RAPID SCREENING OF LARGE-AREA MAGNETIC DATA FOR UNEXPLODED ORDNANCE

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Abstract

Airborne magnetic surveys can cover hundreds of hectares with very close sensor spacing in a single day. Over unexploded ordnance (UXO) contaminated areas this can translate to thousands of anomalies. Any tool that permits one to rapidly classify anomalies as probable non-UXO and probable UXO is useful. Several geophysical characteristics can be exploited to sort the anomalies, among them signal amplitudes, estimated source depth, and indicators of magnetic remanence. We have developed a grid-based technique that combines information from the total field residual anomaly, the analytic signal, and sensor height to estimate source depth and remanent magnetization. We can then use these and other indicators in statistical schemes to predict whether the source of an anomaly is or is not ordnance.

Introduction

The problem of clearance of UXO from current or former military gunnery or bombing ranges requires a thorough knowledge of where the ordnance is located, and geophysical methods, particularly magnetic and electromagnetic methods, have been widely used for mapping ordnance. Airborne geophysics is increasingly becoming accepted as a way to screen areas of hundreds or thousands of hectares for UXO (Doll, Gamey, and Holladay, 2001). Such surveys typically produce thousands or tens of thousands of anomalies that could be produced by UXO. Early on it was recognized that the vast majority of these anomalies are not caused by hazardous ordnance, but by exploded ordnance fragments or from lost or discarded ferrous articles (e.g., tools, wire, vehicle parts). Methods that reliably discriminate ordnance from non-ordnance can thus save a great deal of time and expense on subsequent cleanup by reducing the number of items to be investigated. To date, model-fitting methods such as the dipole-fitting approach used in the MTADS DAS software (Nelson and McDonald, 1999) have been successfully applied to ordnance discrimination. However, the software in its current state requires the user to choose one anomaly at a time from a grid of total field magnetic data isolate a zone around it, and then performs the inversion. Although results are generally reliable for isolated anomalies, it is ill suited for dealing with dense UXO concentrations, such as occur in the center of a target. Furthermore, the procedure can quickly become tedious for analysis of the considerable number of anomalies resulting from a low level airborne survey. In this paper we describe two alternate approaches based on statistical analysis by which large airborne data sets can be examined quickly for discrimination of UXO.

Statistically based UXO discrimination

We have only recently begun investigating statistically based discrimination methods, after an analysis of dig results based on data collected at the former Badlands Bombing Range (BBR) in South Dakota showed statistical differences between ordnance and non-ordnance. In no instance was the statistical difference so strong that a single parameter could predict whether the source of an anomaly was UXO or not, but the possibility for discrimination increased as more parameters were considered. We used a routine developed to our specifications by Geosoft to rapidly identify and characterize anomalies above a given threshold from an analytical signal map. From these peaks we identified the associated magnetic field anomaly and sensor altitude, and computed a number of parameters that could be used directly or otherwise combined as statistically relevant predictors. From this point we used two different approaches for discrimination—a univariate and a multivariate methods.

Univariate method

What we call the univariate method relies on correlations from dig results based on airborne magnetic data collected at two different sites: an East Coast site and BBR. Both sites were geologically 'clean' in that neither contained basaltic rock or magnetic soils that could complicate any interpretations. We chose six parameters showing correlation with known UXO, and at each anomaly location evaluated whether the parameters fell within the range of the majority of known measured UXO. Each of the six parameters was scored zero if the parameter fell outside a specified range, and one if it fell within the range. For example, almost all ordnance in our known sample pool yielded peak-to-peak magnetic anomalies between 1.0 and 80 nT. Any anomaly falling outside this range was scored zero, as non-UXO. The six characteristics were scored and summed, so that items could have a sum total ranging from 6 (all characteristics in the range of UXO) or zero (all characteristics outside the range for UXO). The six parameters used in the univariate analysis were analytic signal amplitude, magnetic anomaly peak-to-peak magnitude, the distance between the magnetic anomaly peak and low, the ratio of the positive magnetic anomaly lobe to the peak-to-peak magnitude, the estimated source depth, and the angle between magnetic north and the line connecting the positive and negative lobes of the magnetic anomaly (denoted theta).

Multivariate method

Multivariate analysis should provide more information than the univariate approach described above so long as some or all of the variables are correlated, and if the number of known samples is large enough to obtain reliable statistics. The parameters must also be appropriately normalized to remove the effects of different magnitudes for the given parameters. We derived a vector of standard mean parameters μ_0 from a set of measurements over known ordnance items, and compute the symmetric covariance matrix $\mathbf{S}$ from the covariances computed for the different variable combinations. The statistical similarity between the known ordnance and the parameter vector $\mathbf{x}$ associated with an unknown is given by the Mahalanobis distance (Swan and Sandilands, 1995)

$$D = \{(\mathbf{x} - \mu_0)^T \mathbf{S}^{-1} (\mathbf{x} - \mu_0)\}^{1/2}. \qquad (1)$$

The smaller the Mahalanobis distance the more closely the unknown resembles ordnance from the known pool of items. The vectors $\mathbf{x}$ and μ_0 each have five entries: analytic signal peak, the magnitude of the negative lobe of the magnetic anomaly, the ratio of the positive magnetic anomaly lobe to the peak-to-peak magnitude, the ratio of the distance between the magnetic anomaly positive peak and the analytic signal peak to the instrument height added to the estimated source depth, and theta, as described in the univariate section. The differences in the variables used in the two methods of analysis occurred because the univariate analysis was done prior to a more complete statistical look at the data led to the multivariate approach.

Field results

The methods were applied to a data set acquired by Oak Ridge National Laboratory (ORNL) at an artillery test range in the continental U.S. At one site ordnance was buried for instrument calibration purposes in an area not used as a firing range, and we were given information on ordnance type and location. Descriptions of the ten ordnance items are given in Table 1. Figure 1 shows the residual magnetic field anomaly from a low level survey, flown at a nominal 1.5 m sensor height above ground level using a system developed at ORNL (Doll, Gamey, and Holladay, 2001). Overlain and marked by '+' symbols are locations of ten inert, intact ordnance items commonly found at the test ranges. The smallest items were 60 mm illumination rounds (items 1, 2), followed by 81 mm shells (items 3, 4), 2.75 in rockets (items 5, 6), 105 mm shells (items 7, 8), and the largest targets, 155 mm shells (items 9, 10). The ordnance was buried in two rows, with the items on the west (left) side having an east-west orientation for the long axis of the UXO, and the east (right) row oriented north-south. Shown in Figure 2 is the analytic signal map derived from the magnetic residual. For the 73 analytic signal anomalies in the entire map area at or above 2.0 nT/m, univariate and multivariate statistical analyses were applied. The circle symbols represent the 22 anomalies that were chosen using the univariate classification system as being in the top two categories of probable UXO, i.e. anomalies in which at least five of the six UXO predictors were positive for UXO. Of these 22 anomalies predicted to be UXO, eight occur at or very near the known UXO. Item 2, a 60 mm shell, did not produce enough of an anomaly to register above the 2-nT/m cutoff. The anomaly from item 6, a 2.75 in rocket, is obscured by the large backgrounds anomaly of unknown origin. The triangle symbols represent the same number of items (22) ranked at the top of the multivariate analysis list as most probable UXO. This method ranked nine of the ten known UXO items in the top 22 candidates. The only item missed was item 2, which as previously mentioned, failed the 2.0 nT/m analytic signal cutoff, and so was not included in the pool for statistical analysis. Both methods chose other items as probable UXO as well, and the methods coincided on six of these choices. These anomalies have not been investigated, so we do not know what their sources are. Possibly a few are UXO, but as this site was not in a test firing range, it is more likely they represent non-ordnance: scrap metal, lost tools, or infrastructure.

Table 1. Ordnance description and results of statistical predictions.

Item Number	Ordnance description	Long axis orientation	Univariate prediction	Multivariate prediction
1	60-mm round	E-W	UXO	UXO
2	60-mm round	N-S	undetected	undetected
3	81-mm shell	E-W	UXO	UXO
4	81-mm shell	N-S	UXO	UXO
5	2.75 in rocket	E-W	UXO	UXO
6	2.75 in rocket	N-S	Non-UXO	UXO
7	105-mm shell	E-W	UXO	UXO
8	105-mm shell	N-S	UXO	UXO
9	155-mm shell	E-W	UXO	UXO
10	155-mm shell	N-S	UXO	UXO

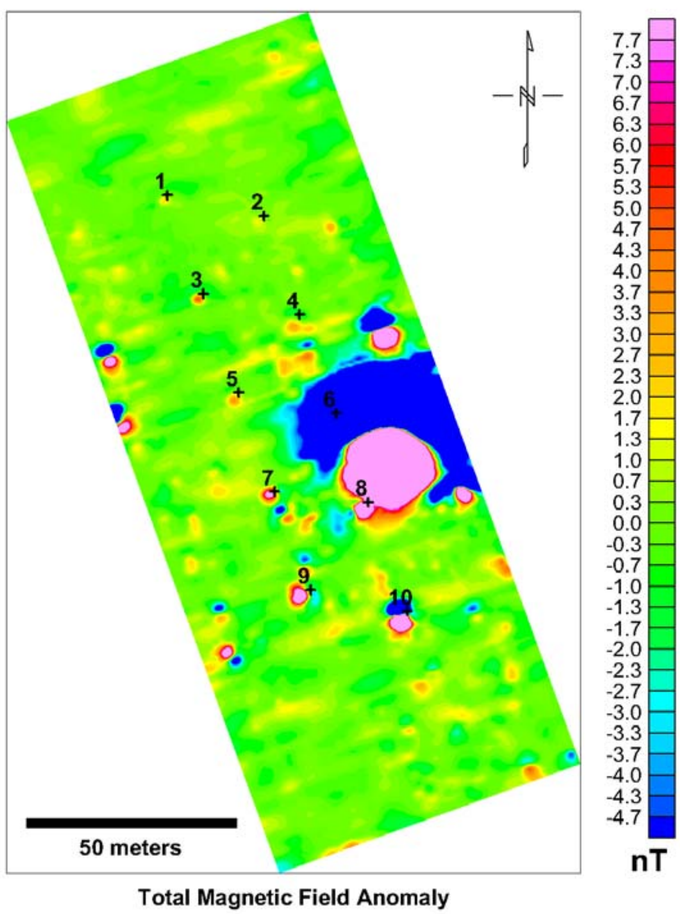

Figure 1. Magnetic anomaly map of helicopter data over calibration grid with known ordnance items overlain.

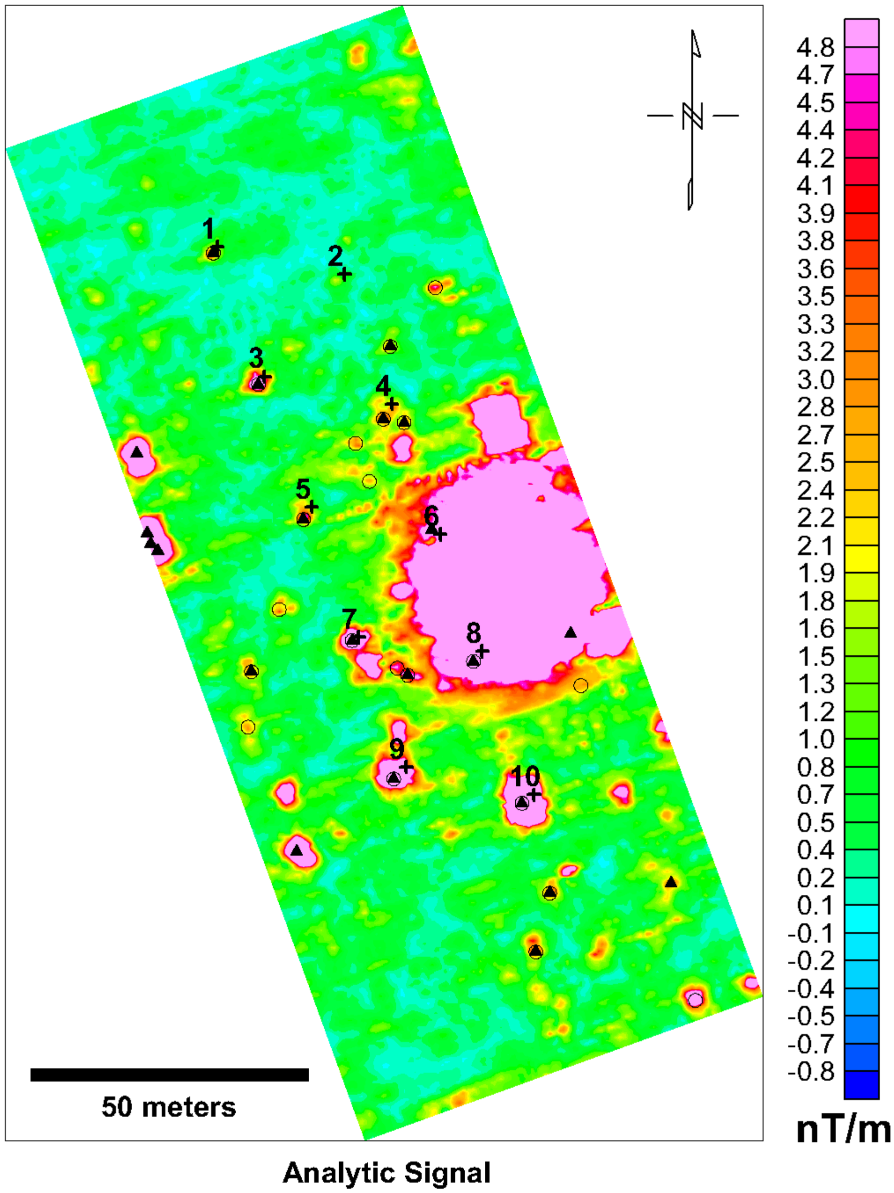

Figure 2. Analytic signal map of calibration grid showing ordnance items and predicted UXO from the univariate approach (circles) and the multivariate approach (triangles).

Discussion and Conclusions

It is difficult to reach any firm conclusion regarding the efficacy of statistical ordnance discrimination at this early stage of work. We have used both inverse model fitting and univariate and multivariate statistical methods for assigning dig locations at several different sites, but at the present time digging has not been done at some sites, and results from digs at the other sites have not been made available as yet. From areas where known items have been buried, each of the three methods reliably predicts known ordnance to be ordnance, but also predicts some of the unknown anomalies to be ordnance as well. It is distinctly possible that some of these anomalies are produced by ordnance, but we do not yet have information with which to address this matter. The primary difference between the dipole fitting approach in its current state and the statistical approaches is the number of anomalies picked. Our statistical methods pick anomalies from analytical signal peaks that exceed a certain threshold, whereas using the dipole-fitting algorithm the interpreter must choose likely candidates from total field magnetic data. The statistical methods pick on the order of ten times more anomalies for evaluation than is typically chosen by an interpreter using model fitting because so many of the anomalies appear too weak or are insufficiently isolated for inversion. If the highly ranked items on the dig lists produced by statistical methods prove to be mostly real ordnance, then more is good. As dig results become available, we should be able to improve our pool of characteristics of known ordnance items and improve the reliability of the statistical methods.

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