TARGET SHAPE CLASSIFICATION USING THE *MTADS*

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Abstract

The Naval Research Laboratory is conducting several programs whose goal is enhancing the target classification abilities of the *MTADS* system. One of these, supported by ESTCP, is premised on the use of pulsed-induction signatures to obtain information about the size, shape, and orientation of a target. The first field test of this approach was conducted in February 1999 at the NRL Ordnance Classification Test Site at Blossom Point, MD. This test site contains a series of ferrous and non-ferrous shapes, selected clutter items, and inert ordnance buried at known locations and orientations. Survey data were collected at the field using a variety of deployment approaches and array orientations for the pulsed-induction sensors to determine the most cost-effective approach for classification. Using these methods, we were able to correctly classify 97% of the cylindrical objects, inert ordnance and simulants, and 40% of the flat objects, clutter. This paper describes the test site and discusses the results of the application of the new analysis routines on the target objects.

Background

Traditional methods for buried UXO detection, characterization and remediation are labor-intensive, slow and inefficient, relying on the use of hand-held detectors operated by explosive ordnance disposal (EOD) technicians who slowly walk across the survey area. This process, commonly referred to as "Mag and Flag," has been documented as inefficient and marginally effective.[1] In typical Mag and Flag survey and remediation, a large portion, often 70-75% , of the total budget is spent on digging targets that are not intact UXO.

The Environmental Security Technology Certification Program, ESTCP, has supported the Naval Research Laboratory in the development of the Multi-sensor Towed Array Detection System, *MTADS*, to address these deficiencies. The *MTADS* incorporates both cesium vapor full-field magnetometers and pulsed-induction sensors deployed as linear horizontal arrays that are towed over survey sites by an all-terrain vehicle. Sensor location is provided by state-of-the-art Real Time Kinematic (RTK) GPS receivers. The data acquired in an *MTADS* survey is analyzed using an NRL-developed Data Analysis System, DAS. The DAS was designed to locate, identify and categorize all military ordnance up to its maximum self-burial depth. It is efficient and simple to operate and provides model-based target position, depth, and size predictions.

The performance of the *MTADS* has been demonstrated at a number of prepared sites and live ranges over the past two years.[2-8] It detects and locates ordnance with accuracy on the order of 15 cm.[5] However, even with careful mission planning and preliminary training based on small area digs there are still significant numbers of non-ordnance targets selected for remediation. Thus, to reduce remediation costs, more effective discrimination algorithms are required. The Naval Research Lab is conducting several programs whose goal is to enhance the discrimination capabilities of the *MTADS*. One of these, sponsored by ESTCP, is premised on the use of magnetometry data to establish position and depth of a target and the pulsed-induction data to obtain information about the shape and orientation of the target. This paper reports the results of the first field demonstration of this program.

Analysis Methodology

This program is organized around the belief that classification based on shape is central to the problem of discriminating between intact unexploded ordnance (UXO) and clutter. Most ordnance fit a specific shape profile: they are long and slender with typical length-to-diameter aspect ratios of four or five (the aspect ratio of rockets is typically 8 – 12). Most clutter items, on the other hand, do not fit this profile. Using pulsed-induction sensor data, we have developed a model-based estimation procedure to determine whether or not a target is likely to be a UXO item based on how its shape matches this profile. The model relies on exploiting the dependence of the induced field on target size, shape and orientation.

The EM61 is a time domain instrument. It operates by transmitting a magnetic pulse that induces currents in nearby conducting objects. These induced currents produce secondary magnetic fields that are measured by receiver coils after the transmitter pulse has ended. The sensor response is measured as voltage induced in the receiver coil by these secondary fields; it is proportional to the time rate of change of the magnetic flux through the coil. The EM61 integrates this induced voltage over a fixed time gate and averages over a number of pulses.

The model used in this demonstration has been jointly developed by NRL and AETC, Inc., the concept was described last year at this Forum.[9] Briefly, it relies upon the fact that the EM61 signal is a linear function of the flux through the receiving coil. The flux is assumed to originate from an induced dipole moment at the target location which is given by

$$\mathbf{m} = UBU^T \cdot \mathbf{H_o} \qquad (1)$$

where $\mathbf{H_o}$ is the peak primary field at the target, U is the transformation matrix between the coordinate directions and the principal axes of the target, and B is the effective magnetic polarizability tensor. This tensor contains information about the target (i.e. size, shape and composition), as well as the details of the EM61 (i.e. transmitter pulse and receiver time gate characteristics).

For a spheroidal object, B is a diagonal tensor with only two unique coefficients, corresponding to the longitudinal (β_l) and transverse (β_t) directions:

$$B = \begin{pmatrix} \beta_l & 0 & 0 \\ 0 & \beta_t & 0 \\ 0 & 0 & \beta_t \end{pmatrix} \qquad (2),$$

in the more general case, the βs would be unique. In the static limit, these coefficients reduce to the magnetostatic polarizabilities for a spheroid. To obtain information on target shape, the axially induced field (i.e. the field induced based on the component of the primary field along the longitudinal axis of the target, or equivalently β_l) is compared to the transversely induced field (β_t). An empirical relationship between the ratio of these coefficients and the length-to-diameter aspect ratio of targets has been determined. In general, for a prolate (long and slender) spheroid, $\beta_l > \beta_t$, while for an oblate (short and flat) spheroid, $\beta_l < \beta_t$.

We have developed several implementations of this model for evaluation in this program. In this demonstration, we fit the pulsed-induction responses observed to models with combinations of two or three response coefficients, β, and two or three orientation angles. The details of the implementation and use of these models and their application to *MTADS* data collected during the JPG IV demonstration are described by Barrow and Nelson[10] at this conference.

NRL Test Site Description

The design and implementation of the NRL Ordnance Classification Test Site at Blossom Point is described in an NRL report.[11] The design of the field is briefly described here.

Prior to establishing the test field, an *MTADS* survey of an 8-acre area was conducted using both the magnetometer and pulsed-induction sensor arrays. These surveys were used to locate the cleanest portion of the site for the baseline grid and to pick approximately 225 anomalies for remediation on the grid. A 30 x 100-m area in the middle of the cleaned site was chosen for the baseline targets. This area was subjected to three cycles of surveying and cleaning to the 10-mV peak EM-61 signal level on the *MTADS*.

The design layout of the baseline area is shown in Figure 1. The nominal grid spacing is 6 meters. Each of the individual target's signatures were independently measured in an adjacent test pit to ensure that their signature was contained in this area without overlapping adjacent target signatures. Each of the ordnance items and simulants placed in the test area was carefully degaussed using a commercial tape degausser so that the remnant contribution to their magnetic signature was less than 10% of the total signature. In most cases the remnant moment was less than 5% of the induced moment.

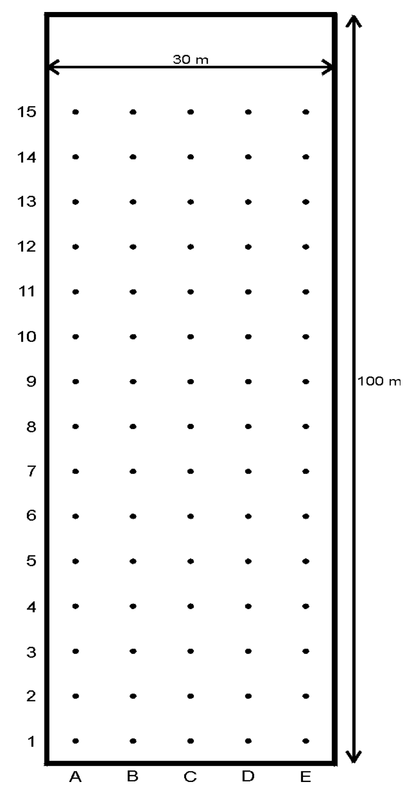

Figure 1 — Layout of the NRL ordnance classification test site at Blossom Point

The ordnance and clutter simulants and inert ordnance in the test set are shown in Figure 2 and listed in Table 1 along with their design burial depths and orientations.

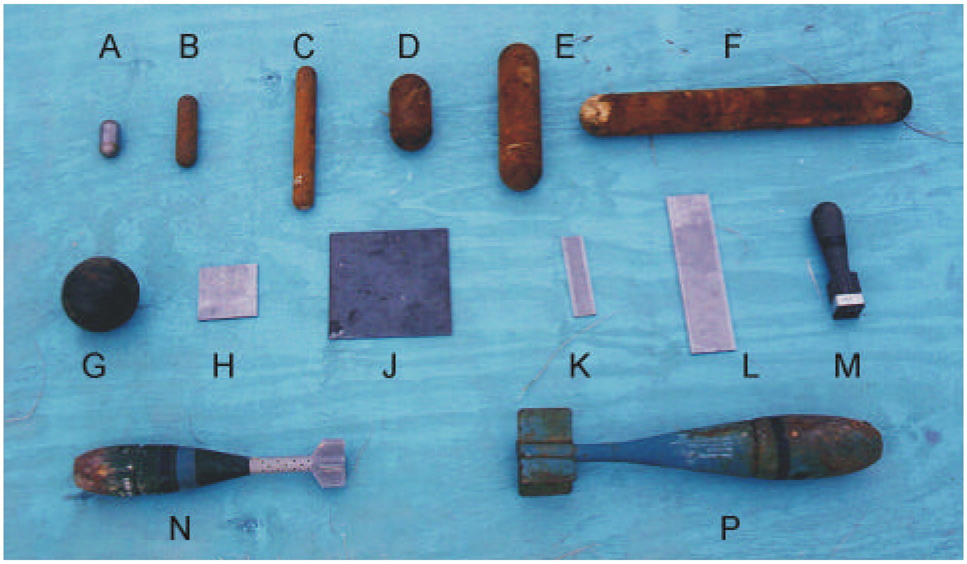

Figure 2 — The ordnance and clutter simulants and ordnance in the NRL baseline test area.

Table 1 – Description of the items in the baseline test field

Item ID	Description	Depths (m)	Orientations (Azimuth, Inclination)
A	1½" x 3" solid steel cylinder	0.05	0°,0° & 0°,90°
B	1½" x 6" solid steel cylinder	0.10 & 0.20	0°,0° & 0°,90°
C	1½" x 12" solid steel cylinder	0.35 & 0.50	0°,0° & 0°,90°
D	3" x 6" solid steel cylinder	0.10 & 0.25	0°,0° & 0°,90°
E	3" x 12" solid steel cylinder	0.35 & 0.50	0°,0° & 0°,90°
F	3" x 24" solid steel cylinder	0.75 & 1.00	0°,0° & 0°,90°
G	16 lb steel shotput	0.25	
H	4" x 4" x ¼" steel plate	0.05	45°,0° & 0°,90°
J	8" x 8" x ¼" steel plate	0.25	45°,0° & 0°,90°
K	1½" x 6" x ¼" steel plate	0.05	0°,0°, 90°,0°& 0°,90°
L	3" x 12" x ¼" steel plate	0.25 & 0.50	0°,0°, 90°,0°& 0°,90°
M	Mk-23 practice bomb	0.25 & 0.50	0°,0° & 0°,90°
N	81 mm Mortar	0.50 & 0.75	0°,0° & 0°,90°
P	BDU-33	1.00	0°,0° & 0°,90°

The azimuth and inclination angles in Table 1 are defined in Figure 3. Azimuth is defined as positive clockwise from North. Inclination is measured from parallel to the ground surface and is positive with the object's nose pointed down.

The ordnance scrap and indigenous clutter items included in the field are shown in Figure 4 and listed in Table 2. Each of them is designated with item ID Q and an individual serial number as shown in the table. Both a 250 and 500 lb. bomb are planned for the North edge of the area although they have not been emplaced at this time.

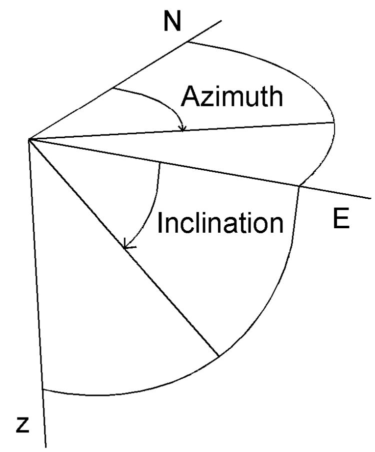

Figure 3 — Angles as used in this report.

Figure 4 — Clutter items in the NRL baseline test area.

Table 2 – Clutter items in the baseline test field

Item ID	Serial Number	Description	Depth (m)
Q	1	4" x 4" x ¼" Al plate	0.05
Q	2	2" x 8" x ¼" Al plate	0.05
Q	3	Flattened Al soda can	0.03
Q	4	Box fin scrap (M 38)	0.03
Q	5	Box fin scarp (M 38)	0.15

Item ID	Serial Number	Description	Depth (m)
Q	6	Slip joint pliers	0.05
Q	7	Al fin assembly(2.75" rocket)	0.10
Q	8	Shovel blade	0.23
Q	9	Banding material	0.10
Q	10	Box fin assembly (M 38)	0.15
Q	11	Barbed wire	0.10
Q	12	Horseshoe	0.05
Q	13	8" round steel plate	0.15
Q	14	Twisted steel scrap	0.23
Q	15	Chain-link fence post cap	0.08

Results

The major goal of this demonstration was to quantify the classification performance improvement possible using several different survey modes and model fitting methods as a function of the additional survey time and analysis resources required. To accomplish this, we collected a magnetometer survey of the test site along with five pulsed induction surveys. Three of these were collected with the EM-61 coils mounted parallel to the ground (the traditional *MTADS* configuration), a N-S survey, an E-W survey, and a NE-SW survey oriented 45° to the major axis of the test area. Additionally, we collected data with the coils rotated 90° from the horizontal while surveying in both N-S and E-W directions. The coils deployed in this manner are shown in Figure 5. This results in five pulsed-induction survey data sets for evaluation by the models.

Figure 5 — The *MTADS* EM-61 array rotated 90º.

We analyzed these data sets as seven combinations: NS alone, EW alone, NS + EW, NS + Vertical NS, EW + Vertical EW, NS + EW + Vertical NS, and NS + EW + Vertical EW. For each of these combinations, we applied the two β, two angle and three β, three angle versions of the model using the magnetometer fit predictions (when available) for x,y and depth as the starting points in the EM model fit. The most appropriate description of the target was chosen based on the resulting χ^2 of the fits. As an example, a cylindrical object should be well described by a two β, two angle model as the EM response is independent of rotation about the symmetry axis. In this case, the best description of the target would involve one large β and two smaller, identical βs. Based on the relationship of the three βs obtained, we classified the target as LONG, FLAT, IRREGULAR LONG, IRREGULAR FLAT or IRREGULAR. The fit results for three representative targets in the training portion of the field to the data in the combined NS + EW surveys are listed in Table 3.

Table 3 — Selected fit results from the application of the model to the NS + EW survey data set.

ID	Actual Depth (m)	Model Depth (m)	β1	β2	β3	Classification
B	0.20	0.17	0.938	0.227	0.227	LONG
H	0.05	0.10	0.287	0.995	0.995	FLAT
L	0.25	0.30	3.788	0.553	0.553	LONG

Two of these targets, items B and H, are classified correctly. Item B is a 1½" diameter cylinder with length-to-diameter aspect ratio of 4 and the fitted βs reflect that. Item H is a 4" square x ¼" thick plate and the βs derived also are appropriate to that target shape. The final item in Table 3 is representative of the majority of the items misclassified in this demonstration. Item L is a ¼" thick steel plate with dimension 3" x 12". The βs derived are representative of those expected for a cylinder and thus the object was incorrectly classified as LONG. We are in the process of examining these misclassified targets individually in an effort to improve the performance of the modeling procedure.

As shown for the three targets in Table 3, the depth prediction of the model was excellent in all cases. This is in contrast to the EM fit module of the baseline *MTADS* DAS that is based on the symmetric response expected from a sphere and thus returns an unreliable depth for shallow complex targets. The model-derived target locations are also excellent as might be expected from our previous results using magnetometer fits for x and y. Interestingly, there was no significant improvement in the fit performance when we used the magnetometer results as starting points for the EM fit. Presumably, this means the χ^2 surface is relatively steep in these (x and y) dimensions with no significant local minima.

We find similar good agreement with the predicted orientations, with one notable exception. As an example, item B in Table 3 is oriented in the plane of the ground aligned magnetic North-South. The predicted orientation is within 5º of this in both angles. The performance is less good for axisymmetric objects oriented vertically. Here, the signature should be symmetric. We have a small timing fluctuation among the three EM-61 sensors in the *MTADS* array that introduces some artifact asymmetry into the measured signature. This causes the model to predict target tilt in these cases. We are working with the sensor manufacturer to eliminate this timing fluctuation.

The results of the model fits for three of the survey combinations are detailed in Table 4. The first thing to note from these results is the excellent classification results achieved. We estimate that there is enough information (signal asymmetry, non-dipole shape, etc.) in the baseline *MTADS* signatures to correctly classify small percentage of targets as not UXO. The simplest case demonstrated here, a single EM survey, results here in almost perfect classification of the

Table 4. – Summary of the results of this demonstration

Surveys Used	Correct Classification as Long or Long Irregular	Correct Classification as Flat or Irregular Flat	Correct Classification as Other*
NS only	32/34	8/25	0/2
EW only	29/34	10/25	1/2
NS + EW	33/34	10/25	0/2

*The shotput (sphere) and box fin assembly (near cube) have aspect ratios near 1 and therefore do not fit neatly into the other shape classes.

LONG and LONG IRREGULAR items; the shape classes that contain the ordnance and ordnance simulants. Use of two orthogonal surveys allowed us to correctly classify 40% of the FLAT and FLAT IRREGULAR targets. This is equivalent to a 40% reduction in the false alarm rate; a significant achievement if these results extrapolate to a live site. No significant increase in classification performance was obtained when we used data sets consisting of three surveys.

Summary

We have applied several implementations of a new modeling approach to EM-61 data collected at the NRL Ordnance Classification Test Site using the *MTADS*. Using a data set made up of the results of two surveys, a N-S survey and an E-W survey, we are able to correctly classify 97% of the LONG and LONG IRREGULAR objects and 40% of the FLAT and FLAT IRREGULAR targets. This corresponds to a 40% reduction in the false alarm with effectively no reduction in probability of detection of cylinders. We are examing the signatures of the misclassified objects in detail in an effort to reduce the false alarm rate further. We will demonstrate these techniques on a live site in the Summer of 1999 and report the results from that test next year.

References

1. "Hand-held Gradiometer Survey Test at The Marine Corps Air Ground Combat Center, Twentynine Palms, CA," NAVEODTECHCEN TR, September 1992. This report describes hand-held gradiometer surveys of the MCAGCC Magnetic Test Range conducted by military EOD teams. Their ordnance detection efficiency varied between 25 and 35%.
2. "*MTADS* TECHEVAL Demonstration, October 1996," H. H. Nelson, J. R. McDonald, and Richard Robertson, NRL/PU/6110—97-348.
3. "Results of the *MTADS* Technology Demonstration #2, Magnetic Test Range, Marine Corps Air Ground Combat Center, Twentynine Palms, CA, December 1996," J. R. McDonald, H. H. Nelson, R. A. Jeffries, and Richard Robertson, NRL/PU/6110—97-349.
4. "Results of the *MTADS* Technology Demonstration #3, Jefferson Proving Ground, Madison, IN, January 13-24, 1997," H. H. Nelson, J. R. McDonald, R. A. Jeffries, and Richard Robertson, NRL/PU/6110—99-375.
5. "*MTADS* Unexploded Ordnance Operations at the Badlands Bombing Range, Pine Ridge Reservation, Cuny Table, SD, July 1997," J. R. McDonald, H. H. Nelson, J. Neece, Richard Robertson and R. A. Jeffries, NRL/PU/6110—98-353.

6. "*MTADS* Demonstration at the Former Ft. Pierce Amphibious Base, Vero Beach, FL, March 1998," J. R. McDonald, H. H. Nelson, R. A. Jeffries, Richard Robertson, and K Blankinship, NRL/PU/6110—98-372.

7. "*MTADS* Live Site Survey, Bombing Target #2 at the Former Buckley Field, Arapohoe County, CO, August 1998," J. R. McDonald, H. H. Nelson, and Richard Robertson NRL/PU/6110—99-379.

8. "*MTADS* Live Site Survey and Remediation at Bombing Targets N-9 and N-10 on the Laguna Pueblo Reservation, Laguna, NM, August 1998," J. R. McDonald, H. H. Nelson, Richard Robertson and R. A. Jeffries, in preparation

9. "Target Shape Classification using Electromagnetic Induction Sensor Data," Nagi Khadr, Bruce J. Barrow, Thomas H. Bell and H. H. Nelson, Proceedings of the UXO Forum 1998, Anaheim, CA, May 5-7 1998.

10. "Model-Based Characterization Of EM Induction Signatures For UXO/Clutter Discrimination Using The *MTADS* Platform," Bruce J. Barrow and H. H. Nelson, Proceedings of the UXO Forum 1999, Atlanta, GA, May 25-27 1999.

11. "Design and Construction of the NRL Baseline Ordnance Classification Test Site at Blossom Point," H. H. Nelson, J. R. McDonald and Richard Robertson, in preparation