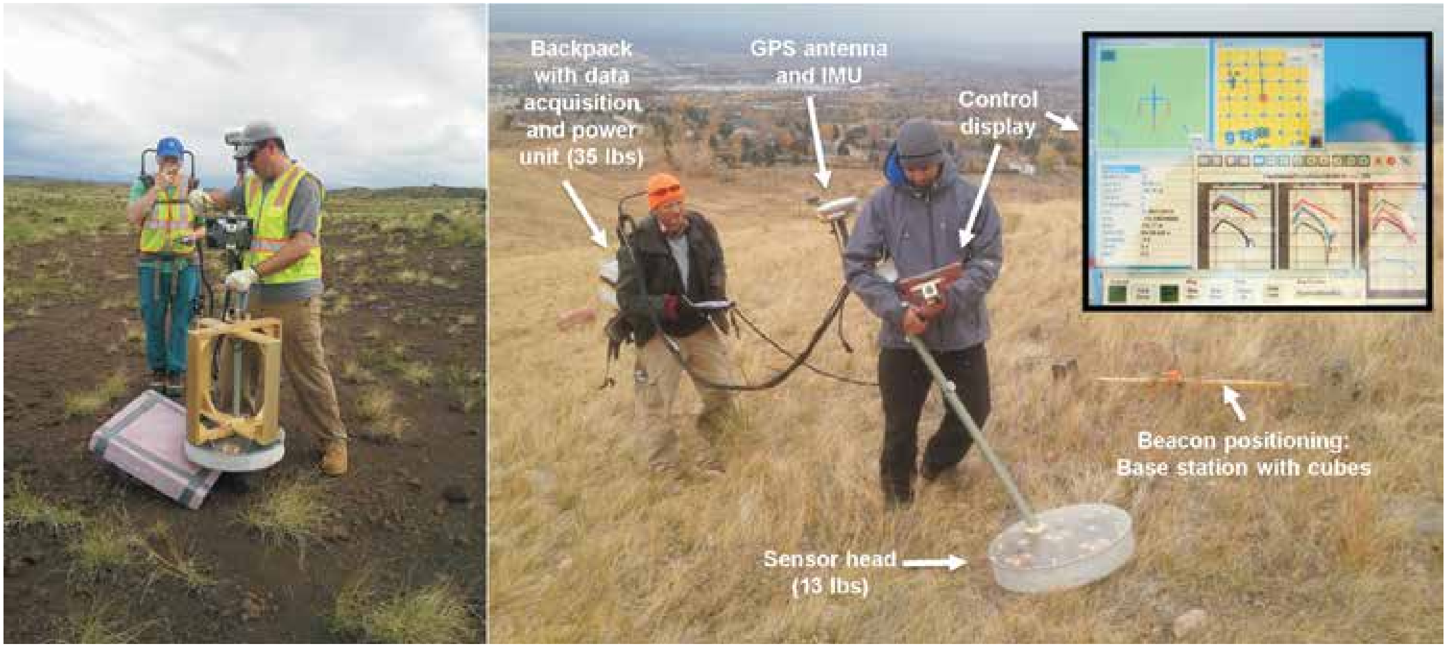

Figure 3: MPV3D measurements being made in Waikoloa, HI (on left). The MPV as deployed at Camp George West, CO in October 2012 (on right).

MPV System Description

All of the advanced UXO detection and classification systems, including the MPV, are used essentially in either two surveying modes.

- A dynamic or mapping mode where the objective is to generate a map of a whole site or sub-site in order to detect targets and generate a cued target list. In this mode, data are collected continuously as the system is moved along pre-planned lines.
- A cued mode where the objective is to carefully observe a single target that has previously been detected and roughly located, and to attempt to precisely locate that target and to classify it as possibly-UXO or definitely-not-UXO. In this mode, when only a single transmitter coil is available, multiple soundings are collected over the target. The MPV commonly uses a five point pattern where the outer four positions form a square with a side on the order of 75cm (see right panel of Figure 7). When the MPV is used with its optional horizontal-axis transmitters, a single sounding over the target is sufficient.

Requirements for spatial accuracy are different for dynamic-detection surveys and single-transmitter cued-classification surveys. Detection mapping has decimeter accuracy requirements and can be performed using an RTK GPS receiver, a spool-mounted cotton thread and optical encoder, or other procedures such as that described in the section entitled "Heavily Wooded Environment: New Boston Air Force Station, NH". Cued classification based on multiple soundings generally requires centimeter-level positioning accuracy (Bell, 2005).

For navigation in cued classification surveys in difficult environments, the Beacon positioning system was developed for the MPV. The Beacon provides accurate local positioning when GPS positioning is unreliable. See the section "Beacon Assembly". The MPV System consists of a sensor assembly, a data-acquisition system (DAQ) and its software, an optional beacon assembly, and an optional horizontal-axis transmitter assembly. The system has been used in three configurations:

- a standard configuration using only the sensor assembly,
- a 'beacon' configuration using the sensor assembly and the beacon assembly, and
- a '3D transmitter' configuration using the sensor assembly and the horizontal-axis transmitter assembly.

Each system component is described next but all of the configurations use the data acquisition system and may or may not include traditional navigation sensors (an RTK GPS receiver and an Attitude Heading Reference Sensor). The data acquisition system, the GPS receiver, and the AHRS sensors are all commercial-off-the-shelf components. The GPS receiver and the AHRS sensors are interfaced to a computer in the DAQ through RS232 serial ports.

Sensor Assembly

The MPV is a wide-band, time-domain, EMI sensor. The sensor head is made of a 50cm transparent disk, and a vertical-axis transmitter coil is wound around the disk. Five three-component receivers, each an 8cm cube, are contained inside of the disk. The head is mounted on a handle that provides separation geometry between a GPS antenna and the sensor head. An Attitude-Heading-Reference-Sensor (AHRS) is mounted below the GPS antenna so that the coordinates of the head can be computed from the observed coordinates at the GPS antenna. The sensor assembly also provides a mounting bracket for a display that communicates by wire or by wireless to the CPU in the data acquisition system. The display provides the user with an interface to control the sensor.

Beacon Assembly

The beacon positioning system (San Filippo et al., 2007; Lhomme et al., 2011) locates the origin of the MPV transmitter with a pair of EMI receivers rigidly attached to a portable beam that serves as a base station. The horizontal and vertical location of the center of the MPV head and its roll and pitch can be predicted from the beacon measurements. The heading is provided by a 3-axis attitude sensor that also records roll and pitch, which in turn can be compared with the predicted roll and pitch for quality control. Field trials showed 1-2 cm and 1-2 degrees accuracy for position and roll-pitch – similar to GPS and attitude sensors – out to distances of 3-4 meters (m) away from the beacon boom.

3D Transmitter Loop Assembly

Two horizontal-axis transmitter loops, shown in Figure 3 (left panel), were recently added to the MPV. This configuration has been dubbed the MPV3D. Using these two extra loops allows cued measurements to be made without the beacon positioning system and potentially even without GPS positioning. Because each target is characterized with a single measurement, the relative positioning required for the multi sounding measurements is no longer necessary. An ancillary benefit of this configuration is that a single measurement is faster than multiple soundings, so production rates are improved.

Data Acquisition System

A data acquisition system is carried on a backpack by a second crew member and is physically connected to other components in the system. When used, the optional beacon assembly or the optional 3D transmitter assembly is carried by the second crew member. The heart of the data acquisition system is an off-the-shelf system manufactured by National Instruments Inc. A custom transmitter module produces the current to drive each of the transmitter loops and a custom receiver module conditions signals from each of the receiver cubes before digitization. Lithium-ion batteries are typically used but lead-acid batteries can also be used – the system requires (9V to 30V) power to drive the data acquisition system and +12V/-12V nominal to power the transmitter.

Data Acquisition Software

The CPU in the data acquisition system is a personal computer (PC) running Microsoft Windows. The application EM3D controls all aspects of data acquisition and provides operator feedback for data-quality monitoring and navigation. (EM3D is proprietary software developed by G & G Sciences Inc.) The system console is provided through a touch-screen display (right inset in Figure 3).

The EM3D software has three data acquisition modes. First is a dynamic mode where data are continuously collected and recorded until the operator terminates data collection. Second is a multi-point static mode where multiple static data points are collected and then stored in a single file – this is the mode used for single-transmitter cued measurements. Third is a pure static mode where a single data point is stored in a single file. For all of these measurements, a single data point is defined as a snapshot of all received data for each transmitter that has been selected.

All aspects of the data acquisition process are selectable and adjustable to specific needs of any survey through EM3D: hardware setup, timing, data-quality displays, navigation feedback, and data recording. A dynamic detection survey typically consists of a full-coverage sweep where dynamic data are collected for digital geophysical mapping (DGM). Fast EMI signals are used, typically 2.7ms time decay, and short data blocks are used so that the sensor can continuously move along a path. Some targets can be classified directly from dynamic data and for targets where the quality of dynamic data is not sufficient for high reliability target classification, cued measurements are acquired. A cued target classification survey consists of static measurements where data quality is maximized. A slower EMI signal is used, typically 25ms time decay, and the observed signal is stacked for longer periods to reduce noise, typically 10s to 30s. This later-time information has been shown to improve distinction between intact ordnance and thinner walled shrapnel and cultural debris (Billings et al., 2007).

The EM3D software has real-time data monitoring capabilities. The data is displayed to verify data quality and detect potential disturbances caused by the presence of, for example, magnetic soil or a damaged receiver. The past and present sensor location is displayed on a map along with preset survey points or lines to verify spatial coverage and to guide the user. Several error conditions are automatically detected and displayed to the user – for example degraded GPS performance or low transmitter current. The EM3D package is capable of rudimentary target detection in real-time for a dynamic survey. It shows a detected target as it appears to move past the sensor.

Importantly, the EM3D software has a capability for data inversion. Immediately after cued data have been collected, the data can be inverted and the target's location and principal polarizability curves displayed. In cases where the cued measurements were not acquired closely enough to the target, the sensor can be repositioned to acquire a repeat measurement. These features assist the user in efficient and high quality data collection.

Examples of MPV Performance in Challenging Environments

Steep Terrain: Former Camp George West, CO

The 135-acre Camp George West Artillery Range Munitions Response Site (MRS) was used by the Colorado Army National Guard (ARNG) for artillery training from 1930 to 1945 as an impact area for 75mm high explosive (HE) projectiles. The MRS (impact area) is currently owned by the city of Lakewood and includes public trails used for hiking and mountain biking. ESTCP chose the Camp George West site because of the steep terrain which made surveying with cart or vehicle based system unsafe and unpractical. Photos of the MPV surveying at the site are shown in Figure 2 and Figure 3.

In MPV surveys at previous ESTCP live site demonstrations, the MPV sensor would revisit anomalies for cued measurements that were picked from detection maps based on EM61 dynamic surveys. The MPV surveys at Camp George West marked the first time that the MPV was deployed as the sole sensor to perform both a detection survey in dynamic mode and cued measurement survey on picked targets. Surveying in a dynamic mode with advanced EMI sensors offers the potential advantage of collecting higher resolution data (multiple receivers versus a single receiver loop for the EM61). And importantly, such surveys offer the possibility of performing classification directly from the dynamic data in order to reduce the number of follow up cued measurements. Two acres of the site were surveyed in dynamic mode and 530 cued targets were picked from the detection map created from the dynamic MPV data. The survey was completed in 8 field days consisting of 0.5 days making test pit measurements with site-specific targets of interest (TOI) to build a library of reference polarizabilities and to determine appropriate detection thresholds, 3.5 days of dynamic surveys, and 4 days of cued measurements over picked targets. Even though open sky conditions meant that RTK GPS was available, cued measurements were made with the beacon positioning system in order to compare data quality achieved when using only RTK GPS, only the beacon, and both the GPS and beacon.

This survey provided an excellent opportunity to test the limits of target classification using only dynamic data because there were only a few types of relatively large TOI - 75mm and emplaced "industry standard objects" (ISOs) - and the target densities as shown in the detection map of Figure 4 were relatively low. Classification was performed separately on dynamic and static data by independent analysts, one using only dynamic data, and the other using only static data. In both cases, UXOLab software was used for processing. (UXOLab is proprietary software developed by Black Tusk Geophysics personnel) A library of principal axis polarizabilities was developed from test-pit measurements and augmented by clusters of self-similar polarizabilities potentially indicating additional unique targets not in the library. Target's polarizabilities were matched to library polarizabilities as shown by an example in Figure 5. Upon review of the data, training data requests were made to verify that items suspected to be TOI were in fact TOI and to identify items which did not match items in the library yet had polarizabilities characteristic of UXO targets. After training data were received, the reference library was tailored to represent a site specific collection of TOI and classification was performed to generate a prioritized dig-list based on matches of observed polarizabilities to library polarizabilities.

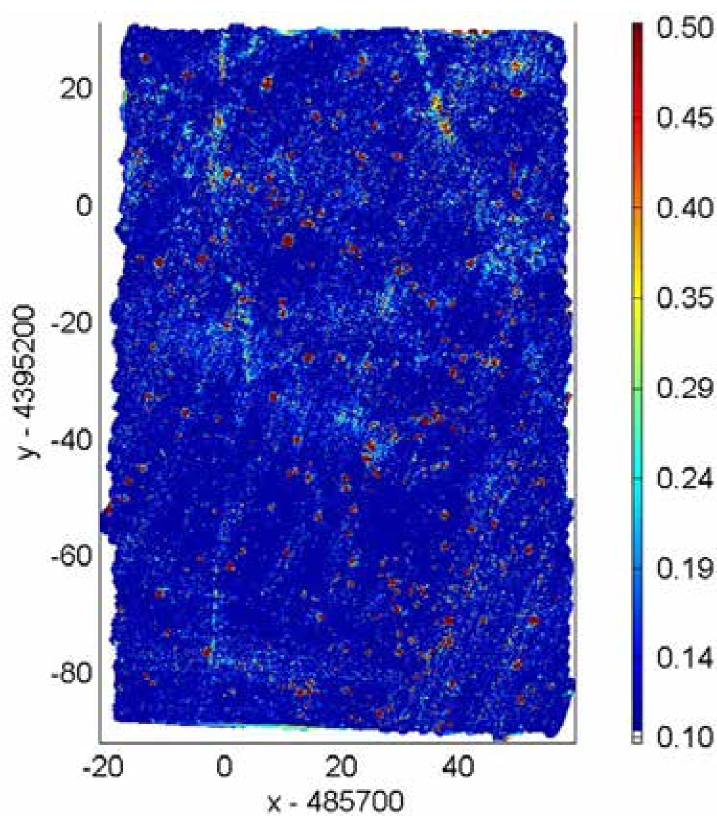

Figure 4: Detection map created from dynamic MPV data collected at Camp George West, CO. A detection channel of 1.4ms was used to exclude some of the fast decaying anomalies. Walking trails that passed through the survey area are evident running in a north-south orientation. Units for both horizontal and vertical axes are meters and colour scale units are mV/Amp.

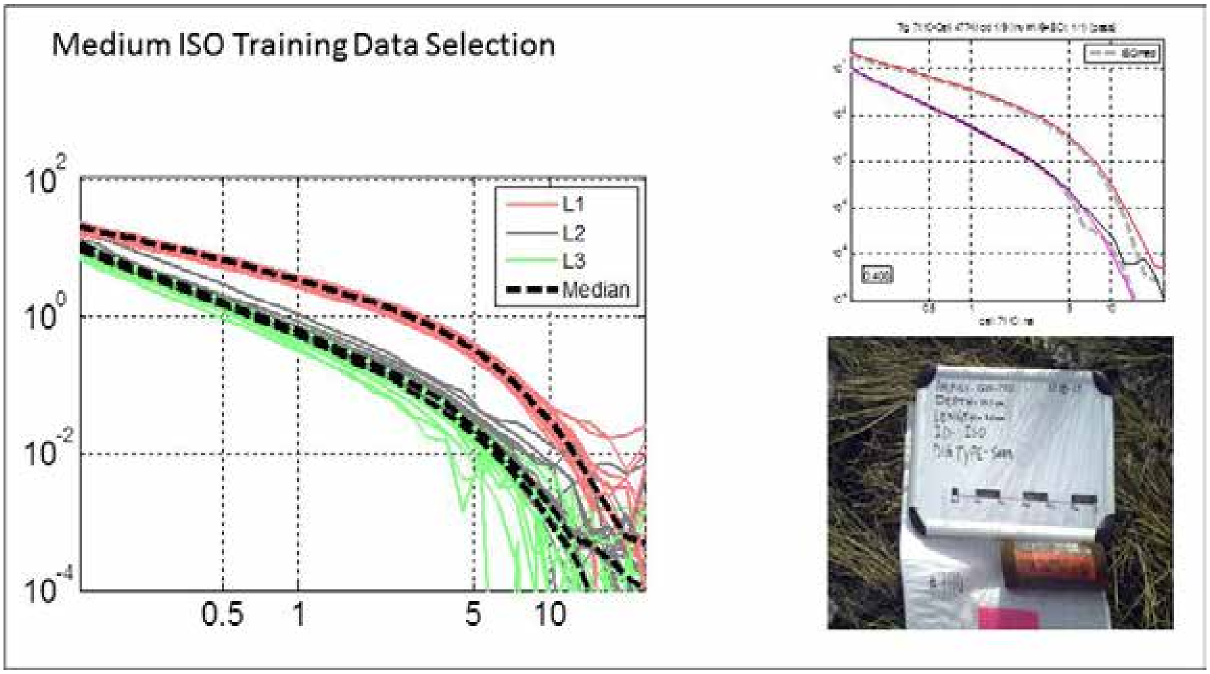

Figure 5: Cued data classification - Training data requests for potential medium ISOs. Plot on left shows all polarizabilities matching the reference medium ISO. The top plot on the right shows polarizabilities for a training data request (the reference library medium ISO is the dashed grey line) and the bottom right ground truth photo confirms a medium ISO. Units on the horizontal axis of polarizability plots are time in milliseconds while vertical axis units are dimensionless amplitude.

Final results of the two classification dig-lists are shown via the receiver operating characteristic (ROC) curves of Figure 6. The dynamic data result shown on the left of Figure 6 identifies all TOI except for one item which was the result of a mislabeled target by the analyst. The data shown on the right of Figure 6 identifies all TOI. However, the ROC curves show that about 60 non-TOI items would have to be dug if using only dynamic data while only about 20 items would have to be dug if using the static data. In the static data, 100% of TOI were correctly classified while 92% of clutter was rejected.

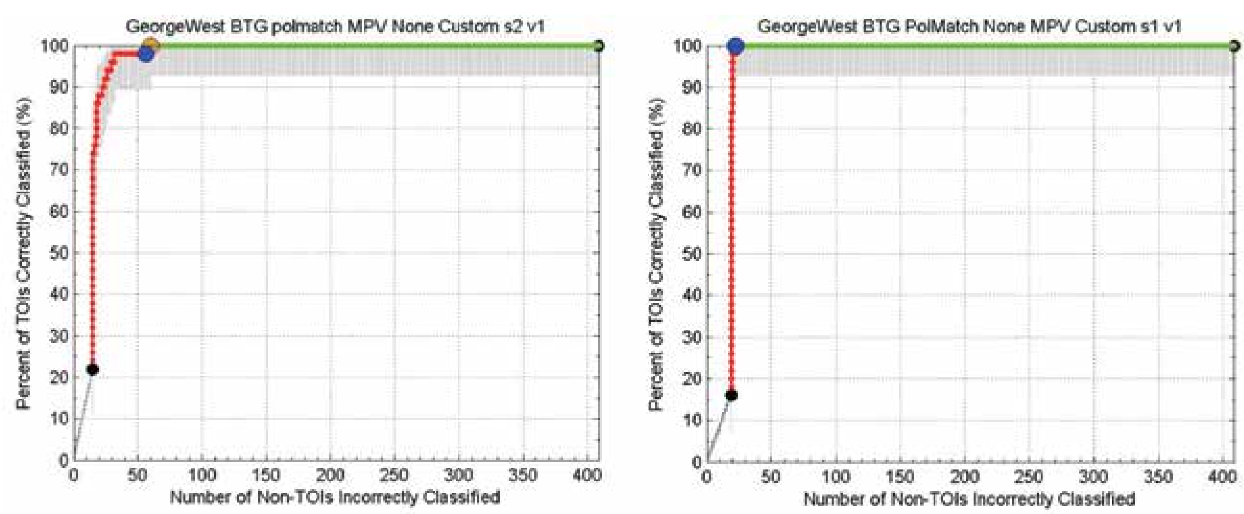

Figure 6: Receiver operating characteristic (ROC) curves for classification of MPV dynamic data (on left) and cued data (on right). The grey portion of curve from the origin to the black dot represents training data requested by each analyst, the red portion represents targets marked as dig by the analyst while the green portion represents targets that the analyst designated as do not dig. The blue dot represents the analyst's stop dig point and the yellow dot represents the operating point where all TOI have been identified.

Heavily Wooded Environment: New Boston Air Force Station, NH

ESTCP chose the New Boston Air Force Station (AFS) site for testing advanced classification EMI sensors because it combined an open area accessible to a range of sensors as well as a treed area that provided significantly more challenging survey conditions. Without a reliable GPS signal, dynamic surveys were performed by laying out well defined lanes and collecting short segments that were stitched together (see Figure 7). Targets for re-acquisition were picked from this map.

When re-acquiring a cued target coordinate, the real-time display of the MPV was used to assure that a target was present and roughly centered at the position being acquired. Five-point static measurements were collected for each cue in a typical pattern as shown in the right panel of Figure 7. The cm level positioning required for classification quality data was obtained via the MPV's novel beacon positioning system.

Figure 7: On left: Dynamic MPV surveys at New Boston AFS in a wooded area. MPV sensor is moved along short segments of well-defined lanes to build a detection map. In middle: Cued MPV surveying at New Boston AFS. On Right: Five-point static measurement pattern for MPV measurements.

The detection map shown in Figure 8 illustrates that New Boston had high target densities with multiple anomalies routinely falling within the footprint of the sensor. There were many small targets (20mm) throughout the site. This makes the classification problem particularly challenging and difficult when multiple target signatures overlap. Classification is further complicated when the size of scrap fragments is similar to the size of TOI, e.g. 20mm projectiles. Classification was performed on the cued data but final results are not yet known because final ground truth is not yet available.

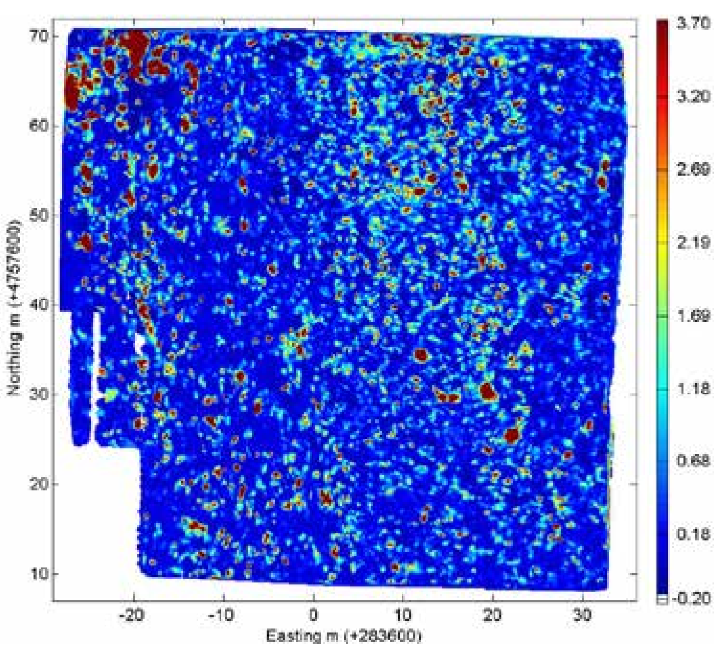

Figure 8: MPV detection map for New Boston AFS. The left third of the image was collected in a heavily wooded environment while the rightmost 2/3 were collected in an open field. Units for both horizontal and vertical axes are meters and colour scale units are mV/Amp.

Complex Geology and Surface Obstacles: Former Waikoloa Maneuver Area, HI

In January of 2014, the MPV was deployed to Waikoloa in Hawaii. The 100,000-acre Former Waikoloa Maneuver Area, a Formerly Used Defense Site (FUDS), was acquired by the Navy in 1943 and used as a military training camp and artillery range for 50,000 troops until 1945. Two surface clean-up activities were done in 1946 and 1954. The 1946 cleanup was done after the departure of the military. The 1954 clean-up followed an accidental detonation of a dud fuse or shell killing two civilians and seriously injuring three others. Munitions and explosives continue to be discovered at the Former Waikoloa site. Investigation and clearance continues in areas planned for development and where the risk assessments were rated moderate to high. To date, over 100 different types of munitions have been found including mortars, projectiles, hand grenades, rockets, land mines, and Japanese ordnances. Over 1,800 munitions and explosives of concern (MEC), 117,000 pounds of military debris, and 149,000 pounds of munitions debris (MD) have been cleared from 22,600 acres. The work currently being performed is under the direction of the US Army Corps of Engineers Honolulu District.

This site was selected for MPV deployment because of its challenging terrain and magnetic soil effects. Prior to deployment of the MPV, data had been collected using both an EM61 and a MetalMapper. Figure 9 compares the along line, median filtered EM61 data with that same data re-leveled to show how the background response varies across the site. The data gaps in both Figure 9 images represent rocky outcrops that could not be surveyed with either the EM61 cart or the vehicle mounted MetalMapper. While the MPV could survey in these areas, the large boulders (see right panel of Figure 2) meant that the sensor was lifted over certain areas, limiting the MPV's signal penetration into the subsurface.

A 10 day field survey was planned for the MPV over the same 1.5 acre site shown in Figure 9. The first 5 field days were spent acquiring full coverage dynamic data to produce an MPV detection map (see right panel of Figure 10) from which targets were picked. The rate of data acquisition in dynamic mode was approximately 0.1 acre/hr. Of the 10 days planned, two days were lost due to heavy and persistent rains. Nonetheless, all 459 cued measurements were completed at a rate of 24 cued measurements per hour using the five-point pattern. A subset of the five-point measurements were also acquired using the MPV3D averaging 41 cued measurements per hour.

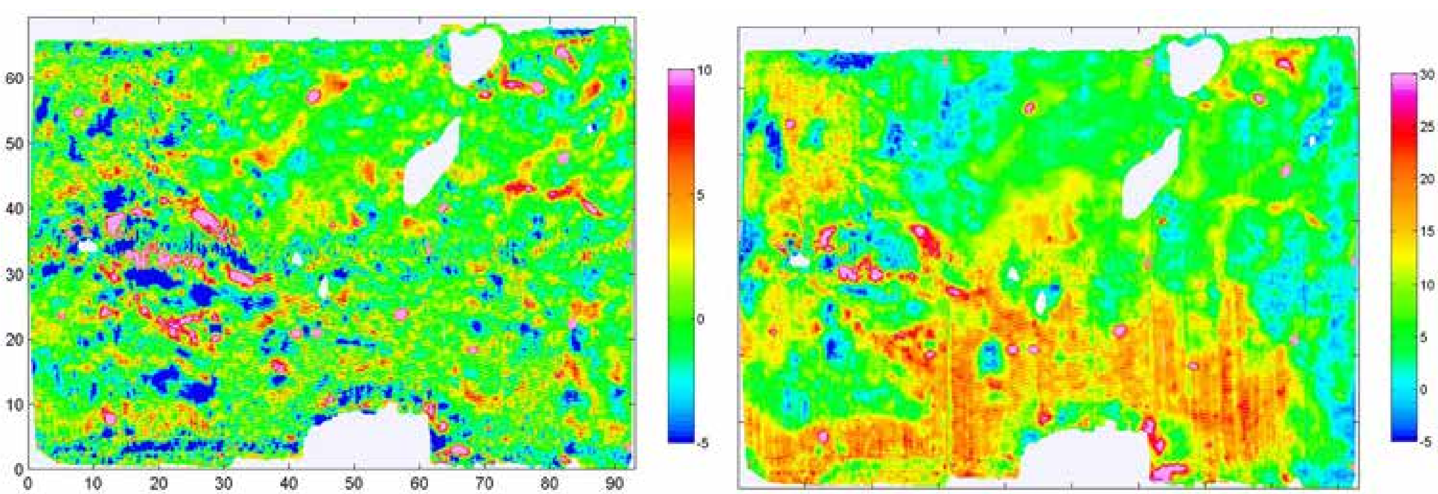

Figure 9: EM61 data acquired at Waikoloa TO20 Area A South. Median filtered data (on left) and the data leveled to show geology (on right). The regions of negative values in the median filtered data image are due to filtering artifacts. Units for both horizontal and vertical axes are meters and colour scale units are mV/Amp.

The MPV DGM map shown in Figure 10 is based on the vertical-component receiver data, which is less sensitive to variations and errors in sensor location and orientation. Each line profile was filtered to remove noise from the geologic background. The choice of a detection channel and associated threshold was made with the intention of both detecting all potential UXO to a certain depth and minimizing the number of anomalies selected for reacquisition. Given that the sensor records decays in the 0.1 to 2.6 ms time range in dynamic mode, the 1.6 ms channel was chosen as a tradeoff between using late time data and maintaining sufficient signal to pick above noise . (UXO are generally composed of thick shells relative to other debris, and therefore typically exhibit a slower time decay. But later time data always have poorer signal to noise ratios than earlier time data). The amplitude of the detection threshold was derived from simulations of the worst case detection scenarios for the target of interest and validated through test pit measurements. Targets were automatically picked by running an algorithm that selected locations along line profile data where the detection channel exceeded the defined threshold.

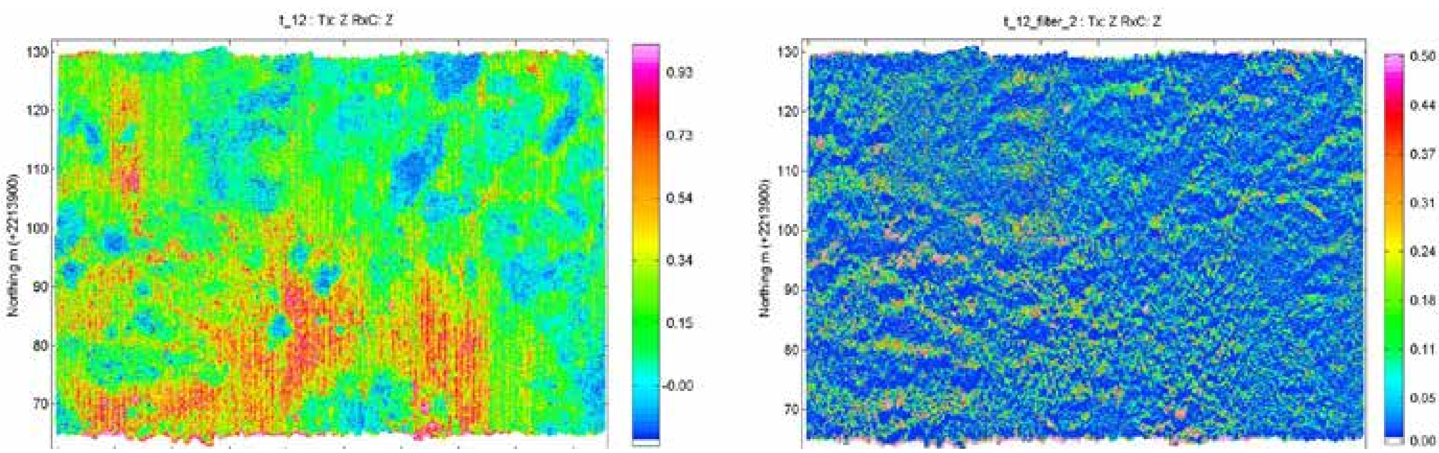

Figure 10: On left: Raw detection channel on MPV Z-component receivers at 1.66 ms. The geologic background shows the same distribution for the MPV and EM-61 surveys (compare the above image with that of Figure 9) . Regions with negative values (blue color) correspond to rocky outcrops where the MPV sensor was lifted (the EM-61 cart was not able to access these locations). On right: Filtered detection channel on MPV for Waikoloa. Units for both horizontal and vertical axes are meters and color scale units are mV/Amp.

Out of 459 anomalies selected for cued interrogation, a subset of 139 cued targets were selected for MPV3D measurements. The selection was based on the highest amplitude targets from the detection survey due to limited time remaining on the final day of deployment. Waikoloa marked the first field deployment of the MPV3D and the initial results were very encouraging. Recovered polarizabilities over multiple IVS days are shown in Figure 11 and illustrate consistent, repeatable polarizabilities derived from MPV3D measurements. Direct comparisons of recovered polarizabilities obtained from the MPV five-point measurements with those obtained with the MPV3D were nearly identical for all high amplitude cued targets from the Waikoloa site. The hourly production rate with the MPV3D was 1.7 times greater than the production rates achieved using the five-point pattern. Classification was performed on the cued data (both the five-point and MPV3D measurements) from Waikoloa, but scoring of the results is not yet available.

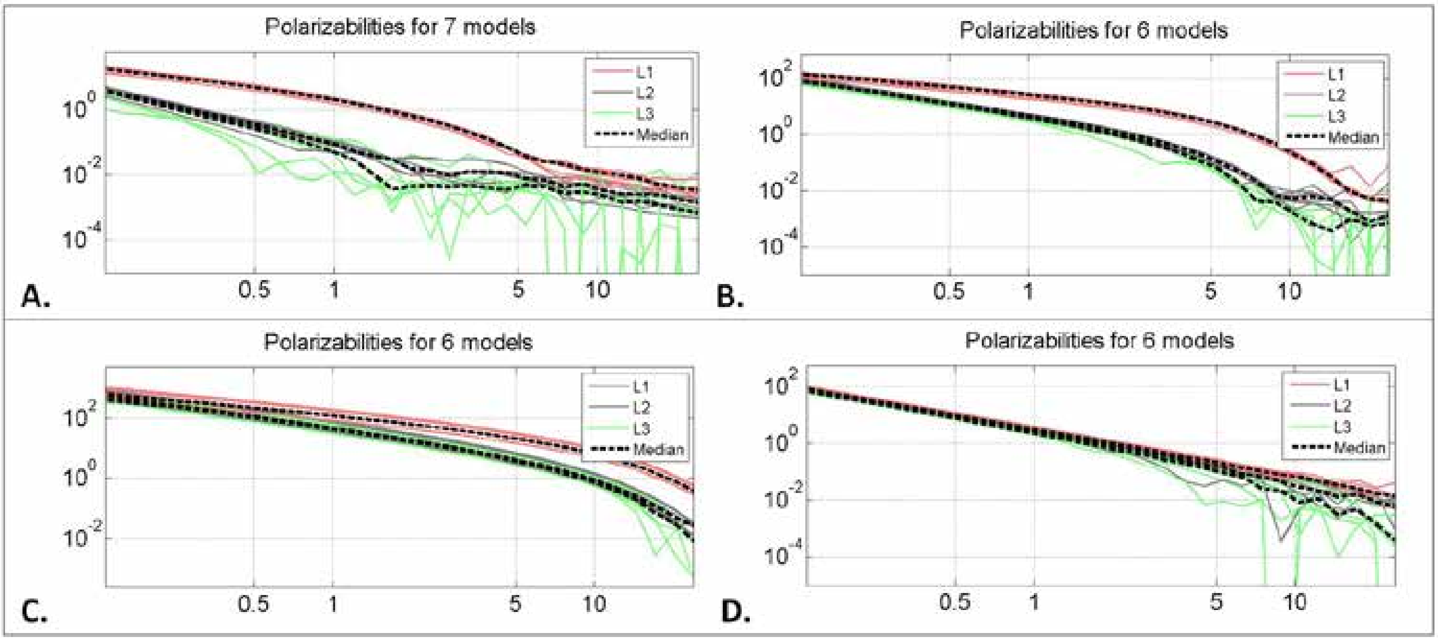

Figure 11: MPV3D recovered polarizabilities for 4 IVS items. A. Small ISO at 11 cm depth, B. Medium ISO at 12 cm, C: Large ISO at 16 cm, D: Sphere at 19 cm. These MPV3D derived polarizabilities were an excellent match to the IVS polarizabilities derived from MPV five-point measurements. Units on the horizontal axis of polarizability plots are time in milliseconds while vertical axis units are dimensionless amplitude.

Conclusions

Both the MPV and MPV3D have shown to be useful for collecting advanced EMI data in challenging survey environments where cart and vehicular based EMI systems cannot be deployed. Direct comparisons of MPV data quality and classification performance with other advanced EMI sensors at ESTCP Live Site demonstrations has illustrated similar performance. Recent testing of the MPV3D at Waikoloa indicated similar data quality to the MPV with improved production rates. While the second generation MPV is still considered a prototype, a smaller and lighter weight data acquisition system has been developed which combined with plans to substantially ruggedize the measurement head will lead to a robust, commercially available system in the near term.

Acknowledgements

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DYNAMIC UXO CLASSIFICATION SENSORS: ADVANCED DIGITAL GEOPHYSICAL MAPPING FOR MUNITIONS RESPONSE SITES

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Abstract

Digital Geophysical Mapping (DGM) is a critical part of the remediation process for sites containing Munitions and Explosives of Concern (MEC). Specifically, implementing Electromagnetic Induction (EMI) sensor surveys at these sites is an effective method for identifying potential Unexploded Ordnance (UXO) or other MEC. Such contaminants often contain significant amounts of metal that produce electromagnetic anomalies in the DGM survey data. In recent years, a new class of advanced EMI sensors has demonstrated the additional capability to discriminate innocuous clutter from potentially hazardous UXO/MEC. These advanced sensors incorporate multi-axis transmitters and receivers to better characterize magnetic field anomaly sources, thus enabling not only detection of MEC contaminants, but also clutter discrimination as well as classification of specific MEC types. We have developed a next generation set of advanced EMI sensors, which combine the mapping capabilities of previous DGM survey instruments with the high-resolution discrimination and classification capabilities of advanced characterization arrays. Here we present results from recent field tests demonstrating the detection and classification capabilities of two advanced systems: one configured as a towed array and the other as a man-portable system. By enabling high-resolution mapping, as well as discrimination and classification of MEC, these systems provide a significant advancement in geophysical survey capabilities over those of current industry workhorse instruments, particularly for sites containing large quantities of non-hazardous clutter. By integrating the detection, clutter rejection, and UXO/MEC classification stages in one survey, these capability improvements are realized through a reduction in the number of excavations required for scrap/clutter, a reduction in the total survey time required for detection and classification, and superior Quality Control (QC) due to the use of a single sensor for detection and classification.

Keywords: Munitions and Explosives of Concern (MEC), Unexploded Ordnance (UXO), Electromagnetic Induction (EMI), Digital Geophysical Mapping (DGM).

Introduction

Over the past 5 years or so, a significantly improved EMI technology has emerged and demonstrated the ability to provide high spatial and temporal resolution data that can be used to effectively discriminate clutter from UXO/MEC. These systems, which were primarily developed under the auspices of the U.S. Department of Defense (DOD) Environmental Security Technology Certification Program (ESTCP) Munitions Response program, incorporate multi-axis transmitter and receiver configurations that greatly increase the information contained in the data compared to data from the previous generation of EMI systems. These advanced systems have enabled a new classification approach that utilizes physical models to accurately predict the magnetic field from subsurface objects in order to extract useful model parameters corresponding to physical properties of potential UXO. These classification features may then be used to distinguish clutter from MEC during subsequent analysis of the features. Because the vast majority of the mapped anomalies are due to innocuous items such as metal scrap, litter, or fragmentation and munitions debris that are free of explosives, the ability to classify clutter and targets has become an extremely valuable way to reduce the time and costs associated with unnecessary excavations of non-hazardous debris (Andrews and Nelson, 2011).

These new advanced EMI systems were intended to operate as part of a secondary "cued" survey developed as an add-on to the existing geophysical survey workflow for UXO cleanup projects. By relying on the older style DGM survey data (such as those acquired from a Geonics EM-61 sensor) for anomaly identification (i.e., target picking), advanced sensors could be implemented in cued mode to revisit the location of each anomaly within the survey area and acquire very high resolution data with minimal impact to the overall flow.

Numerous demonstrations of this cued survey approach have shown it to be extremely effective for discriminating clutter from MEC at both demonstration and production sites (Andrews and others, 2011); however, the requirement for conducting an additional time consuming survey reduces the efficiency of the remediation process. Furthermore, because a lower resolution DGM sensor is often used to cue the target locations for the advanced EMI survey, it is sometimes difficult to reconcile the two data sets. This disconnect can lead to sensor placement errors during the cued survey that result in sub-optimal characterization of the target space (Miller and others, 2013).

With the proven performance of advanced EMI sensors and the trend towards acceptance of these technologies in the production environment (see www.serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives), the possibility now exists for shifting the focus of classification technology development from improved performance to improved efficiency and feasibility. Specifically, the development of sensors that provide both detection and target classification from the DGM survey would significantly enhance the efficiency and reliability of the classification process. Removing the cued survey from this process eliminates the costs and time associated with mobilization and deployment of a second system. Additionally, using one high resolution DGM data set to perform both the target picking and target classification stages enables a direct correlation between the 2-D map features and the classification features associated with each anomaly. This correlation is particularly useful for sites that contain high anomaly densities, environments that can be particularly challenging for deployment of cued sensors. Combining detection and UXO classification stages in one DGM survey, it is possible to make efficient and reliable decisions that lead directly to a substantial reduction in the number of unnecessary digs performed during remediation.

Classification: How Do Advanced EMI Systems Classify UXO and Clutter?

Advanced EMI sensors that produce high spatial and temporal resolution data provide the basis for munitions classification. The data produced by these sensors enable the application of physical models to data fitting methods, which yield useful classification parameters corresponding to physical properties of the object. A key requirement for classification sensors is the ability to produce multi-directional magnetic field illumination of objects in the subsurface. This capability is often achieved by incorporating multiple transmitters in the design. By producing three approximately orthogonal magnetic field vectors below the array, the sensor energizes objects within this space along three unique axes (Figure 1). This illumination generates electrical eddy currents that are distributed over the object as a function of the object's physical properties including its size, shape, and shell thickness. These eddy currents produce a secondary magnetic field that is measured by the induction coil receivers in the sensor array.

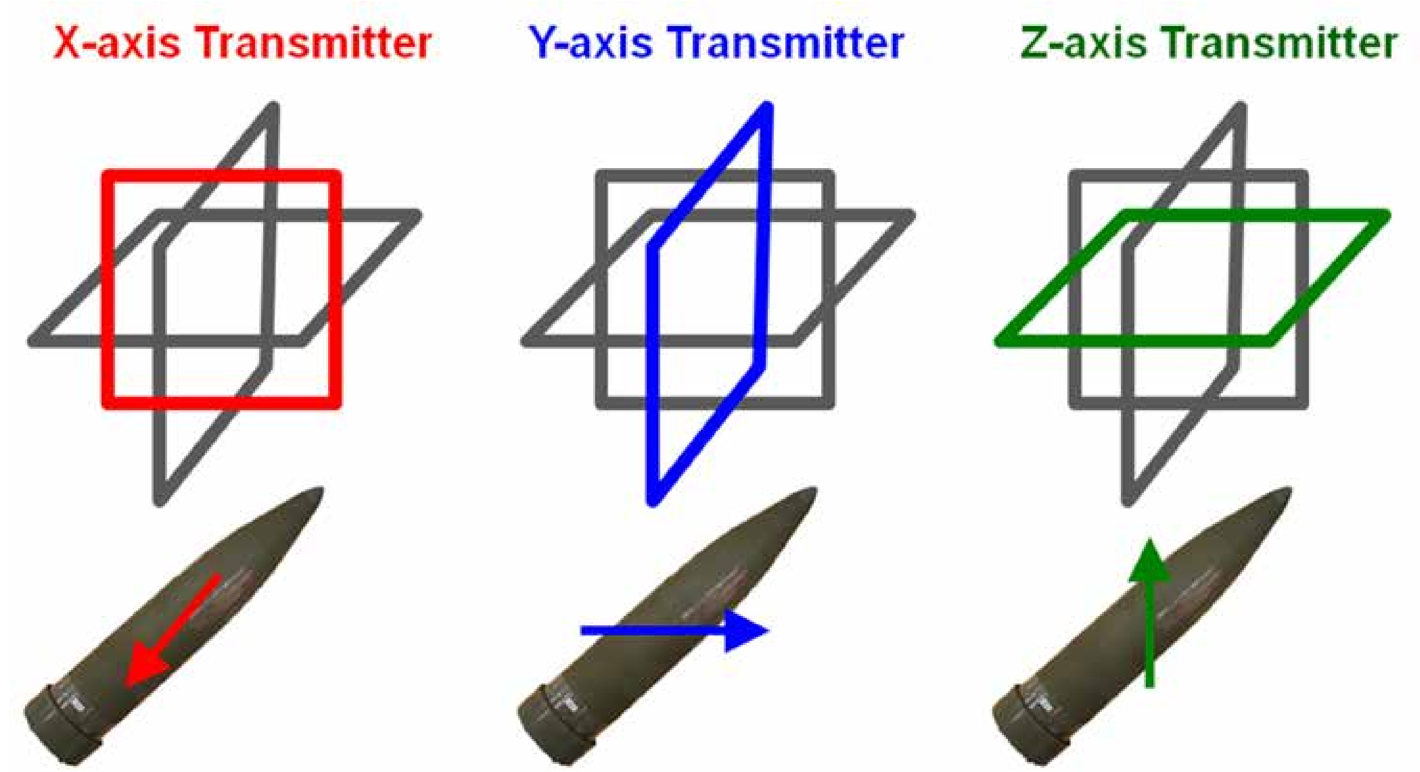


Figure 1: Advanced EMI sensors provide multi-axis illumination of an object by using multi-directional transmitters (TOP). Each transmitter produces a field that energizes a unique component of the object under interrogation (BOTTOM).

By energizing the object along three unique axes, the sensor produces eddy currents within the object that generate secondary fields similar to those produced by a set of equivalent magnetic dipoles oriented along the three principal axes of the object. The secondary fields measured by the sensor's receivers decay as a function of these three principal electromagnetic polarizabilities, which describe the object's electromagnetic response along each principal axis to the transmitter fields. As long as the transmitter fields are approximately orthogonal, these three principal polarizabilities will be well characterized by the data, regardless of the object's orientation or location relative to the sensor. In other words, the principal polarizabilities are intrinsic to each object and therefore produce effective and reliable classification features.

For an advanced EMI sensor data set, the principal polarizabilities may be extracted from the data using an iterative search method (i.e., geophysical inversion) to determine the model parameters that produce the closest match between the equivalent dipole model values and the observed data (e.g., Shubitidze and others, 2005; Bell and others, 2001). In this case, the objective function parameters include the object location parameters (e.g., x, y, z in Cartesian coordinates) and the three Euler rotation angles that determine the object's orientation. Once the objective function is minimized, the resulting dipole model polarizabilities can be used to classify an object as a target of interest (TOI) or clutter item (Figure 2). A TOI decision can be made by matching the extracted polarizabilities to those of known TOI libraries, or through feature based analysis using model parameters such as polarizability size and decay.

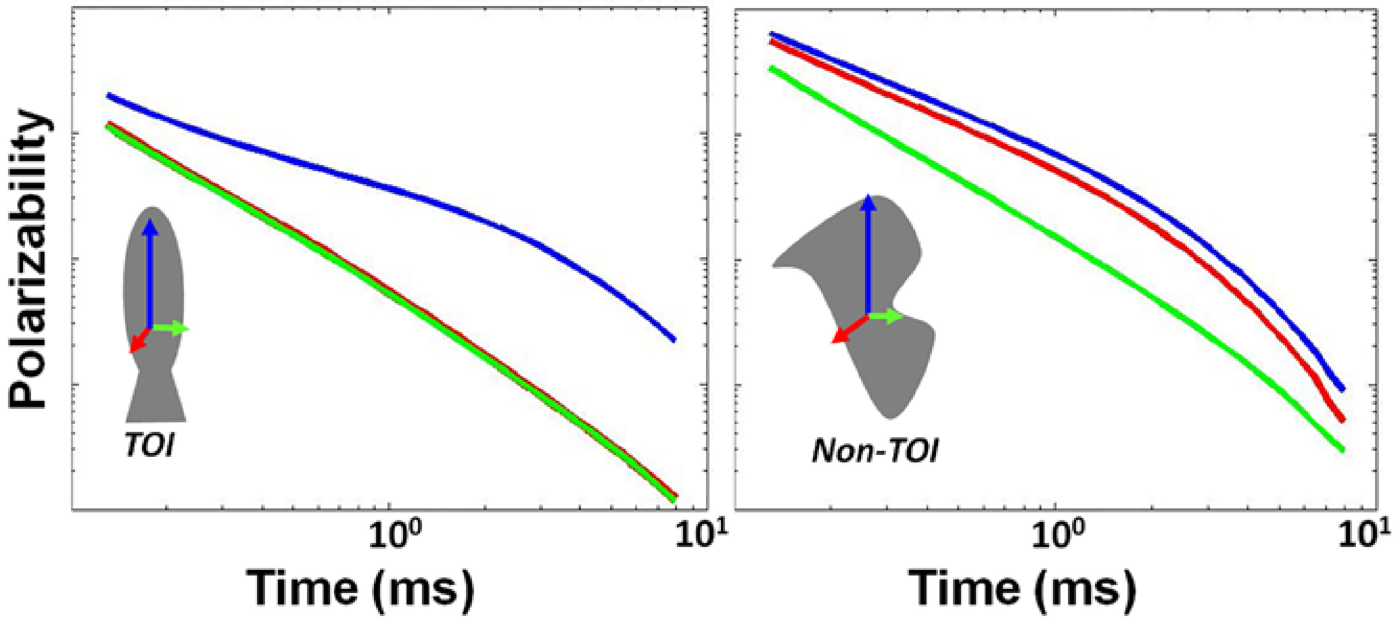


Figure 2: Primary (blue), secondary (red), and tertiary (green) polarizabilities associated with a TOI (LEFT) and a clutter item (RIGHT). The polarizabilities are associated with intrinsic object properties and can therefore be used to reliably make classification decisions. The symmetry of the TOI produces equivalent secondary and tertiary polarizabilities, whereas the asymmetry of clutter object produces three distinct polarizabilities. Polarizability units are arbitrary and are based on the output units of the sensor.

DGM Detection and Classification On-the-Move

The main challenge of performing effective classification using DGM survey data is to ensure all targets in the MRA are energized along three unique axes by the DGM sensor transmitter(s). With cued sensor classification, there is some a priori knowledge of target locations that is deduced from the DGM data analysis and can therefore guide the placement of the cued sensor. DGM sensors, however, are typically deployed along straight transects; thus, the sensor can encounter targets anywhere across its swath. Consequently, it is important that the DGM survey be designed to ensure effective multi-axis characterization for any target encountered in the swath covered while the sensor maintains an efficient survey pattern.

We developed a new DGM classification methodology that provides robust multi-axis characterization of targets in a DGM mode while mapping the survey area dynamically. We recently demonstrated two advanced DGM sensors at a DOD Standardized UXO Technology Demonstration Site. One system is a vehicle-towed sensor array designed for high production rates in open field areas; the other system is a smaller man portable array designed for operation in more challenging terrain. Our methodologies are tailored to the physical configurations of each sensor; however, both approaches produce effective clutter discrimination and UXO/MEC classification.

In the following sections, we provide a brief overview of how each of these systems works and we present some preliminary performance results from these recent field tests. These results clearly demonstrate the potential cost-savings of the combined detection/classification DGM approach that can be realized through an overall increase in survey efficiency, a reduction in the number of unnecessary digs, and an improvement in the reliability of the QC process.

Vehicle-Towed Array: Point Methodology

Our “OPTEMA” vehicle-towed array uses a configuration of five transmitter coils and 14 three-axis receiver coils spread across a 1.8m swath. The transmitter configuration comprises a large horizontal base transmitter (2m wide by 1m long) that encompasses four smaller (1m tall by 1m wide) vertical coils. The four vertical coils are connected in series pairs so that the transmitter array produces three effective coils (Figure 3).

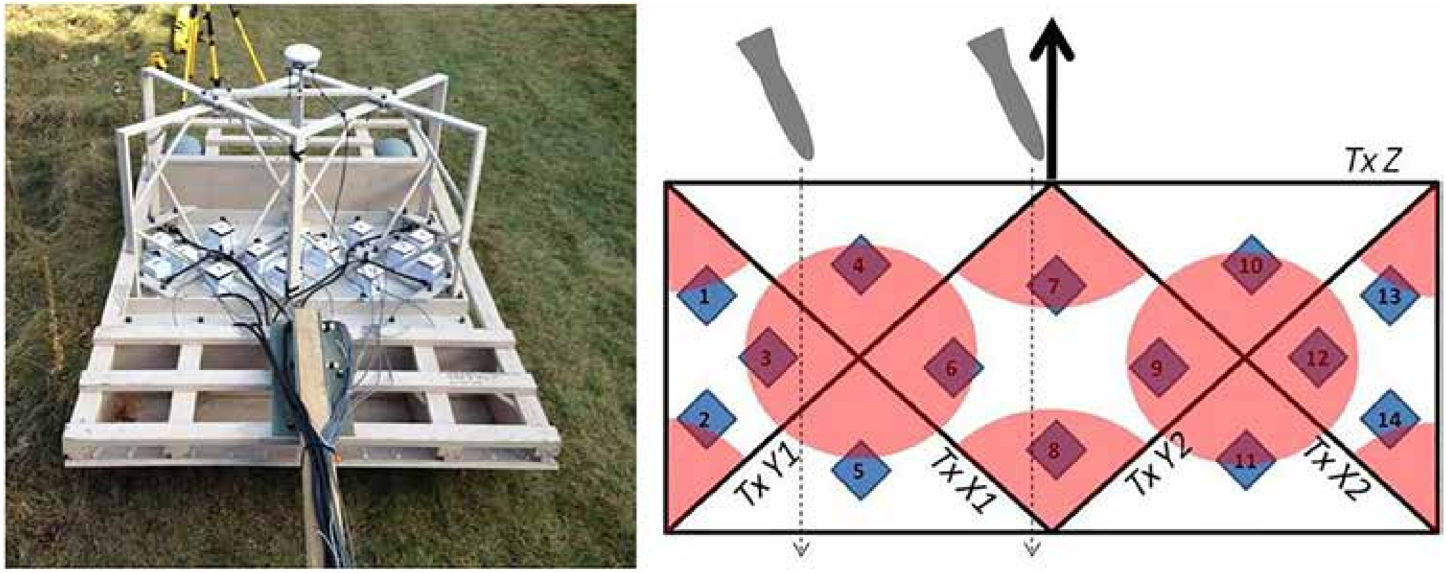
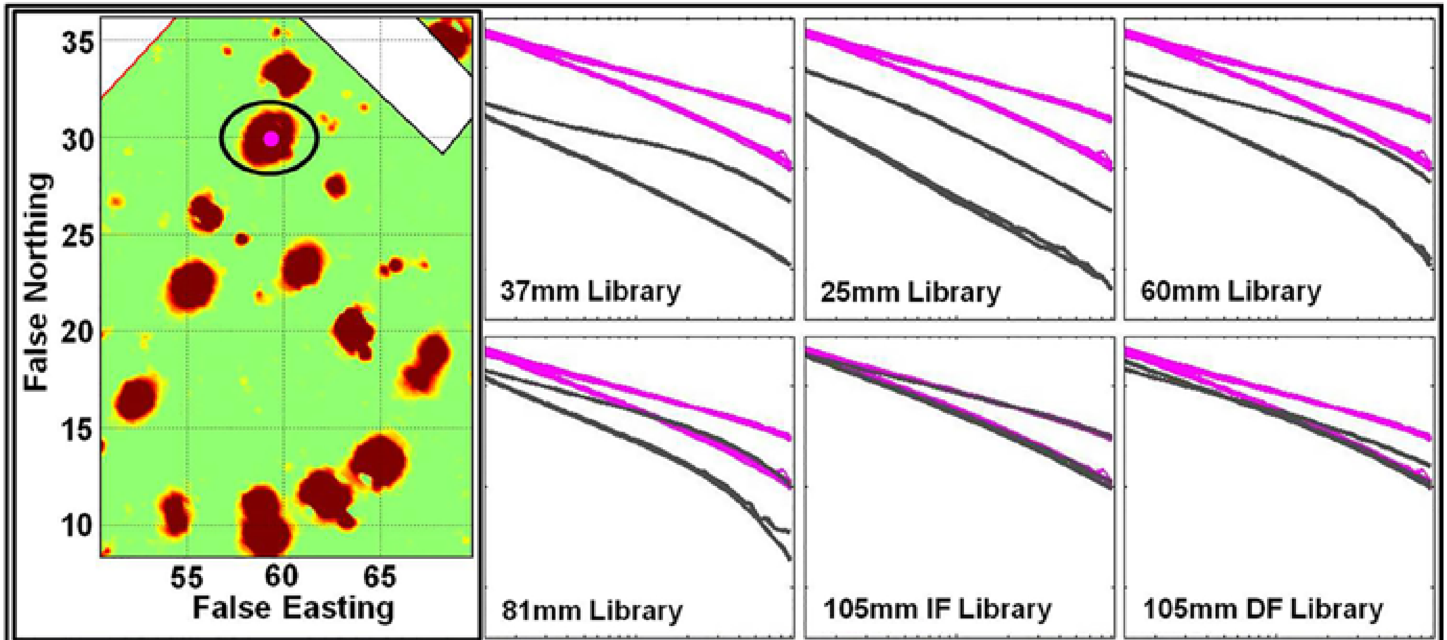


Figure 3: LEFT: Photograph of the OPTEMA sensor array tow platform. The multi-axis array is designed to provide good orthogonal magnetic field illumination across the entire sensor swath. The combination of full swath multi-axis illumination and high-spatial resolution sampling over the entire decay time period (0.1 to 8 ms) provides improved survey data over other advanced EMI systems that are limited in dynamic mode. RIGHT: Top-view of the transmitter and receiver layout. Regions that provide good orthogonal illumination are highlighted (red) around the transmitter coil (black lines) intersections. As the array passes over an object, the object will enter at least one of these regions regardless of its across track location. The resulting field scattered by the object is measured in one or more of the 14 three-axis receivers (blue diamonds).

This transmitter configuration ensures sufficient multi-axis illumination across the entire sensor swath. The orthogonality of the three transmitter fields is dependent to some extent on the depth of the target beneath the array; however, as a general guideline, the regions that contain the best multi-axis illumination from the transmitters are located below the intersections of three transmitter coils (Figure 3). Soundings acquired while the target passes through these regions provide data that fully constrain the inversion of all three principal axis polarizabilities and therefore each of these soundings enables classification of the target.

By treating each sounding (i.e., point location methodology) as a unique target encounter it is possible to obtain multiple sets of classification features for each DGM anomaly. The repeatability of various model parameters (e.g., target location, depth, orientation, polarizabilities, etc.) over multiple soundings associated with an anomaly may be used to build confidence in the classification decision. As an example, Figure 4 provides the set of model parameters associated with each sounding acquired in proximity to the anomaly circled in the DGM map. These parameters are consistent for each sounding, indicating the anomaly is well characterized.

One significant benefit of obtaining classification features from a single point location along each transect line is the reduced dependency on position and orientation data. Because there is no reliance in the inversion algorithm on point-to-point changes in the sensor array's position and orientation, it is possible to make effective classification decisions without high quality position and orientation data. This approach is particularly robust when high quality GPS and inertial data are not available or for instances when it may be difficult to track platform pitch and roll errors accurately.



Sounding	Northing Error (m)	Easting Error (m)	Depth (m)	Azimuth (deg)	Dip (deg)
1	-0.003	0.026	-0.433	51.0	17.1
2	-0.009	0.027	-0.448	44.4	17.2
3	-0.003	0.000	-0.452	55.3	8.6
4	0.002	-0.001	-0.453	50.2	13.7
5	0.000	0.002	-0.455	40.7	10.5
6	-0.006	-0.002	-0.459	46.1	14.3
7	0.000	-0.008	-0.457	46.7	14.7
8	0.003	-0.017	-0.451	42.5	14.5
9	0.014	-0.029	-0.437	42.2	14.0

Figure 4: TOP LEFT: OPTEMA DGM Map (nanoTesla/sec) showing several anomalies (red blobs) in a portion of the MRA. The anomaly of interest is circled in black with the model-based estimated location shown as the magenta dot. TOP RIGHT: Library matching for six different UXO targets. These magnetic polarizability curves are plotted as a function of time (logarithmically spaced) from 0.1 to 8 ms. Polarizability units are arbitrary and correspond to the sensor output units. Soundings corresponding to the anomaly are selected for inversion and the resulting nine sets of polarizabilities (each set comprises a primary, secondary, and tertiary polarizability) are plotted in magenta against the TOI library polarizabilities (shown in dark grey). The polarizabilities obtained from these consecutive soundings are almost identical and show a clear match to the 105mm Indirect Fire munition type. BOTTOM: Estimated model parameters corresponding to each sounding. Parameters are highly consistent for each sounding, indicating a high confidence decision can be made. The Northing and Easting errors for each sounding are within +/- 3cm of the mean estimated location (shown as the magenta dot in the DGM map). Depth estimates are consistent to within +/- 2cm and orientation estimates are consistent within +/- 6 degrees.

Man-Portable Array: Line Methodology

Our "EMPACT" man-portable array features a compact 1.0m by 0.5m horizontal transmitter coil that encompasses 5 three-axis receiver coils. Because this sensor has only one transmitter coil, we aggregate the data from consecutive soundings along the transect line (i.e., line methodology) in order to ensure the target receives the required multi-axis illumination from the transmitter.

As the transmitter passes over the target, any offset of the sensor from directly over the target produces a different angle of incidence between the impinging transmitter field and the target (Figure 5).

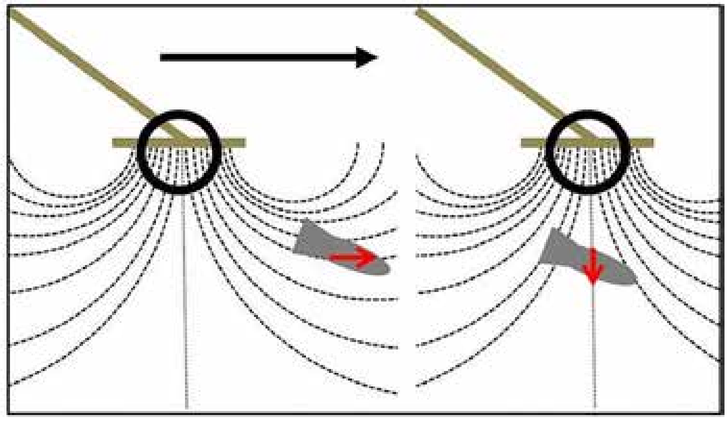


Figure 5: LEFT: The EMPACT man-portable array includes a single 1.0m wide by 0.5m long horizontal transmitter coil and 5 triaxial receivers. RIGHT: Because the sensor utilizes a single transmitter, effective classification is performed using a combination of multiple soundings along a transect line. As the array passes over the target, the change in the magnetic field (dashed lines) incident angle produces different angles of excitation within the target (indicated by red arrows).

For optimal classification results, we have found that it is best to include soundings from adjacent transect lines in the composite data set to ensure complete three-axis characterization of the target. Greater overlap in adjacent transects will produce higher quality classification; however, it is possible to achieve effective clutter rejection (discrimination) without overlap in sensor coverage. The line method uses point-to-point position and orientation tracking of the sensor as it acquires soundings along the transect line. Real Time Kinematic Differential GPS (RTK DGPS) or a linear positioning system (e.g., line encoder) providing 3-5 cm accuracy is sufficient for obtaining effective classification features. For operations in relatively flat terrain, orientation tracking of the array is not necessary; however, for sensor pitch and roll variations exceeding ~10 degrees, an inertial tracking unit can be used to monitor orientation changes. Figure 6 shows classification features and model parameters produced by inverting a composite set of soundings acquired along two adjacent DGM transect lines over an anomaly. An RTK DGPS provided the point-to-point position data for each sounding.

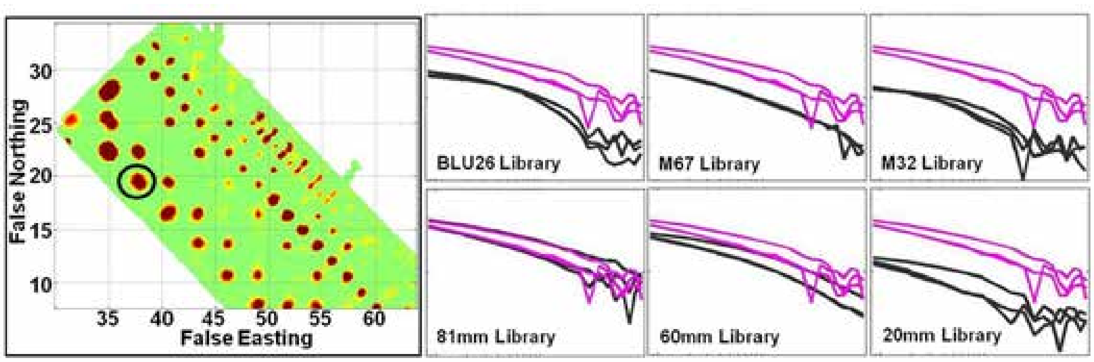


Figure 6: LEFT: EMPACT man-portable system DGM map (mV) showing the anomaly of interest circled in black. Soundings acquired along adjacent transect lines covering the anomaly are aggregated to form a composite data set for inversion. RIGHT: One set of polarizabilities (primary, secondary, and tertiary shown in magenta) are obtained from the inversion of the composite data. Polarizabilities are plotted as a function of time (logarithmically spaced) from 0.1 to 10 ms against library polarizabilities (dark grey curves) showing a match to the 81mm TOI. Polarizability units are arbitrary and correspond to the sensor output units.

Advanced DGM: Target Picking and Classification

We recently demonstrated both DGM systems at a Standardized UXO Technology Demonstration Site for performance assessments. We conducted mapping surveys with both systems operating in blind test field areas within the site (Figure 7). The objective of these demonstrations was to evaluate the ability of each system to enable both detection and classification of MEC items from data acquired during the mapping surveys. We treated each survey as a standard DGM operation, running both sensors along straight line transects across the survey area at approximately 2.5 km/h.

Figure 7: Vehicle-towed (LEFT) and man-portable (RIGHT) systems during DGM surveys at one of the DOD Standardized UXO Technology Demonstration Sites.

The initial post-survey analysis includes standard filtering and gridding of the survey data to produce two-dimensional maps corresponding to all survey areas. From these maps, we identify all anomalies exceeding our pre-determined threshold. These anomalies are then used as inputs to our inversion and classification software toolbox, which selects soundings for inversion and generates a set of classification features corresponding to individual regions of interest (ROI). The final step in the post-survey analysis processing chain is classification ranking (i.e., high probability UXO at the top of the list to high probability clutter at the bottom of the list) of each ROI. Initial ranking is based on an analysis of features such as size, decay, and symmetry and matching of polarizabilities to known UXO target polarizabilities. After initial ranking, the analyst performs a final quality control (QC) check of each ROI ranking.

During our QC analysis, the benefits of advanced DGM classification were exceedingly evident. The ability to correlate classification features with 2-D map features acquired from the same data set has a significant advantage over the two-step DGM + cued approach when analyzing data acquired in high anomaly density areas. This is exemplified in Figure 8 where data acquired over two targets produced overlapping anomalies in the 2-D detection map. Using a standard peak detection target picking algorithm, it is difficult to separate the anomaly into separate responses. In this case, if a cued sensor were to follow a standard DGM sensor, the target picking analysis might direct the cued sensor to a location between the two targets and fail to characterize them individually. Using the advanced DGM data, however, we can clearly separate soundings associated with one object from soundings associated with the adjacent object during the classification analysis. In this case, one group of soundings clearly indicates a TOI (81mm) while the other group of soundings indicates a large piece of clutter. Because both objects are of comparable size and emplaced at similar depths in close proximity, it would be difficult to distinguish their locations for a follow-up cued survey using the standard DGM approach.

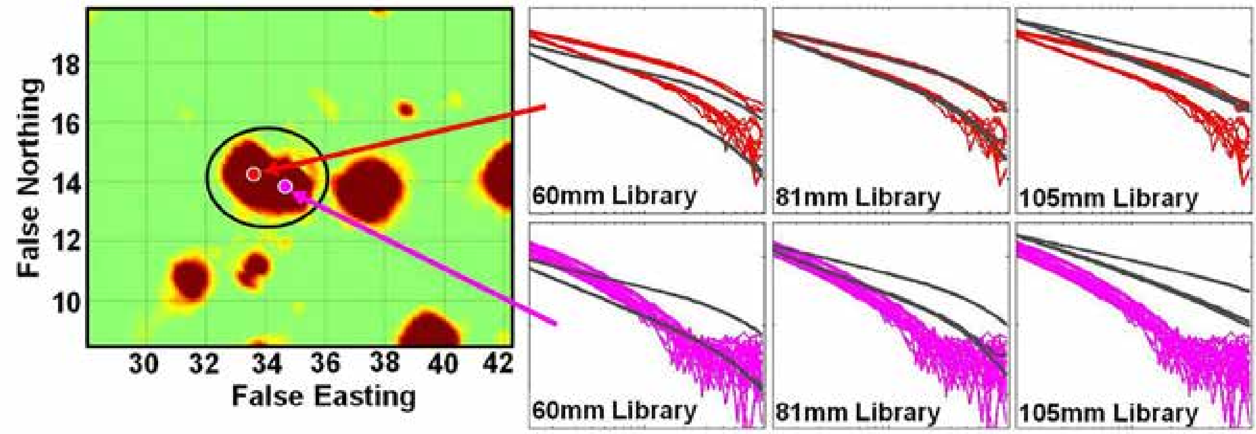


Figure 8: LEFT: OPTEMA DGM data map (nanoTesla/sec) showing the anomaly of interest circled in black. Using the 2-D data, it is difficult to resolve the location of the sources; however, classification analysis of the data reveals two distinct sources. RIGHT: Polarizabilities in arbitrary units (red and magenta curves) generated from classification analysis of the data plotted as a function of time (logarithmically spaced) from 0.1 to 8 ms against library polarizabilities (dark grey curves). Soundings from within the ROI (circled in black) are inverted for classification features. One set of soundings clearly indicates the presence of an 81mm TOI (red polarizability curves corresponding to a source location indicated by the red dot on the map) while another set of soundings indicates a large piece of clutter (magenta polarizability curves corresponding to a source location indicated by the magenta dot on the map).

The second example is presented in Figure 9, which shows data acquired over an area containing a bunch of clutter items. In this case, the peak detector identifies eight potential target sources. If a follow-up cued sensor were used here, the cued sensor would need to be moved around to eight different locations, requiring several minutes to complete. Using the advanced DGM data for classification, however, it is apparent that there are only three significant sources in the area, all of them similar clutter objects.

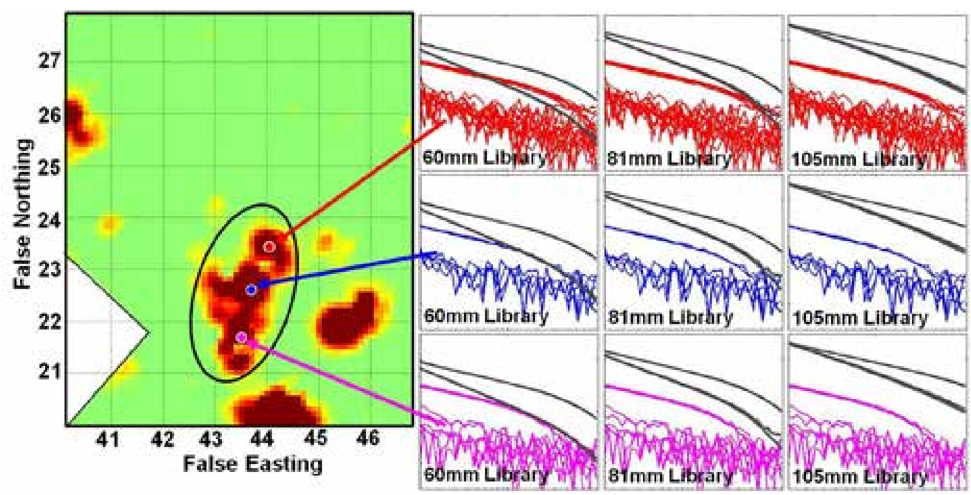


Figure 9: LEFT: OPTEMA DGM map showing the ROI circled in black (nanoTesla/sec). This ROI corresponds to a cluster of targets. Using the threshold target picking algorithm, the peak detector generates eight potential source locations in the ROI. If a follow-up cued survey were used, it would entail soundings at each of these eight locations, requiring several minutes to complete. RIGHT: Polarizabilities (red, blue, and magenta curves) generated from classification analysis of the data plotted as a function of time (logarithmically spaced) from 0.1 to 8 ms against library polarizabilities (dark grey curves). The polarizabilities in arbitrary units are divided into three groups (red, blue, magenta), each group corresponding to the location of a distinct clutter object in the DGM map (red, blue, magenta dots).

System Performance Summary and Conclusions

Results from recent performance evaluations show the ability of advanced DGM methods to enable a high degree of clutter rejection from mapping survey data. The vehicle-towed system enabled rejection of 85% of the clutter with 100% detection rate. This clutter rejection rate is comparable to those provided by advanced cued systems (McClung and others, 2009a; McClung and others, 2008; McClung and others, 2011) while the detection capabilities exceed those of standard DGM arrays (McClung and others, 2009b). This combination of high quality detection and discrimination from an advanced DGM survey makes it possible to greatly improve the productivity of the existing two-step detection/cued classification approach while retaining the same level of clutter rejection (typically >75%).

Analysis of data collected at the DOD UXO Demonstration Site emphasizes the significance of performing target picking and classification steps using one data set. By providing high resolution mapping data, the advanced DGM approach enables direct correlation of classification features to a set of 2-D map coordinates. This capability greatly improves the confidence of classification decisions made in high anomaly/clutter density areas by providing the analyst with a complete understanding of the target space.

Our recent tests indicate that advanced DGM classification is an efficient and reliable solution for munitions response site projects. Combining the anomaly detection, clutter rejection, and UXO/MEC classification stages in one DGM survey offers significant improvements to the two-step detection/classification approach currently used for many classification-level projects. These improvements are realized through a reduction in the number of excavations required for non-hazardous objects, a reduction in the total survey time required for detection and classification of all MEC contaminants, and greater reliability of the QC process due to the use of a single sensor for detection and classification.

Acknowledgments

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HIGHER-RESOLUTION MAPPING FOR UXO INCLUDING DETECTION OF 20MM PROJECTILES AT DEPTH

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Introduction

Cued investigations for unexploded ordnance (UXO) with advanced classification tools require accurate detection-level survey data to guide initial target picks and clean background locations. The sensitivity of these cued instruments is such that standard EM61-Mk2 results are oftentimes inadequate. Multiple targets may appear as a single anomaly, or small clutter may contaminate background locations. To address this problem, Battelle has developed and demonstrated a new ground-based TEM system based on the TEM-8 airborne configuration. This new instrument (TEM-8g) has sufficient sensitivity to detect 20mm projectiles to a depth of 20x diameter and to resolve locations to approximately 5cm.

This system was inspired by a request from the U.S. Army Engineering Support Center, Huntsville for a system capable of reliably detecting 20mm projectiles which resulted in ESTCP project MR-201105. It is based on the successful Battelle TEM-8 airborne system electronics with the transmitter and receiver configuration optimized for small ground targets. It features a single transmitter with eight receivers across a 1.75m swath width towed behind an all-terrain vehicle (Figure 1). In this article we summarize the results of the final ESTCP demonstration at the Aberdeen Proving Ground (APG) Standardized UXO Technology Demonstration Site, Maryland from May 2013.

Although the detection depth using the TEM-8g is nearly doubled (20x instead of 11x), the system is operationally comparable to an EM61 array. Survey speeds and swath widths are similar but the data density for the TEM-8g is much higher, the resolution is much finer, and the sensitivity is greater. The data processing flow is also comparable, requiring only a low-pass filter and background leveling to produce final grids and decay profiles. These are sufficient for general characterization and picking as one would from a standard EM61 array. The greater sensitivity of the TEM-8g typically leads to more detections and longer dig lists. If threshold analysis is insufficient to meet project requirements, full polarizability inversion can also be applied to TEM-8g data. This requires a second pass over the site in an orthogonal survey direction in order to obtain sufficient "look angles" at the targets (Figure 2). For the purposes of the ESTCP demonstration and reporting requirements, data were acquired in two orthogonal passes over the site, which served as the basis of the system assessment.

Polarizability inversion codes were developed by Leidos and the results were used first to develop a target library and subsequently to classify targets. Where target samples were not

Keywords: Unexploded Ordnance (UXO), Transient Electromagnetic (TEM), Cued Investigations, Polarizability, Receiver Operating Characteristic (ROC) Curve.

available in the Calibration Grid, results from libraries for other systems such as TEMTADS and MetalMapper were used. The system was demonstrated at the APG Standardized UXO Technology Demonstration Site over the Blind Grid and the new Small Target Grid. The Small Target Grid included small munitions (20mm, 37mm, 40mm) at depths down to 20x diameter. This area had high background soil susceptibility and considerable native clutter. In addition, numerous cells included a deliberate surface clutter cap placed directly over the target location in order to better represent live-site conditions.

Figure 1: Photo of TEM-8g instrument cart and tow vehicle.

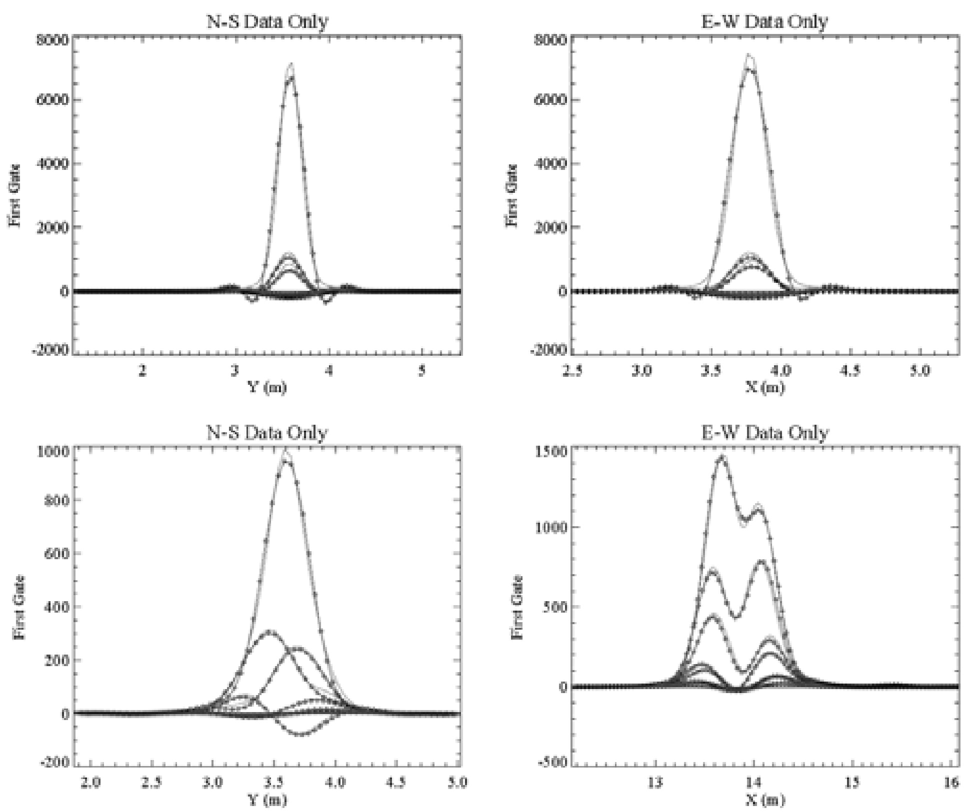

Figure 2: Modeled and measured response for all eight receivers to a shallow buried target. The variability in response with target orientation and survey direction illustrates the multiple-look angles. (top-left) NS pass over vertical target. (top-right) EW pass over vertical target. (bottom-left) NS pass over EW target. (bottom,-right) EW pass over EW target. Note that for the horizontal target, the transverse single-peak response is comparable in amplitude to the corresponding trough response in the orthogonal survey data.

Calibration Sites

Testing and calibration of the system was conducted in two phases. The first was at Battelle's UXO Test Site in West Jefferson, OH. Both 20mm and 37mm projectiles were seeded at depths between 5x and 20x diameter (Figure 3). Non-UXO frag items were chosen specifically for their similarity to 20mm projectiles and were buried at depths similar to that of the projectiles. All targets, regardless of depth, were detected for anomaly amplitudes greater than a 10ppm threshold (10:1 signal-to-noise ratio), yielding a Pd (probability of detecting a target above the response threshold) of 100% down to 20x diameter. The average radial target location error was 0.06m with a standard deviation of 0.04m. The average depth error was 0.02m with a standard deviation of 0.03m. Inversion results were sufficiently tightly clustered that two variants of 37mm targets could be isolated, and the 20mm targets could be isolated from the same-size frag based on their conductivity response.

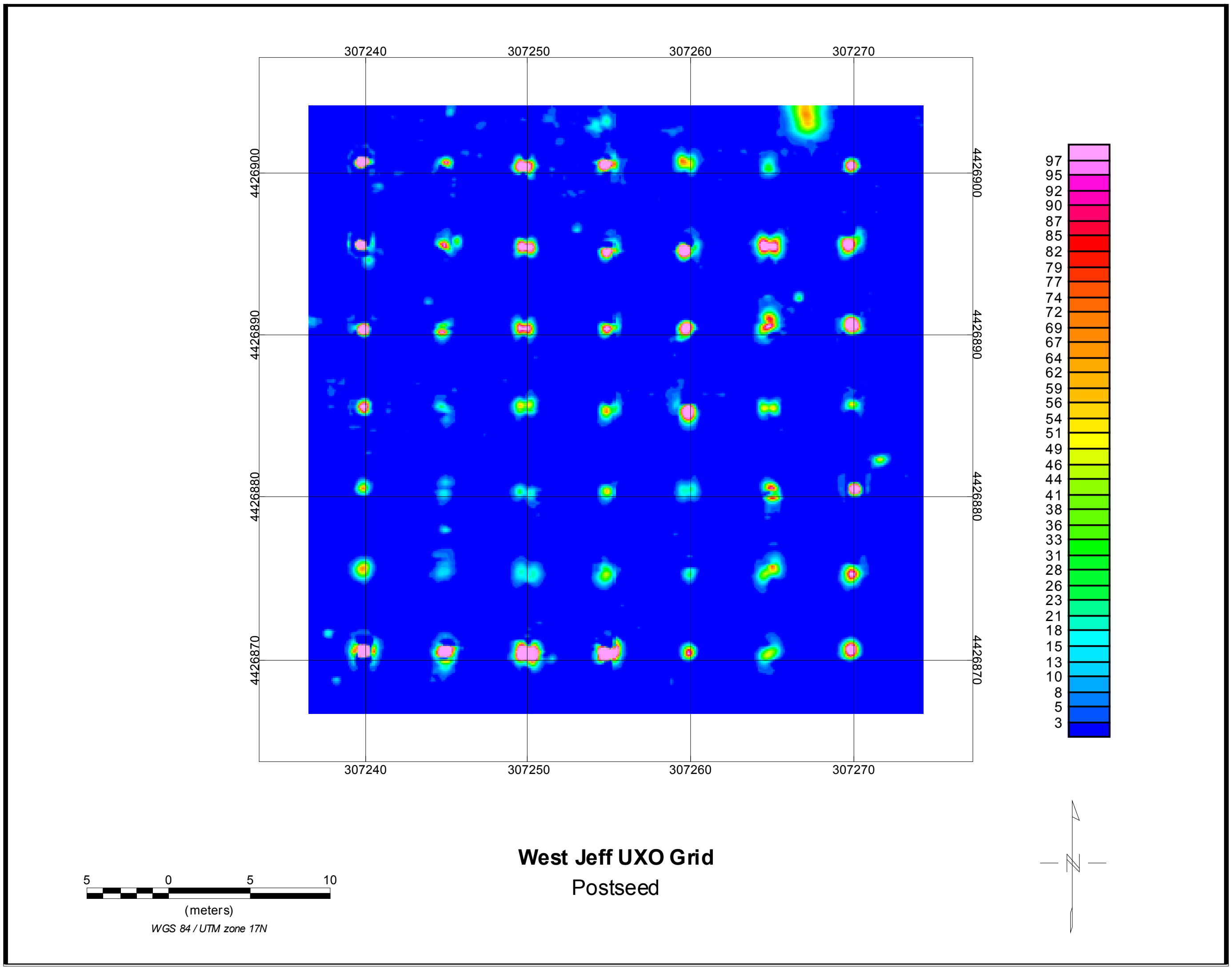

Figure 3: Bin2 response over the West Jefferson test grid with 20mm, 37mm, and clutter at depths to 20x diameter. Measurement units in ppm.

The second phase was at the Standardized UXO Technology Demonstration Site at Aberdeen Proving Ground, MD. Targets at this site included 20mm, 25mm, 37mm, 40mm, 60mm, 81mm, and 105mm ordnance plus a variety of clutter. The four survey grids here were designated the Calibration Grid (Figure 4), Small Calibration Grid (Figure 5), Blind Grid (Figure 6) and Small

Target Grid (Figure 7). The Calibration Grid contained a full range of targets at depths down to 11x diameter. The Small Calibration Grid contained 20mm, 37mm and 40mm projectiles at depths down to 11x diameter. The Blind Grid contained six different ordnance types (25mm, 37mm, 60mm, 81mm, 105mm and 105mm HEAT) at depths down to 11x diameter. The Small Target Grid contained 20mm, 37mm and 40mm projectiles down to 20x diameter. The two blind grids included buried frag items. The Small Target Grid contained additional surface clutter of unknown size.

All items in the calibration grids were detected and their signatures added to the library of response signatures (Figure 10 and Figure 11). All inversion responses clustered tightly around the expected library points except for the 25mm, 37mm and 20mm targets. The 25mm responses were more broadly distributed across the parameter space than most other targets with no clear center. The 37mm targets were tightly clustered, but were all of the same variant. The 20mm targets were clustered into two new library points (distinct from the responses measured at the West Jefferson site). This made selection of an appropriate library reference for the blind grids difficult.

Survey Results

The survey data from all four APG sites were processed in the same manner with one exception. The Small Target Grid showed a strong background response and considerable native clutter. Although the readings were consistent across the grid, the inversion process requires the removal of the local background response. Failure to remove this background biases the inversion results and makes classification difficult. This process was achieved by creating a grid of the background response alone and subtracting this from the anomalous responses. Figures 7-9 show the response before and after background correction. It is our expectation, that with further development, this background response map can be calibrated for direct application to cued instruments, thus removing the requirement for numerous interruptions for local background checks and providing improved efficiency in the cued survey.

These figures also show the level of native clutter present on this grid in comparison with the other three grids. The 20cm receiver coils provide much higher resolution of individual anomalies than systems with larger coils. The Calibration Grid results illustrate this in Figure 12. Two targets less than 1m apart are clearly defined as separate anomalies with sufficient resolution that they can both be inverted and classified. Multi-dipole inversion was critical to the successful inversion and classification. Cued surveys typically use this technique and then choose the most likely solution. If the number of dipoles within range of the inversion response can be independently verified from the detection survey, this should improve the overall performance of the cued survey and classification.

After processing, anomalies were picked from the gridded data. In the Blind Grid, all targets above the 10ppm threshold were selected. Those cells below the threshold were declared “Blank”. Results of the ground truth analysis were presented in several formats. The first was a Receiver Operating Characteristic (ROC) curve. This shows the probability of detecting a true target (ordnance) against the probability of detecting a false target (clutter) when using a prioritized dig list. Two lines are plotted corresponding to two prioritizing techniques. The orange line (Figure 13) is the ROC curve if the dig list is sorted based on response amplitude only. The blue line is for the dig list based on the inversion and classification results.

An investigation threshold for the response-stage and classification-stage dig lists was established prior to analysis of the ground truth. The response-stage threshold (red star) represents the point below which targets are not considered detectable. This was set at an amplitude of 10ppm, which is approximately 10x the noise floor of the sensor system. The classification-stage threshold (green star) represents the breaking point between ordnance and non-ordnance in the prioritized list. This threshold is set based solely on the classification results. In practice, this initial threshold will be modified by subsequent ground-truth reports from the field.

A similar process was used for the Small Target Grid. Scoring results were divided into capped and uncapped subgroups. The uncapped group replicates the standard seeding procedure used throughout the APG demonstration facility where the area around the target has been cleared of all (most) metallic debris. The capped group has additional clutter items placed directly on top of the target locations in order to mask the signature and make classification more challenging. This is more representative of what may be presumed to be found in a live-site situation rather than a typical controlled test plot. The combination of small targets, increased burial depth, native clutter and high levels of soil susceptibility, represent a worst-case scenario for APG demonstration purposes.

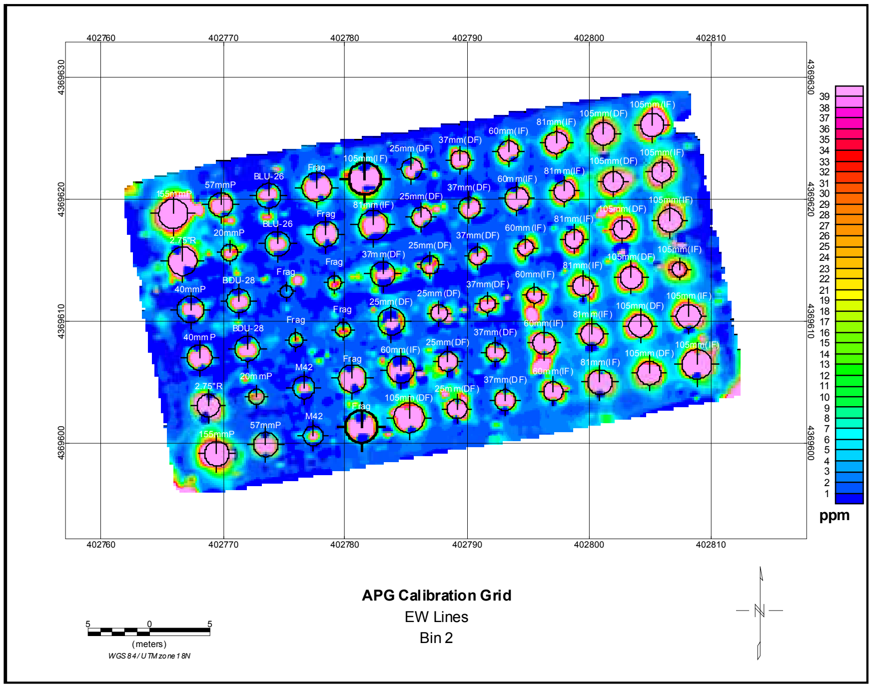

Figure 4: Bin2 response over the APG Calibration Grid with targets at depths to 11x diameter.

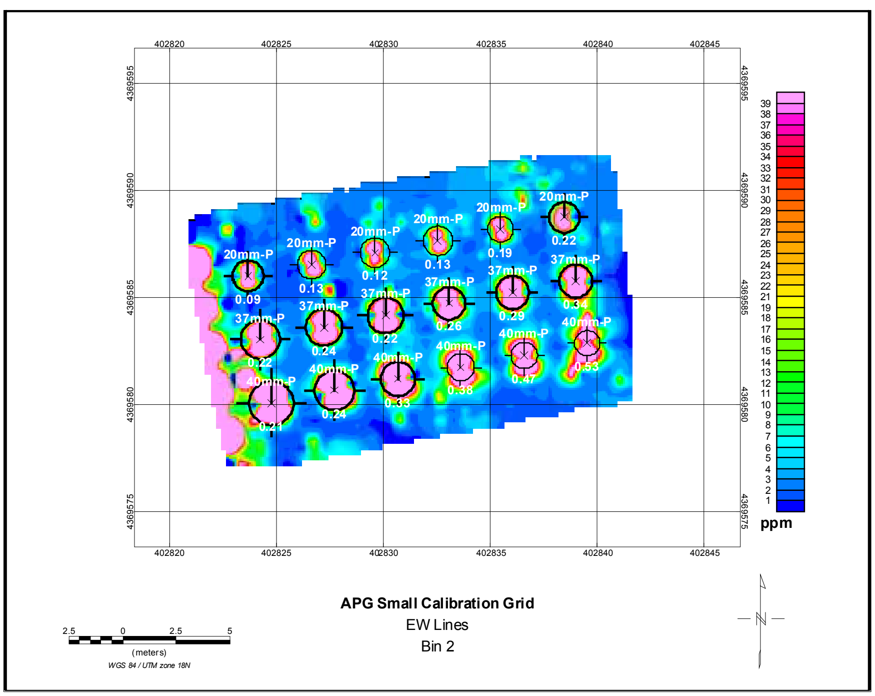

Figure 5: Bin2 response over the APG Small Calibration Grid with targets at depths to 11x diameter.

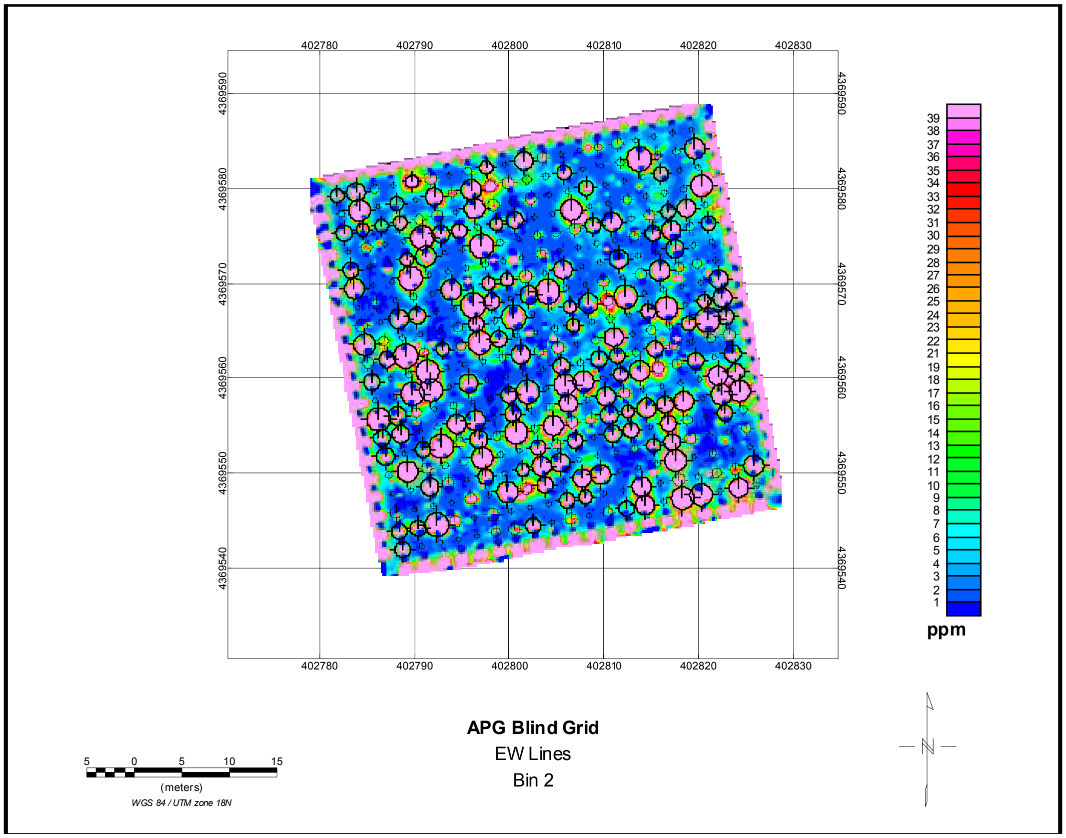

Figure 6: Bin2 response over the APG Blind Grid with targets at depths to 11x diameter.

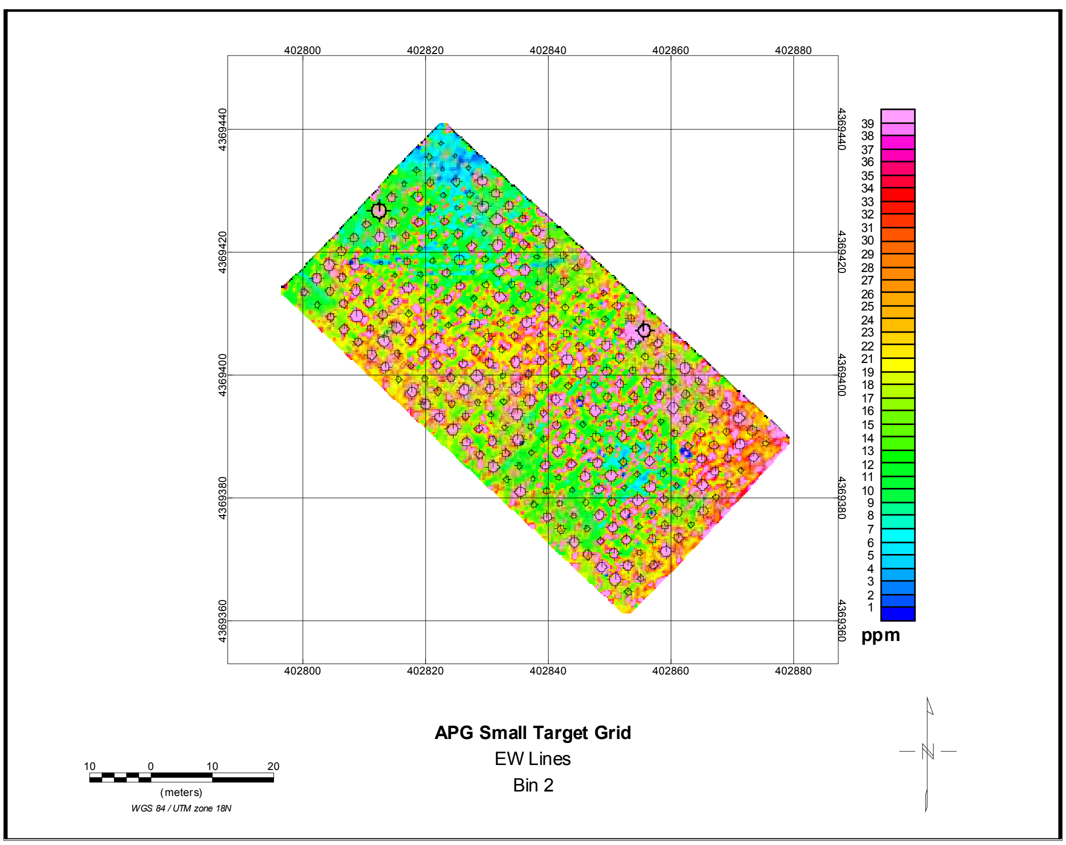

Figure 7: Bin2 response over the APG Small Target Grid with 20mm/37mm/40mm targets at depths to 20x diameter before removal of background response. Note change in background response levels from other APG sites.

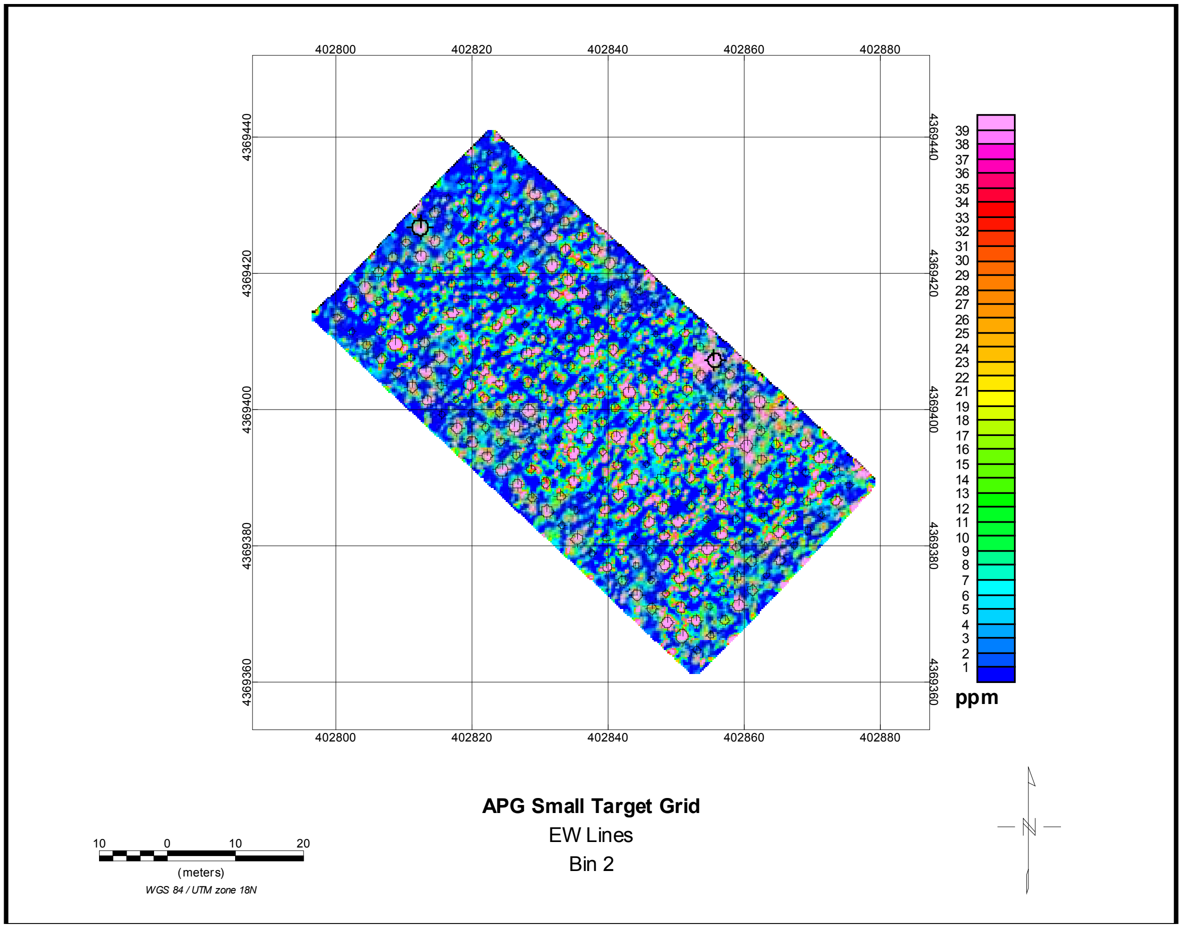

Figure 8: Bin2 response over the APG Small Target Grid with 20mm/37mm/40mm targets at depths to 20x diameter after removal of background response.

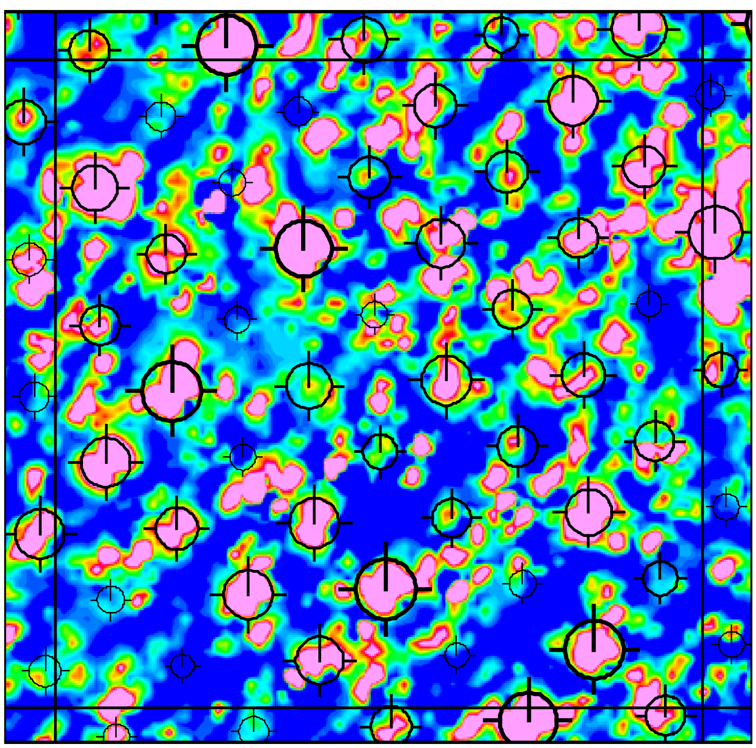

Figure 9: 20m x 20m extract of the Small Target Grid response in ppm (color scale is the same as Figure 8) after removal of background response to illustrate anomalous responses from seeded targets and native clutter.

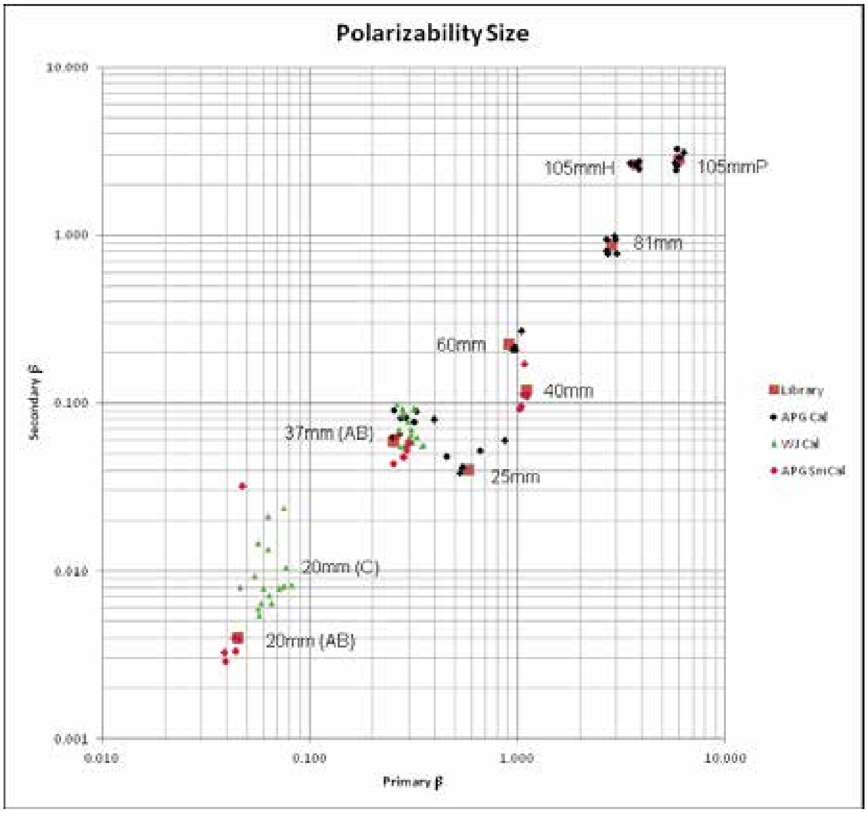

Figure 10: Plot of secondary vs. primary polarizability amplitude for calibration items. Points include individual results from the West Jefferson and APG Calibration grids, as well as the final library reference point used for classification of the APG grids.

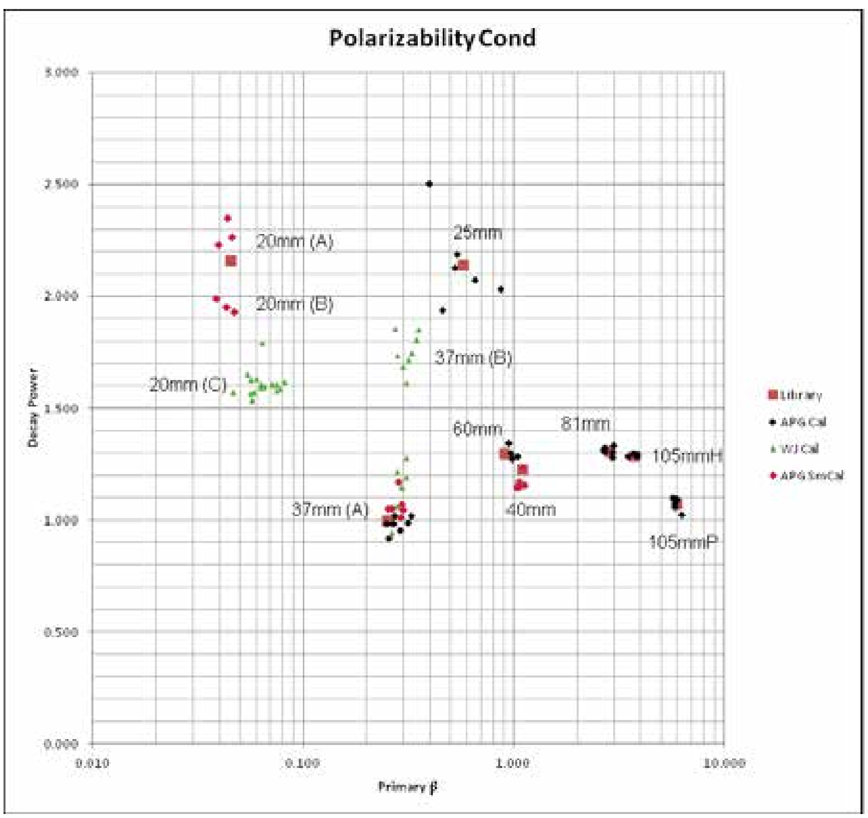

Figure 11: Plot of primary polarizability decay power vs. amplitude for calibration items. Points include individual results from the West Jefferson and APG Calibration grids, as well as the final library reference point used for classification of the APG grids.

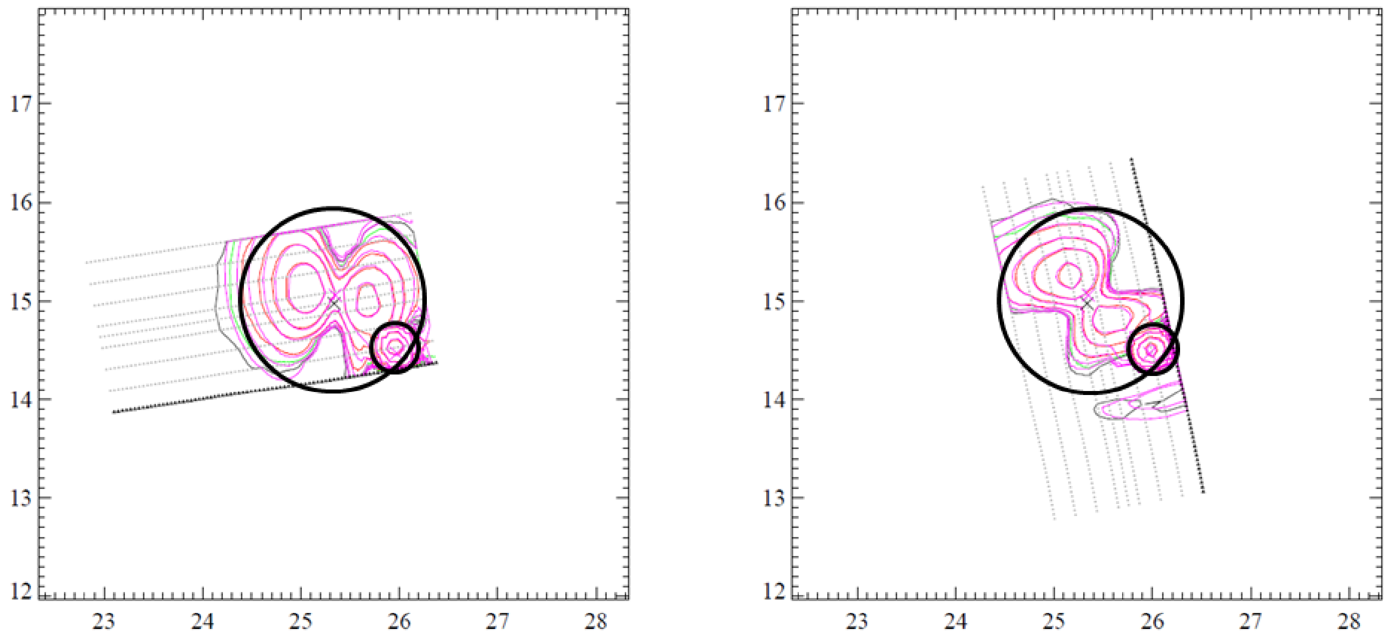

Figure 12: EW and NS profiles over APG Calibration Grid cell F4 showing seeded item and unintentional clutter item at 0.87m offset from the seed item. Signatures overlap but both are clearly resolved as separate items and can be inverted. Contour lines represent values in ppm.

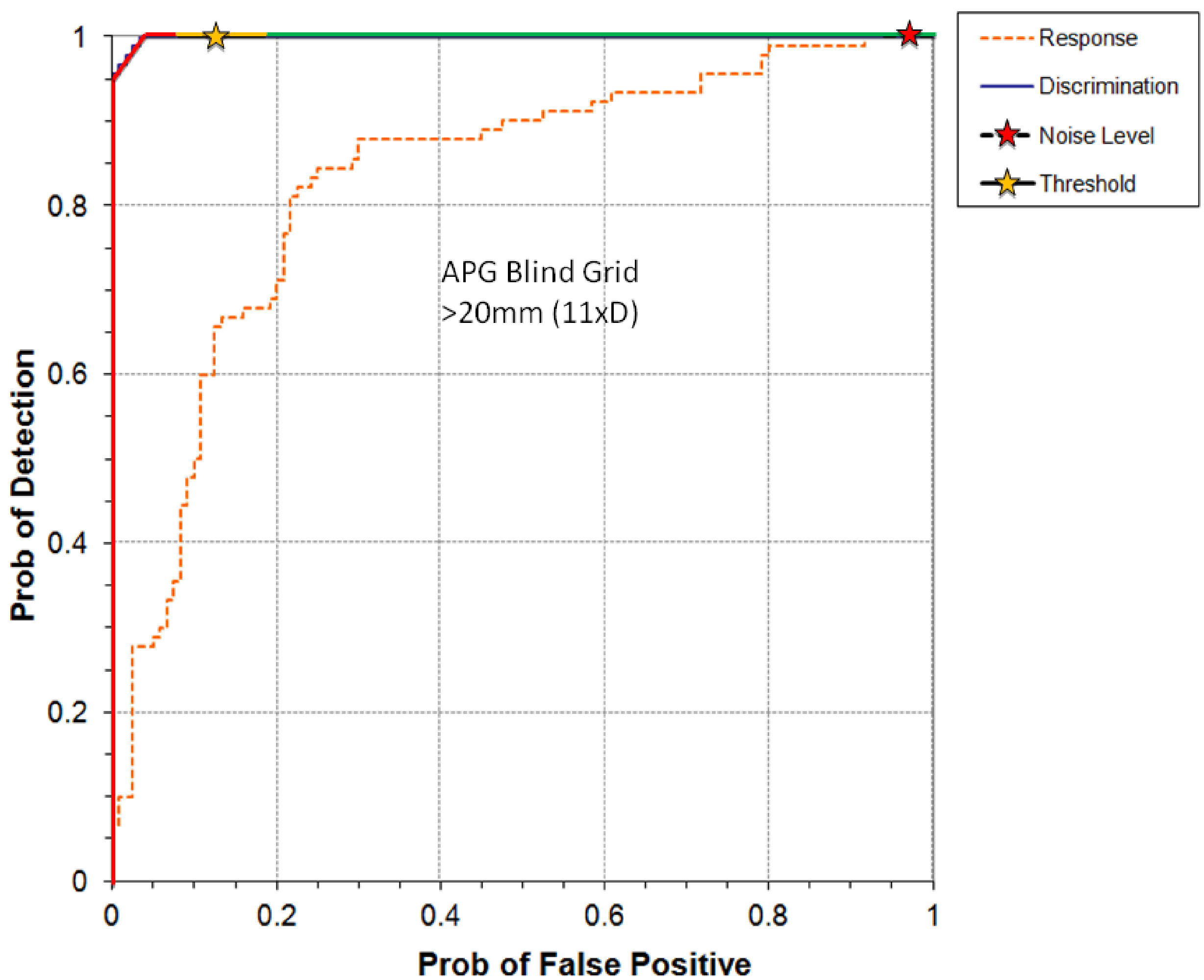

Figure 13: ROC curve for all targets on APG Blind Grid (>20mm, depths to 11x).

Scoring Analysis

The scores for the Blind Grid (targets >20mm, to 11x depth) demonstrate near-perfect detection, classification and clutter rejection capabilities for targets between 25mm and 105mm sizes at standard depths. The "knee" of the ROC curve (Figure 13) occurs at Pdisc=100% (probability of accurately classifying the target as ordnance) and Pcc=97% (probability of accurately classifying the target as clutter, equals 1-FP on the ROC curve). In retrospect, the threshold limit was set slightly higher than necessary, allowing some clutter items into the classified dig list. Given the size and depth of the targets in this grid, the Blind Grid results should be used when comparing TEM-8g system performance to that of other dynamic classification instruments, since this is the only grid that is common to all ESTCP system demonstrations.

The results from the Small Target Grid were excellent but require more detailed analysis. For the 37mm/40mm targets at greater depths (20x diameter), classification was nearly as good as the shallow depths with Pdisc=100% with Pcc=80% (Figure 14). For 20mm targets only, the classification Pdisc was 100% to 11x depth and 90% to 20x depth for cells without a clutter cap (Figure 15). A key factor to the successful inversion was the ability to accurately map the background corrections required over the entire survey block.

The combination of extra depth and a clutter cap had a minor impact on the 37mm/40mm targets (Figure 16). The worst case scenario is the combination of the smallest targets at the greatest depth with a clutter cap (Figure 17). In this case, the "elbow" of the ROC curve is at approximately Pdisc=85% and Pcc=85%. The list eventually reached Pd=100% but the discrimination threshold was set higher at Pdisc=96% and Pcc=52%. The "uncapped" results (Figure 15) were slightly better with an elbow at Pdisc=90% and Pcc=90% and a threshold point at Pdisc=97% and Pcc=61%. The additional clutter cap had little impact on the Pdisc but decreased the Pcc by approximately 10%. This result suggests that the cap disguised the clutter response, making clutter more likely to be declared ordnance, presumably by adding ambiguity to the inversion results.

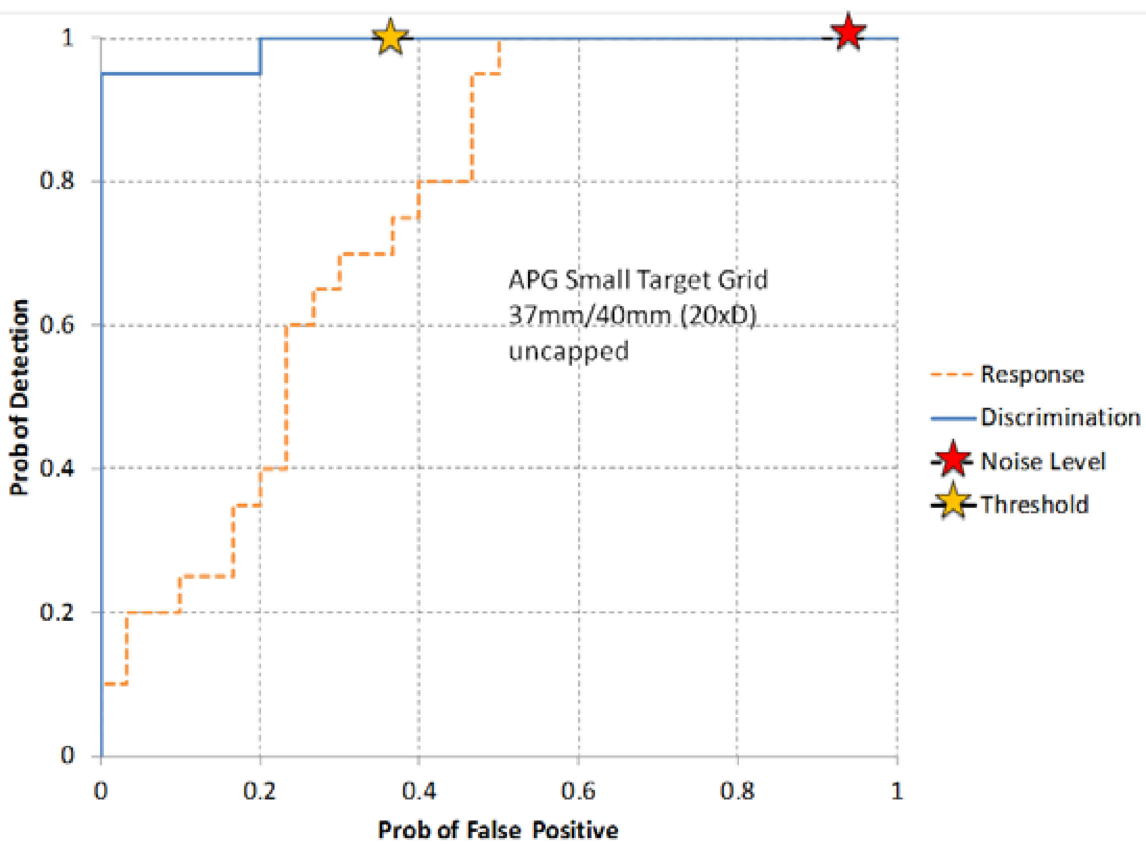

Figure 14: ROC curve for 37mm/40mm targets to depths of 20x diameter excluding cluttered cells.

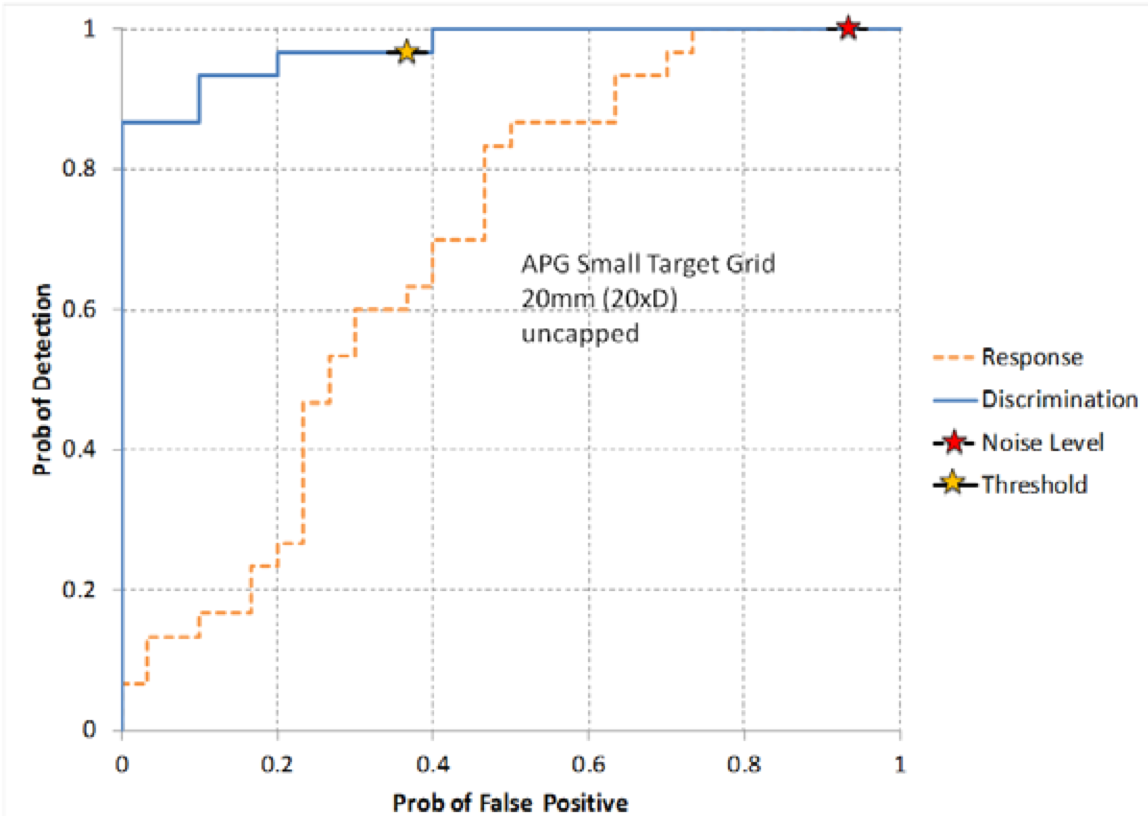

Figure 15: ROC curve for 20mm targets to depths of 20x diameter excluding cluttered cells.

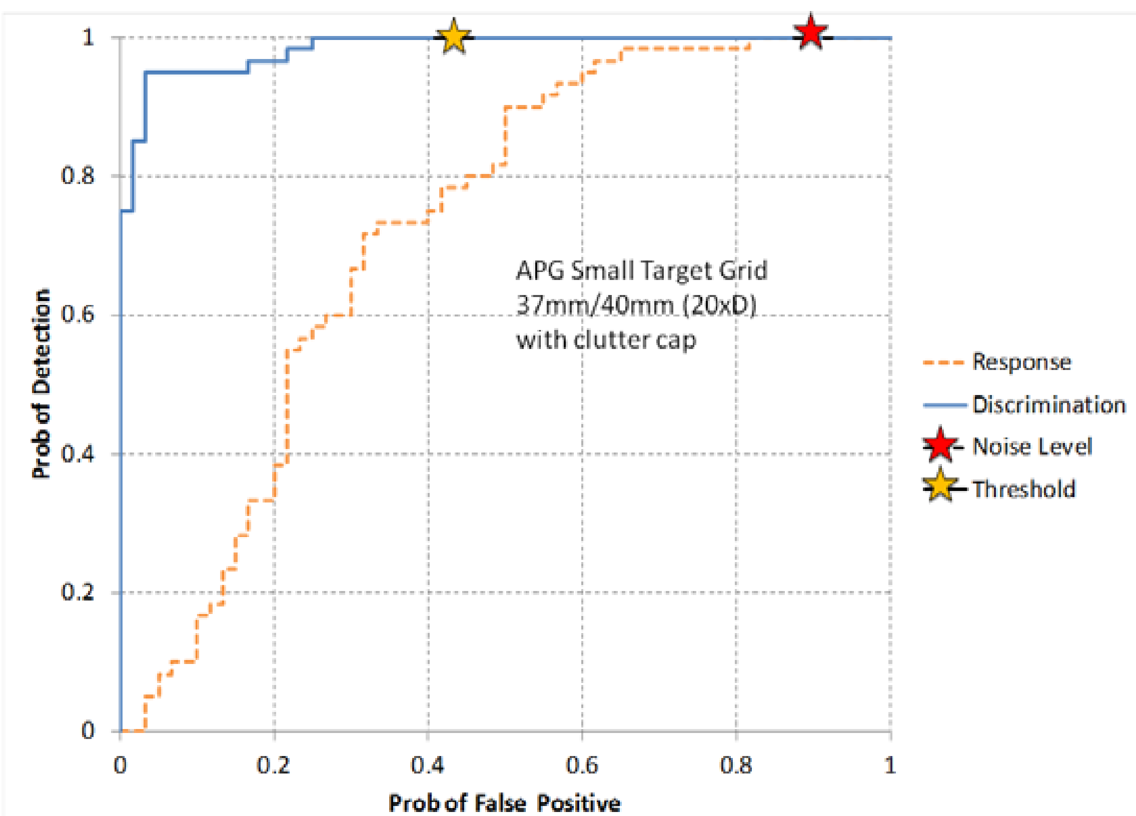

Figure 16: ROC curve for 37mm/40mm targets to depths of 20x diameter with clutter cap included.

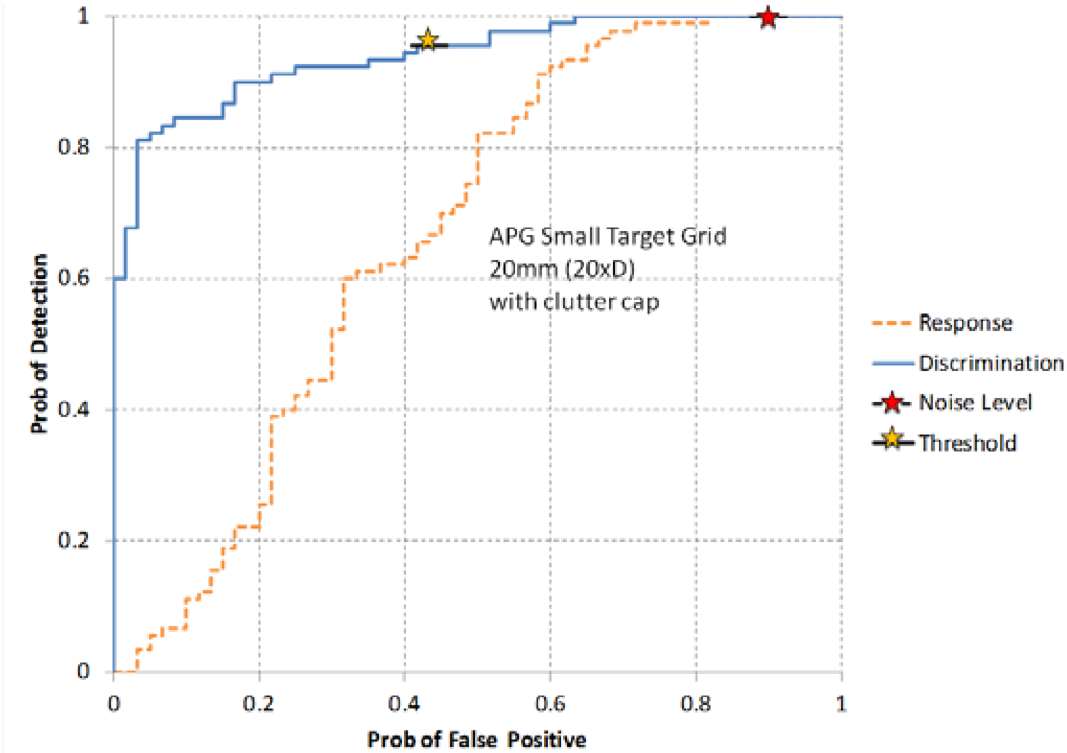

Figure 17: ROC curve for 20mm targets only to depths of 20x diameter with clutter cap included.

Conclusions

All targets in the Blind Grid and Small Target Grid were detected in the response-stage, resulting in Pd of 100%. In the discrimination-stage, all targets in the Blind Grid and all 37mm and 40mm targets in the Small Target Grid were detected at all depths, resulting in a Pdisc of 100%. The 20mm targets had Pdisc reduced to 87% / 90% (capped/uncapped), primarily at the greater depths. Classification of clutter (Pcc) was slightly lower than the corresponding Pdisc, reflecting a cautious approach to declarations. Pcc was 87% in the Blind Grid, and 52% / 61% (capped/uncapped) in the Small Target Grid.

The TEM-8g system was originally designed and developed as a high-resolution detection tool that could potentially replace the standard EM-61 array used in ordnance classification surveys. In that respect, the TEM-8g has effectively doubled the detection depth for ordnance items down to 20mm projectiles. Evaluation of the system indicates that it may improve the results of a cued survey in several ways. Higher-resolution responses make it easier to identify the number of dipoles that should be included in the cued investigation, or at least serve to independently verify the final selection. Complete mapping of the background response improves the selection of cued background locations that are both free of metallic sources and truly representative of the anomalous sample site. With additional calibration, the mapped background response may be used directly with the cued instrument, thereby reducing or even removing the requirement for periodic background measurements with the cued instrument.

The TEM-8g system also has the potential to be used as a dynamic classification tool. In spite of its monostatic configuration, this system is capable of full polarizability inversion of targets to depths of 20x diameter with a Pdisc approaching 100% and 20mm targets with a Pdisc of 85-90%. Results may be used to down-select the list of targets that require cued investigation. Such classification requires orthogonal surveying, but given the array size and survey speed (~2m/s), it still requires substantially less time on the grid than other dynamic classification tools. Those familiar with the processing work-flow required of the advanced classification tools will also appreciate that the simplified work-flow of the TEM-8g is more amenable to automation, which further improves efficiency.

ADVANCED CLASSIFICATION: WHAT WE'VE LEARNED AND WHERE WE'RE HEADING

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Introduction

As a result of decades of live-fire testing and training, the Department of Defense (DoD) has a Military Munitions Response Program (MMRP) liability estimated to be over 14 billion dollars. That estimate is based on remedial actions using traditional unexploded ordnance (UXO) remediation methodologies, which include "mag and dig" (experienced UXO technicians utilizing a handheld magnetometer to locate metallic objects) and digital geophysical mapping (DGM) (sensors that allow for a simple detection threshold to select targets). Advanced Classification allows for the ability to classify subsurface metallic objects into targets of interest (TOI) such as unexploded ordnance and non-targets of interest (non-TOI) such as fragments from functioned ordnance, horseshoes, and other non-hazardous debris. If the non-TOI can be correctly identified then they do not need to be excavated, and the costs in addressing the MMRP liability will be greatly reduced.

Since 2009, the Strategic Environmental Research and Development Program (SERDP), Environmental Security Technology Certification Program (ESTCP), and United States Army Corps of Engineers (USACE) have teamed up to push forward this new branch of technology. Collaboration began with ESTCP's Live-Site Advanced Classification Demonstration Program, which has overseen the successful application of this technology on over 20 live sites across the United States. It has since progressed to full implementation on a growing number of remedial actions every year. The intent of the following paper is to provide a USACE perspective on the current state of the industry through a series of case study summaries from some of these full implementation projects, and end with a summary of topics being worked to further transition advanced classification to mainstream use.

Basic Overview of Technology

All of the advanced electromagnetic induction (EMI) sensors function upon the same basic premise- multiple transmitter loops, multiple receiver loops, and precise time gate sampling extending deep into the decaying induced electromagnetic field. The two primary instruments that

Keywords: Unexploded Ordnance (UXO), Electromagnetic Induction (EMI) Sensors, Polarizability, Dynamic Data Collection, Cued Data Collection, Targets of Interest (TOI).

have been used on USACE remedial action projects are the Geometrics MetalMapper and the Naval Research Laboratory (NRL) TEMTADS. Figure 1 depicts the coil configuration for the Geometrics MetalMapper and Figure 2 depicts the coil configuration for the TEMTADS. Each receiver cube consists of three mutually orthogonal coils with a total of seven cubes in the MetalMapper and four in the TEMTADS. The transmitter structure differs between the two in that the MetalMapper has three large 1 meter x 1 meter orthogonal coils and the TEMTADS has four small z-axis transmitter coils. In addition to these two instruments, there are several more in various phases of development; however, to date, none have been utilized in production mode on a USACE project. The key to all these configurations is the ability to 'illuminate' a buried object with multiple transmit pulses so that all the object's primary polarizability axes are energized during the measurement cycle.

Figure 1: Figure 1a (left) depicts the coil configuration for the Geometrics MetalMapper. In red, blue, and green are the orthogonal transmitter coils. The cubes labeled numbers 1-7 each contain three orthogonal receiver coils. Figure 1b (right) shows a typical deployment platform for MetalMapper.

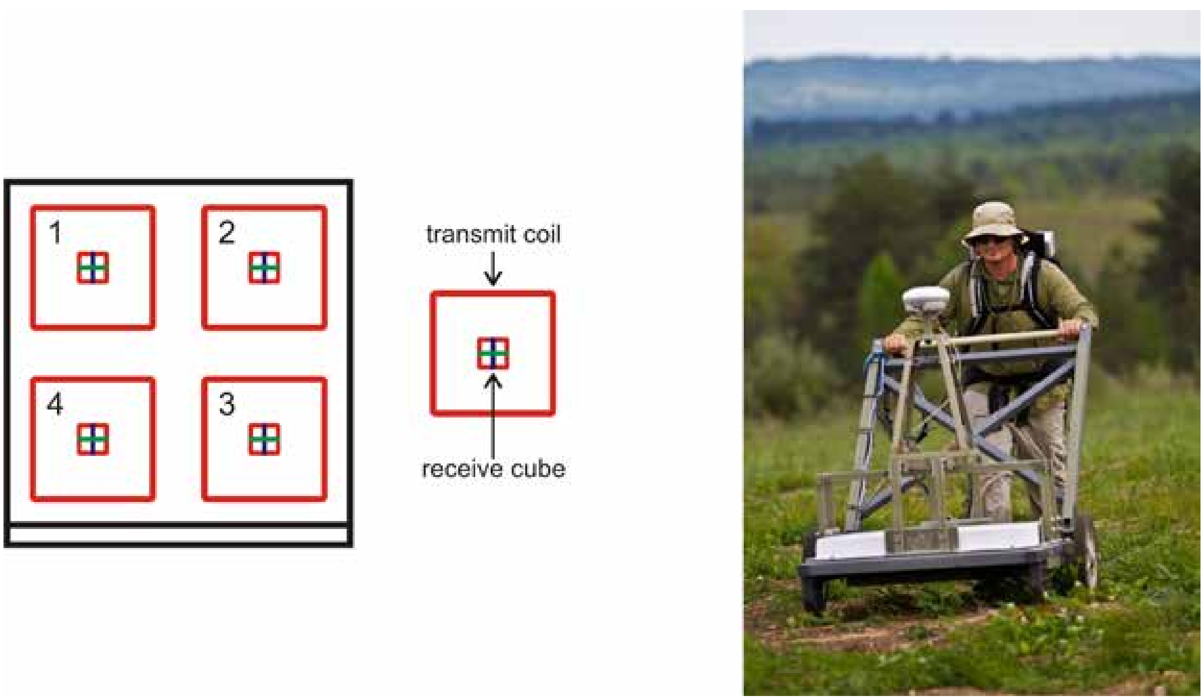

Figure 2: Figure 2a (left) depicts the coil configuration for the Naval Research Lab TEMTADS. Each of the boxes labeled 1-4 contain a Z-axis transmitter and a cube with three orthogonal receiver coils. Figure 2b (right shows dynamic data collection with the TEMTADS.

Advanced EMI data is collected in one of two deployments. Dynamic data collection, similar to an industry standard Geonics EM61 survey, consists of a series of transects or swaths across the project site. Because these sensors have a greater number of receivers, are equipped with an inertial measurement unit (IMU), and can be configured to stack data to match survey speeds, the dynamic data are of very high quality and resolution. Where previously a single large anomaly arising from several closely located pieces of buried metal would be detected using older technologies, distinct anomalies associated with each piece of metal can now be resolved. The second method is cued data collection, which consists of placing the sensor over the center of a previously detected anomaly and collecting stacked data for 30-60 seconds. Currently, most classification inversions and decisions are made solely from the cued datasets but dynamic inversion algorithms are in development and being tested.

Each piece of metal can be modeled by a polarizability tensor, with three directional components, which fully describes the far-field EMI dipole response to an applied electromagnetic field. Processing of advanced EMI sensor data includes inversion of the collected data to estimate those three principal-axis polarizabilities. Each is intrinsic to the piece of metal and is a function of its physical dimensions and properties. With the high resolution data obtained by the additional time gates and the improved positioning from incorporating IMU data, error is minimized and, more importantly, polarizability curves are accurately estimated. There are several processing methodologies used to complete this analysis, the premise for all is to compare the recovered data from the polarizability curves and perform a library comparison between known munitions response curves and the recovered curves. High confidence matches are selected as TOI (Figure 3) and later investigated. Those with low matches are confidently identified as clutter (Figure 4) and left in the ground.

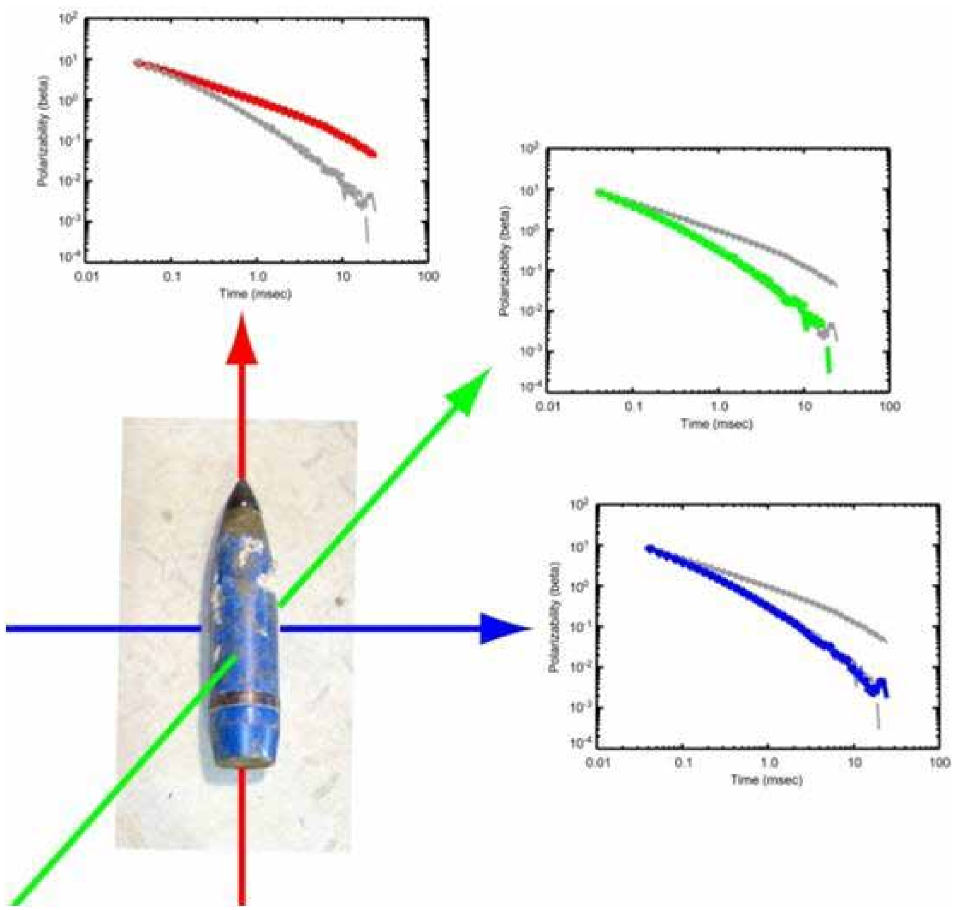

Figure 3: Intrinsic responses, or polarizabilities, along the principal axis directions of a 105mm. Illumination of target and receiver response from all directions allows for a fully characterized EMI signal. As expected from a cylindrical object, β1 has a stronger amplitude response than β2 and β3, which are equal. (X-axis in msec and Y-axis is polarizability in beta values.)

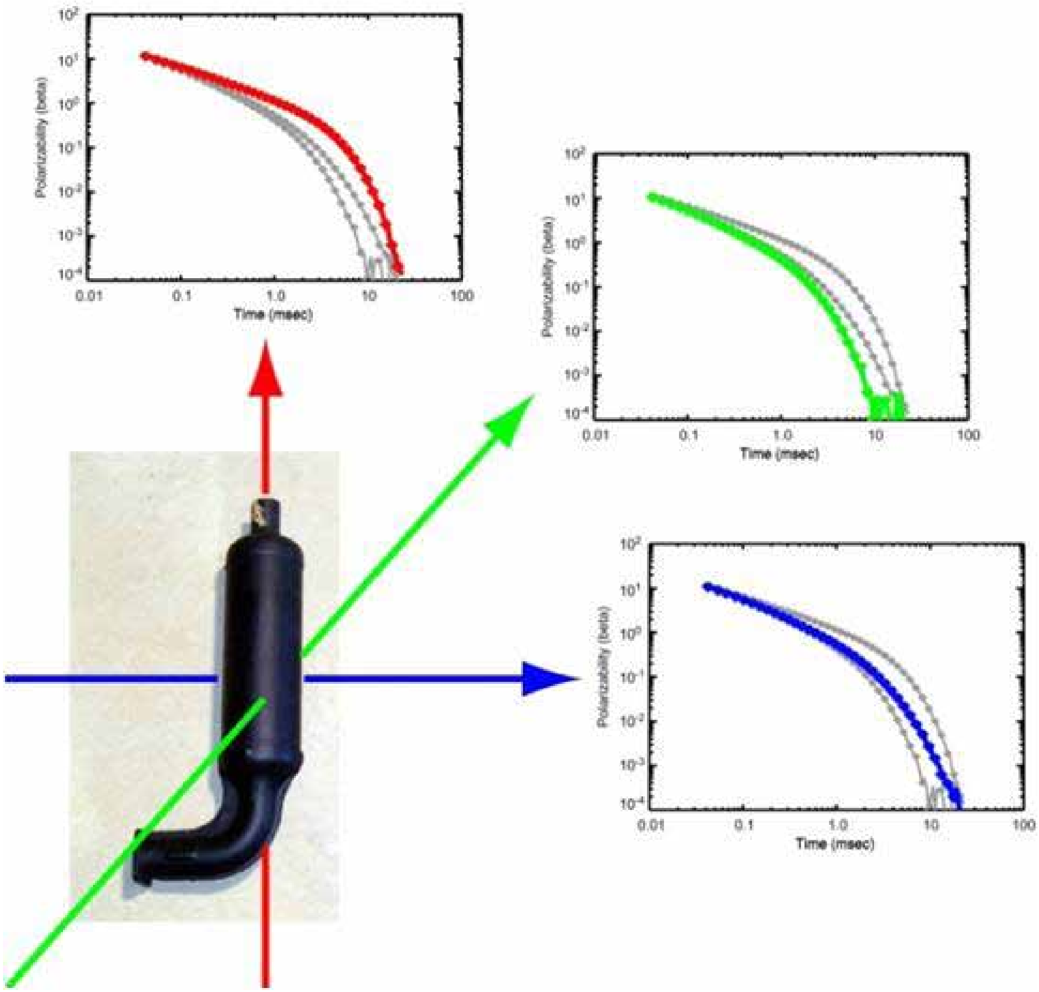

Figure 4: Similar to the 105mm depicted in Figure 3, β1 is stronger than both β2 and β3 for a muffler. However, due to the elbow, β2 is now stronger than β3. Furthermore, due to the thinner metal, the response decays much quicker in time. (X-axis in msec and Y-axis is polarizability in beta values.)

Implementation on USACE Projects to Date

Over the past two years several projects have evolved from the ESTCP demonstration projects into USACE production level efforts. All projects have demonstrated success at the technical level with multiple lessons to learn from as the industry heads forward.

Former Camp Beale

In 2011, ESTCP performed a demonstration project at the junction of four overlapping ranges at Former Camp Beale in California. The success of the demonstration encouraged USACE's Sacramento District and Environmental and Munitions Center of Expertise to team with the California Department of Toxic Substance Control (DTSC) and expand the existing demonstration project from nine acres to 36 acres. The purpose was to perform a Pilot Study on the contracting of advanced classification. As such, the contracting of the field work was broken up into three phases: Phase 1 was the blind seeding, Phase 2 was the cued data collection on previously selected EM61 targets, and Phase 3 was the intrusive investigation. Both the MetalMapper and TEMTADS platforms were utilized in the open spaces and wooded areas, respectively. Final processing and classification of both instrument datasets resulted in greater than 90% reduction in unnecessary digging of clutter items.

Of special note to this project was the early agreement between USACE and DTSC to leave non-hazardous debris in the ground. At that time, it was the first project to work under such an agreement as all of the previous ESTCP studies had been performed as a proof of concept, in which all detected pieces of metal were excavated. The idea to stop digging at the analyst's stop dig point after all TOI had been identified was new and necessitated a validation plan. Validating the non-TOI list required careful understanding of the classification scheme and close collaborations with the state regulators to determine the correct number of validation digs to select from the non-TOI list. Nearly ten percent of the anomalies on the non-TOI list were selected as validation digs, none resulting in any targets of interest. It was later mutually agreed amongst all team members, including DTSC, that ten percent was likely too many validation digs and the same assessment could have been performed with far fewer.

A number of additional concepts were identified at Camp Beale, which have been carried forward as lessons learned on more recent projects. These include: (1) the need for readily available replacement parts to avoid unnecessary production shut downs; (2) an appropriate tractor or vehicle with a well designed sled fitting the tractor mount; (3) the ability to store and transfer a large (~2-10gb/day) amount of data on a regular basis; (4) a higher resolution (i.e., tighter line spacing) EM61 dataset from which to cue targets would have resulted in far fewer cued locations and additional cost savings of roughly $7K/acre ; and (5) initial engagement of state regulators to discuss overall project goals and remedial action objectives would allow for early acceptance of project direction.

Former Camp Sibert

Former Camp Sibert's Site 18 and Range 28 Area A in Alabama were originally scheduled for a removal action, consisting of EM61 survey and intrusive investigation, during field work planned for 2013. The sites each had large sections of open field, flat topography, and a single suspected munitions type (4.2" mortar) making them ideal candidates for geophysical classification using MetalMapper. The project team, led by USACE-Huntsville Center in collaboration with the Alabama Department of Environmental Management (ADEM), determined that based on these site characteristics, results from previously conducted ESTCP demonstrations at Site 18, and proven contractor capability, that classification could be successfully implemented at Camp Sibert in support of a removal action. The opportunity to shorten the time frame of the removal action and the land owners' desire to minimize the number of holes dug in their fields also played a role in the decision to try classification at these sites.

Cued MetalMapper data were collected on geophysical targets identified from EM61 data. Utilizing a very conservative classification approach, 85% of the clutter was left in the ground with all of the known TOI correctly classified, demonstrating a significant success in regards to utilizing advanced classification during a removal action. Part of the conservative approach included placing the 2.36" rocket into the site specific library. These items were not expected at this site but had been found on other nearby areas of Camp Sibert. Additionally, conservative thresholds were selected for the validation digs, placing the stop dig point well beyond where the last seed and native munitions and explosives of concern (MEC) items were found. And lastly, classification and removal of munitions to 'depth of detection' were required to meet the Decision Document, even though there was significant evidence indicating they should be present only within the surface to 2-foot interval. A consequence of having to select low signal to noise (SNR) anomalies to meet the 'depth of detection' requirement was that a large number of anomalies were conservatively matched to large, deep munitions in the classification process, though most resulted in hot soil and none were found to be metal of any significant size. (Recent analysis of the data suggests that without this conservative approach, 100% successful classification would have been achieved while digging no more than three to four percent of all the anomalies detected.) A key concept from this work for future production efforts is to fully utilize the site specific data and high quality MetalMapper data to smartly set boundaries on the required amount of necessary digging to both recover TOI and validate the classification process. In the end, the conservative approach was a success and full stakeholder concurrence was achieved.

In addition to the multiple benefits of reduced digging, knowing when to expect specific munitions items was very helpful. After analyzing the classification results, including seeds, USACE was able to inform the field team of a high likelihood UXO item. This information was especially useful because the 4.2" mortars at Site 18 are potentially liquid filled (likely tearing agent), which requires a series of notifications and additional security measures, including scheduling military Explosive Ordnance Disposal (EOD) availability. Knowing in advance that an item might be liquid filled, the team was able to schedule the dig with EOD ahead of time. This helped minimize exposure to the item, manage risks to the property owner, and control costs associated with security.

Bellows Air Force Station

The Bellows Air Force Station project consisted of collecting cued MetalMapper data on previously selected EM61 targets. The advanced classification effort, led by USACE-Omaha District, was part of a time critical removal action on the Large Bomb Range at Bellows Air Force Station in Hawaii. During the remedial investigation, MEC items, including 25-lb Mk III Cooper Bombs, a 100-lb Mk I Practice Bomb, and fragments of a 100-lb M38A2 Practice Bomb, were found and all were added to the site specific classification library. Advanced Classification resulted in a 90% reduction in the number of anomalies requiring intrusive investigation.

Multiple issues were discovered during the field work, which have resulted in many of the current standard operating procedures utilized today. Due to large variations in local geologic response, an appropriate understanding of site geology and background response was necessary. Prior to the start of MetalMapper interrogation activities, transects were collected using the MetalMapper in dynamic mode to assess the impact of soil variability. As a result, a set number of pre-determined background locations were established and frequent background measurements were made (approximately one each hour) during cued collection. This approach has been extended to all sites with potential for variable backgrounds.

Also seen at other sites, the requirements at Bellows for positioning the sensor relative to the selected target location and the inverted location needed to be relatively strict in order to achieve a high signal to noise ratio necessary for classification. Additionally, it was determined that chasing inverted anomaly locations beyond the arc of the original target selection was unnecessary and project objectives could be achieved without doing so. Similar decision rules and quality control metrics have now been placed in all subsequent planning documents on other USACE projects.

The validation plan adopted for this project involved adding targets after the stop dig point and focused on anomalies with higher uncertainty in their inversion results. Four criteria were identified for selecting non-TOI: adding anomalies immediately after the stop-dig point, deep targets with relatively low amplitude EM61 data, large objects in high-density areas, and visual polarizability curve comparisons to library items by multiple analysts. Approximately 1.5% of the non-TOI list was selected and a failure was identified—a UXO was recovered. The root cause analysis revealed that the anomaly had been selected as a TOI early in the project, however it was subsequently removed from the TOI list as adjustments to the stop-dig threshold were made based on interim excavation results. After the error was discovered, the stop-dig point was revised to a more conservative stop-dig threshold and all anomalies above the new threshold were excavated. No UXO were recovered at those locations.

Joint Base Cape Cod (JBCC)

A team of geophysicists from three USACE districts (Baltimore, Huntsville, and Dallas-Fort Worth) was established to support efforts by USACE-New England District on the ongoing National Guard Bureau's Impact Area Groundwater Study Program (IAGWSP) at Joint Base Cape Cod (also known as Camp Edwards or Massachusetts Military Reservation (MMR).) The goals of this project were unique in that the removal is designed to reduce potential ground water contaminants from a heavily used impact area on an active installation. It is not necessary to remove all the UXO; the Decision Document requirement is to remove 75-95% of the net explosive weight on the site. The site is particularly challenging with a wide range of munitions and the highest anomaly densities (in terms of anomalies per acre) seen to date.

The team successfully participated in the ESTCP Phase I demonstration in 2013 and correctly classified 96% of the TOI while reducing the unnecessary digs by approximately 70%. After this demonstration the team performed a second demonstration in two ¼-acre grids within the Central Impact Area. The classification results from this demonstration were sent to ESTCP for official scoring, which indicated 89% of the TOI were correctly classified and the number of unnecessary digs was reduced by over 80%. The combined results of the two demonstrations prove the Decision Document's net explosive weight recovery requirements are easily achieved; it was estimated approximately 97% of the net explosive weight was recovered using advanced classification. The process further precludes digging 73% of the non-TOI.

Currently, the USACE team is nearing completion of data collection and processing on an additional 24 acres within the Central Impact Area to meet DoD's cleanup requirements for JBCC. This site has repeatedly demonstrated the limits of the multi-object inversion software within UXAnalyze; however, 95% success is attainable with careful analysis and proper quality control procedures. The project was also one of the first to demonstrate the need for in-field inversion software for real-time analysis. Both JBCC and Camp Beale demonstrated the importance of having decision rules in place for adding unexpected munitions to the site specific library.

Former Camp San Luis Obispo and the Uniform Federal Policy- Quality Assurance Project Plan

The most recent collaboration between ESTCP and USACE is ongoing at Former Camp San Luis Obispo (SLO) in California. Camp SLO was a former training range utilized in World War II and the Korean War. A wide range of munitions, from 37mm up to 5-inch rockets, have been found across this munitions response site. Early discussions with the state allowed for a preliminary remedial action objective to be agreed upon for this demonstration: a detection threshold established to detect all 37mm within the top foot and the correct classification of all munitions detected at that threshold. The work is being performed as a treatability study on 7 acres of the munitions response site, the results of which will inform the on-going Remedial Investigation and Feasibility Study for the former Camp SLO. USACE anticipates this treatability study will show remedial actions that use advanced classification for the remaining 2717 acres of this site can be achieved for between 30 and 50% lower cost than current conventional remedial technologies.

This is the first end-to-end demonstration contracted by USACE that includes dynamic detection using advanced sensors, cued interrogation of all anomalies, a stakeholder approved validation plan, and a Uniform Federal Policy Quality Assurance Project Plan (UFP-QAPP) for geophysical advanced classification. The QAPP for this site was developed in conjunction with the creation of a template for project plans for utilizing geophysical classification. This template has been produced by the Intergovernmental Data Quality Task Force (IDQTF) to assist project managers and team members in planning for the investigation of buried munitions at DoD installations and formerly used defense sites (FUDS). The IDQTF is a collaborative effort involving representatives of the Department of Defense (DoD), the Department of Energy (DOE), and the U.S Environmental Protection Agency (EPA). The development of this tool followed extensive research and development of geophysical classification technology and initial guidance established under ESTCP. It also draws upon similar efforts by the Interstate Technology & Regulatory Council (ITRC) Geophysical Classification for Munitions Response Team. The QAPP template documents the systematic planning steps leading to in-situ detection of munitions items and other debris followed by the use of advanced sensors for geophysical classification. Use of this template will help project teams generate a complete QAPP, i.e., a stand-alone document addressing all elements of the national consensus standard ANSI/ASQ E4, *Quality Systems for Environmental Data and Environmental Technology Programs*, for the collection and use of environmental data at Federal facilities.

Recent interim guidance from USACE (EM 200-1-15) mandates the use of the UFP-QAPP as the planning document for all military munitions work. Work at Camp SLO is being performed under the "alpha" template of the GCMR-QAPP with a subsequent project in 2015 to be performed under the "beta" template before finalizing the template for industry wide use by the end of the year.

Moving Forward

With the significant success of advanced classification demonstrated across both ESTCP and USACE projects, it is clear that the processes utilized will become common place as stakeholders continue to gain confidence in the technology and accept the final product. In order to assure this confidence and continue to produce high quality data, there are several key issues that will need to be addressed.

Accreditation

While modern classification technologies have dramatically increased the accuracy and quality of geophysical investigations, it cannot be assumed that 100% of all munitions items can be identified and removed at all sites. Furthermore, the advanced processing required to estimate geophysical properties and develop the TOI list requires extensive skill and should not be taken lightly by DoD or other stakeholders. The systematic planning process being developed in the QAPP helps to alleviate some concern by addressing quality control and quality assurance issues; however, there remains unease with how to assure the quality and ability of the geophysicist processor and the company that employs him. Many ideas continue to be developed, but one concept, still in its infancy but gaining traction, is the concept of accreditation.

As part of a second initiative by the IDQTF, the DoD Environmental Data Quality Workgroup (EDQW) proposes to develop the DoD Advanced Geophysical Classification Accreditation Program (DAGCAP) to provide a unified DoD program through which organizations providing advanced geophysical classification technologies can demonstrate competency and document conformance to the international standard ISO/IEC 17025:2005, General Requirements for the Competence of Testing and Calibration Laboratories. Modeled after the highly successful DoD Environmental Laboratory Accreditation Program, the DAGCAP would use third-party Accreditation Bodies (ABs) to assess and accredit geophysical testing organizations. Participation by both ABs and geophysical testing organizations would be voluntary. The DAGCAP would apply to geophysical testing organizations wishing to do business with DoD, regardless of their size or volume of business. It would apply to the use of advanced geophysical classification at all DoD Munitions Response Sites.

Under DAGCAP the geophysical testing organizations themselves would bear the expense of assessments and accreditation, allowing DoD to focus its resources on providing project-specific quality assurance oversight. If implemented, DAGCAP would:

- Promote fair and open competition among commercial geophysical testing organizations,
- Streamline the process for identifying and procuring competent geophysical testing organizations,
- Promote interoperability among the DoD Components, and
- Promote the collection of data of known and documented quality.

Validation Seeding and Digging

As seen in the case study summaries above, validation plans will play a significant role as the industry pursues stakeholder acceptance. There are two main components of a complete validation plan- validation digging (i.e., digging a selection of non-TOI) and validation seeds. Validation digging should be a fairly straightforward concept that will be site, data, and project team specific. Methods for selecting validation digs focus on decision points in the classification process, such as how the stop-dig threshold is defined, how useable data is defined (e.g., signal to noise ratio), etc.

Defining the number of validation digs is less intuitive. Based on the above case histories, quantities ranging from several tens to one or two hundred additional validation digs would be expected to meet most stakeholder needs.

Validation seeding would also be project specific, but how this component would be implemented in overall project execution strategies is still being debated. The central issue is defining the consequence of a failure (i.e., not correctly detecting and classifying the seed). This problem is not trivial because the consequence must be tied to performance and competency, but also implementable within the contracting strategies used in the DoD's Military Munitions Response Program. Regardless of the manner in which the consequence is defined, the outcome of such a failure will need to reinforce stakeholder confidence that the actions taken fully address and correct the true cause of the failure.

Dynamic Classification

One of the many benefits of utilizing the advanced sensors in dynamic mode is a much more robust dataset. The greater number of receivers results in increased resolution of individual targets, as shown in Figure 5; however, all of the additional information is not currently being fully utilized in anomaly selection. ESTCP researchers are currently working on more advanced dynamic processing algorithms that will allow for classification of dynamic data, resulting in an initial reduced list of anomalies necessitating cued interrogation. Camp SLO is an initial test site of a dipole inversion algorithm with initial results indicating it provides more accurate anomaly selection positioning and a more accurate list of anomalies associated with potential buried munitions.

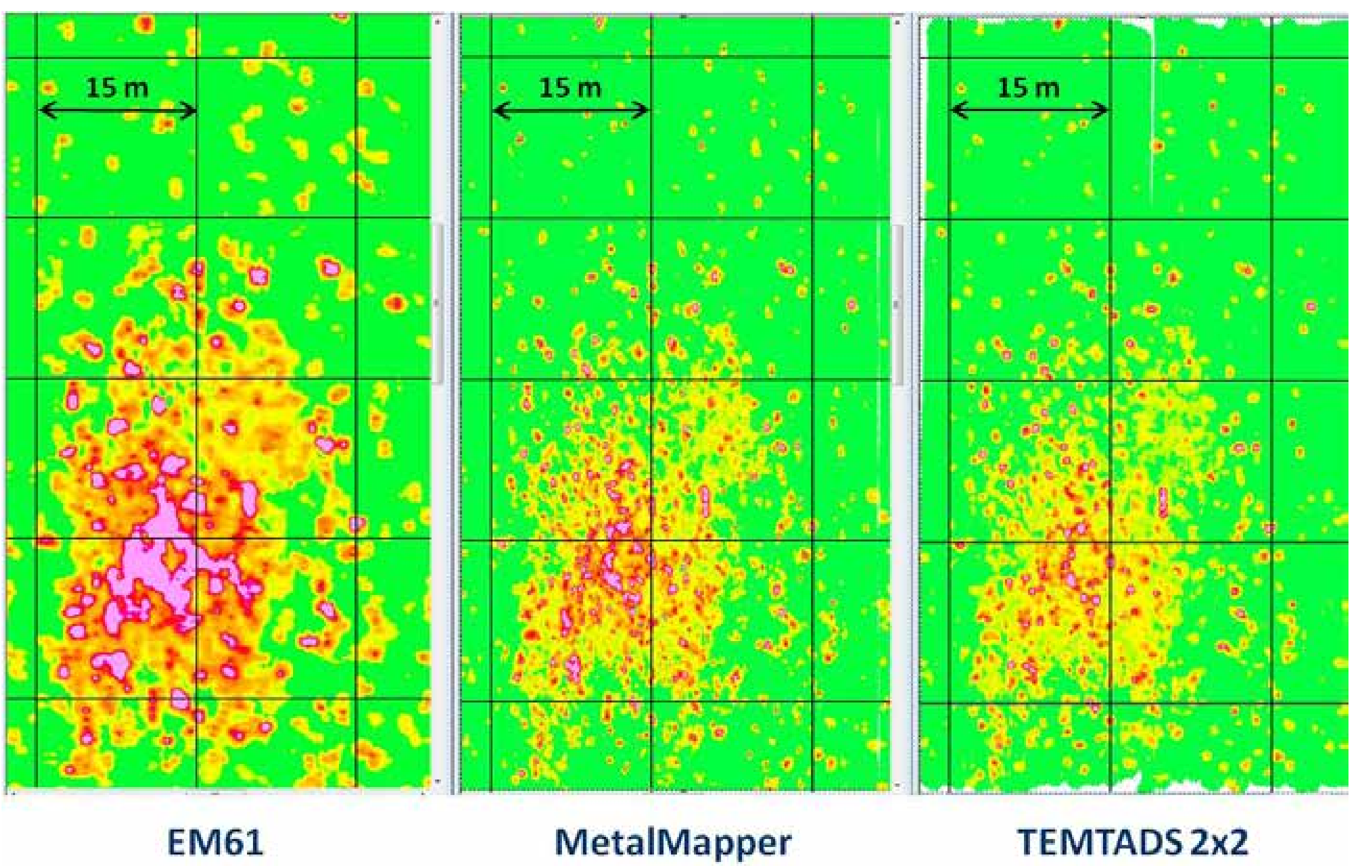

Figure 5: Figure 5 depicts the varying resolution capabilities of the three common instruments. Due to the greater number and smaller receiver coils, the advanced EMI sensors can better resolve individual anomalies. Future work aims to utilize more components of the data than simple amplitude thresholds which could result in the ability to better resolve, and potentially classify, targets. (EM61 measurement units are mV and MetalMapper and TEMADS 2x2 measurement units are mV/amp.)

Handheld Sensors

One of the instruments still in development is the Man Portable Vector (MPV) sensor. There are obviously many munitions response sites where pulling a cart is not feasible and a handheld sensor is the only way to fully cover the terrain. It is hoped that further acceptance of advanced classification spurs industry to produce a handheld instrument and acquisition procedures that can efficiently provide data of the quality needed to perform classification.

Conclusion

As ESTCP passes the baton of advanced classification to industry, USACE is taking the lead in developing the expertise and knowledge base to ensure success. There are already multiple projects contracted by USACE that have been completed and produced successful results. Looking forward, USACE expects advanced classification to become both the industry standard and a cost effective technology to address DoD's large fiscal liability posed by munitions on the many munitions response sites across the nation. The QAPP template being produced by the IDQTF will provide an easy solution to systematic planning and quality control of advanced classification processes, which in turn will lead to greater stakeholder acceptance and help DoD meet its munitions clean-up needs.

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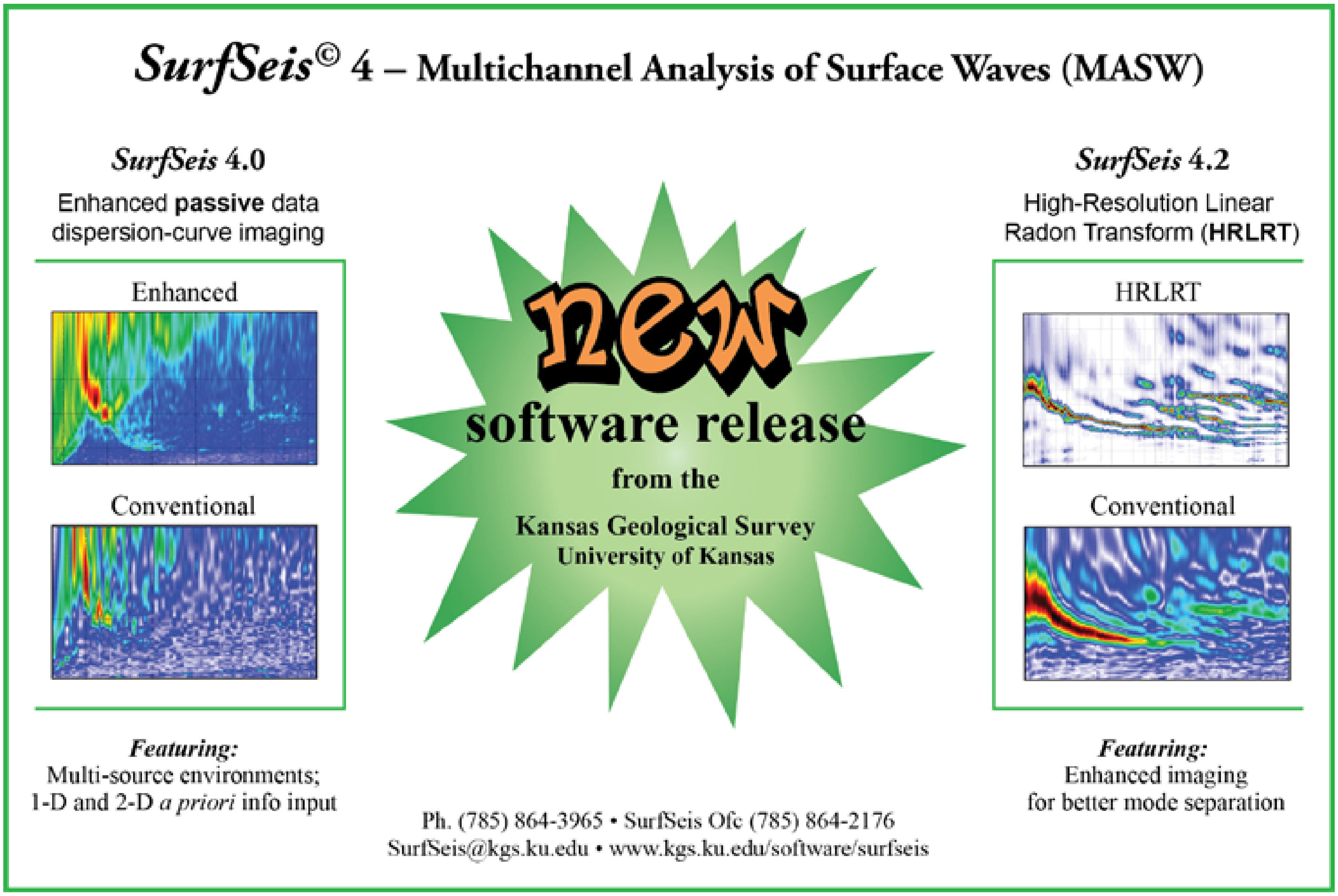
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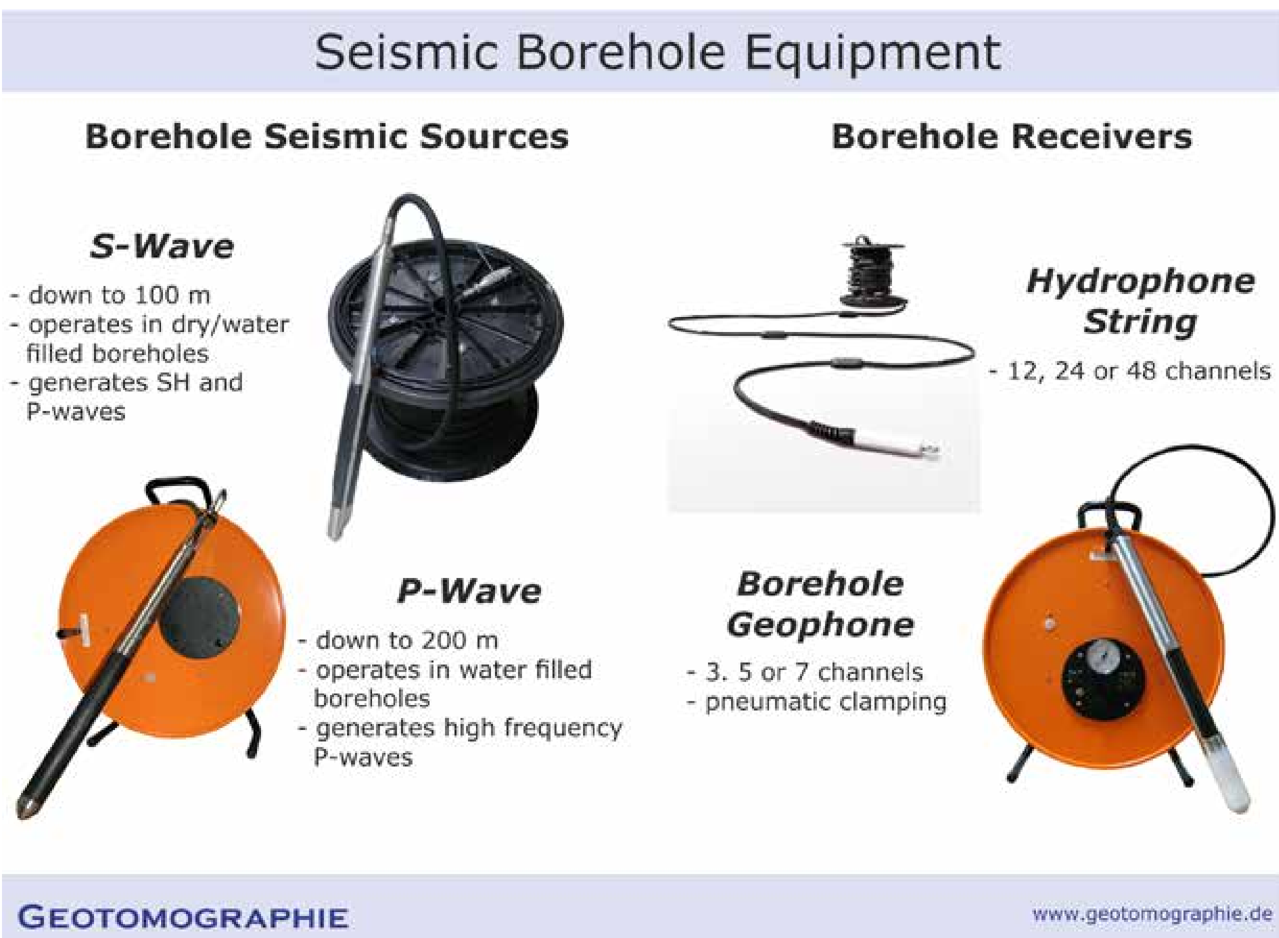
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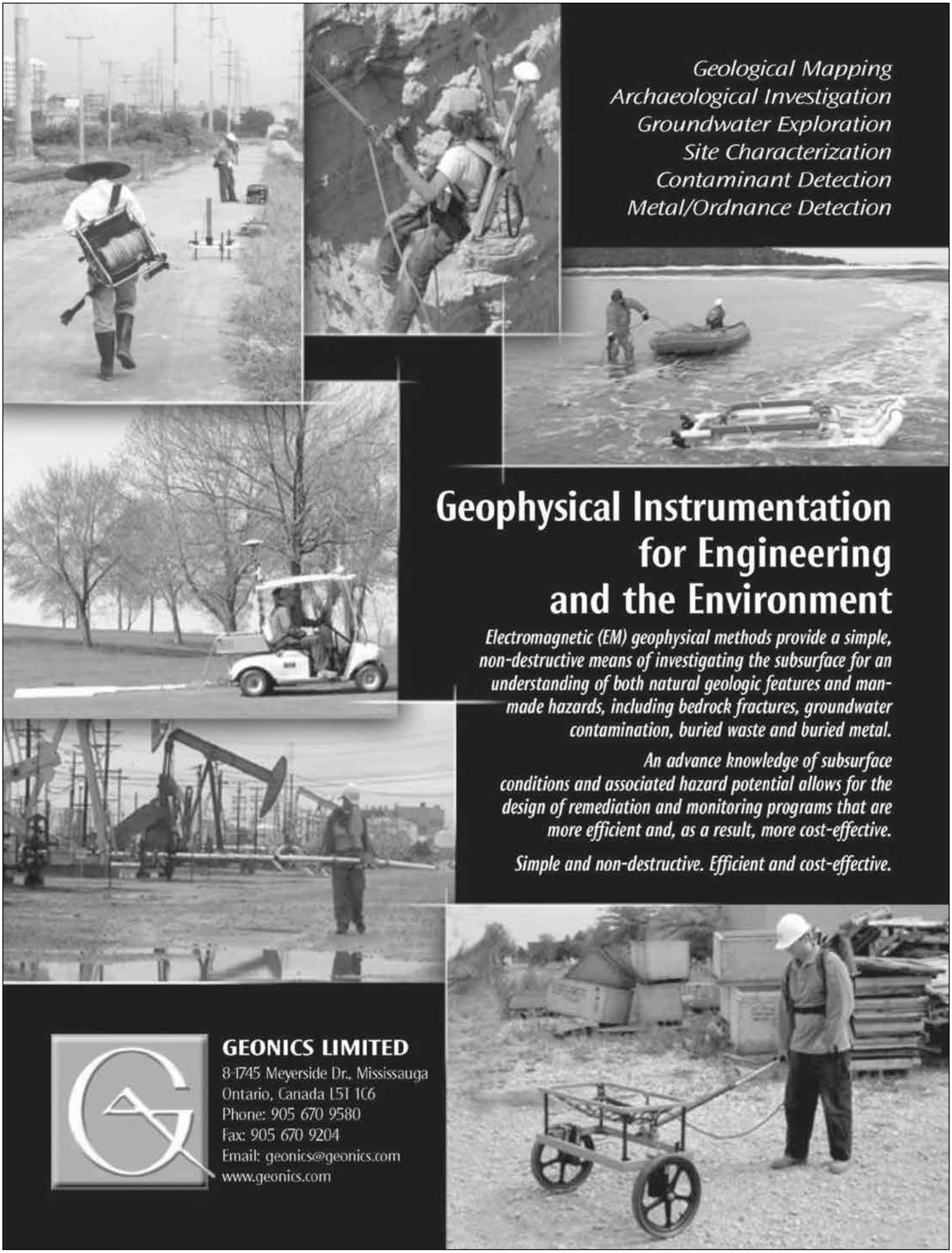
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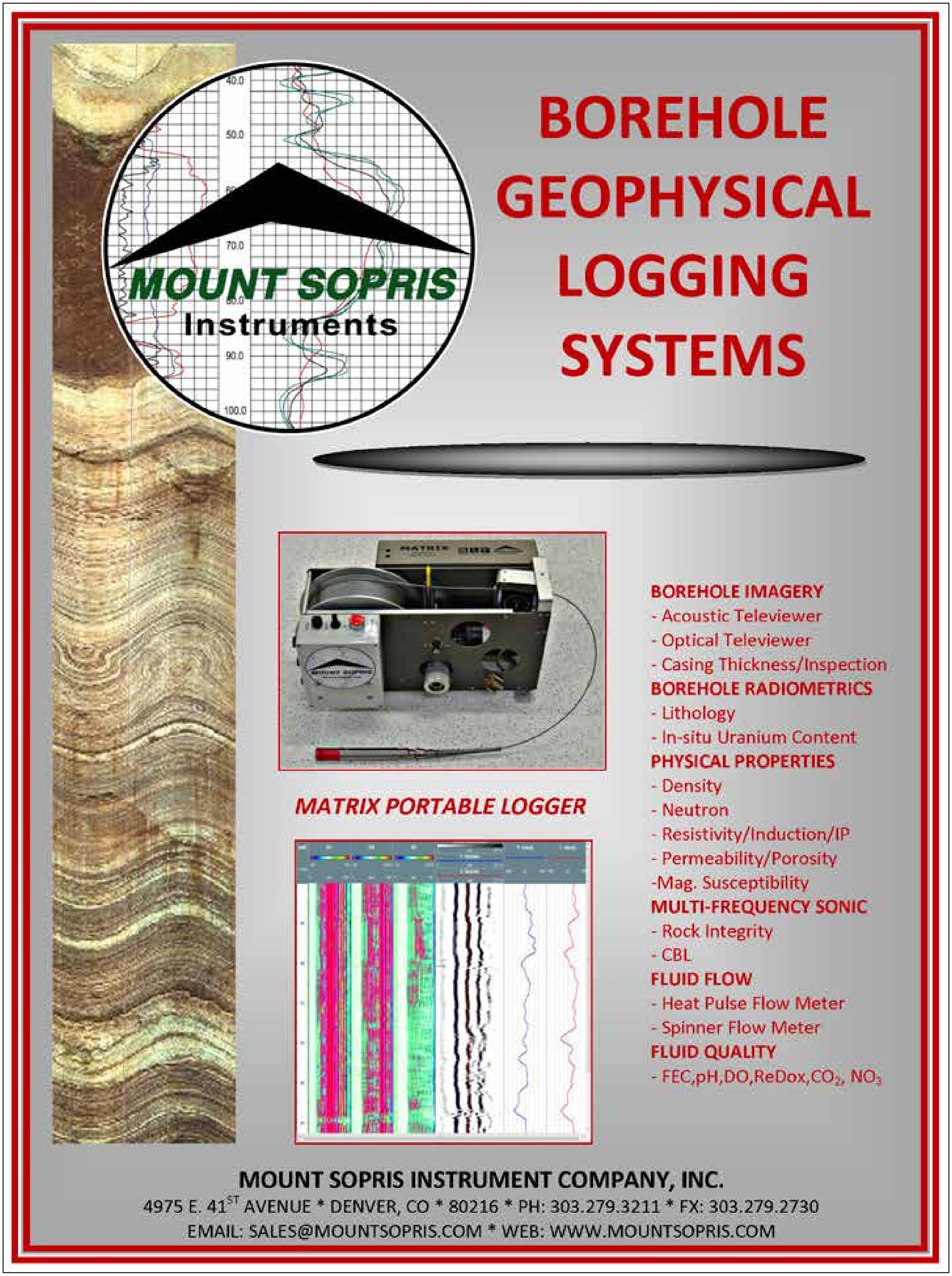
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www.tetratech.com
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Tetra Tech MEC/UXO Detection System Deploys via Neoteric Hovercraft

Tetra Tech, Inc., in collaboration with Neoteric Hovercraft, Inc., has produced a new environmentally-sensitive munitions detection system capable of accessing shallow areas where no other watercraft is able to travel and where sensitive habitat is only inches beneath the water's surface. Tetra Tech's in-house developed TEMA (Towed Electromagnetic Array) attaches to the company's customized Neoteric hovercraft to permit MEC/UXO detection in areas previously accessible only by more expensive, less sensitive aircraft-based systems.

Richard Funk, Senior Geophysicist with Tetra Tech's Marine Mapping Group, describes the TEMA's unique features: "*Unlike a magnetometer, the TEMA is an active sensor that can detect all metals, ferrous and non-ferrous. Its detectors are focused, so they're not affected by nearby metal structures such as piers, bulkheads and bridges. Data from all devices – multiple high-power EM sensors, altimeters, positioning sensors and video/still cameras – is recorded in real time. The 3-meter swath coverage and the use of high-power EM units increases survey power, with lower operational costs and better detection capabilities."*

Tetra Tech has researched the use of hovercraft for MEC/UXO survey for many years, particularly for use in difficult areas for data collection, such as shorelines and surf zones. "*Our goal is to push it to the next level so we can go where other people can't go,"* Funk says, "*A hovercraft takes you places you can't go with conventional craft, places that are too shallow for a boat, places you can't walk."*

Tetra Tech selected Neoteric to manufacture their hovercraft because "*Neoteric's HoverTrek™ outmaneuvers other hovercraft on the market, and our projects demand that increased control*," said Funk. "*Additionally, Neoteric has decades of experience custom-manufacturing their hovercraft to client specifications, and we were impressed by the company's mandate that repeated testing be performed throughout the customization of our hovercraft.*" The craft's customizations include mounting points for the TEMA sensor array, mounts for the electronics modules, mounts for the pilot's display and data collectors' displays, a table for data collectors, TEMA battery mounts, GPS antenna mounts, and a bimini top.

The unusual maneuverability of the Neoteric hovercraft is attained through a patented fly-by-wire reverse thrust system, which makes it the only hovercraft on the market with effective brakes. As Neoteric President Chris Fitzgerald explains, "*Our reverse thrust system surpasses jet aircraft in efficiency; while most aircraft deliver an average of 18 percent thrust in reverse, the HoverTrek™ delivers 60 percent. Unlike other hovercraft, the HoverTrek™ can fly backward, spin, and hover over ice and on swift water*."

Tetra Tech will deploy its new hovercraft-based munitions detection system in early 2015 to conduct Phase 2 of an ongoing MEC/UXO remedial investigation and feasibility study at a Defense Environmental Restoration Program (DERP) for Formerly Used Defense sites (FUDS) area in the Caribbean. The site was an impact range for aerial bombs and rockets, missiles, mortars and naval projectiles from 1903 until 1975.

The entire site comprises 1,030 acres; the area to be surveyed with the TEMA-equipped Neoteric hovercraft is more than 200 acres of shallow coral reefs with listed and protected corals. This area was originally excluded from the survey due to the potential for damaging the coral. By using the Neoteric HoverTrek™, which hovers nine inches above the surface of the water, Tetra Tech can now complete the survey with confidence that the coral reefs are in no danger of harm.

The pairing of the TEMA system with the Neoteric hovercraft's low environmental footprint - less than 1/30th that of a human foot – is an excellent example of how the perfect vehicle for the job can also be the perfect vehicle for the environment, allowing personnel to work safely and efficiently while protecting sensitive habitat.

About Tetra Tech:
Founded in 1966, Tetra Tech is a consulting, engineering, construction management and technical services firm with 14,000 employees and 330 offices worldwide. Based in Pasadena, California, Tetra Tech has decades of experience with MEC/UXO detection and remediation for the U.S. Navy, U.S. Army Corps of Engineers and commercial clients.
www.tetratech.com

About Neoteric Hovercraft, Inc.:
Founded in 1960 and based in Terre Haute, Indiana, Neoteric Hovercraft, Inc. is the world's original light hovercraft manufacturer. The Neoteric HoverTrek™, the only hovercraft in the industry with effective brakes, is utilized in commercial, rescue, recreational and military operations in more than 50 countries.
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In an early prototype developmental model Neoteric hovercraft, the TEMA system is tested and evaluated to determine the optimal pivoting and pushing system.

Tetra Tech's fully customized Neoteric HoverTrek™ is prepared for its final over-water testing.

Quality Assurance for Deep Foundations

Pile Dynamics, Inc.

September 24, 2014

PRESS RELEASE FOR IMMEDIATE RELEASE

Pile Dynamics, Inc. has new model of Pile Integrity Tester

For more than 20 years the Pile Integrity Tester – PIT - has been the go-to instrument for low strain integrity testing of deep foundations. In its simplest configuration, PIT performs pulse echo tests and consists of a main unit, one accelerometer and one hand held hammer. The hammer is used to impact the top of the foundation, producing a wave that propagates down the shaft and reflects back up. The reflected waves are received by an accelerometer which is attached (typically with wax) to the pile top. The main unit provides the testing professional with a velocity as a function of time log that may reveal a compromised foundation element. Some PIT models enable tests where two accelerometers are used, or where the hand held hammer is instrumented with an accelerometer, for an alternate method of integrity analysis (transient response/frequency domain analysis).

A few years ago, Pile Dynamics, Inc (PDI) released the PIT-X, a very compact Pile Integrity Tester that weighs only 500 grams and has a wireless configuration option (no cables connecting accelerometers or instrumented hammers to the main unit).

PDI has now reengineered the traditional Pile Integrity Tester giving it a large and bright color screen, a lighter enclosure and a USB port for data transfer. This model is available with one (PIT-V) or two (PIT-FV) channels of data acquisition, both traditional (wired). The PIT-FV is most often supplied with one accelerometer (provides velocity data through integration) and one instrumented hammer (force data, hence the name PIT-FV), but may also be used with 2 accelerometers (some special technical applications require two acceleration inputs).

In addition to the PIT, PDI offers a full line of instruments for quality assurance of deep foundations. For more information visit www.pile.com/PIT.

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Frank Frischknecht Leadership Award Winner – Motoyuki Sato

Congratulations to Professor Motoyuki Sato of Tohoku University, Sendai, Japan, for having been selected for the 2014 NSGS/EEGS Frank Frischknecht Leadership Award. The award will be presented during the NSGS reception at the upcoming SEG annual meeting.

Dear Prof. Sato,

It is with great pleasure that I can inform you that you were selected by the Award Committee of the Near Surface Geophysics Section (NSGS) of the Society of Exploration Geophysicists (SEG) as the winner of the 2014 Frank Frischknecht Leadership Award.

The Frank Frischknecht Leadership Award is jointly presented by the NSGS and the Environmental and Engineering Geophysical Society (EEGS). The Frank Frischknecht Leadership Award is established to recognize an individual who shows extraordinary leadership in advancing the cause of near-surface geophysics through long-term, tireless, and enthusiastic support of the near-surface geophysics community. Such leadership is often boldly displayed by an invention, a new methodology or technique, a theoretical or conceptual advancement, or a unique innovation that transforms the nature and capabilities of near surface geophysics.

The Award Committee lauds your sustained and important contributions to near-surface geophysics in the field of ground-penetrating radar. Specifically, the committee recognizes your accomplishments in the development of polarimetric borehole radar techniques, directional receiving antennas, and slim-hole logging sondes; applications of airborne and ground-based SAR for environmental assessment and monitoring; and the use of ground-penetrating radar for humanitarian work, including for demining and tsunami relief efforts.

The NSGS and EEGS are therefore very happy to call you the deserving winner of their 2014 Frank Frischknecht Leadership Award.

Sincerely,

Remke Van Dam

2013-2014 NSGS President

ANOUNCEMENTS AND COMING EVENTS

The EEGS / Geonics Early Career Award

Nomination Deadline: November 30, 2014

The Environmental and Engineering Geophysical Society and Geonics Limited are pleased to announce that nominations are now open for the 2013 EEGS / Geonics Early Career Award, which acknowledges academic excellence and encourages research in near-surface geophysics. The award is presented annually at SAGEEP to a full-time university faculty member who, *by the nomination deadline;* is

- *fewer than five years beyond the starting date of his or her current academic appointment;*
- *within ten years post-completion of his or her PhD.*

The award acknowledges significant and ongoing contributions to the discipline of environmental and engineering geophysics. The recipient may have any specialty that is recognized as part of the environmental and engineering geophysics discipline. This specialty is not restricted to departments, colleges, or geographic regions (international applicants are welcome). A committee of four or five members (two or three university faculty, one corporate or consulting representative, and one government laboratory representative), appointed by the EEGS Board, is responsible for selecting the awardee.

The award carries the following benefits:

- *Free registration to the SAGEEP conference at which the award will be presented*
- *A plaque, suitable for display*
- *A $1000 cash award*
- *A 30-minute time slot to present the awardee's research and vision at SAGEEP*
- *The citation and, if available, the awardee's presentation published in **FastTIMES** and distributed to cooperating societies*

The awardee is expected to be present during the EEGS Luncheon at SAGEEP 2013 in Denver, Colorado. Nominations should be sent electronically to:

Dr. Jonathan Nyquist, Chair of the Early Career Award Committee
Temple University
1901 N 13th Street, Philadelphia, PA 19122-6081
Phone: 215-204-7484
nyq@temple.edu

Nomination packages must include:

- *A comprehensive vitae for the candidate*
- *A letter of recommendation outlining the candidate's qualifications for the award*
- Copies or PDF files of three representative publications

ANOUNCEMENTS AND COMING EVENTS

SAGEEP 2015

March 22-26 TEXAS USA

Call for Abstracts - Online Submission Site Open

Key Submission Dates

Oct. 31, 2014 - Deadline for Initial Short and Extended Abstracts
Nov. 20, 2014 - Notice of Abstract Acceptance, Suggested Revisions or Rejection
Jan. 19, 2015 - Deadline for Final Abstracts and Optional Extended Abstracts

The Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP) provides geophysicists, engineers, geoscientists and end-users from around the world an opportunity to meet over a 5-day period to discuss near-surface applications of geophysics and learn about recent developments.

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Agricultural Geophysics Webinar Series

Videos of the presentations and panel discussions for the first two agricultural geophysics webinars can be accessed at http://www.ag-geophysics.org. The title of the first webinar was "*Application of Geophysics to Agriculture: Methods Employed*", and title of the second webinar was "*Using Ground Penetrating Radar in Agriculture*". This is an ongoing series, with the next webinar scheduled for February 2015. Information and registration (no cost) for the next webinar will be available through http://www.ag-geophysics.org in early January 2015.

Environmental and Engineering Geophysical Society	Renew or Join Online at www.EEGS.org
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EEGS is the premier organization for geophysics applied to engineering and environmental problems. Our multi-disciplinary blend of professionals from the private sector, academia, and government offers a unique opportunity to network with researchers, practitioners, and users of near-surface geophysical methods. Memberships include access to the *Journal of Environmental & Engineering Geophysics (JEEG)*, proceedings archives of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), and our quarterly electronic newsletter *FastTIMES*. Members also enjoy complimentary access to SEG's technical program expanded abstracts, discounted SAGEEP registration fees, books and other educational publications. EEGS offers a variety of membership categories tailored to fit your needs. Please select (circle) your membership category below:

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The Founders Fund has been established to support costs associated with the establishment and maintenance of the EEGS Foundation as we solicit support from larger sponsors. These will support business office expenses, necessary travel, and similar expenses. It is expected that the operating capital for the foundation will eventually be derived from outside sources, but the Founder's Fund will provide an operation budget to "jump start" the work. Donations of $50.00 or more are greatly appreciated. For additional information about the EEGS Foundation (an IRS status 501(c)(3) tax exempt public charity), visit the website at http://www.EEGSFoundation.org.

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This Endowed Fund will be used to support travel and reduced membership fees so that we can attract greater involvement from our student members. Student members are the lifeblood of our society, and our support can lead to a lifetime of involvement and leadership in the near-surface geophysics community. Donations of $50.00 or more are greatly appreciated. For additional information about the EEGS Foundation (a tax exempt public charity), visit the website at http://www.EEGSFoundation.org.

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	0032	2010 Application of Time Domain Electromagnetics to Ground-water Studies – David V. Fitterman	$20	$30
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	0007	2002 - UXO 101 - An Introduction to Unexploded Ordnance - (Dwain Butler, Roger Young, William Veith)	$15	$25
	0009	2001 - Applications of Geophysics in Geotechnical and Environmental Engineering (HANDBOOK ONLY) - John Greenhouse	$25	$35
	0011	2001 - Applications of Geophysics in Environmental Investigations (CD-ROM ONLY) - John Greenhouse	$80	$105
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	0004	1998 - Global Positioning System (GPS): Theory and Practice - John D. Bossler & Dorota A. Brzezinska	$10	$15
	0003	1998 - Introduction to Environmental & Engineering Geophysics - Roelof Versteeg	$10	$15
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Miscellaneous Items

	0031	Advances in Near-surface Seismology and Ground Penetrating Radar—R. Miller, J.Bradford, K.Holliger Special student rate - $95.00	$109	$149
	0021	Geophysics Applied to Contaminant Studies: Papers Presented at SAGEEP from 1988-2006 (CD-ROM)	$50	$75
	0022	Application of Geophysical Methods to Engineering and Environmental Problems - Produced by SEGJ	$35	$45
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