DIGITAL GEOPHYSICAL MAPPING FOR UXO:
State of the Practice

By

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Abstract

Digital Geophysical Mapping (DGM) to obtain valuable subsurface information for the detection of Unexploded Ordnance (UXO) or other Ordnance Explosive (OE) items requires a systematic approach in order to be successful. Potential target(s) of interest require identification through records search and an evaluation of site conditions, such as, terrain, geology, and any potential cultural interferences must occur. Once complete, a geophysical test plot is established with inert targets representative of the site. These prove-out targets are seeded at various depths and orientations in a metallic free area with similar geologic conditions. The purpose of the prove-out is to evaluate multiple sensors, platforms, positioning systems, survey parameters, and data processing techniques. These standard tests are performed daily.

Detailed grids are surveyed for comprehensive UXO\OE identification, while random walk surveys are performed for statistical evaluation. Sensor and positioning data are evaluated immediately after a survey session to validate the data. Once validated, data is ready for processing and interpretation. Response thresholds identified during test plot data processing are used for target selection. Dig-sheets are prepared and provided for quality assurance (QA). As quality control (QC), a portion of the survey area is swept with a hand-held audio/ or digital sensor to verify an ordnance free environment.

This systematic approach to DGM surveys for UXO is required to insure that survey objectives have been met, the expectation of stakeholders are met and surpassed, and to insure that valuable land is suitable for reuse.

Introduction

The United States Department of Defense (DOD) reports that over 60 million acres of land owned or controlled by the military have been released under the Formerly Utilized Defense Sites (FUDS) program. This includes about 2100 former ranges. DOD believes that about 8 million acres require further action. Approximately 100 former installations have been closed under the Base Realignment and Closure (BRAC) program during the last decade (Young, 2002) The DOD currently owns or controls more than 30 million acres of land at active installations. As these lands are turned over to private ownership for redevelopment, encroachment occurs as a result of urban sprawl, or as military missions increase or change, the value of these lands and the potential danger becomes apparent.

The impact of years of military training exercises have littered current and former training grounds with UXO\OE items to a point where safety of the general population is at risk, groundwater quality is compromised, or important military missions vital to our national security are prevented or impeded. In order to address these issues UXO detection and removal investigations are performed.

UXO projects in the past typically were performed by the Explosives Ordnance and Disposal (EOD) community utilizing “mag and flag” survey techniques. “Mag and Flag” surveys are conducted by several EOD technicians walking side-by-side sweeping the surface with metal detectors or magnetic locators. All detected objects are flagged for follow-up intrusive investigations. The draw back of this method is that the standard “Mag & Flag” equipment use audible tones to indicate a positive response. Since no digital output is displayed or recorded, track maps can not be generated documenting the area covered by the investigation. Also, target discrimination can not be performed and all positive responses must be investigated intrusively. This usually results in a significant amount of targets most of which turn out to be non UXO\OE related items. This results in high removal costs.

Technological advancements of digitally recorded detectors, positioning equipment, and processing software have streamlined the process of conducting Digital Geophysical Mapping (DGM). DGM surveys usually result in a digital record of survey area, target distribution and intensity, georeferenced information that is useful long after survey markers have disappeared. Color track and contour maps can be generated to document the coverage area and produce a plan view record of the data. The digitally recorded data can be used for target discrimination and allow for the reduction in targets that are not UXO\OE related items. As a result of these added benefits a greater reliance will be place upon technology applications involving the use and interaction of digital geophysical methods (DGM) and geographic information systems applications (GIS).

In order for a DGM to be successful and reliable, a systematic approach must be implemented. This includes a record search, planning and implementation of a geophysical prove-out, daily standardization of equipment, conducting geophysical surveys, process and interpret data based on geophysical prove-out results, and evaluating the results of the intrusive investigation to evaluate data processing.

Historical analysis is used to help identify survey objectives. Two major questions that must be answered are: what are you looking for and where. Document search related to historical and current uses provide information to the type of UXO that may be present and where training and testing activities were conducted. Information as to site conditions such as topography, vegetation cover, geology, and potential cultural interferences should also be determined. Next, the survey objectives must be determined. This is primarily dependant on how the land will be used in the future. Once this information is determined, decisions as to the type, quantity, and quality of data are needed to meet the survey objectives. For instance, if the goal of the project is footprint reduction to determine areas that warrant more detailed investigation, meandering path or transect sampling may be appropriate. If the goal is to provide a degree of assurance that the areas are free of UXO so that access may be gained by the general population, then detailed fixed grid surveys will be required. The next step is to perform geophysical standardization test on the equipment.

Geophysical Prove-outs

Digital Geophysical Mapping Prove-outs are used to identify the most optimum and accurate sensor, sensor platform, positioning methods, data density, and data processing techniques. The geophysical prove-out is a cornerstone in the performance of the subsequent DGM surveys. The prove-outs should be conducted in an area that has similar topography, geology, and vegetation cover of the actual survey area under the same conditions anticipated during the DGM surveys. The prove-out should also resemble the type UXO and anticipated depths to which they may be found at the site. The Project Team should evaluate the information on detection depth capabilities, production rate, false alarm rate, and cost to determine the optimum method for that site. In addition, the prove-out can be used to ascertain the capabilities of operators and the functionality of the geophysical sensors.

The geophysical prove-out typically ranges from one quarter acre to one acre in size for large survey areas. Based on historical information, the test plot is seeded with 20-50 separate targets representing probable munitions to be found at the site. For sites with smaller mapping areas, smaller less complex test plots are utilized. The seed targets are buried at different depths and orientations. In some cases, it may be necessary to install more than one test plot in areas where geologic conditions change and these changes may have an affect on instrument application.

Detector Types

The most common methods used for DGM activities are magnetics and time domain electromagnetics. Some recent work has been done utilizing frequency domain electromagnetics and shows promise for the detection of small targets at shallow depths. Traditional DGM systems include the Geonics EM31, EM61, EM61 MK2 metal detectors and the Geometrics G858 cesium vapor magnetometer

Magnetometers - Fluxgate magnetometers can be utilized for rapid, inexpensive field reconnaissance of sites containing ferrous UXO. Detection of a target is based on the metal mass of that target relative to the proximity of the sensor to the target. Magnetometers are capable of identifying small ferrous UXO targets when closely spaced lanes are utilized. Magnetometers can acquire data up to 10 times per second. This results in high data resolution along a traverse and increases the likelihood of detecting and discriminating small targets. These sensors can be configured in a towed array for high production surveys.

EM61/EM61 MK2 - Conventional inductive metal detectors for detecting small objects at shallow depths. These instruments can be used to distinguish near-surface metals from metal objects buried at depths by using two separate coils. Both units pulse at 150 times per second with data acquisition rates up to 10 times per second. This permits the acquisition of high data resolution along a traverse. This higher data resolution increases the likelihood of detecting and discriminating small targets. The EM61 collects data at a fixed time-gate. Its **predecessor**, the EM61 MK2 collects 4 time-gates of data simultaneously. The availability of the additional time gates holds promise for the advancement of target discrimination. These sensors can be configured in a towed array for high production surveys.

EM31 Terrain Conductivity Meter - The terrain conductivity meter is typically a tool to map waste pits and trenches. SAIC uses a Geonics Model EM31-DL conductivity meter with digital recording capabilities. By observing the magnitude of the in-phase signal (magnetic susceptibility) that is dependant on subsurface metals and the quadrature phase signal (subsurface conductivity), an interpretation concerning the effects of subsurface metal interference can be preformed. This instrument is not capable of detecting small, isolated UXO targets since the measurement field\footprint is quite large.

Geophysical Investigation Position Locating

Geophysical surveys can be improved for UXO by the collection of high-resolution and position-correlated survey data. Highly accurate positioned data allows for computer modeling and analysis to be performed to locate and discriminate target(s) for efficient reacquisition and subsequent remediation. Several methods are available which include Global Positioning Systems, Ultrasonic Systems, standard surveying techniques, and if warranted the Mag & Flag approach.

Global Positioning Systems – GPS utilizes timing signals from a network of satellites to triangulate positions on earth. Depending on the grade of the GPS receiver and the quality of the signal submeter and centimeter accuracy can be obtained. These data are then integrated with sensor data.

Ultrasonic Location Methods - Depending on the site environment, sufficient satellite coverage may be present, but satellites may not be detected due to topography, structures, or vegetation. Numerous UXO laden sites suffer from these conditions, and the application of GPS systems can not be used. Since large areas must be covered efficiently, the use of the standard survey grid is both impractical and costly. Ultrasonic positioning systems employs ultrasonic and radio-frequency time of flight technology to triangulate position.

Fudicial - In areas where GPS and ultrasonic positioning methods are not very reliable, traditional survey methods are deployed. This requires that a controlled grid be established with predetermined, equal distanced fiducial markings. Data is then collected along traverses with the acquired data spatially distributed between equal-distance fudicial marks. These data are than georeferenced during the data processing. The application of total station, measuring tape and stadia rod grid construction can be both slow and tedious. In many instances, the time to develop a survey grid takes 3 – 5 times longer then the time to perform the geophysical survey over that grid with GPS or ultrasonics. Ultimately, these data are georeferenced using GIS techniques. Under some conditions these methods must be considered because of the high accuracy of the DGM location requirements and rough terrain that may be encountered which would limit the GPS or ultrasonics.

"Mag & Flag" Methods – In areas where vegetation and terrain limit the use of the above locating methodologies, the "Mag & Flag" method can be effective. This method utilizes hand-held detectors to map an area. Whenever the sensor detects a target, the operator places a small flag in the ground at the target location. The disadvantage of this technique is that without recorded digital data, target discrimination analysis cannot be performed and usually results in a large amount of non OE targets. In areas where there is insufficient contrast between UXO and other metallic features such as fragment or debris exists and no digital discrimination is possible, the "Mag and Flag" technique may be the optimum method for UXO detection.

Standardization Tests

Prior to the initiation of the geophysical prove-out equipment standardization tests must be performed to ensure that quality data is being collected. These include instrument calibration, static test, and lag tests. These results of these tests are evaluated in the field do ensure both geophysical instruments and positioning tools are functioning properly.

Calibration Check

Instrument calibrations are conducted in an area that has been predetermined to be free of metal and representative of background site conditions. Instrumentation is calibrated using the manufacturer's recommended calibration procedures. This usually involves recording digital instrument output and conducting a static test (equipment not in motion). While collecting this data the operator adjusts the instrument so that the instrument response is normalized relative to background conditions and relative to previous calibration test. In order for the calibration to be sound, the positioning equipment and geophysical sensor must be configured in the same fashion as it will be used during the production surveys. Therefore, when possible, calibrations shall be conducted at the same location. Once calibrated, the instrument is ready for static testing.

Static Test

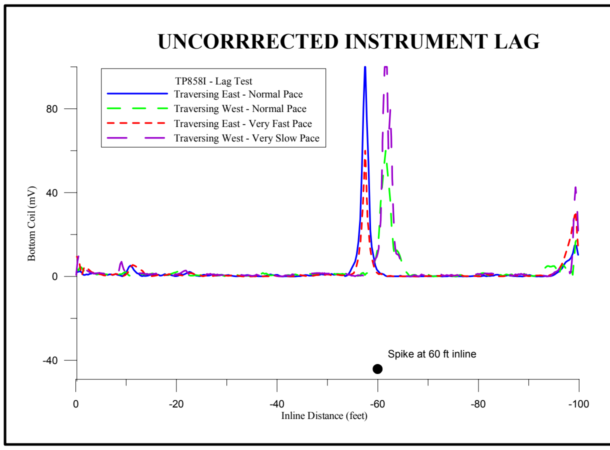
The purpose of the static test is to evaluate the response of the instrument over a period of time. The data collected will provide information on local noise levels and sensitivity to metallic and non-metallic sources of interference or potential targets. Typically two types of static test are performed. The first is conducted over an area that is free of metallic debris. The second static test is conducted over the same area; however, a "spike" such as a trailer ball hitch is placed beneath the sensor to evaluate instrument sensitivity and response. Sensor measurements are digitally recorded with the operator paying close attention to the recorded measurements. These tests are conducted for at least two minutes. A trained operator should be able to identify any data deficiencies or inconsistencies in instrument operation based on these tests. An instrument reading differing more than 1 standard deviation from the mean reading may suggest equipment failure or procedural error. If an instrument does not meet the standard it will be re-calibrated, repaired or replaced. Once the static tests are complete, Instrument Lag tests are performed.

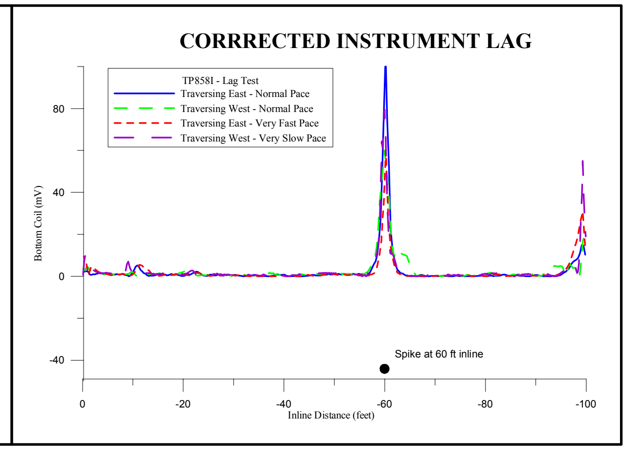
Lag Test

Lag tests are performed to identify any latency in position measurement vs. sensor measurement when it is recorded to a data file. This is conducted by establishing a traverse that is at least 100 feet long, and placing a metallic "spike" at some distance off the center mark and conducting four bidirectional passes over the target. The first up and down passes are conducted in normal survey speed while the third pass is conducted very fast and the last pass is conducted at a very slow pace. When these data are plotted, determinations can be made if there is position lag as a result of unsynchronized sensor measurement and position measurements. If lag is present, temporal offset can be determined and applied to data real-time or during data processing. If significant lag is present and is not addressed, positioning errors will be observed and may result in multiple targets when bidirectional surveys are conducted.

Once these standardization tests are completed and evaluated, digital mapping of the geophysical prove-out test area may begin.

Data Acquisition





Once the geophysical prove-out is completed and approved, digital geophysical mapping may begin. The field survey teams will utilize the approved sensor using the same survey parameters, data acquisition, and data processing methods as identified during the geophysical prove-out. It is good practice to conduct the standardization tests daily (calibration, static test, and lag tests). Constant monitoring of these data will allow the well-trained geophysical survey team to identify equipment problems before data is collected and will minimize the need to recollect data over a grid and maximize productivity. It will also qualify and validate the data collected.

Another data validation test that is performed during geophysical mapping is called the Line test or Line Repeatability test. This test is a comparison of data form a traverse conducted at the beginning of a survey session with data from that same traverse surveyed at the end of the session. This is to monitor instrument drift and sensitivity. Ideally, profiles of these data should be nearly identical with respect to anomaly locations and amplitude. If not, this may indicate a problem. If the baseline of the response is slightly shifted, then a determination must be made if (1) it is acceptable, (2) if preprocessing of the data must be performed, or (3) if data recollection is required (once the problem is identified and corrected). It is important that this data be evaluated as soon as reasonably possible to prevent the collection of useless data. Significant problems should be obvious to a trained geophysical instrument operator during standardization tests and corrected before data acquisition begins.

Data Processing Methods

The most common software packages used for digital data processing include Surfer by Golden Software and Geosoft UX-Detect module developed by Geosoft, Inc. After reviewing the standaradization tests, preprocessing of raw data may be required to remove positioning effects (lag and heading corrections), and compensate for instrumentation response drift. A well-trained data acquisition team should be able to identify these effects during infield standardization test evaluation and correct for prior to data acquisition.

Data analysis includes visually identifying anomalous areas of interest in the processed georeferenced data and using appropriate target selection alogorithms as identified during the instrument prove-out data processing. The data processor utilizes these methods because they have been validated against known targets. The analyst then reviews each target to determine if the model match results (e.g. location, depth, and size estimates) agree with the analyst's experience. In some cases the analysts may choose to add or omit, the targets based on there proximity to other targets or the geometry of the target. Once processing is complete, all logged targets are reported in a dig-sheet for target reacquisition. Both processed and dig-sheet data are than available for independent QA. In some cases, additional QA targets may be added to the dig-sheet for further evaluation.

Target Reacquisition

Once the processed data and target selections have been validated through an independent QA review, the Team can mobilize for the Target Reacquisition Task. The presence of a target will be verified using the same navigation equipment used to conduct the DGM task and via an approved handheld detector such as a Schoenstedt magnetic gradiometer (for ferrous targets only). Anomalies are marked and labeled using non-metallic pin flags for easy relocation. Any observed spatial deviations (azimuth and distance) between the dig-sheet coordinate and the actual anomaly location are documented and conveyed to the geophysical data processor and independent QA for evaluation.

Quality Control

All geophysical instruments and equipment used to gather and generate field data are calibrated with sufficient frequency and in such a manner that accuracy and reproducibility of results are consistent with the manufacturer's specifications. Calibration, repair, or replacement records should be filed and maintained by the Geophysical Survey Team Leader and may be subject to audit by the QA manager. Testing records of the field instrumentation should be archived with project folder after the fieldwork is completed.

A qualified geophysical scientist should review all geophysical data to verify data that the data represent information instead of instrument noise. This review will serve to double check the field data review for QA/QC purposes.

Data processing quality control is required to ensure data quality after it has been entered into the GIS system. Potential data problems include source data errors, data entry errors, data editing errors, data corruption errors, and user errors. Data review should be implemented to anticipate, identify, and correct these errors.

Data analysis quality control checks should be conducted in accordance with accepted and appropriate methods to ensure all data analysis results are reproducible and objective, 10-20 percent of all data should be analyzed by a qualified scientist, not involved with the prior analysis, to validate the accuracy of all data manipulation procedures.

Summary

A systematic approach to DGM surveys is imperative for the successful completion of the geophysical survey and detection of UXO. Procedures include:

- Selecting the most appropriate sensor and navigation for the project;
- Testing and calibrating equipment;
- Validate and process DGM data
- Provide independent QA data processing and target selection
- Reacquire targets and providing feedback to data processing
- Evaluate dig results and determining if improvements need to be made to the digital mapping program.
- Encouraging client, regulator and stakeholder input in the decision process.

Each project team member should be qualified, with appropriate training and experience to support placement in their respective position. Periodic QC audits are necessary to ensure proper implementation/execution of the operational plans. The Quality Control procedures outlined ensure that all critical site activities are inspected, that the results of these inspections are recorded and reported, and that the overall objectives of the DGM project are achieved. Quality must be integrated into all aspects of the DGM operations.

Following these procedures will insure that the best available technology has been applied to the project and that acquired and process data is validated. Following these procedures will result in a project that is completed on time, on budget, and to the satisfaction of the client, regulators and stakeholders.

Bibliography

Young R., 2002, UXO Geophysics 101. SAGEEP'02 (Symposium on the Application of Geophysics to Engineering and Environmental Problems), Las Vegas, Nevada, February 10-14 2002.