Classification of Unexploded Ordnance using Geophysics – A Practical Reality

Darren Mortimer, Nick Valleau

Introduction

During an unexploded ordnance (UXO) or munition clean-up project, most of the items excavated are not UXO, but are harmless scrap metal. On a number of projects in the United States, it has been estimated that over 95% of the objects investigated were "clutter" - harmless metallic debris or geology (Andrews & Nelson, 2011). In 2003 it was estimated that there are approximately 10 million acres (4 million hectares) in the United States impacted by UXO. If 75% of the metallic targets found were not UXO, US$52 billion could be spent just to dig up scrap metal (Delaney & Etter, 2003).

If items can be determined to be non-hazardous without digging, they can be left unexcavated, or can be excavated in a less costly way (i.e. not requiring a large exclusion zone or evacuations). Classification is the process of analysing data (in this paper, electromagnetic data) to decide whether each target is a hazard or not, and in some cases, even deciding which specific type of munition may be present. Such classification (or discrimination) decisions, centred on physics-based analysis that is transparent and reproducible, will enable significant savings to be realized. This in turn will allow limited clean-up funds to effectively clear a greater number of areas.

Data Collection Technology

Classification as part of UXO surveys is nothing new; common field methods involve implicit discrimination. For example, using the common 'Mag and Flag' process (using hand-held detectors and placing pin flags where a strong signal is heard), decisions are made in the field based on the operator's judgment. However, results will vary between operators, and this approach does not provide an auditable decision record, as the decision cannot be archived. It has been documented in many demonstrations that Mag and Flag is not as reliable as once accepted (Banta, et al., 2007, Andrews & Nelson, 2011).

Digital Geophysical Mapping (DGM) provides the ability to archive and document the survey and the process of finding and selecting targets. This permits quality control of the surveys. DGM surveys are carried out using "second generation" sensors including high resolution magnetometers and electromagnetic (EM) devices such as the Geonics EM61. Interpretation of the results still involves professional judgement, but the results and decisions can be reviewed at any time. The target selection criteria are typically based on a combination of geophysical anomaly amplitude, footprint, and shape. This is another form of classification, and may work to a limited extent if data collection procedures are appropriate. But the interpretation is based on features of the data that are not necessarily related to feature of the object causing the geophysical anomaly. At US demonstration sites with large munitions (such as 4.2-inch mortars) or a mix of medium and large munitions, classification based on EM61 data achieved reasonable results in some cases (correct identification of 100% of the munitions and 50% of the clutter). However, on sites where munitions and clutter items were of similar size to each other, no worthwhile classification was achieved by any of the analysts using EM61 data (Andrews & Nelson, 2011).

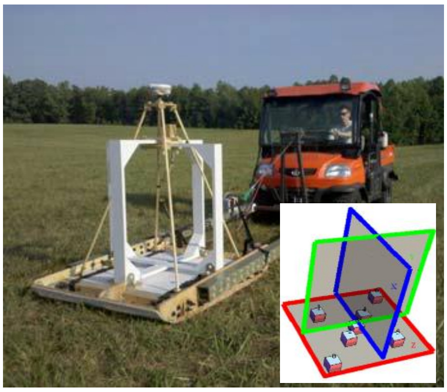

Figure 1: MetalMapper EM system showing three orthogonal 1m transmitter coils and 7 receiver cubes (each with three orthogonal receiver coils) (Keiswetter, 2013).

"Third generation" sensors have been specifically developed to facilitate the classification of UXO. Development began in the late 1990s with the funding and support of two US Department of Defence (DoD) agencies, the Strategic Environmental Research and

Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP). Through these projects, a number of new advanced electromagnetic sensors were developed and tested. Of these, two have so far proven to be practical and are now being regularly used for surveys. Both are time-domain electromagnetic (TEM) systems: the MetalMapper by Geometrics Inc. and TEMTADS by Naval Research Laboratory.

These new sensors have three key differences from the previous (second generation) EM sensors:

- multiple transmitter and receiver coils in various orientations to measure multiple components at a single point in space,
- finer sampling of the time decay curve, and
- sample longer periods in time.

The MetalMapper system is the most mature of the systems and is commercially available from Geometrics Inc. (Snyder et al., 2010, Geometrics, 2014). The MetalMapper consists of 3 orthogonal transmitter loops that are 1m x 1m in size (Figure 1). There are seven 3-component receiver coils mounted within the horizontal transmitter coil (Figure 1). This results in 63 datasets, with recording of the decay curve up to 9ms after transmitter turn-off, which permits 'full illumination' of a target.

To date, classification data has most often been collected in static or 'cued' mode, where the sensor is parked or stationary over a target that has been previously detected, often with the second generation sensors. This allows collection of stable, low-noise data. Work is ongoing to use the new sensors in a dynamic (moving) survey mode to acquire data for classification.

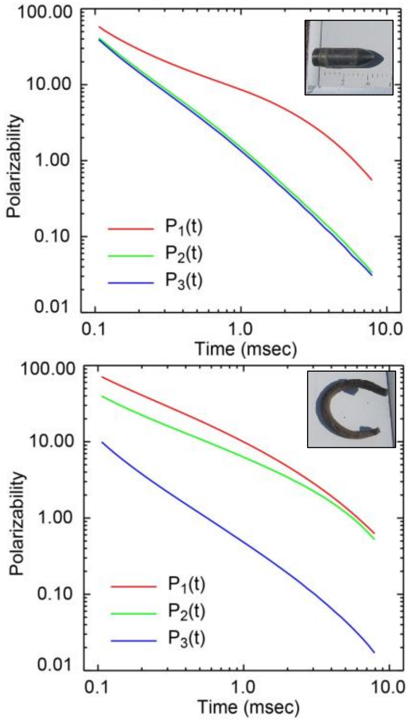

Figure 2: Example polarizabilities for UXO and a clutter item (Keiswetter, 2013).

Data Processing

Classification depends on calculating model parameters that relate to intrinsic physical features of the objects rather than external features such as location, and orientation of the target. After checking data quality and preliminary processing, these model parameters are determined through forward modelling and inversion of the measured survey data, where the model parameters are continuously adjusted until a calculated solution is found that accurately reproduces the measured data. This inversion process also yields a more accurate location and depth of the buried object.

Intrinsic features that can be determined in this manner are polarizabilities and decay. The polarizabilities (also called Betas) relate to the object size and shape, whereas decay relates to the material properties and wall thickness. UXOs are typically long cylindrical objects; therefore they have one strong (or primary) polarizability and two weaker (secondary/tertiary) but equal polarizabilities (Figure 2). This is a very clear distinguishing characteristic of cylindrical objects.

Classification

The classification process determines the likelihood that an item is a UXO. There are two main types of classifiers: direct and library matching. Direct classifiers evaluate the calculated model parameter values directly and establish mathematical relationships to determine which combinations of feature values make an object look like a UXO. Direct classifiers can easily be visualized through a plot of "feature space"; the most commonly used one is size vs decay. In the feature space plot, you can also display representative examples of library items (known munitions) and see whether the unknown item is in the same vicinity.

Other classifiers match target features to those from a signatures library made up of UXO suspected to exist at the site. If an unknown object or target has a set of polarizability curves that are mathematically similar to those of a known library item, then the unknown object can be said to match the library item (Figure 3). This method has been found extremely successful in classifying UXO vs. non-hazardous objects, and in some instances being able to distinguish the type of UXO. However, care must be taken to avoid misidentifying objects that are munitions not yet included in the library.

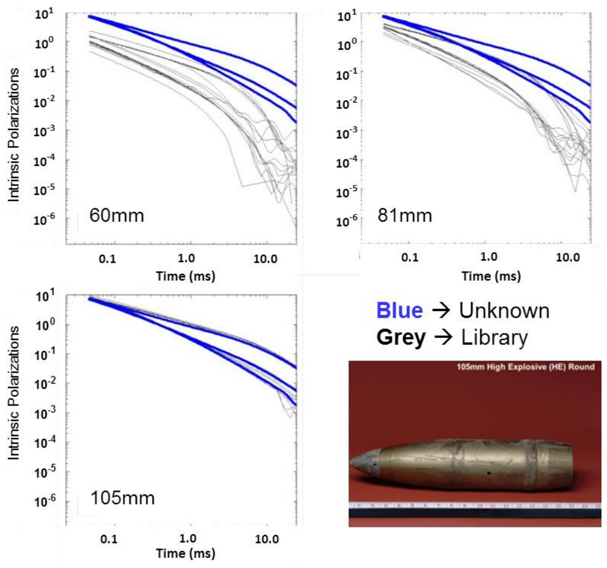

Figure 3: Example of matching polarizabilities to a library (Keiswetter, 2013). A simple visual examination of the graphs allows us to confidently say that this particular unknown object is a 105mm munition.

The output from library matching is the likelihood that an item is a known UXO. This is usually expressed as a value between 0 and 1, where 1 indicates a strong match and likely is a UXO, and 0 indicates that there is no match. This metric is a 'relative' indicator, and requires quite a high value on most sites (well over 0.9) to ensure confidence in a match. The items are then sorted into a ranked list based on the output from the classifiers.

The final product of the data analysis is a dig list, ranking all of the detected targets by the likelihood that they are UXO or 'target of interest' (TOI). While the primary objective is to identify UXOs, depending on the site, there can be requirements to also identify other items, for example rocket bodies and motors.

This ranked list is categorized into four groups:

- Cannot Analyse: Targets where the signal to noise ratio or other factors prevent reliable analysis; must be excavated.
- Highly Confident TOI: Targets an analyst is certain are UXO or targets of interest, based on strong matches to the signature library and are to be excavated.
- Cannot Decide: Targets that can be reliably modelled and analysed, however it is not possible to state with a high degree of confidence whether the item is either a target of interest or not a target of interest.
- Highly Confident non-TOI: Targets that an analyst is certain are not UXO or targets of interest.

As the classifiers typically do not indicate a sharp distinction between the TOI and non TOI, (in the ranked list) the geophysicist/analyst will need to determine a "stop-digging" threshold. Typically a detailed review of the data and calculated parameters is required for a small population that were not automatically classified with high-confidence. These "Cannot Decide" items are assessed by the analyst based on factors specific to the site, including anomaly amplitudes, anomaly size and decay rate, and other factors. In the process of reviewing the parameters (e.g. Size and Decay plots) and comparing curves to other target items, some clusters of self-similar items may be identified. These clusters may be sampled by digging some of the targets, to determine whether they are TOI and should thus be added to the signature library.

This review stage is iterative as new information of the site is gained. Factors such as geological "noise", target depths and expected target sizes should also be taken into account, and the decision process documented. In the final classification no items should remain "Cannot Decide"; while they may not have strong confidence, they should be all classified as either TOI and to be excavated, or non-TOI.

The targets to be excavated are compiled into a ranked 'dig list'. The dig list provided to excavation teams should include the updated target location along with the parameters (size, shape, and depth) determined from modelling (where possible). Finally the geophysicist/analyst should review the results from the excavation work in order to verify that the item recovered from the hole is consistent with the data interpretation.

Inversion and classification tools are commercially available in the Oasis montaj software package as part of the UX-Analyze module, built by Geosoft Inc. (Geosoft, 2014) with ESTCP funding. In addition the Oasis montaj software has tools for data quality control, target picking and mapping of both second and third generation geophysical sensor data.

Conclusion

Since 2011 these new advanced EM sensors and processes have been evaluated at a number of live-site demonstrations that span a range of munitions types, vegetation, and terrain (SERDP-ESTCP, 2014). Each demonstration is conducted by multiple survey contractors on a former or current US military installation where UXO are known to be present. Once the survey has been completed, all anomalies are excavated to confirm each technology's performance. Demonstrators are then scored based on their ability to eliminate non-hazardous items and identify all munitions.

Reliable classification of suspected UXO targets using geophysical survey data is now possible. These technologies and processes have been thoroughly proven in the live-site demonstrations. Government program managers and regulators have been included in the demonstrations, and they are now beginning to require the use of UXO classification technologies in investigations on their sites.

Classification decisions can now be made based on principled physics-based analysis that is transparent and reproducible. In the evolution of geophysical approaches to munitions response, the classification process represents a major step in providing an auditable decision record for each geophysical anomaly encountered on a site.

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