Evaluation of EarthRadar Unexploded Ordnance Testing At Fort A.P. Hill, Virginia

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INTR0DUCTION

The February issue of the *IEEE Aerospace and Electronic Systems Magazine* contained an article by Dr. Khosrow Bakhtar and Ms. Ellen Sagal LEO [1] that made remarkable claims for the performance of the Bakhtar Associates ground-penetrating radar (GPR) in detecting and classifying buried unexploded ordnance (UXO). 1n this article, we report the results of the series of blind tests on the EarthRadar carried out during the Fall of 2000 and Spring of 2001, which led to very different conclusions regarding the radar's performance. The contents of this article are excerpted from the final report on the testing [2], prepared by the Institute for Defense Analyses (IDA). The report is available in its entirety on the UXO Center of Excellence website at: http://www.uxocoe.brtrc.com/techlibrary/TechRpts/d2625-final.pdf.

TEST DESCRIPTION

EarthRadar testing was carried out at the Joint UXO Coordination Office (JUXOCO) Pilot Site at Fort A.P. Hill, Virginia. For these tests, data were collected in two 70 m × 1 m calibration lanes and in thirteen 20 m × 1 m blind lanes. Each of the active lanes is divided into 1 m × 1 m grid squares. Before lane setup, the entire area was graded and surveyed with a metal detector. All detected metallic objects were removed, and the area was smoothed. At the center of each square, an 18-inch diameter hole was dug with an auger. A UXO object, a clutter object, or nothing (designated an "empty" square) was placed in the hole, and then the hole was refilled. The entire area was subsequently rolled to provide a smooth surface. Four plastic pegs, one at each corner, mark each grid square. The burial process creates a somewhat artificial soil context, but it is the same for all cases; that is, digging a hole in each square, whether or not a target was to be buried in it, provides no intrinsic clue about whether a target is buried there. In addition, the digging allows removal of unintended clutter objects from the test area. The Pilot Site provides a highly controlled site for UXO testing, one where factors such as site coverage and geolocation ability that can affect primary detection ability have been purposely eliminated. Thus, the site can be thought of as primarily testing the ability to do target discrimination at known locations.

For each of the calibration squares, the EarthRadar contractor was provided precise information concerning the identity, depth, and orientation of the buried object (in each square that contained an emplaced object). Within the 260 blind lane squares, the contractor knew that objects of interest occurred only in the center of each grid square, but did not know what might be placed in any given square. The contractor was provided pictures and dimensions of each target type and a range of burial depths for each type target. Small targets tend to be found at real-world UXO sites at shallower burial depths than do larger targets, and that is reflected in the Pilot Site burial depths. Data provided by the US Army Engineering and Support Center in Huntsville, Alabama, were employed to select the range of target depths used. [3] The following 11 types of UXO were buried in the calibration and blind lanes:

- 20 mm, 40 mm, 57 mm, 105-mm HEAT, and 155 mm projectiles;
- 60 mm and 81 mm mortar rounds;
- Mk 118 Rockeye;
- M42, BLU-26, and BLU-63 submunitions.

Clutter items covered a range of sizes and physical configurations, but in each case, scrap items were chosen that did not physically resemble any of the buried ordnance.

DATA

The final report submitted by the EarthRadar contractor [4] documents the UXO blind tests and presents the results of the contractor's data analysis. It provides declarations of the contents of 112 of the 260 blind squares. The EarthRadar report covers the results of only 43 percent of the blind squares because of contractor problems that slowed data collection and

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Table 1. EarthRadar performance statistics

Parameter	Definition	Value (%)
Probability of response	(number of UXO or clutter squares declared either UXO or clutter)/ (total number of UXO plus clutter squares)	73
Probability of false response	(number of empty squares declared UXO or clutter)/ (total number of empty squares)	75
P_d (UXO declared UXO)	(number of UXO squares declared UXO)/ (total number of UXO squares)	33
Probability that a UXO square was declared empty	(number of UXO squares declared empty)/ (total number of UXO squares)	29
Probability that a UXO square was declared clutter	(number of UXO squares declared clutter)/ (total number of UXO squares)	38
P_{rn} (empty or clutter squares declared UXO	(number of empty plus clutter squares declared UXO)/ (total number of empty plus clutter squares)	14

reduction. The main contributor was self-interference of the EarthRadar transmitter with its on-board Global Positioning System (GPS). Although the site grid provides excellent geolocation, EarthRadar software requires GPS position for its data acquisition and subsequent data processing. for each square declared to contain a UXO object, Reference [4] provides a number of radar plots, including the dimensional (3-D) plot from which the declaration is made. The depth, orientation, and assessed ordnance type are called out. For squares declared to contain clutter objects, an assessed object depth is provided in some cases (20 out of 65). Because confidence levels were not provided for declarations, no information on the receiver operating characteristic (ROC) curve of the sensor could be determined.

RESULTS

Standard ordnance-detection equipment performance-evaluation procedures were applied to the declarations reported in Reference [4]. Table 1 provides the detection statistics derived from the data. To protect the status of the pilot site for further blind testing, the results are couched in terms of percentages.

In addition to the detection statistics, an analysis was conducted to determine the magnitude and distribution of the errors in radar-declared target depth. Radars generally provide accurate depth measurements, so an evaluation of depth errors constitutes another measure of radar performance. IDA generated a Monte Carlo simulation using the actual depths of the clutter and UXO in the squares where EarthRadar had correctly declared an object. To provide synthetic radar data, the Monte Carlo simulation generated uniform, random, depth estimates for each of the targets. Minimum and maximum depths were identical to EarthRadar minimums and maximums. Five hundred repetitions of the Monte Canto produced a near-Gaussian distribution of depth error standard deviations with a mean of 11.1 inches and a distribution variance of 2 inches. The actual EarthRadar data gave a depth error standard deviation of 10.2 inches, well within the $\pm 1\ \sigma$ point of the Monte Carlo results (9.7 to 12.5 inches). Hence, the EarthRadar depth error performance is consistent with the results for a system making random guesses, or at best, a system making mostly random guesses, with only an occasional depth call associated with an actual target.

Based on the results of the Fort A.P. Hill testing reported in [4] and the subsequent analysis provided in [2], we draw the following conclusions:

- *The EarthRadar showed no capability to distinguish squares containing emplaced UXO or clutter from empty squares.*
  This conclusion is supported by the nearly identical response rate for squares with emplaced objects (73 percent) and empty squares (75 percent).
- *In squares containing UXD, the EarthRadar declarations were consistent with random guesses among the three possibilities.*
  This conclusion is supported by the detection performance, where the declarations in squares that actually contained UXO appeared to be equally distributed (33 percent correctly declared UXO, 38 percent incorrectly declared clutter, and 29 percent incorrectly declared empty).
- *Most, if not all. of the UXO and clutter declarations were based on self-clutter signals generated by the EarthRadar, rather than on returns from actual targets.*
  This conclusion is supported by the response and detection performance discussed above, but is bolstered by the depth-error statistics. The fact that the

depth-error standard deviation for EarthRadar declarations closely resembles that provided by random depth guesses strongly implies that most object declarations have no relation to actual targets.

- *The EarthRadar concept for target detection and identification is Ju4damentallyflawed.*
  The EarthRadar depends on diffuse scatter from targets and for sub-wavelength resolution for image formation. In the frequency bands available to GPR, UXO targets scatter specularly. Neither electromagnetic theory nor signal-processing laws support obtaining the required range and cross-range resolutions, given the frequencies and bandwidths employed by the EarthRadar. Arbitrary and subjective scaling and thresholding allow the operator to create object-like images from the data, but there is no evidence that the resulting image shape and the original data have any definite correlation. That most of the declarations in these tests appeared to be based on system-generated self-clutter and the poor performance in the tests support the hypothesis that the 3-D images produced have little or no relationship to scattering objects beneath the radar antennas.

The reasons for the poor performance stem partly from system design problems and partly from erroneous assumptions concerning target-scattering characteristics at GPR frequencies. In summary, they are as follows:

- Strong direct coupling between the transmit and receive antennas hides shallowly buried targets;
- Multiple reflections between the antennas create system self-clutter that can either hide targets or be mistaken for targets;
- The bandwidth employed and the real-aperture processing do not achieve resolutions in any dimension sufficient to provide accurate size information on many of the targets; and
- The imaging software used by the EarthRadar allows arbitrary scaling and thresholding to be applied to the data separately in each image dimension. Such data manipulation can produce misleading 3-D images, particularly in the case where the target configuration is known.

In short, the EarthRadar provides no operational, technical, functional, or performance benefit to the unexploded ordnance detection problem. The system architecture and signal processing employed are well understood in the GPR community. Given the frequency band and bandwidth constraints under which any GPR must operate, the laws of physics do not support production of optical-like images of UXO targets, images on which EarthRadar depends for target detection and identification. There is no reason to expect that modifications to the current radar could provide enhancements that would allow it to perform better than other currently deployed systems.

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