Geophysical Classification for Munitions Response

Technical Fact Sheet | June 2013

The Interstate Technology and Regulatory Council (ITRC) Geophysical Classification for Munitions Response Team developed this fact sheet (the second of three) to provide basic information about geophysical classification for munitions response. For more information, please visit the ITRC website at http://www.itrcweb.org.

Introduction

For decades, the Department of Defense (DOD) has produced and used military munitions for live-fire testing and training to prepare the United States military for combat operations. As a result, unexploded ordnance (UXO) and discarded military munitions (DMM) may be present on former ranges and former munitions operating facilities (such as production and disposal areas). Over 4,400 sites in the United States require a munitions response, with an estimated cost to complete of $15.2 billion and completion date of 2158.

To identify munitions for removal at these sites, DOD and its contractors have historically used various types of detection instruments to simply detect buried metal items. Consequently, on munitions response sites, most detected items must be uncovered and examined to determine whether they are military munitions. Typically, highly-trained UXO-qualified personnel excavate hundreds of metal items for each munition recovered. Given the costs associated with this inefficiency, only limited acreage can be addressed with existing resources and budgets.

DOD's Environmental Security Technology Certification Program (ESTCP) and its research partners in academia and industry have developed and demonstrated a new approach, using a process called *geophysical classification,* to improve the efficiency of munitions response. As before, geophysicists use electromagnetic sensors to detect metal items beneath the ground surface. Then, using advanced sensors to collect additional data, geophysical analysts can estimate the depth, size, wall thickness, and shape of each buried item. Geophysical classification is the process of using these data to make a principled decision as to whether a buried metal item is potentially hazardous or can be left in the ground. This technique can focus a munitions response on investigating only those anomalies identified as being potentially due to munitions, with required quality assurance investigations of other anomalies, resulting in a more rigorous, better understood, and better documented product. For example, at the former Camp Beale demonstration site, geophysical classification would have reduced the estimated number of debris items excavated by 78%, from 1310 to 285.

This fact sheet provides an overview of the geophysical classification technology and process, the types of terrestrial sites where this technology may be applicable, and data quality considerations. This fact sheet benefits scientists, engineers, and other environmental professionals who are familiar with or have experience executing or managing munitions responses. This target audience may include, but is not limited to, state and federal environmental regulators as well as munitions response managers and technical staff.

Geophysical Classification Overview

The geophysical classification process normally consists of three steps:

1. Measure the response of a buried metal object to an electromagnetic field using an advanced geophysical sensor.
2. Analyze the measured response to determine target parameters such as depth, size, aspect ratio, and wall thickness.

3. Use these parameters as inputs to a classifier to help decide whether the detected item is most likely a munition that must be investigated to determine whether it is potentially hazardous.

Classification data are collected using electromagnetic induction (EMI) sensors. These sensors produce a magnetic field in the earth's near surface by running a pulse of current through a transmit coil deployed just above the ground. When this induced field is rapidly turned off, eddy currents are created in nearby metal objects that are then sensed in a receiver coil (Figure 1). The amplitude and decay properties of these eddy currents are determined by the size, shape, material composition, and wall thickness of the buried item as well as its location and orientation relative to the sensor. Advanced EMI sensors use sets of transmit and receive coils oriented as two-dimensional and three-dimensional arrays that completely measure the response of the buried item.

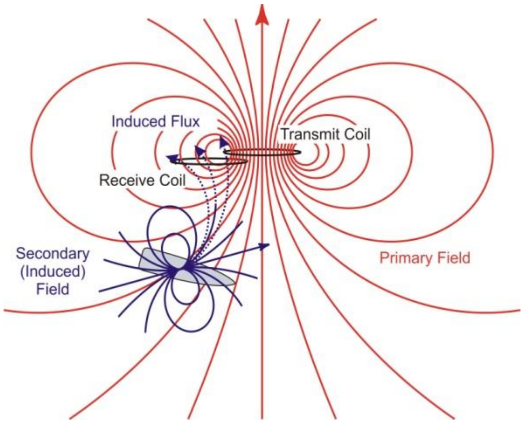


Figure 1. Diagram of a typical electromagnetic induction sensor.

The measured EMI decays depend both on parameters that can help classify the target (such as size, aspect ratio, and wall thickness) and parameters related to the target's location and orientation relative to the sensor. The contribution of each parameter is determined individually by fitting the observed EMI decays to a physics-based model. The process results in an estimation of the objects' intrinsic EMI response (also known as the EMI response along the object's principal axes, or "EMI fingerprint"), the location, and the orientation of the object.

These EMI responses are used as the input data for the classification decision (Figure 2). Once the parameters, or features, of the buried item are determined, the classification decision is made in one of two ways. The most straightforward method is to compare the EMI responses of the unknown item to a library of known munition responses. If the unknown item shows the same EMI characteristics as a munition in the library, then it is classified as a munition. The other method is to use a statistical classifier. In this method, machine-learning techniques are used to train the classifier to recognize EMI responses that indicate a possible munition. Both of these approaches are based on matching the EMI responses, or EMI fingerprint. In the first case, the match is to a pre-existing library of EMI responses of munitions, while the statistical classifier creates its own library from training data. The process of building a standard classification library is ongoing, with EMI responses from munitions continually being added to Oasis Montaj, the software most commonly used by the UXO-industry to classify anomalies.

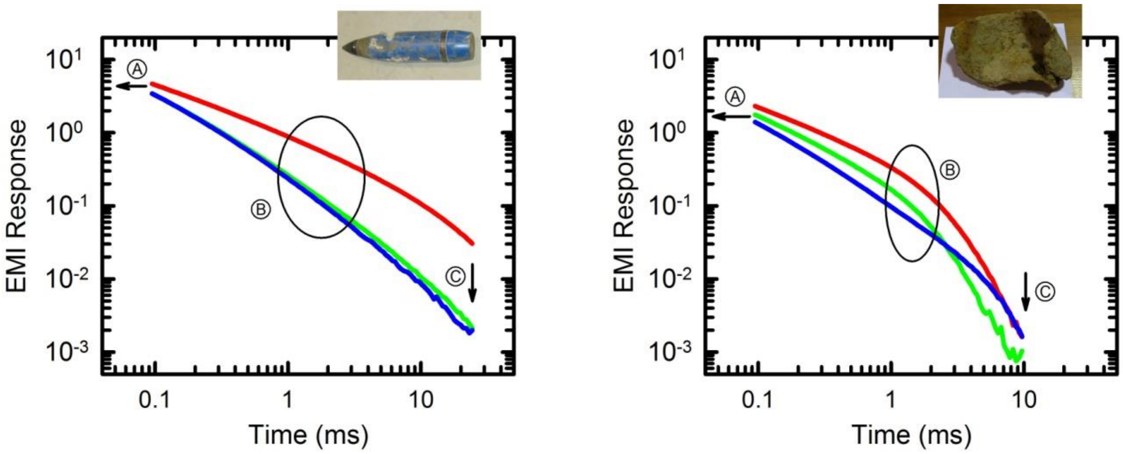


Figure 2. Comparison of the EMI responses for two metal objects.

In Figure 2, the overall amplitude of the response (A) is related to the volume of the object; the projectile on the left is larger than the fragment on the right and the responses are about twice as large. The projectile is cylindrical, which results in one large response corresponding to the long axis and two smaller, but equal, responses corresponding to the other two axes (B). The fragment is not symmetric and exhibits three distinct responses. The decay of the curves is related to the wall thickness of the object. The responses of the thick-walled projectile persists (C) for a longer time than the fragment.

Appropriate Applications

Geophysical classification can generally be used at any terrestrial site where high-quality geophysical EMI data can be collected. It has been used successfully at a variety of sites across the country in different types of terrain and in areas of varying vegetation. Typically, if the sensors can be towed or pushed across the site, or handheld equipment can be walked in a grid, then geophysical classification can be used.

Geophysical classification is not applicable in every situation. Some limitations for this approach involve the technology itself, while others involve site-specific characteristics that impose limitations on access to portions of the site, such as areas of dense vegetation; extremely rough, unstable or steep terrain; or areas subject to electromagnetic interference. In addition, advanced EMI sensors are not currently used on airborne or underwater platforms.

Technological Limitations - Presently, EMI sensors do not consistently detect deeply buried, smaller munitions or differentiate munitions in high density target areas. While larger towed units have a similar depth range to EM sensors currently used today, current versions of portable/handheld advanced EMI sensors are lighter weight and less powerful. They are primarily useful for collecting advanced classification data on items in the upper one to two feet of the subsurface, although they can sometimes detect deeper items. Because 80 to 90 percent of clutter is detected in the upper two feet, portable units should be sufficient to either classify an anomaly as due to a TOI (most likely a munition), non-TOI, or to determine it cannot be classified and add it to the dig list with the TOIs.

Although recent ESTCP demonstrations have shown success in classifying multiple overlapping objects, overlapping high density anomalies can be difficult to differentiate. The more knowledge and experience the geophysicist has with the software that analyzes overlapping signatures, the greater the success in classifying targets. Even when target data are clear, a wide range of unknown items or various versions of munitions (such as damaged or bent rounds) must still be added to the classification library of munitions. Additionally, over time a library of EMI responses for non munition items (for instance, horseshoes, mufflers, or gas cylinders) will also be developed. The library of EMI responses from various munitions continues to expand with each survey and has been used to detect a wide range of munitions types, including some in various states of damage (Figure 3).

Figure 3. Damaged munition.

Site Limitations – Commercially available advanced EMI sensors are typically mounted on platforms that can be pushed or pulled across an area. This approach tends to preclude their use in difficult site conditions such as thickly vegetated areas, rocky conditions, extreme terrain, highly muddy conditions, or in areas covered by water. In addition, since location data are typically tied to GPS, areas that cannot receive GPS signals or receive only spotty signals make the process more difficult. Also, as with all EMI sensors, geologic conditions can generate severe interference (for instance, areas with primarily mafic or ultramafic rocks such as basalt). Additionally, sites where electromagnetic interference is an issue (such as sites near electrical substations or transmission equipment), or sites adjacent to large metallic structures either above or below ground are not conducive to current advanced EMI technology.

***Cost Effectiveness* –** Geophysical classification is cost effective when the additional costs to perform the cued interrogation are expected to be offset by the reduction in intrusive investigations. Production rates typically vary from 175 to over 300 cued measurements per day. The higher production rates are achieved when the terrain is not difficult and anomalies are of high amplitude and easier to locate. At some sites, however, the use of geophysical classification may not be cost effective. For example, if the site is a high density area that is heavily cluttered with munitions or other metal debris (munitions fragments), then geophysical classification may not be as useful; therefore, it may not significantly reduce the number of excavations and the increased expense of a classification survey would not be offset by cost savings.

Cued Interrogation (Data Collection) *- Static data collection over an anomaly detected in a separate survey for improved classification performance. Anomalies identified in a dynamic survey are typically used to cue follow-on measurements using a static sensor.*

Geophysical Classification Process

Typically, metal detectors are used to detect subsurface metallic objects in a time-domain EM survey or a magnetometer survey. Refer to *Survey of Munitions Response Technologies*, June 2006 (ITRC UXO-4) for a comprehensive overview of how these technologies are used during munitions response. High quality detection data with tight survey line spacing, precise geolocation, and low noise result in accurate anomaly locations and few false detections. These data characteristics lead to efficient classification. Each location of a detected anomaly is marked to be revisited with an advanced EMI sensor to collect data needed to classify the source of the anomaly (Figure 4). These data are acquired in a cued mode, which requires the advanced EMI sensor to remain stationary over each anomaly for approximately thirty seconds. During this time thousands of spatial and temporal measurements are recorded from a variety of angles and locations. Field-level quality control checks should be performed at this stage to confirm that adequate signal-to-noise ratios are achieved, the sensor was properly located over the anomaly location, and all geophysical hardware was functioning as designed. All data are recorded and thus may be revisited as needed to verify data quality.

Figure 4. Advanced EMI sensors include hand-held (left), sled-mounted (middle), and cart-mounted (right) units.

Data that meet the quality control (QC) criteria are then passed along to powerful computer software that derives the EMI response for each item interrogated, as described previously. These polarizability decay curves, or EMI fingerprints, are used as input to a classifier. Subsequently, each item identified as a TOI is passed along to an excavation crew for recovery and disposal.

***Blind Seed** - Inert munition or munitions surrogate (such as an Industry Standard Object) placed on the site to serve as a process QC check. The location and identities of these seeds should be blind to the data collectors, analysts, and intrusive crew.*

On many sites, especially those similar to previous sites on which classification has been successfully performed, site-specific validation may not be required. On these sites, the classifier and thresholds from earlier work can be used directly. At some sites, in addition to the use of a standard instrument verification strip (IVS) during the survey, a small pilot study to demonstrate the applicability of classification to the site conditions is performed as a component of the feasibility study or prior to beginning a response (removal or remedial) action. This pilot study is generally conducted on a small portion of the site with a significant number of blind seeds to ensure confidence in the results. Detection and classification are performed within the study area with all anomalies intrusively investigated. The classification process is judged by its success in detecting and correctly classifying the QC seed items and other TOI encountered and by the reduction in the number of anomalies selected for investigation that are not munitions. Once validated, the classification method should be able to be confidently applied to the remainder of the site.

Quality Considerations for Geophysical Classification

Geophysical classification can be divided into subprocesses and tasks that have associated metrics, which can be used to ensure the quality of the work performed. Quality on a munitions response site using geophysical classification is just as important as on a site using standard geophysical sensors, although the differing processes require differing quality procedures. The quality considerations for each step in the process—detection, cued data collection, parameter estimation, and classification—are described below. If all of the geophysical classification processes meet the quality requirements, the project team can have a high degree of confidence in the results from the use of geophysical classification at the site.

To ensure quality in the initial survey to detect buried metal items throughout the site, verify that all equipment checks and geophysical sensor warm-up procedures were performed satisfactorily. The project geophysicist documents these and other quality checks with standardized forms. Equipment check forms include verification of daily static checks within the required metrics (typically +/- 10% of the expected values for the time gates). Another criteria to ensure quality in the initial survey is the measurement of consistent peak signal results from the IVS surveys. The initial detection survey should also detect all blind seeds in the survey area and place them on the list for cued interrogation.

Quality considerations for the collection of high-fidelity geophysical data at each anomaly also require verification that all equipment checks and warm-up procedures are performed satisfactorily for the advanced geophysical equipment. Because advanced sensors have multiple transmitters and receivers, site personnel must verify that all relevant transmitters and receivers are operating properly in order to have confidence in the model parameters. Figure 5 illustrates a case in which one of the measured decays was spurious. Including these results would have led to the incorrect conclusion to not dig the item. Excluding this spurious channel from the analysis allows the geophysicist to correctly identify the item as a TOI.

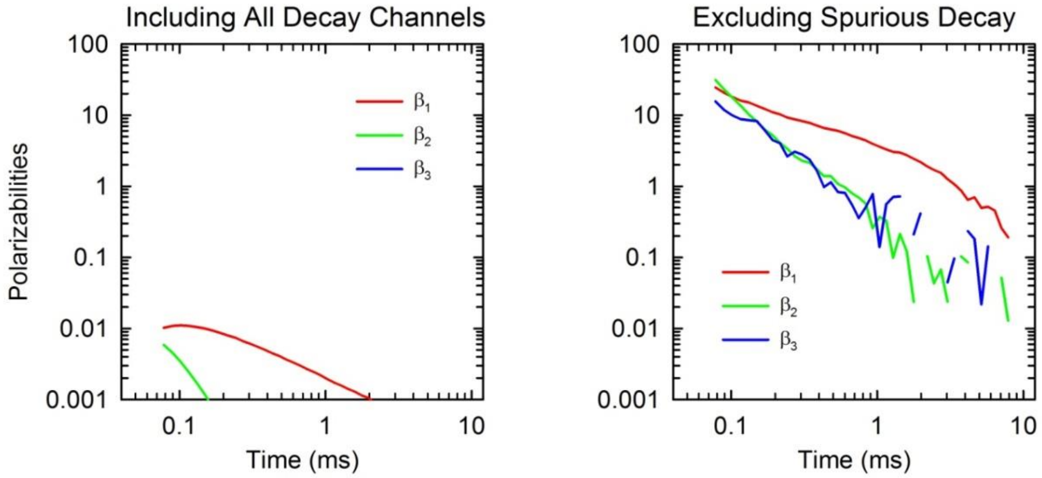
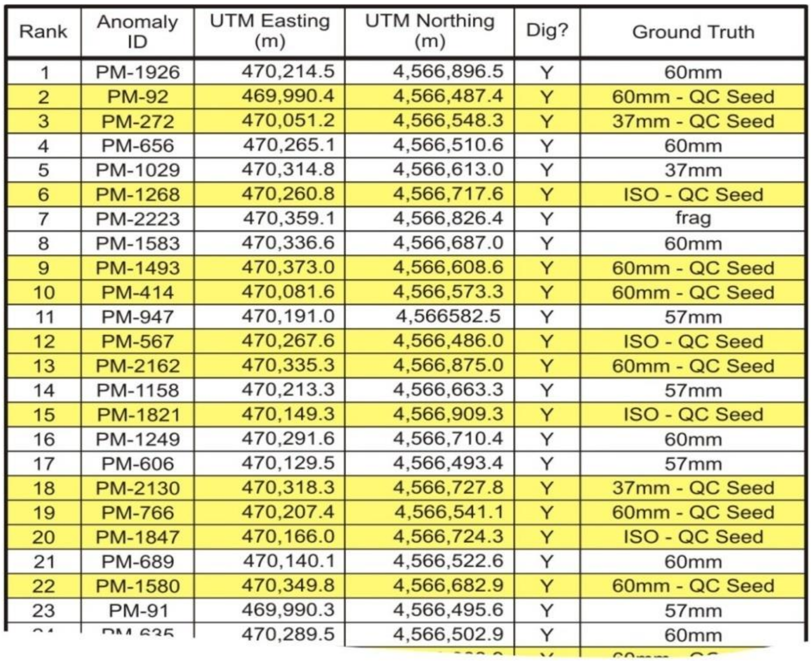


Figure 5. QC plot for a cued measurement for all decay channels including one spurious channel (left) and one in which the spurious decay was removed (right).

To ensure proper placement of the instrument over an identified anomaly, the target depth and size, as well as the physical size of the instrument's transmitters and receivers, must be taken into account. For example, advanced EMI instruments should not be more than 40 cm off-center over a small, shallow anomaly to collect high-fidelity geophysical data. In addition, the signal-to-noise ratio should be high enough to extract parameters from the data. A method that has been used to verify the quality of the work performed using the IVS has been to ensure that the daily generated EMI responses of the items in the strip match the library parameters within 95%.

Blind seeding can also assess the quality of the identified parameters. The blind seeds' size and shape can be compared to the estimated targets' size and shape to ensure the reliability of these estimates. For instance, 37 mm blind seeds should have similar extracted parameters that are distinct from 75 mm blind seeds.

Blind seeding can build confidence in the development and quality of the classifier and can verify work in production areas. Typically, at least one blind seed should be encountered on a daily basis. The seeds used should reflect the types of munitions expected to be encountered at the site (i.e. site TOI). To assess an anomaly's classification (i.e. remove or leave in place), verify that all blind seeds are properly classified and that other items dug fit the expected shapes and sizes from the classifier. This process can include digging an agreed upon number of anomalies that have not been classified as due to a munition to confirm proper classification. Figure 6 is a ranking of anomalies from a submitted dig list. This figure illustrates that all QC seeds must be properly classified and the individual QC seeds must be located on the submitted dig list. All of the blind seeds (highlighted in the table) were correctly classified as items that must be dug. Additionally, the seeds were interspersed with the existing munitions on the ranked list indicating they were no easier or harder to classify than the existing munitions at the site.



Rank	Anomaly ID	UTM Easting (m)	UTM Northing (m)	Dig?	Ground Truth
1	PM-1926	470,214.5	4,566,896.5	Y	60mm
2	PM-92	469,990.4	4,566,487.4	Y	60mm - QC Seed
3	PM-272	470,051.2	4,566,548.3	Y	37mm - QC Seed
4	PM-656	470,265.1	4,566,510.6	Y	60mm
5	PM-1029	470,314.8	4,566,613.0	Y	37mm
6	PM-1268	470,260.8	4,566,717.6	Y	ISO - QC Seed
7	PM-2223	470,359.1	4,566,826.4	Y	frag
8	PM-1583	470,336.6	4,566,687.0	Y	60mm
9	PM-1493	470,373.0	4,566,608.6	Y	60mm - QC Seed
10	PM-414	470,081.6	4,566,573.3	Y	60mm - QC Seed
11	PM-947	470,191.0	4,566582.5	Y	57mm
12	PM-567	470,267.6	4,566,486.0	Y	ISO - QC Seed
13	PM-2162	470,335.3	4,566,875.0	Y	60mm - QC Seed
14	PM-1158	470,213.3	4,566,663.3	Y	57mm
15	PM-1821	470,149.3	4,566,909.3	Y	ISO - QC Seed
16	PM-1249	470,291.6	4,566,710.4	Y	60mm
17	PM-606	470,129.5	4,566,493.4	Y	57mm
18	PM-2130	470,318.3	4,566,727.8	Y	37mm - QC Seed
19	PM-766	470,207.4	4,566,541.1	Y	60mm - QC Seed
20	PM-1847	470,166.0	4,566,724.3	Y	ISO - QC Seed
21	PM-689	470,140.1	4,566,522.6	Y	60mm
22	PM-1580	470,349.8	4,566,682.9	Y	60mm - QC Seed
23	PM-91	469,990.3	4,566,495.6	Y	57mm
24	PM-635	470,289.5	4,566,502.9	Y	60mm

Figure 6. Ranked anomaly list from the ESTCP Pole Mountain demonstration.

Future Technological Advances

Geophysical classification is continually improving and the conditions under which geophysical technologies and processes are applicable are expanding. For example, emerging advanced sensors have been designed on smaller and more portable platforms deployed to address difficult site conditions. Research studies are currently being conducted for geophysical classification on underwater sites and in areas exhibiting a high density of anomalies. Additionally, studies on the use of non-GPS technology for location positioning are also underway. As innovative applications of this technology are developed and brought to market, the detection survey and cued survey may be combined. In this scheme, detection and some level of classification will be accomplished using dynamic survey data collected by an advanced sensor. Prototypes of such systems are now in development and testing.

Summary

Geophysical classification technologies and processes have been successfully demonstrated and have transitioned to production-level surveys. The use of geophysical classification and processes have proven, based on a number of demonstrations, capable of improving the efficiency of munitions responses on a variety of sites. As with all technologies, their use has some limitations and should be considered on a site-by-site basis. The successful use of geophysical classification requires that the initial detection survey provides quality data and that additional quality measures have been implemented specific to the classification process, such as those related to cued data collection, feature extraction and classification. In addition, experienced geophysicists must participate in designing the investigation, operating the equipment, and processing and interpreting the data for successful classification.

For More Information

ESTCP has completed a number of technology demonstrations at munitions response sites across the country and is currently conducting additional demonstrations. For further information, please see the ESTCP website at http://serdp-estcp.org/Tools-and-Training/Munitions-Response/Classification-in-Munitions-Response.

The ITRC Geophysical Classification for Munitions Response Team is reviewing the results of the ESTCP technology demonstrations as part of the process for developing supplementary fact sheets, guidance, and training on geophysical classification. The guidance will document when and where the use of the geophysical classification method is appropriate, as well as the geophysical expertise and experience necessary for the successful use of geophysical classification technologies and recommendations for appropriate quality control and quality assurance procedures.

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