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2011–2012 ESTCP Live Site Demonstrations

ESTCP MR-201165
Cost and Performance Report
TEMTADS Demonstration

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14. ABSTRACT
The TEMTADS 5×5 Array was demonstrated at two sites, the former Mare Island Naval Shipyard, CA, in 2011, and the former Spencer Artillery Range, TN (fSpAR) in 2012. The MP System was demonstrated at the former Camp Beale, VA, in 2011, and the Central Impact Area of the Massachusetts Military Reservation and fSpAR in 2012. For each site and system, 180 or more target locations were investigated per day with limited rework required. The limited data set of dynamic data collected with the MP System at fSpAR was used to ultimately detect all seed items within the area. Approximately 70 percent of the detected anomalies could be classified from the dynamic data alone. Using a combination of results from dynamic and cued data, 100% of the identified UXO were correctly classified, and the number of necessary digs could be reduced by at least 75 percent.

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Multi-sensor Towed Array Detection System (MTADS)	TEMTADS	

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Acronyms

Abbreviation	Definition
AOL	Advanced Ordnance Locator
APG	Aberdeen Proving Ground
ASCII	American Standard Code for Information Interchange
ATC	Aberdeen Test Center
CRREL	U.S. Army Cold Regions Research and Engineering Laboratory
DGPS	Differential GPS
EMI	Electro-Magnetic Induction
ESTCP	Environmental Security Technology Certification Program
fMINSY	former Mare Island Naval Shipyard, CA
fSpAR	former Spencer Artillery Range, TN
FQ	Fix Quality
GPS	Global Positioning System
IAGWSP	Impact Area Groundwater Study Program
IDA	Institute for Defense Analyses
IMU	Inertial Measurement Unit
IVS	Instrument Verification Strip
MP	Man-Portable
MPV2	Man-Portable Vector Sensor, version 2
MR	Munitions Response
MTADS	Multi-sensor Towed Array Detection System
NMEA	National Marine Electronics Association
NRL	Naval Research Laboratory
PMA	Production Manufacturing Area
POC	Point of Contact
(PTNL,)GGK	Time, Position, Position Type, DOP NMEA-0183 message
QC	Quality Control
RMS	Root-Mean-Squared
RTK	Real Time Kinematic
Rx	Receiver
SAIC	Science Applications International Corporation
SERDP	Strategic Environmental Research and Development Program
SLO	San Luis Obispo
SNR	Signal-to-Noise Ratio
TEM	Time-domain Electro-Magnetic
TEMTADS	Time-domain Electro-Magnetic MTADS
TOI	Target of Interest
Tx	Transmit(ter)
UXO	Unexploded Ordnance

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EXECUTIVE SUMMARY

BACKGROUND

The U.S. Naval Research Laboratory (NRL) and SAIC have participated in several programs funded by the Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) whose goal has been to enhance the classification ability of the Multi-sensor Towed Array Detection System (MTADS). The NRL Time-domain Electromagnetic MTADS (TEMTADS) 5x5 Array incorporated an advanced electromagnetic induction (EMI) sensor specifically designed for UXO classification.

The team further undertook efforts to transition this successful technology to smaller, man-portable and hand-held systems for deployment in more confined terrains. The man-portable (MP) System was constructed as a 2x2 array of upgraded sensors based on those from the original TEMTADS, but with tri-axial receiver cubes in place of the original single, vertical receiver loops. The MP System was designed to be deployable in increasingly inaccessible areas where vehicle-towed sensor arrays cannot be used.

OBJECTIVES OF THE PROJECT

The objective of this project was to validate the performance of the 5x5 Array and MP System in blind demonstrations conducted at live munitions response (MR) sites. Performance metrics include production rate and accuracy and variability of extracted target parameters.

Based on the success of the MP System as cued sensor, an effort was made to operate the system in a dynamic, or survey, mode at one demonstration. Operating such allows for the collection of anomaly detection data and more excitingly, the potential for classification based on the dynamic data for a significant portion of the detected anomalies. If borne out, this mode of operation could dramatically improve the efficiency and accuracy of UXO classification efforts and therefore save money during UXO remediation efforts.

DEMONSTRATION RESULTS

The 5x5 Array was demonstrated at two sites, the former Mare Island Naval Shipyard, CA in 2011 and the former Spencer Artillery Range, TN (fSpAR) in 2012. The MP System was demonstrated at the former Camp Beale, CA in 2011, and the Central Impact Area of the Massachusetts Military Reservation and fSpAR in 2012. With the exception of a small area at fSpAR, all data collection was done in a cued mode. For each site and system, 180 or more target locations were investigated per day with limited rework required. Based on Instrument Verification Strip results, the accuracy and variability of fit locations and target parameters were well within the requirements for conducting UXO/Clutter classification. The limited data set of dynamic data collected with the MP System at fSpAR was used to ultimately detect all seed items within the area. Approximately 70 percent of the detected anomalies could be classified from the dynamic data alone. Using a combination of results from dynamic and cued data, 100%

of the identified UXO were correctly classified and the number of necessary digs could be reduced by at least 75 percent.

IMPLEMENTATION ISSUES

The objective of this project was to demonstrate high-quality data collection with an advanced EMI sensor to support UXO/Clutter classification decisions. The introduction of a second generation of advanced sensors focused on being practical field instruments was part of this effort. Designed to be used in rugged / restrictive terrain and by industrial community members aids in the transition of these technologies from being research prototypes to use in the industrial community. The mechanics of collecting classification-grade advanced EMI cued data with these systems have been shown to be fairly routine in the research community. As part of the ESTCP Munitions Response Live Site Demonstrations, industrial partners have been exposed to the MP System and the associated data collection and processing procedures. The success of this effort will be evaluated on an ongoing basis through the Live Site demonstrations. In the past, analysis of data from these systems has been somewhat of a specialty, requiring specific software and knowledge to proficiently conduct. The successful transition of the processing and analysis procedures for MP data to the Geosoft Oasis montaj environment provides a clear pathway forward.

1.0 INTRODUCTION

1.1 BACKGROUND

The characterization and remediation activities conducted at Department of Defense sites contaminated with unexploded ordnance (UXO) using traditional geophysical sensors such as the Geonics EM61 often yield unsatisfactory results and in practice are consistently more expensive than budgeted for. In part, this is due to the inability of the sensor technology to distinguish between UXO and non-hazardous clutter. Field experience cited by the Corps of Engineers is that seldom more than 1% or 2% of the items excavated at a site are UXO [1].

Attempts to identify buried objects using conventional geophysical survey data have produced uniformly unsatisfactory results. The Naval Research Laboratory (NRL) and SAIC have participated in several programs funded by the Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) whose goal has been to enhance the classification ability of the Multi-sensor Towed Array Detection System (MTADS). The NRL Time-domain Electromagnetic MTADS (TEMTADS) vehicle towed 5x5 Array incorporated an advanced EMI sensor specifically designed for UXO classification [2]. This technology was transitioned to smaller systems for deployment in more confined areas in ESTCP Projects MR-200807 and 200909 [3]. The man-portable (MP) System was constructed as a 2x2 array of upgraded sensors based on those from the original TEMTADS, but with tri-axial receiver cubes. The 5x5 Array and MP System were both demonstrated at a series of live sites.

1.2 OBJECTIVES OF THE PROJECT

The objective of this project was to validate the performance of the 5x5 Array and MP System in blind demonstrations conducted at a live munitions response (MR) site. Performance metrics include production rate and accuracy and variability of extracted target parameters. At one site, a dynamic survey mode for the MP System was introduced and demonstrated. The success of the MP System for cued target identification in the Camp Beale demonstration [4] was the primary motivating factor for adapting the system for dynamic or survey mode operation in this project.

1.3 REGULATORY DRIVERS

Stakeholder acceptance of the use of advanced EMI sensor systems for UXO/Clutter classification on real sites will require demonstration that these systems and the associated classification techniques can be deployed efficiently and with high probability of discrimination. Demonstration at live sites with extensive ground-truth validation will facilitate regulatory acceptance of the UXO classification technology and methodology.

Manuscript approved February 26, 2014.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

2.1.1 TEMTADS EMI Sensors

Two types of advanced EMI sensors are discussed in this document. The first is the EMI sensor developed for the 5x5 Array under ESTCP project MR-200601 and described in the next paragraph, consisting of a single transmitter loop coaxially located with a single vertical-axis receiver loop. The second is the 'TEMTADS/3D' sensor in which the same transmitter coil is used but the receiver coil is replaced by an 8-cm, 3-component 'cube' receiver that was first developed by G&G Sciences under a Navy-funded project known as the Advanced Ordnance Locator (AOL). NRL has developed systems made from multiple copies of these sensors, assembled in a variety of array configurations. Minor modifications were made to the AOL control and data acquisition infrastructure to make it compatible with our deployment schemes.

A photograph of a standard TEMTADS sensor element (as used in the MR-200601 array) is shown under construction in the left panel of Figure 2-1. The transmit (Tx) coil is wound around the outer portion of the form and is 35 cm on a side. The receive coil is wound around the inner part of the form which is re-inserted into the outer portion and is 25 cm on a side. An assembled sensor with the top and bottom caps used to locate the sensor in the array is shown in the right panel of Figure 2-1.

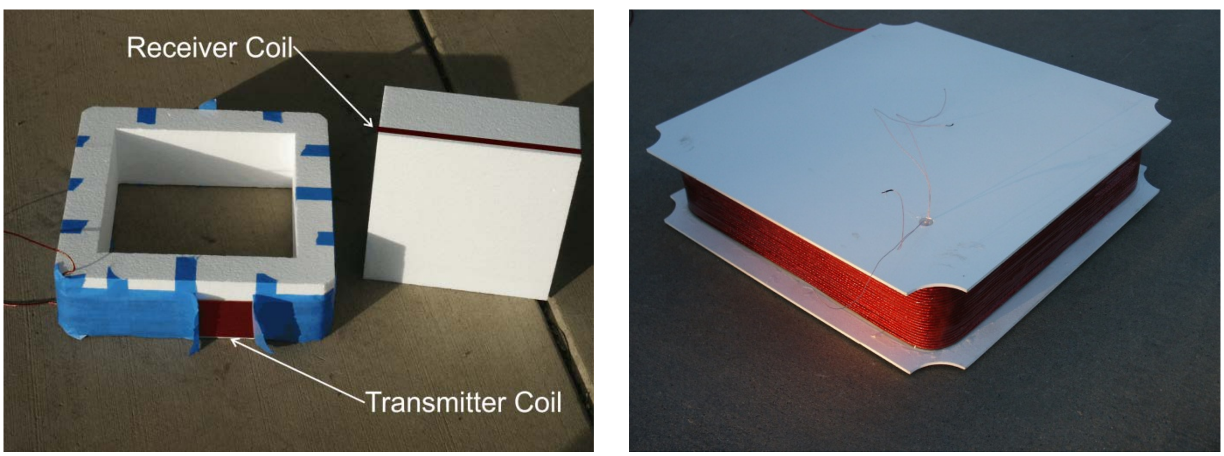

Figure 2-1 – Construction details of an individual standard TEMTADS EMI sensor (left panel) and the assembled sensor with end caps attached (right panel).

2.1.2 TEMTADS/3D EMI Sensor

The original design of the MP System utilized the standard TEMTADS EMI sensor. Based on the results of the MP System demonstration at the APG Standardized UXO Test Site in August, 2010 [5], revision of the sensor technology was indicated. A modified version of the sensor element was designed and built, replacing the single, vertical-axis receiver coil of the original sensor with a three-axis receiver cube. These receiver cubes are similar in design to those used in the second-generation AOL and the Geometrics MetalMapper (ESTCP MR-200603) system with dimensions of 8 cm rather than 10 cm. The CRREL MPV2 system (ESTCP MR-201005) uses an array of five identical receiver cubes and a circular transmitter coil. The new sensor elements are designed to have the same form factor as the original, aiding in system integration. A TEMTADS/3D coil under construction is shown in Figure 2-2.

Figure 2-2 – Individual TEMTADS/3D EMI sensor with 3-axis receiver under construction.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The 5x5 Array was designed to combine the data quality advantages of a gridded survey with the data coverage efficiencies of a vehicular system. The resultant data should therefore be equal, if not better, in quality to the best gridded surveys (the relative position and orientation of the sensors will be better than gridded data) while prosecuting many more targets each field day.

There are obvious limitations to the use of this technology. The 5x5 Array is 2-m square in area, mounted on a trailer, and requires a tow vehicle. Fields where the vegetation or topography interferes with passage of a trailer of that size will not be amenable to the use of the array.

With the upgraded TEMTADS/3D sensors, the MP System offers similar production rates in difficult terrain and treed areas that the 5x5 Array cannot access. The MP System is 80 cm on a side and mounted on a man-portable cart. Terrain where the vegetation or topography interferes with passage of a cart of that size will not be amenable to the use of the system. While not available for this project, a litter-carry option has since been developed for the MP System.

For all systems, there is a limiting anomaly density above which the response of individual targets cannot be separated individually. We have chosen relatively small sensors for this array which help mitigate this problem but we cannot eliminate it completely. Recent developments, including solvers designed for classification in multiple-object scenarios such as SAIC's multi-target solver, [6] are being evaluated and their performance characteristics in cluttered environments determined.

In dynamic mode, the MP system offers higher data density and correspondingly finer resolution of targets than is typically seen for systems with larger transmitter and receiver coils, such as the iconic Geonics EM61-MK2, although depths of detection and signal-to-noise ratios (SNR) are comparable between the EM61-MK2 and the MP System. However, this rich data set comes at a productivity cost. A complete transmit cycle of the MP System in dynamic mode has a repetition rate of 7.5 Hz. Systems with few transmitters can cycle faster, resulting in higher along-track data density. Recent advances in smart, or dipole-based, target picking indicate that the additional richness of data collected with the advanced sensors, if used to its full potential, could improve detection performance beyond that of traditional technologies.

3.0 PERFORMANCE OBJECTIVES

A summary of the performance objectives for the demonstration are given in Table 3-1 to provide a basis for evaluating the performance and costs of the demonstrated technology. Additional information can be found in the appropriate Demonstration Data Reports [7-10]. Overall project objectives were given in the overall demonstration plans generated by ESTCP. The objectives are divided into two parts, the objectives for all data collection, and dynamic survey-specific objectives.

3.1 OBJECTIVE: INSTRUMENT VERIFICATION STRIP (IVS) RESULTS

This objective demonstrates that the sensor system was in good working order and collecting physically valid data each day. The Instrument Verification Strip (IVS) was surveyed twice daily. The amplitudes of the derived response coefficients for each emplaced item were compared to the running average of the demonstration for reproducibility. The extracted fit locations of each item were compared to the reported ground truth and the running average of the demonstration.

3.1.1 Metric

The reproducibility of the measured responses of the sensor system to the emplaced items and of the extracted locations of the emplaced items defines this metric.

3.1.2 Data Requirements

The tabulated fit parameters for the data corresponding to each emplaced item in terms of derived response coefficients, location, and depth.

3.1.3 Success Criteria

The objective was considered met if the RMS amplitude variation of the derived response coefficients was less than 10% and the down-track fit location of the anomaly was within 10 cm of the corresponding seeded item’s stated location.

Table 3-1 – Performance Results for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria	Success? (Yes/No)
All Surveys Objectives				
Instrument Verification Strip (IVS) Results	Fit results from each emplaced item Measured locations of emplaced items	Daily IVS data	Down-track location ±10 cm Polarizabilities: βs ±10%	*Cued*: Yes *Dynamic*: No
Cued interrogation of anomalies	Instrument position	Cued survey data	100% of anomalies where the center of the instrument is positioned within a given distance of the actual target location *TEMTADS 5x5*: 60 cm *TEMTADS 2x2*: 40 cm	Yes
Dynamic Survey Objectives				
Along-line measurement spacing	Point-to-point spacing from data set	Mapped survey data	98% < 25 cm along-line spacing	Yes
Complete coverage of the demonstration site	Footprint coverage	Mapped survey data	Calculated using UX-Process Footprint Coverage QC Tool and a sensor footprint of 80cm	Yes
Detection of all targets of interest (TOI)	Percent detected of seeded items	Location of seeded items Anomaly List	100% of seeded items detected within a 60 cm halo	No

3.1.4 Results

The RMS amplitude variations for the magnetic polarizabilities for cued surveys all fell below the 10% cutoff. For the MP system dynamic surveys, RMS variation in the polarizabilities was typically 10 – 20% with the worst case being for the shotput at 30%. As discussed in Reference 13, the particular shotput did not appear to have a sphere-like response which affected both the polarizabilities and the fitted depth. It should be noted that the dynamic MP system data collection at fSpAR was only two days long, resulting in only four measurements of the IVS and limiting the value of the statistical results.

The aggregate horizontal position error statistics for the IVS items are defined as the fit position (or, equivalently, the inverted position parameter) minus the ground truth position. The RMS variation in the position errors for each emplaced IVS item was under 3 cm. The RMS variation in the depth errors for each emplaced IVS item was under 3 cm. For this project, the MP System did not record platform position, so no statistics are available for horizontal position, only depth. Depth errors were less than 3 cm for all platforms.

3.2 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

To collect EMI data of the highest quality for UXO/clutter classification, the anomaly must be illuminated along its three principle axes. To insure this, the data collection pattern (in this case the TEMTADS array) must be positioned directly over the center of the anomaly.

3.2.1 Metric

The metric for this objective was the percentage of anomalies where the center of the instrument was within the acceptable distance range from the actual target location.

3.2.2 Data Requirements

Demonstrators provided the ESTCP Program Office a weekly list of the location of the center of their instrument for each cued anomaly interrogated in the preceding week. The USACoE, Huntsville reviewed the offsets for the QC seeds and provide feedback to the demonstrator if their instrument was not within the acceptable distance. In the case of a failure, the demonstrator would have been required to reacquire data for those anomalies interrogated during the effected period and perform a root cause analysis for each failure.

3.2.3 Success Criteria

The objective was considered met for the 5x5 Array if the center of the instrument was positioned within 60 cm of the actual anomaly location for 100% of the cued anomalies. For the MP system, no global positioning was available. For the MP system, the criterion was that the fit location of the anomaly was within 40cm of the array center.

3.2.4 Results

After the 5x5 Array survey was complete, a list of the recorded array center for each anomaly was forwarded to the Program Office and USACoE. All recorded locations corresponding to seeds were found to be within the 60cm requirement. For the MP System cued measurements, the position is not recorded. As such, the metric of requiring that the inverted location of each anomaly not fall outside the sensor footprint (40 cm from the array center) was used. If a fit location indicated that the anomaly was outside the sensor footprint, a new data set was required with a refined position until the criterion was met or the indicated position was determined to be unreachable, such as located under a tree.

3.3 OBJECTIVE: ALONG-LINE MEASUREMENT SPACING

The value of the collected dynamic data depends on the extent of coverage of the site that it represents. Gaps in coverage impede or prevent analysis of the data. This objective concerns the ability to collect dynamic data with acceptable along-line data density.

3.3.1 Metric

The metric for this objective was the percentage of data points within acceptable along-line spacing. Provisions for exceptions based on typography / vegetation interferences were made, but not required.

3.3.2 Data Requirements

A mapped data file was used to judge the success of this objective.

3.3.3 Success Criteria

This objective was considered met if at least 98% of the mapped data points were within 25 cm of the neighboring data points along the survey line.

3.3.4 Results

The average along-track separation for the Dynamic Area dynamic survey was 13.8 cm. The percentage of mapped data points within 25 cm of the neighboring data points was 99.8%.

3.4 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The value of collected dynamic survey data depends on the extent of coverage of the site. This objective concerns the ability to completely survey the site and obtain sufficient data coverage. Provisions for exceptions based on typography / vegetation interferences were made, but not required.

3.4.1 Metric

The metric for this objective was the footprint coverage as measured by the UX-Process Footprint Coverage QC tool.

3.4.2 Data Requirements

A mapped data file was used to judge the success of this objective.

3.4.3 Success Criteria

This objective was considered met if the survey achieved at least 85% coverage at 0.5-m line spacing and 98% at 0.75-m line spacing, as determined using the UX-Process Footprint Coverage QC tool.

3.4.4 Results

The demonstration was successful for this objective. The UX-Process Footprint Coverage QC tool report indicates 100% coverage of the site with a sensor footprint of 80cm.

3.5 OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST (TOI)

Quality data should lead to a high probability of detecting the TOI at the site.

3.5.1 Metric

The metric for this objective was the percentage of seed items that were detected using the specified anomaly selection threshold.

3.5.2 Data Requirements

Each demonstrator prepared an anomaly list. USACoE personnel evaluated the detection probability of the seeded items as part of their data Quality Assurance (QA) review.

3.5.3 Success Criteria

The objective was considered to be met if 100% of the seeded items were detected within a halo of 60 cm.

3.5.4 Results

At the completion of the dynamic survey of the Dynamic Area, a target list was produced using the criteria outlined in Section 6.2. As this was the first live-site demonstration of this sensor in this mode of operation, a data analyst manually evaluated each target selection. The resulting target list was submitted to the Program Office for evaluation by the USACoE, Huntsville. One seed item was missed by the data analyst even though the data for that location met the selection criteria. A root-cause-analysis determined the threshold exceedance for the late time gate was not well-formed and discarded by the data analyst. Additionally, the centroids of the peaks at the early and late time gates did not line up well. With the aggressive schedule required for this demonstration, fatigue and time pressure on the data analyst played an additional role. In future demonstrations, an automated version of the target picking process will be used and will prevent this type of error.

4.0 SITE DESCRIPTION

The information in this Section was extracted from the corresponding ESTCP Live Site Demonstration Plans [11-14]. Further details can be found within.

Each demonstration site selected by ESTCP in their series of Live Site Demonstrations was chosen to provide opportunities to demonstrate the capabilities and limitations of the classification process on a variety of site conditions. The first site in the series, former Camp Sibert, AL had only one TOI and item "size" was an effective discriminant. A hillside range at the former Camp San Luis Obispo in California was selected for the second of these demonstrations for more challenging terrain and a wider mix of munitions, including 60 mm, 81 mm, and 4.2-in mortars and 2.36-in rockets. The third site chosen was the former Camp Butner, NC. The Butner site is contaminated with items as small as 37 mm projectiles, adding yet another layer of complexity into the process.

4.1 FORMER CAMP BEALE

4.1.1 Site Selection

A hillside range at the former Camp Beale, CA was selected because it is partially wooded and is thought to contain a wide mixture of munitions. These two features increase the site's complexity and both characteristics are likely to be encountered on production sites. The tree cover poses a navigation challenge by increasing the difficulty of obtaining accurate GPS readings. The MP System on station at the site is shown in Figure 4-1.

Figure 4-1 – MP System collecting data at the former Camp Beale, CA demonstration site

4.1.2 Site History

Prior to Department of Defense (DOD) usage in 1940, the property was a settling point for retired gold miners. They used the land for agriculture and cattle grazing. Currently, the former Camp Beale project area consists of multiple land use property areas. The east region is predominantly undeveloped and used for cattle grazing. The central section is designated as the Spenceville Wildlife and Recreation Area. Both the southeast and southwest regions of the former Camp Beale are moderately populated with rural residential areas. Many of the surrounding areas are used for ranching activities and remain undeveloped.

The former Camp Beale property area was acquired by the U.S. Government prior to 1940 and consisted of 85,654 acres. It was originally established as a training post for the 13th Armored Division. Two other Divisions (the 81st and 96th infantries) also trained at Camp Beale. The camp was used for various other military activities such as a personnel replacement depot, an overseas replacement depot, an induction center, a prisoner of war encampment, and a West Coast separation center. From 1943 until its closure in 1947, Camp Beale was selected for a variety of Chemical Warfare School (CWS) activities. In May 1947, the Camp Beale reservation was declared surplus by the War Department and a large number of the buildings were sold.

In early 1948, the Air Force acquired the land (designated it as Beale AFB). Through 1957, the Navy began using two of the target areas. In 1957, a large portion of the site (approximately 65,000 acres) was declared excess.

4.1.3 Munitions Contamination

The suspected munitions for the demonstration area include, but are not limited to, 37mm projectiles, 60mm mortars, 81mm mortars, and 105mm projectiles

4.2 FORMER MARE ISLAND NAVAL SHIPYARD

4.2.1 Site Selection

The former Mare Island Naval Shipyard (fMINSY) in Vallejo, CA, was selected because of an opportunity in the Navy’s remediation schedule at fMINSY to conduct the study in the midst of their ongoing munitions response project and prior to the upcoming removal action in 2012. This collaboration was a scenario to promote technology transfer by engaging the site team. It was also possible to leverage previously collected geophysical survey data and use a subset of the previously-selected anomalies as locations for cued data collection. The 5x5 Array collecting data at the site is shown in Figure 4-2.

This site is also unique from prior demonstrations because it was an ammunition production and storage/handling area, rather than a former munitions range. It is suspected that the distribution of native UXO will be higher and there will be less munitions-related scrap, as these items were not fired during live training and became buried as part of intentional burial pits or incidental loss during storage/handling.

Figure 4-2 – 5x5 Array collecting data at the fMINSY, CA demonstration site

Conversely, the items identified as non-hazardous will likely be more culturally or geologically related rather than munitions related compared to prior demonstrations.

4.2.2 Site History

fMINSY was established in 1854 and operated until it was closed in 1996. The primary mission of the fMINSY was to build, maintain, and repair Navy ships and submarines. It also served a critical role as a munitions storage and production facility from 1857 until 1975.

4.2.3 Munitions Contamination

The suspected munitions in the Production Manufacturing Area (PMA) include 1-pound Hotchkiss projectiles (approximately 37-mm in diameter), 3-inch projectiles, 4-inch projectiles, 6-inch projectiles, 8-inch projectiles, and 16-inch projectiles.

4.3 FORMER SPENCER ARTILLERY RANGE

4.3.1 Site Selection

The former Spencer Artillery Range, TN (fSpAR) is located in north-eastern Tennessee. This site was selected for demonstration because it is more heavily wooded than prior demonstrations and is thought to contain an even-wider mixture of munitions. Additionally, a 1.3-acre area of the site was chosen for the demonstration of advanced EMI sensors in dynamic, or survey, mode. Both the 5x5 Array and the MP System collecting data at the fSpAR demonstration site are shown in Figure 4-3.

4.3.2 Site History

In 1941, construction began on the 30,618 acre Spencer Artillery Range and documentation identifies establishment of two impact areas: Jakes Mountain (5,060 acres) and Bald Knob (2,090 acres). Troop training took place until September 1944, by which time Army ground forces had either departed or were under orders to depart.

Figure 4-3 – 5x5 Array (left) and MP System (right) collecting data at the fSpAR demonstration site

Subsequent arrangements were made for Dyersburg Army Air Field to use the Spencer Artillery Range as an air-to-ground gunnery range. The land reverted back to the original 25 leaseholders in the summer of 1946. Several surface decontamination sweeps were completed on portions of the former range in the 1950s. Since then, numerous tracts of land have been sold and/or subdivided, significantly increasing the number of property owners from the original 25 to several hundred landowners today.

4.3.3 Munitions Contamination

The suspected munitions at this site include 37 mm projectiles, 75 mm projectiles, 76 mm projectiles, 105 mm projectiles, and 155 mm projectiles. In close proximity to the particular site of this demonstration, 37 mm and 155 mm projectiles were observed during the Remedial Investigation as well as large quantities of unidentified munitions debris.

4.4 CENTRAL IMPACT ARRAY, MASSACHUSETTS MILITARY RESERVATION

4.4.1 Site Selection

The Massachusetts Military Reservation (MMR) is located on the western edge of Cape Cod, MA. The site was selected for the program because of an opportunity to incorporate the work as part of the ongoing National Guard Bureau’s Impact Area Groundwater Study Program (IAGWSP) on two discrete 3-acre areas of the Central Impact Area (CIA) after vegetation clearance. The MP System, operated in an ad hoc litter-carry mode, moving between data collection points at the MMR CIA is shown in Figure 4-4.

4.4.2 Site History

Portions of MMR were used by the military beginning in the early 1900s. The CIA has been used for artillery and mortars from the late 1930s until 1997. During the late 1940s, the CIA also contained Navy air-to-ground rocket ranges that utilized 2.25-in rockets.

Figure 4-4 –MP System collecting data at the MMR CIA demonstration site

These munitions include high explosive (HE) charges designed to explode upon impact, and practice or “inert” rounds which do not contain an HE charge but may contain a spotting charge designed to emit smoke upon impact.

The predominant HE charge used in pre-WWII munitions contained TNT. Post-WWII artillery and mortar munitions used Composition B for the HE charge, which is a mixture of RDX and TNT. The Low-Intensity Training Round (LITR) is an artillery practice projectile that was introduced in 1982 to reduce the noise associated with HE explosions, since this noise was a source of complaints from the public. The LITR includes a spotting charge containing perchlorate. The use of HE artillery projectiles was discontinued in 1989, and the firing of all munitions into the CIA was discontinued in 1997. HE munitions that did not explode (UXO) or that partially functioned (UXO low order) have accumulated within the CIA during its use. UXO located along roadways or at other locations that presented a safety hazard due to human access have historically been blown in place using an explosive donor charge. Blow-in-place (BIP) operations were also used to clear areas for site investigation under the IAGWSP starting in 1997. Post-BIP soil sampling and removal of soil contaminated by BIP activities have been conducted since 1999 under the IAGWSP.

4.4.3 Munitions Contamination

The munitions of primary interest for the demonstration area include 4.2-in mortars, 60-mm mortars, 81-mm mortars, 105-mm projectiles, and 155-mm projectiles. These larger munitions contain a high percentage of the mass of explosives remaining in the CIA.

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The cued-only demonstrations were executed in two stages. The first stage was to characterize the TEMTADS platforms being demonstrated with respect to the site-specific TOI and to the site-specific geology. Measurements of site-specific TOI not already in our libraries were made on site. The site-specific geology was characterized through monitoring the background response of the demonstration site, as measured by the TEMTADS platforms, for the duration of data collection.

The second stage of each demonstration was the cued survey proper. The sensor system was positioned roughly over the center of each anomaly on the source anomaly list and a data set collected. For the MP System, a plastic pin flag is placed on each anomaly location prior to data collection. Each data set was then inverted using the data analysis methodology discussed in Section 6.0, and estimated target parameters determined. The results and the archive data were then submitted to the Program Office.

For the demonstration at fSpAR, a third stage was added to the demonstration. A dynamic survey of the Dynamic Area was conducted, followed by data analysis to produce an anomaly list, prior to the cued survey for the same area.

5.2 SITE PREPARATION

Please refer to the appropriate ESTCP Live Site Demonstrations Plan [11-14].

5.3 SYSTEMS SPECIFICATION

This demonstration was conducted using the NRL MTADS tow vehicle and subsystems, the 5x5 Array, and with the MP System. Each component is described further in the following sections.

5.3.1 MTADS Tow Vehicle

The MTADS has been developed by NRL with support from SERDP and ESTCP. The MTADS hardware consists of a low-magnetic-signature vehicle that is used to tow sensor arrays over large areas (10 - 25 acres / day) to detect buried UXO. The MTADS tow vehicle and TEMTADS 5x5 Array are shown in Figure 4-2 and Figure 4-3 (left).

5.3.2 RTK GPS System

Positioning is provided using cm-level Real Time Kinematic (RTK) Global Positioning System (GPS) receivers. To achieve cm-level precision, a fixed reference base station is placed on an established first-order survey control point near the survey area. The base station transmits corrections to the GPS rover at 1 Hz via a radio link (450 MHz). The 5x5 Array is located in three-dimensional space using a three-receiver RTK GPS system shown schematically in Figure

5-1 (left) [15]. The three-receiver configuration extends the concept of RTK operations from that of a fixed base station and a moving rover to moving base stations and moving rovers. All GPS measurements are recorded at full RTK precision, ~2-5 cm.

For the cued-mode survey, the 10-Hz GPS position and platform orientation are averaged for 2 seconds at the beginning of the data acquisition cycle. The averaged position and orientation information are then recorded to the position (.gps, ASCII format) data file.

In dynamic mode, geolocation for the MP System is provided with a single RTK receiver mounted above the array center on a tripod at 10 Hz. The MP system with the GPS-antenna tripod installed is shown in Figure 5-1 (right).

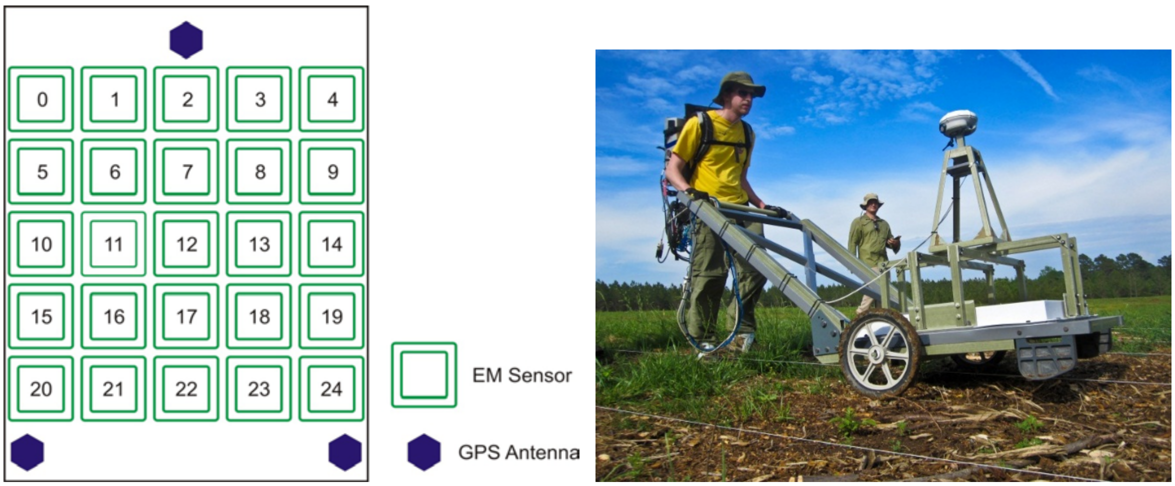

Figure 5-1 – (left) Schematic of the EMI sensor array showing the position of the 25 sensors and the three GPS antennae (right) TEMTADS MP 2x2 Cart with GPS Antenna Tripod. Photograph by Harry Wagner.

5.3.3 TEMTADS 5x5 Array

The 5x5 Array is comprised of twenty-five individual TEMTADS EMI sensors arranged in a 5 x 5 array, as shown in Figure 5-1 (left). The center-to-center distance is 40 cm yielding a 2 m x 2 m array. The bottom of the array is positioned at a ride height of 17 cm above the ground. The rationale of this array design is discussed in Reference 16. Sensor numbering is indicated in Figure 5-1 (left). Also shown in Figure 5-1 (left) is the position of the three GPS antennae that are used to determine the location and orientation of the array for each cued measurement. A picture of the array mounted on the MTADS EMI sensor platform is shown in Figure 5-2.

The transmitter electronics and the data acquisition computer are mounted in the tow vehicle. Custom software written by NRL provides both navigation to the individual anomalies and data acquisition functionality. After the array is positioned roughly centered over the anomaly, the data acquisition cycle is initiated. Each transmitter is fired in a sequence winding outward clockwise from the center position (12). The received signal is recorded for all 25 receiver (Rx) coils for each transmit cycle. The transmit pulse waveform duration is 2.7s (0.9s block time, 9 repeats within a block, 3 blocks stacked, with a 50% duty cycle). While it is possible to record the entire decay transient at 500 MHz, we have found that binning the data into 122 time gates simplifies the analysis and provides additional signal averaging without significant loss of temporal resolution in the transient decays as discussed in Section 2.1.1 [17]. The data are recorded in a binary format as a single file with 25 data points (one data point per Tx cycle). The filename corresponds to the anomaly ID from the target list under investigation.

Figure 5-2 – Sensor array mounted on the MTADS EMI sensor platform.

5.3.4 TEMTADS MP 2x2 Cart

The MP System is a man-portable system comprised of four of the TEMTADS/3D EMI sensors discussed in Section 2.1.2 arranged in a 2x2 array as shown schematically in Figure 5-3. The MP system, shown in Figure 5-1 (right) at the former Spencer Artillery Range, TN, is fabricated from PVC plastic and G-10 fiberglass. The center-to-center distance is 40 cm yielding an 80 cm x 80 cm array. The array is deployed on a set of wheels resulting in a sensor-to-ground offset of approximately 18 cm. The MP system can be operated in two modes: dynamic (or survey) mode and cued mode. A GPS antenna and an inertial measurement unit (IMU) are mounted above the TEM array as shown in Figure 5-1 (right). In cued mode, the locations of the anomalies are flagged for acquisition in advance.

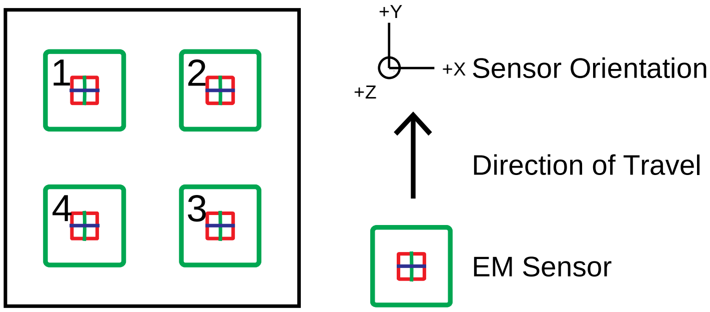

Figure 5-3 – Sketch of the EMI sensor array showing the position of the four sensors. The tri-axial, revised EMI sensors are shown schematically.

5.4 DATA COLLECTION PROCEDURES

5.4.1 Scale of Demonstrations

At each site, NRL conducted a series of cued data collections within the defined demonstration site. The 5x5 Array investigated 2,061 anomalies within the PMA area at fMINSY and 1,168 anomalies in the Open Area at fSpAR. The MP system investigated 913 anomalies within the 50-acre Man-Portable area at the former Camp Beale, 1,001 anomalies within the northern 1.2 acres of the 3-acre Man-Portable subarea of the 330-acre CIA at MMR, and 714 anomalies from the Wooded Area at fSpAR. For the Dynamic Area, a dynamic survey was conducted with the MP System, anomalies selected from the survey data, and a cued survey conducted on the union of the dynamic survey anomaly list and EM61-MK2 anomaly list held by the Program Office, for 389 total anomalies.

Performance of the system response was monitored on a twice-daily basis using the onsite IVS. The data segment (chip) for each anomaly was analyzed, and dipole model fit parameters extracted. These results were then provided to the ESTCP Program Office along with the archival data.

5.4.2 Sample Density

The EMI data spacing for the TEMTADS is fixed at 40 cm in both along- and cross-track directions by the array design.

5.4.3 Quality Checks

Preventative maintenance inspections were conducted at least once a day by all team members. Any deficiencies were addressed according to the severity of the deficiency. Parts, tools, and materials for many maintenance scenarios are available in the system spares inventory which will be on site. Status on any break-downs / failures which would have resulted in long-term delays in operations would have been immediately reported to the ESTCP Program Office.

For the 5x5 Array, the GPS data QC procedures and checks were as follows. The status of the RTK GPS system was visually determined by the operator prior to starting the data collection cycle, assuring that the position and orientation information are valid, typical Fix Quality (FQ) 3, during the collection period. A FQ value of 3 (RTK Fixed)[1] is the best accuracy (typically 3-5 cm or better). A FQ value of 2 (RTK Float) indicates that the highest level of RTK has not be reached yet and location accuracy can be degraded to as poor as ~1 m. FQs 1 & 4 correspond to the Autonomous and DGPS operational modes, respectively. Data collected under FQ 3 and FQ 2 (at the discretion of the data analyst) were retained.

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[1] A FQ of 3 indicates "RTK Fixed" for Trimble GPS receivers outputting the *$PTNL,GGK* NMEA sentence. Output of other NMEA sentences and/or other vendors can use different values, but the concept remains the same.

For the 5x5 Array, two data quality checks were performed on the EMI data. After background subtraction, monostatic contour plots were made of the signal at 0.042 ms from the 25 transmit/receive pairs. The plots were visually inspected to verify that there was a well-defined, well-centered anomaly without any extraneous signals or dropouts. QC on the transmit/receive cross terms was based on the dipole inversion results. Our experience has been that data glitches show up as reduced dipole fit coherence.

The vehicle operator has access to a numerical version of the monostatic contour plot, as shown in Figure 5-4, to allow for on-the-fly data QC. An example monostatic contour plot for a high SNR anomaly centered under the array is shown in Figure 5-4a. For any anomaly where none of the central nine monostatic amplitudes (at 42 μs) exceeds the 5 mV/A threshold, as shown in Figure 5-4b, the vehicle operator would reposition the array approximately 20 cm and acquired a second data set. The operator display is not current normalized, so the threshold is 0.030, as expressed in mV.

Any data set deemed unsatisfactory by the data analyst was flagged and not processed further. The anomaly corresponding to the flagged data was logged for future re-acquisition. Data which met these standards were of the quality typical of the TEMTADS system.

The data QC procedures for the TEMTADS MP 2x2 Cart in cued mode were very similar to those described above and are not repeated here. Further details are available in Reference 13.

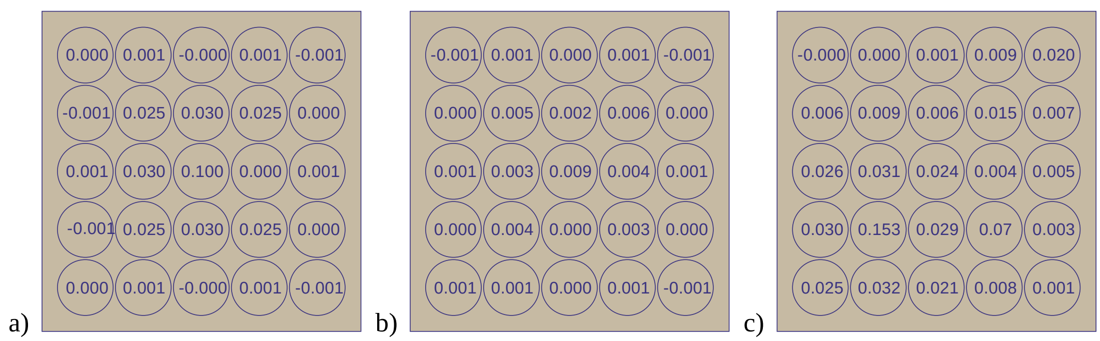

Figure 5-4 – TEMTADS Operator Monostatic Contour Plot Display: a) A single anomaly well centered under the array, b) a low SNR anomaly centered under the array, c) two anomalies, one strong and one weak, with neither directly under the array center. The strong anomaly is sufficiently illuminated to resolve. The weak anomaly is at the array edge and may require reacquisition. These values are in mV (not mV/A) and are not current-normalized.

For the MP system operating in dynamic mode, the data QC process is similar again, but applied to lines of data rather than single data points. The TEM response for data points associated with both background locations and over targets were inspected for reasonable values and variation. A TEM data profile along survey line is shown in Figure 5-5. The recorded transmitter current for each transmit period was inspected to insure a good transmit cycle. A transmitter misfire typically does not reach the average peak value and would have a non-standard waveform.

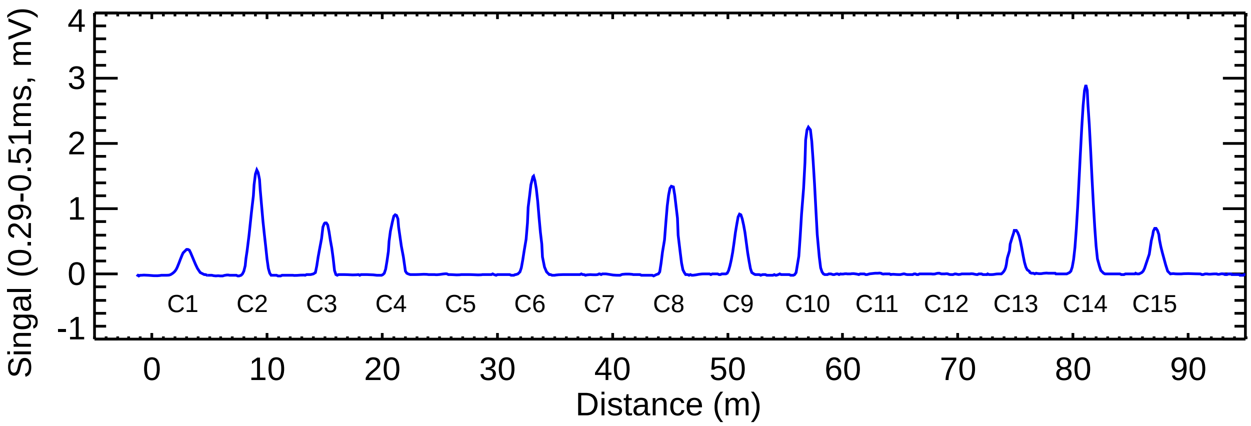

Figure 5-5 – TEMTADS MP 2x2 Cart TEM data profile along a survey line over line C in the NRL Blossom Point Test Field. The Signal is the sum of the monostatic TEM decays for all four sensors summed over the time bins centered from 0.29 to 0.51 ms.

An example is shown in Figure 5-6, where transmitter Tx3 misfired (see Figure 5-3 for sensor numbering). GPS FQ values were evaluated. If the GPS receiver loses its FQ3 RTK solution for short periods, the positions are interpolated over. For longer periods, the data analyst called for recollection.

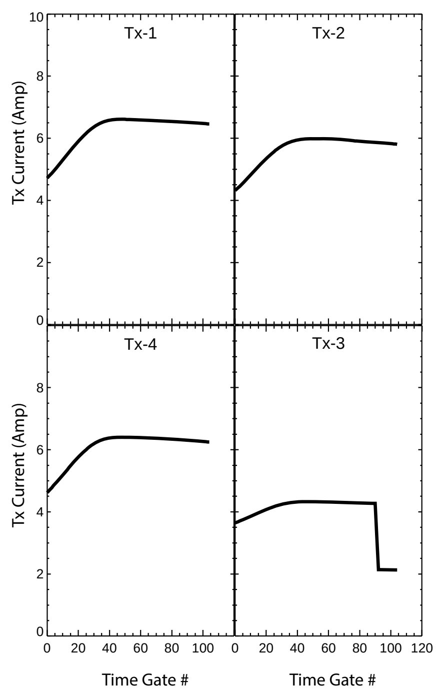

Figure 5-6 – TEMTADS MP 2x2 Cart transmit current waveforms for a bad transmit cycle. In this case, transmitter Tx3 misfired.

5.4.4 Data Handling

Data were stored electronically as collected on the data acquisition computer hard drives. Approximately every survey hour, the collected data were copied onto removable media and transferred to the data analyst for QC/analysis. The data were moved onto the data analyst's computer and the media was recycled. Raw data and analysis results were backed up from the data analyst's computer to external hard disks daily. These results were archived on an internal file server at NRL or SAIC at the end of the survey. All field notes / activity logs were written in ink and stored in archival field notebooks. These notebooks were archived at NRL or SAIC. Relevant sections are reproduced in reports such as this document. Dr. Tom Bell is the POC for obtaining data and other information. His contact information is provided in Appendix A of this report.

5.5 VALIDATION

At the conclusion of data collection activities, all anomalies on the master anomaly list assembled by the Program Office were excavated. Each item encountered was identified, photographed, its depth measured, its location determined using cm-level GPS, and the item removed if possible. This ground truth information, once released, was used by the data analysis demonstrators to evaluate the performance of their methodologies.

6.0 DATA ANALYSIS PLAN

6.1 PREPROCESSING

The MP System has four sensor elements, each comprised of a transmitter coil and a tri-axial receiver cube. For each transmit pulse, the responses at all of the receivers are recorded. This results in 48 possible transmitter / receiver combinations in the data set (4 transmitters x 4 receiver cubes x 3 receiver axes). Although the data acquisition system records the signal over 122 logarithmically-spaced time gates, the measured responses over the first 17 gates included distortions due to transmitter ringing and related artifacts and are discarded. We further subtract 0.028 ms from the nominal gate times to account for time delay due to effects of the receive coil and electronics [18]. The delay was determined empirically by comparing measured responses for test spheres with theory. This leaves 105 gates spaced logarithmically between 0.089 ms and 25.35 ms. In preprocessing, the recorded signals are normalized by the peak transmitter current to account for any variation in the transmitter output. On average, the peak transmitter current is approximately 7.5 Amps.

The background response is subtracted from each target measurement using data collected at a nearby target-free background location. The background measurements are reviewed for variability and to identify outliers, which may correspond to measurements over targets. In previous testing at our Blossom Point test field and during other demonstrations, significant background variability was not observed. It has been possible to use blank ground measurements from 100 meters away for background subtraction. Changes in moisture content and outside temperature have been shown to cause variation in the backgrounds, necessitating care when collecting data after weather events such as rain.

Data preprocessing for the 5x5 Array is very similar to that for the MP System. For the 5x5 Array, there are 625 possible transmitter /receiver combinations in the data set (25 transmitters x 25 receivers x 1 receiver axis). The first seven time gates are excluded, leaving 115 time gates ranging from 0.042 to 25.25 ms. On average, the peak transmitter current is approximately 6 Amps.

For the MP system dynamic survey of the Dynamic Area, data preprocessing is essentially unchanged from the cued mode method described above. Data are collected in survey lines rather than individual points and platform position and orientation information are available.

6.2 TARGET SELECTION FOR DETECTION

Anomaly detection was only involved in the MP system dynamic survey of the Dynamic Area at fSpAR. An anomaly detection procedure similar to the one described in Reference 19 was used. As this was the first outing of the MP system in dynamic mode, a data analyst made each anomaly selection rather than an automated peak picker routine. The anomaly detection criteria were unchanged. A preliminary detection threshold was selected based on physical models of the systems response to the expected TOI, as described in Reference 13. The site-specific background signal levels were considered as well. Anomalies were picked from mapped data. The mapped data from the Dynamic area are shown in Figure 6-1. The data presented are monostatic response from each sensor at the tenth usable time gate, 1.024 ms.

6.3 PARAMETER ESTIMATION

The raw signature data from TEMTADS sensors reflect details of the sensor/target geometry as well as inherent EMI response characteristics of the targets themselves. In order to separate out the intrinsic target response properties from sensor/target geometry effects, we invert the signature data to estimate principal axis magnetic polarizabilities for the targets. The TEMTADS data are inverted using the standard induced dipole response model wherein the effect of eddy currents set up in the target by the primary field is represented by a set of three orthogonal magnetic dipoles at the target location [20].

Figure 6-2 shows an example of the principal axis polarizabilities determined from TEMTADS array data. The target, a mortar fragment, is a slightly bent plate about 0.5 cm thick, 25 cm long, and 15 cm wide. The red curve is the polarizability when the primary field is normal to the surface of the plate, while the green and blue curves correspond to cases where the primary field is aligned along each of the edges.

Not every target on the target list exhibited a strong enough TEM response to support extraction of target polarizabilities. All of the data were run through the inversion routines, and the results manually screened to identify those targets that could not be reliably parameterized.

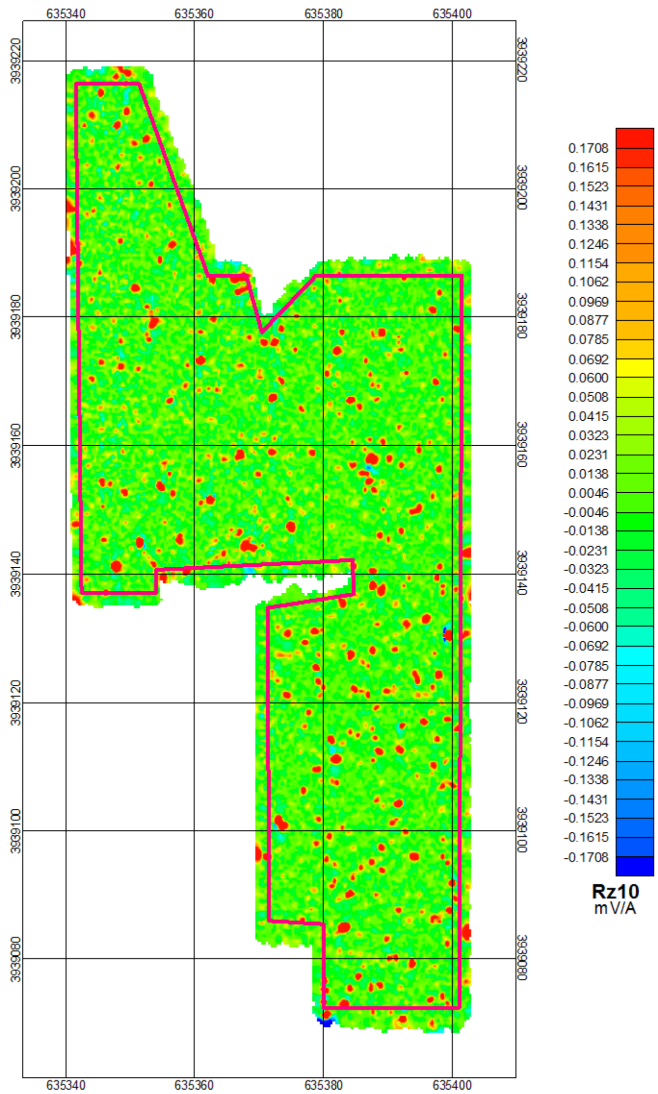

Figure 6-1 – Located and leveled dynamic data (1.024 ms) from the MP System for the Dynamic Area at the fSpAR demonstration site

Several criteria were used: signal strength relative to background, dipole fit error (difference between data and model fit to data), and the visual appearance of the polarizability curves.

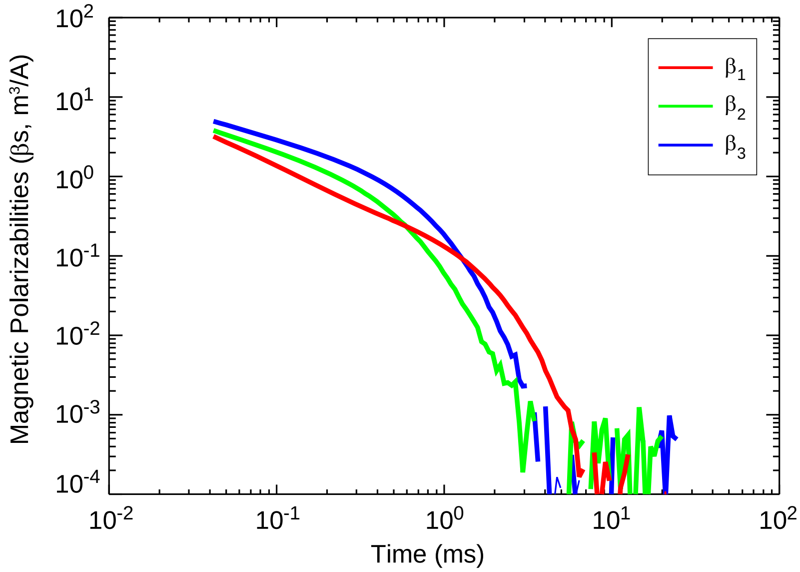

Figure 6-2 – Principal axis polarizabilities for a 0.5 cm thick by 25 cm long by 15 cm wide mortar fragment.

7.0 COST ASSESSMENT

7.1 COST MODEL

The cost elements tracked for this demonstration are detailed in Table 7-1 through Table 7-3. The provided cost elements are based on a model recently developed for cost estimation for the MP system at Camp Beale in 2011 [11]. The model assumes a two-person field crew and one data analyst. Table 7-1 contains the cost model for the 5x5 Array. Table 7-2 contains the cost model for the MP system in cued mode. Table 7-3 contains the cost model for the MP System in dynamic mode. While neither system is currently commercially available, an estimated daily rental rate for the MP system is provided for comparison to other technologies. The rental rate is based, in part, on the costs of items purchased in prototype quantities (single units) and would presumably decrease significantly if the items were procured at production quantity levels. The data analysis level of effort included in the dynamic mode model is based on projections of the production rate that will be achievable with UX-Analyze and not the actual production rate achieved to date.

7.2 COST DRIVERS

Two factors are expected to be strong drivers of cost for this technology as demonstrated. The first is the daily production rate (number of anomalies for cued mode, number of acres for dynamic mode). Higher productivity in data collection equates to more anomalies investigated for a given period of time in the field. The time required for conducting data quality control and analysis can be significantly higher than for other, more traditional methods and could become a cost driver due to the time involvement. The data analysts must be trained to handle the more complex, and richer, data sets properly. The thoughtful use of available automation techniques with operator QC support can moderate this effect.

7.3 COST BENEFIT

The main benefit to using a UXO classification process is cost-related. The ability to reduce the number of non-hazardous items that have to be dug or have to be dug as presumptively-hazardous items directly reduces the cost of a remediation effort. The additional information for anomaly classification provided by these sensor systems provides additional information for the purposes of anomaly classification. If there is buy-in from the stakeholders to use these techniques, this information can be used to reduce costs. Successful implementation of dynamic mode surveying has the potential for further cost reduction by limiting the number of trips to a given area required.

Table 7-1 – TEMTADS 5x5 Array Tracked Costs

<table>
<tr><th>Cost Element</th><th>Data Tracked</th><th>Cost</th></tr>
<tr><td colspan="2">Data Collection Costs</td><td></td></tr>
<tr><td rowspan="3">Pre/Post Survey Activities</td><td>Component costs and integration costs
• Spares and repairs</td><td>$9,500</td></tr>
<tr><td>Cost to pack the array and equipment, mobilize to the site, and return
• Personnel required to pack
• Packing hours
• Personnel to mobilize
• Mobilization hours
• Transportation costs</td><td>$15,600

1
40
3
8
$7,300</td></tr>
<tr><td>Cost to assemble the system, perform initial calibration tests
• Personnel required
• Hours required</td><td>$1,600

3
4</td></tr>
<tr><td>Survey Costs</td><td>Unit cost per anomaly investigated. This will be calculated as daily survey costs divided by the number of anomalies investigated per day.
• Equipment Rental (day)
• Daily calibration (hours)
• Survey personnel required
• Survey hours per day
• Daily equipment break-down and storage (hours)</td><td>$10.64 / anom.

N/A
0.5
2
8
0.5</td></tr>
<tr><td colspan="2">Processing Costs</td><td>$32.50 / anom.</td></tr>
<tr><td>Preprocessing</td><td>Time required to perform standard data clean up and geophysical data QC.</td><td>3 min/anom.</td></tr>
<tr><td>Parameter Estimation</td><td>Time required to extract parameters for each anomaly.</td><td>12 min/anom.</td></tr>
</table>

Table 7-2 – Cued TEMTADS MP 2x2 Cart Tracked Costs

Cost Element	Data Tracked	Cost
Data Collection Costs		
Pre/Post Survey Activities	Component costs and integration costs • Spares and repairs	$3,500
	Cost to pack the array and equipment, mobilize to the site, and return • Personnel required to pack • Packing hours • Personnel to mobilize • Mobilization hours • Transportation costs	$12,450 1 16 3 8 $7,250
	Cost to assemble the system, perform initial calibration tests • Personnel required • Hours required	$780 3 2
Survey Costs	Unit cost per anomaly investigated. This will be calculated as daily survey costs divided by the number of anomalies investigated per day. • Equipment Rental (day) • Daily calibration (hours) • Survey personnel required • Survey hours per day • Daily equipment break-down and storage (hours)	**$7.15 / anom.** $190 0.5 2 8 0.5
Processing Costs		**$10.85 / anom.**
Preprocessing	Time required to perform standard data clean up and to merge the location and geophysical data.	3 min/anomaly
Parameter Estimation	Time required to extract parameters for all anomalies.	2 min/anomaly

Table 7-3 – Dynamic TEMTADS MP 2x2 Cart Tracked Costs

Cost Element	Data Tracked	Cost
Data Collection Costs		
Pre/Post Survey Activities	Component costs and integration costs • Spares and repairs	$3,500
	Cost to pack the array and equipment, mobilize to the site, and return • Personnel required to pack • Packing hours • Personnel to mobilize • Mobilization hours • Transportation costs	$12,450 1 16 3 8 $7,250
	Cost to assemble the system, perform initial calibration tests • Personnel required • Hours required	$780 3 2
Survey Costs	Unit cost per acre investigated. This will be calculated as daily survey costs divided by the number of acres investigated per day. • Equipment Rental (day) • Daily calibration (hours) • Survey personnel required • Survey hours per day • Daily equipment break-down and storage (hours)	**$3,375 / acre** $190 0.5 2 8 0.5
Processing Costs		**$2,340 / acre**
Preprocessing	Time required to perform standard data clean up and to merge the location and geophysical data.	7.5 hr/acre
Target Picking	Time required to extract and QC anomaly pick locations from survey data	0.5 hr/acre
Parameter Estimation	Time required to extract parameters for all anomalies.	2 min/anomaly 300 anom (typ.)

8.0 IMPLEMENTATION ISSUES

The objective of this project was to demonstrate high-quality data collection with an advanced EMI sensor to support UXO/Clutter classification decisions. The introduction of a second generation of advanced sensors focused on being practical field instruments to be used in rugged / restrictive terrain and by industrial community members are improving the implementation story. Another ongoing goal of this and other projects has been to transition these technologies from being research prototypes to use in the industrial community where appropriate. The mechanics of collecting classification-grade advanced EMI cued data with these systems have been shown to be fairly routine in the research community. As part of the ESTCP Munitions Response Live Site Demonstrations, industrial partners have been exposed to the MP system and the associated data collection and processing procedures. The success of this effort will be evaluated on an ongoing basis through the Live Site demonstrations. In the past, analysis of data from these systems has been somewhat of a specialty, requiring specific software and knowledge to proficiently conduct. The successful transition of the processing and analysis procedures for MP data to the Geosoft Oasis montaj environment provides a clear pathway forward.

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