Preface

Special Issue on Geophysics Applied to Detection and Discrimination of Unexploded Ordnance

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Unexploded ordnance (UXO) presents serious problems in Europe, Asia, as well as in the United States. Explosives and mines from World War I and World War II still turn up at European and Asian construction sites, backyard gardens, beaches, wildlife preserves and former military training grounds. The high rate of failure among munitions from 60-90 years ago is cited as one of the main reasons for such a high level of contamination. Apart from war activities, military training has resulted in many uncovered ordnance. It is especially true in the United States, where most UXO has resulted from decades of military training, exercises, and testing of weapons systems. Such UXO contamination prevents civilian land use, threatens public safety, and causes significant environmental concern. In light of this problem, there has been considerable interest shown by federal, state, and local authorities in UXO remediation at former U.S. Department of Defense sites. The ultimate goal of UXO remediation is to permit safe public use of contaminated lands. A Defense Science Board Task Force Report from 1998 lists some 1,500 sites, comprising approximately 15 million acres, that potentially contain UXO. The UXO-related activity for these sites consists of identifying the subareas that actually contain UXO, and then locating and removing the UXO, or fencing the hazardous areas off from the public. The criteria for clearance depend on the intended land end-use and residual hazard risk that is deemed acceptable. Success in detecting UXO depends on the ordnance's size, metal content, and depth of burial, as well as on the ability of geophysical systems to detect ordnance in the presence of metallic fragments from exploded UXO and other metal clutter.

Until recently, magnetometry was the dominant geophysical method for finding UXO. The so-called “mag-and-flag” technique consisted of finding a magnetic anomaly, localizing it, and planting a flag above the location. A team of trained professionals would later excavate the flagged locations, finding scrap much more often than UXO. In practice, the major cleanup cost is excavation and removal, but it is typical to find that more than 90% of the objects detected are non-UXO, and as much as 75% of the cost of excavation is for these non-UXO objects. If the excavation cost for non-UXO could be reduced by a very conservative 10%, cleanup costs would be reduced by at least $10 billion in the United States alone, based on current cleanup costs. The potential savings from improved geophysical systems and techniques have led to a larger emphasis on developing active electromagnetic (EM) systems directed towards improving the probability of detection and reducing the false alarm rate (a measure of how many geophysical anomalies are incorrectly identified as UXO). Many of these EM prototype devices have been used successfully in field trials and have been more successful in both detection and discrimination than "mag-and-flag" technologies. Papers within this special issue describe applications and advances associated with ground geophysical systems exclusively, although similar applications exist for airborne or underwater systems.

Despite the inherent limitations of magnetic systems, recent developments in collecting and processing magnetic data show promise of increasing their efficiency and detection rate. Munschy et al. describe how to use and interpret data from multi-sensor fluxgate 3-axis magnetometers. These fluxgate magnetometers are lightweight and have low power requirements. If accurate system calibration can be done in the field, they can provide results comparable to much more expensive scalar magnetometers. Tchernychev and Snyder introduce an alternative to a commercial software package for magnetic field data interpretation. They present an open-source programming framework that is in the public domain, is easy to use, and can be modified and expanded. Software is currently using a point dipole model to approximate a small magnetic object. However, if desired, alternate object models can be easily implemented.

In another paper within this special issue, Billings and Youmans observed that there is often a significant difference between results under highly controlled research conditions and those obtained in actual production survey. They argue that magnetometry is a viable alternative technology for a production survey under favorable site-specific conditions. Using an example from Chevallier Ranch in Montana, they illustrate that the discrimination using magnetic remanence can significantly reduce the number of excavation locations. In this particular case, the false alarm rate was reduced by more than 50%. They further show that improvements in efficiency and cost reduction of UXO remediation require both technological advances and operational optimization when implemented in a production setting.

Parts of Europe and Asia suffered extensive bombing during World War II, and unexploded bombs (UXB) are a particular problem in construction activities. In situations where UXB may be encountered, borehole magnetometry has proved useful for detecting their proximity. Zhang et al. describe how to detect UXB using borehole magnetometers and discuss the interpretation of total field borehole magnetometer data using a constrained optimization method that utilizes analytically derived parameter bonds by way of excluding unreasonable results, hence minimizing non-uniqueness.

In recent years, multicomponent, active EM systems have been developed with the potential not only of detecting UXO but also of determining the depth, size, shape, and metal content of UXO in the presence of metallic clutter and a heterogeneous background. This capability could significantly increase detection rates, lower false alarm rates, and more importantly enhance our ability to discriminate between intact UXO and scrap metal. The need for multicomponent systems is twofold. First, it allows for more efficient data collection and hence lower survey costs. Second, it provides means of inducing magnetization and current flow in different directions within the object, and measuring the resulting secondary fields at enough points in space to uniquely determine the parameters that characterize the metallic object in the ground. The accuracy of these parameters depends on the accuracy of the system positioning. Huang et al. describe a new broadband frequency-domain EM induction array system with a single transmitter and seven pairs of receivers. This system allows for a high degree of primary field cancellation, dense spatial sampling, and reduction of motion noise. Smith et al. first introduce equivalent dipole polarizabilities as a succinct way to summarize the inductive response of an isolated conductive body at distances greater than the scale of the body. Then they describe a new time-domain multiple-transmitter and multiple-receiver system with primary field nulling through differenced receiver pairs - a system that can determine object equivalent dipole polarizabilities from a single system position, eliminating the effects of inaccurate instrument location.

Also, as a number of the papers indicate, new ways of collecting data require new data processing and interpretation algorithms that address these operational and methodological changes. Asten and Duncan present a scheme for achieving fast inversion by approximating magnetic and nonmagnetic targets with conductive plates composed of a set of conductive ribbons. Benavides and Everett introduce a nonlinear inversion of multi-receiver EM data for UXO using a continuation method. They suggest that it can be used for near-real-time UXO decision-making process, since the method is fast and does not require a highly trained operator. Walker et al. investigate the effect of data quality on time-domain EM discrimination. They describe how data interpretation quality decreases when measurements contain responses not accounted for by numerical modeling. Furthermore, Walker et al. emphasize the importance of a survey design for assuring that sufficient sampling of data anomalies occurs and that the object is illuminated such that all principal polarizations can be excited and measured. In addition to the positioning error mentioned above, they show that the anomaly size, signal-to-noise ratio, line spacing, and station spacing all play important roles in the spread of recovered parameters.

Although UXO shapes are regular, at many sites the types of ordnance present may be highly variable, possibly ranging in size from large bombs to rifle rounds. Ordnance discrimination is markedly simpler at ranges where a single ordnance type predominates than it is at multi-use ranges. For multiple ordnance types, statistical discrimination or data libraries may be useful. Passion et al. illustrate how to use a simple library based algorithm for the identification of isolated UXO, using time-domain EM data. A library of polarization tensors is generated from data acquired over known targets, and then the algorithm determines which target from the library is most likely to produce an observed data anomaly. However, this approach breaks down if more than one object is present. The paper by Shubitidze et al. presents an application of the normalized surface magnetic charge model for discrimination between UXO and non-UXO when more than one object is present. Yet another approach - an independent component analysis for UXO detection and discrimination in highly cluttered areas - is described by Throckmorton et al. As with the technique described by Shubitidze et al., this analysis is applicable for multiple closely spaced surface objects. In addition, the paper discusses factors that influence discrimination performance.

As is shown by the variety of papers in this issue, a wide array of issues is addressed. The effort reflected here has already led to enhanced instrumentation, better processing and discrimination algorithms, and statistical and methodological improvements. Since no single technology can address all remediation needs, it is essential to create the right combination of various approaches that will help to determine whether a suspected site actually contains UXO, what kind of UXO is on the site, locate individual UXO at reasonable cost and with high confidence, and determine the depth, size, and orientation of the suspected UXO. This is the first step to more efficient UXO remediation. All these novel applications need to be demonstrated and validated, so that operational experts can be certain that the new systems are safe and trustworthy, and therefore can replace existing tools and practices.

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