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Evaluation of Multi-Sensor Unexploded Ordnance (UXO) Detection System Developed by Geophysical Solutions

Hollis H. Bennett, Jr., and Morris P. Fields

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Final report

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Abstract: The Multi-Sensor System (MSS) developed by Geophysical Solutions was tested and evaluated in March 2004 at the unexploded ordnance (UXO) test site and the UXO/countermine test stand located at the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. The MSS includes two sensor systems, the Geophex GEM-3-E and Geonics EM-63, as well as the Gem Systems GSMP-40 magnetometer and the NavCom SF-2050 series rover using the Starfire differential global positioning system (GPS).

The MSS was found to be heavy and extreme in its length, thus making it difficult to move the MSS along a straight line. The positioning system for the cart lacked expected accuracy. With the GPS positioned near one of the pivot points, the arc of the other sensors could be moved through without any change in the GPS recording. Also, the GPS occasionally failed to keep a lock on the differential GPS signal, thus decreasing its accuracy.

With the EM-63, the system did not allow for adequate channels to be saved. The EM-63 induced a large signal in the magnetometer that had to be removed. The EM-63 and GEM-3-E both produced data with similar results as those obtained from other GEM-3's and EM-63's used by ERDC.

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Contents

Figures and Tables v

Preface vi

Unit Conversion Factors vii

1 Introduction 1

2 UXO Test Site 2

Location and description 2
Climate 3
Field conditions 4

3 System Description 5

Geophex GEM-3-E 5
System specifications 5
System configuration 5
Geonics EM-63 6
Gem Systems GSMP-40 6
NavCom SF-2050 8

4 Data Collection and Analysis at UXO Test Site 11

Survey procedure 11
Equipment mobilization/breakdown 11
Data collection 11
Equipment/data checks and maintenance 12
Equipment failure or repair 12
QA/QC and data analysis procedures 13
Coverage maps 13
GPS corrections 15
Drift correction 17

5 Data Collection and Analysis at UXO/CM Test Stand 19

Test stand location and description 19
Data collection procedure 19
Data collection with the GEM-3-E 20
Data download 20
GPS sensor data integration 21
Data collection with the EM-63 21
Data download 21
GPS sensor data integration 21
Data collection with the GSMP-40 21
Data download 21

GPS sensor data integration *22*
EM-63 and GSMP-40 magnetometer data comparison *22*

6 System Evaluation 24
GEM-3-E 24
EM-63 25
GSMP-40 26

7 Conclusions and Recommendations 27
Conclusions 27
Recommendations 28

References 30

Report Documentation Page

Figures and Tables

Figures

Figure 1. UXO test site (facing east). 2
Figure 2. UXO test site (facing west). 3
Figure 3. MSS on the calibration lane at the UXO test site. 3
Figure 4. MSS on the first data collection pass. 12
Figure 5. MSS for the 100- by 30-m line path. 14
Figure 6. Idealized uncorrected sensor speed and sensor response versus time. 16
Figure 7. Idealized corrected sensor speed and sensor response versus time. 16
Figure 8. Raw data for passes before lag correction. 17
Figure 9. Data for passes after lag correction. 17
Figure 10. Corrected (green) and uncorrected (red) signal level. 18
Figure 11. ERDC UXO/CM test stand. 20
Figure 12. Multi-sensor EM-63 and GSMP-40 magnetometer geophysical data. 23
Figure 13. Data taken on the UXO/CM test stand using the GEM-3-E. 24
Figure 14. Data taken on the UXO/CM test stand using the EM-63. 25

Tables

Table 1. Climate data summary for Vicksburg, MS. 4
Table 2. Specifications for Geonics EM-63. 7
Table 3. Specifications for GSMP-40 magnetometer. 7

Preface

This report describes efforts undertaken as part of the U. S. Army Environmental Quality Technology (EQT) Program A (1.6.a), Unexploded Ordnance (UXO) Screening, Detection, and Discrimination Management Plan, UXO Detector Design Thrust Oversight (BA2/3) Major Thrust, UXO Technology Demonstration, Work Unit "UXO Multi-Sensor Design." The work documented in this report was performed during the period 6 Jan 2003 through 24 Jul 2004. Dr. M. John Cullinane, Technical Director for Military Works Environmental Engineering and Cleanup, Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), was the UXO Focus Area Manager for EQT. This project was funded through the EQT Program.

John Ballard, EL, and George Robitaille, U.S. Army Environmental Center, were program managers of the EQT BA2/3 and BA4 programs, respectively, during the execution of this project. Hollis "Jay" Bennett, EL, and John O. Curtis, EL, were responsible for monitoring the contract execution. Morris P. Fields, EL, performed contractor facility visits and coordinated the demonstration by the contractor at the ERDC test site. The EL team members who assisted with the analysis were Bennett, Fields, Ricky A. Goodson, and John Cliff Morgan.

This project was performed under the general supervision of Dr. David Tazik, Chief, Ecosystems Evaluation and Engineering Division, EL, and Dr. Elizabeth C. Fleming, Acting Director, EL.

COL James R. Rowan was Commander and Executive Director of ERDC. Dr. James R Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
gallons (U.S. liquid)	3.785412 E-03	cubic meters
pounds (force)	4.448222	newtons
pounds (mass)	0.45359237	kilograms

1 Introduction

This report documents the testing and evaluation of the Multi-Sensor System (MSS) developed by Geophysical Solutions, Inc., Albuquerque, NM. The research for the unexploded ordnance (UXO) MSS design work unit was conducted at the U.S. Army Engineer Research and Development Center (ERDC), Waterways Experiment Station, Vicksburg, MS, and at Geophysical Solutions, Albuquerque, NM.

The MSS was fabricated and initially tested by Geophysical Solutions. A site visit was made by ERDC to Albuquerque in June 2003 to assess the initial progress of the MSS. Initially, it was planned to be collect all the MSS data at the UXO test site in Vicksburg in March 2004. However, because of problems with the MSS hardware, much of the data collected from the test site was lost. Alternate field data were required to complete the evaluation of the MSS. The alternate field data were collected at the UXO/countermine (CM) test stand, located at ERDC, Vicksburg, MS.

This report focuses on usability of the sensor system, evaluation of the noise level of the sensor system, improvements in target detection, and positioning errors of the system. Stability of the system was evaluated through histograms and statistical measurements of data collected during the technology field investigations.

2 UXO Test Site

Location and description

The UXO test site, located at the ERDC, Vicksburg, MS (Figures 1 and 2), is approximately 30 m wide by 100 m long (3000 m^2). The test site contains several different types of munitions buried in the open field area. The buried munitions are the same type as commonly found in typical U.S. Army firing ranges. Clutter items include metal and rocks. The munitions include 500-lb bombs, 155-mm projectiles, 105-mm projectiles, 81-mm mortars, 20-mm practice rounds, scrap metal, and 55-gal drums. Most of the smaller items are located at one end of the site with the larger items located on the opposite end. The larger items are also placed with a larger "blank" area around them to make sure that other nearby items will not influence the signatures generated by the items in the various instruments.

Figure 3 shows the MSS over the calibration lane at the UXO test site. The calibration lane consists of two markers and an open area for placing items on the ground for calibration purposes.

Figure 1. UXO test site (facing east).

Figure 2. UXO test site (facing west).

Figure 3. MSS on the calibration lane at the UXO test site.

Climate

Vicksburg, MS, has a temperate climate with high relative humidity (Table 1). Vicksburg receives an average of approximately 144.78 cm of precipitation yearly, which accounts for the high relative humidity. The local temperature ranges from 0 deg to 39 deg C.

The weather during the data collection was sunny and warm, providing favorable conditions for the survey.

Table 1. Climate data summary for Vicksburg, MS.

Average precipitation	144.78 cm/year
Overall sunshine (year)	55%
Average temperature, monthly (based on last 50 years)	18.6°C
Average relative humidity	62.2%
Elevation above sea level	60.96 m

Field conditions

Geophysical Solutions surveyed the ERDC UXO test site on 11-12 March 2004. The area had several saturated areas due to rain prior to testing.

3 System Description

The MSS is configured with two geophysical sensor systems, either the Geophex GEM-3-E or the Geonics EM-63, and the Gem Systems GSMP-40 magnetometer with the NavCom SF-2050 series rover using the Starfire differential global positioning system (GPS) for positioning. The individual systems are described below.

Geophex GEM-3-E

The GEM-3-E is an enhanced GEM-3, which is a broadband, programmable electromagnetic (EM) sensor. The GEM-3-E consists of a circular sensor, a three-button user interface or Personal Data Assistant graphical interface, the electronics console, and the WinGEM software. The sensor is available in three different sizes. The 64-cm sensor comes mounted on a boom for handheld operation, whereas the 96-cm sensor is usually mounted on a cart (Geophex, Ltd. 1998; Won et al. 1997, 1998).

System specifications

- Multiple-frequency operation: up to 15 frequencies
- Frequency band: 330 to 47970 Hz
- Coil configurations: horizontal coplanar
- Battery: standard 12-volt notebook computer battery (B905S)
- Battery life: ~4 hr
- Weight: 9 lb (4 kg)
- Basic output: inphase and quadrature response in parts per million (ppm)
- PC software: WinGEM2k
- Positioning: Utilizing GPS data or “dead reckoning”

System configuration

The GEM-3-E used at ERDC consisted of the 96-cm head with the data acquisition box, a laptop computer for the controller unit, and a NavCom GPS rover. The GPS rover was secured to the mast of the GPS antenna and the controller was in the data acquisition box. The frequencies used during the data collection were 90, 210, 390, 750, 1470, 2910, 5850,

11430, 21690, and 41010 Hz (Cespedes 2001; Miller et al. 2001; Goodson et al. 2002).

Geonics EM-63

The EM-63 metal detector advances the application of time domain electromagnetic (TDEM) methods to the detection of UXO. Measurement of the full transient electromagnetic response offers improved detection capability and information on target characteristics.

Comparable to the EM-61 Mk. 2, the EM-63 generates a pulse primary magnetic field which induces eddy currents in nearby metallic objects. The decay rate of these eddy currents with time generates a secondary magnetic field with a specific rate of decay that is determined uniquely by the character (the size, shape, orientation, and metal composition) of the object itself (Geonics Limited 2002a, 2002b).

Measurement of the secondary magnetic field decay (the transient response), therefore, will provide important information toward a more complete characterization and classification of the target; identification and rejection of the characteristic response from certain geologic materials (e.g. magnetite); and, consequently, a reduction in target selection error (the “false positive rate”).

The EM-63 measures the complete transient response over a wide dynamic range of time. Measurements are recorded at 26 geometrically spaced gates, covering a time range from 180 μs to 25 ms. Data acquisition is supported by the PRO4000 field computer, with expanded 16-MB data storage capacity, which is able to simultaneously receive GPS data for location control (Juniper Systems 1999). Specifications for the EM-63 are given in Table 2.

Gem Systems GSMP-40

The Gem Systems GSMP-40 magnetometer was used with both the EM-63 and the GEM-3-E. The bucking coil was only used with the EM-63 due to the large amount of noise produced by the transmitter. However, the bucking coil was not used with the GEM-3-E since the magnetic field it produced in the magnetometer was less than the normal background noise at that distance of separation. Specifications for the GSMP-40 magnetometer are given in Table 3.

Table 2. Specifications for Geonics EM-63.

Measured quantities	26 time gates of secondary response in mV covering range from 180 μs to 25 ms
EM source	Air-cored coil, 1 x 1 m in size
Current waveform	Bipolar rectangular current
EM sensors	Main: Air-cored coil, 0.5 x 0.5 m in size, coincident with EM source Focusing: Air-cored coil, 0.5 x 0.5 m in size, 60 cm above main coil
Measuring ranges	10,000 mV
Dynamic range	18 bits
Output monitors	16-line graphic LCD with 24 characters per line
Power supply	12-V rechargeable battery for 8-hr continuous use
Data output	RS232 serial port
Data storage	Solid state memory with capacity of 31,000 data sets
Operating weight & dimensions	Sensor: 100 x 100 x 60 cm : 32 kg Console: 38 x 19 x 6 cm : 4.5 kg Battery: 23 x 21 x 14 cm : 10 kg
Shipping weight & dimensions	104 x 104 x 22 cm (box 1): 60 kg 58 x 48 x 47 cm (box 2): 46 kg

Table 3. Specifications for GSMP-40 magnetometer.

Performance	40-mm sensors
Sensitivity	0.014 nT @ 20 samples / sec
Resolution	0.0001 nT
Absolute accuracy	0.2 nT
Dynamic range	20,000 to 80,000 nT
Gradient tolerance	Over 13,000 nT/m
Sampling rate	1 to 20 readings / sec
Operating temperature	-20ºC to +55ºC
Operating modes	Manual: Coordinates, time, date and reading stored automatically at minimum 1 per second and maximum 20 per second intervals. Base Station: Time, date, and reading at same intervals as manual mode. Remote Control: Optional remote control using RS-232 interface.
Input / output	RS-232 or analog (optional) output using 6-pin weatherproof connector
Storage	4 MB (# of readings)
Walking gradiometer	524,288 nT
Walking mag	1,048,576 nT
Base	524,288 nT
Sensitivity details	0.002 nT @ 1 s/sec 0.005 nT @ 5 s/sec 0.009 nT @ 10 s/sec 0.014 nT @ 20 s/sec

NavCom SF-2050

The GPS was collected with a NavCom SF-2050 series rover using the Starfire system for differential GPS. The rover GPS antenna was mounted on a mast located above the center of the head on the EM-63 unit and to the rear and right of the GEM-3 head. The moving accuracy of the differential GPS (DGPS) for this system is on the order of 10 cm when the Starfire signal is maintained. However, due to the loss of the Starfire signal and rotation of the cart across the long axis, errors of 50 cm or greater can be expected.

The following is taken from the NavCom website:

> NavCom's SF-2050M modular StarFire™ receivers can provide instant position information for decimeter-level position accuracy, anywhere in the world, anytime. Onboard memory, and a geodetic quality antenna enable millimeter level accuracy from post-processing.
>
> The SF-2050 utilizes a compact tri-band antenna capable of receiving GPS and StarFire signals. This antenna provides excellent phase center stability in a small, robust, lightweight format.
>
> Coupled with NavCom Technology's StarFire subscription service, the SF-2050 delivers 10-cm position fixes without the use of a second receiver serving as a base station. Add the RTK option to your SF-2050, and an external radio capable of receiving RTK corrections from a Base station, and now your SF-2050 is able to do RTK level surveys.
>
> (Continued)

FEATURES

- Fully integrated receiver in robust housing
- "All-in-view" tracking on 22 channels (10 L1/L2 GPS + 2 SBAS)
- Global decimeter level accuracy using StarFire™ corrections
- Fully automatic acquisition of StarFire broadcast corrections
- Two dedicated WAAS/EGNOS channels
- L1 & L2 full wavelength carrier phase tracking
- C/A, P1 & P2 code tracking
- 64MB internal memory for data recording
- User programmable measurement and navigation data rates
- Minimal data latency
- Superior interference suppression
- Patented multipath rejection
- Output format NMEA 0183 or NavCom binary format
- CAN bus interface
- 1PPS Output
- Event Marker

PERFORMANCE1

GPS Receiver Performance

- Measurement Precision (RMS):

Raw C/A code:	20 cm @ 42 dB-Hz
Raw carrier phase noise:	L1: 0.95 mm @ 42 dB-Hz L2: 0.85 mm @ 42 dB-Hz

- Real-time StarFire Accuracy (RMS):

Position (H):	<10 cm
Position (V):	<15 cm
Velocity:	0.01 m/s

- Enhanced SBAS (WAAS/EGNOS) Positioning Accuracy (RMS):

Horizontal:	0.5m
Vertical:	0.7m

- Code Differential GPS Positioning <200kms (RMS):

Horizontal:	12 cm + 2ppm
Vertical:	25 cm + 2ppm
Velocity:	0.01 m/s

- User programmable output rates:

Position Velocity Time:	5 Hz (10Hz, 25Hz Optional)
Raw measurement data:	5 Hz (10Hz, 25Hz, 50Hz Optional)

(Continued)

- Data Latency:
  - Position Velocity Time: < 20 ms at all rates
  - Raw measurement data: < 20 ms at all rates
- Time-to-first-fix:
  - Cold Start, Satellite Acquisition: < 60 seconds (typical)
  - Satellite Reacquisition: < 1 second
- Dynamics (Speed & altitude are restricted by export laws):
  - Acceleration: up to 6g
  - Speed: < 1000 knots (515 m/s)
  - Altitude: < 60,000 ft (18.3 km)
- 1PPS Resolution: 12.5ns relative accuracy (SF-2050M Only)

COMMUNICATIONS

- Messages:
  - Data Control: NCT Binary Messages NMEA: ALM, GGA, GLL, GSA, GCT, GSV, RMC, VTG, ZDA
- Corrections: RTCM Code (Msg. 1 or 9) SBAS (WAAS/EGNOS) StarFire™

4 Data Collection and Analysis at UXO Test Site

Data collection at the UXO test site using the MSS occurred 11-12 March 2004. Due to hardware problems with both the Geophex GEM-3-E and Geonics EM-63 sensor systems, the data collected by ERDC and Geophysical Solutions personnel over the UXO test site was corrupted and most was unrecoverable. The data collection units for the GEM-3-E and EM-63 sensor systems had to be returned to their manufacturers for repair before further field evaluation tests were conducted. The data stored on the individual systems was subsequently deleted by the manufacturer before ERDC could complete the analysis of the data. It was deemed necessary to test the individual systems on the ERDC UXO/CM test stand to determine any sensor problems and to determine if the sensors themselves could provide repeatable data.

This chapter provides a description of the survey procedure at the UXO test site, procedures for quality assurance and quality control (QA/QC), and data analysis techniques used for data collected at the UXO test site. The analysis is based on data that was collected and not lost during the 11-12 March timeframe. Chapter 5 provides a description of the data collection and analysis procedure at the UXO/CM test stand.

Survey procedure

Equipment mobilization/breakdown

The survey required the daily mobilization, preparation, and breakdown of the necessary survey equipment. A two-person crew took about 2 hr and 45 min to perform the initial setup and mobilization. Daily equipment preparation took approximately 2 hr, while daily start/stop activities totaled approximately 3 hr.

Data collection

On 11 March 2004, Geophysical Solutions collected data, as shown in Figure 4, for 4 hr and 55 min with the EM-63 and mag systems covering the total 100- by 30-m area. ERDC and Geophysical Solutions personnel also collected data on 12 March 2004.

Figure 4. MSS on the first data collection pass.

Data were collected over the 30- by 30-m UXO test site using the MSS. The test site had lanes designating the possible locations of targets along with flags to show possible locations. These lanes were marked with sections of wooden stakes driven into the ground at 1-m intervals. A 50-m tape was laid at one end of the areas to designate the line spacing. White nylon lines were also used to mark the lines every 2 m. By lining up with the wheels alternating either on the line or straddling it the operator could obtain 1-m spacing.

Equipment/data checks and maintenance

Equipment/data checks and maintenance activities accounted for about 3 hr of site usage time while surveying in the UXO test site. This was mostly due to assembly and calibration of the sensor systems. Careful repositioning of the sensors each morning was required to reduce the noise in the sensor systems.

Equipment failure or repair

No mechanical equipment failures occurred while ERDC and Geophysical Solutions surveyed in the UXO test site. However, ERDC and Geophysical

Solutions personnel experienced problems with the prototype MSS and with the GPS system. The NavCom Starfire GPS system had trouble attaining and holding the DGPS signal, thus degrading the accuracy of the system. When the NavCom system maintained the Starfire signal the system had the 10-cm accuracy; however, most of the data were collected with greater than 50-cm accuracy due to the loss of the StarFire signal. The inability of operators to keep the cart moving a straight line degraded the positioning accuracy. There were 90 min of downtime on March 12 due to problems with the GPS.

There were hardware failures during the later part of the field-testing of these systems. Due to the failures some of the sensor data were damaged and lost.

QA/QC and data analysis procedures

There were a number of standard measures that the ERDC team used to assess and ensure the quality of the data produced during the collection deployment. Inspection of coverage maps was the first step. The data were corrected for GPS drift and viewed in pseudo 3-D to look at the quality of the sensor positioning response. Next, a statistical analysis package from UXOLab was used to determine the signal statistics of the data and the calibration sources responses were analyzed to determine any sensor drift in the data.

Coverage maps

The first QA function was to examine the spatial distribution of the acquired data to ensure that the survey area was adequately covered. After each segment of data was acquired and downloaded, a line path plot was generated. This was to verify if there were significant gaps in the newly acquired data or between the new data and the previously acquired data. When all the data for an area were collected, a coverage map of the area was generated using Geosoft's UX-Detect software module. A grid of a user-selected ground resolution was created and the number of survey points that pass through each grid counted and displayed. Grids with a value of zero (0) indicate gaps in the area coverage at the resolution being displayed. A coverage map was generated for each instrument at two resolutions: 0.5 m, which was the nominal line spacing for this data collection, and 0.75 m. If the survey lines were walked perfectly and no positioning

error occurred, then the 0.5-m coverage map would show 100-percent coverage.

The line path shown in Figure 5 shows the erratic path the MSS followed. Since operators were unable to keep the unit moving in a straight line, several areas were not covered and other areas were covered more than once. Operators attempted to maintain a 1-m line path separation, but failed due to design problems.

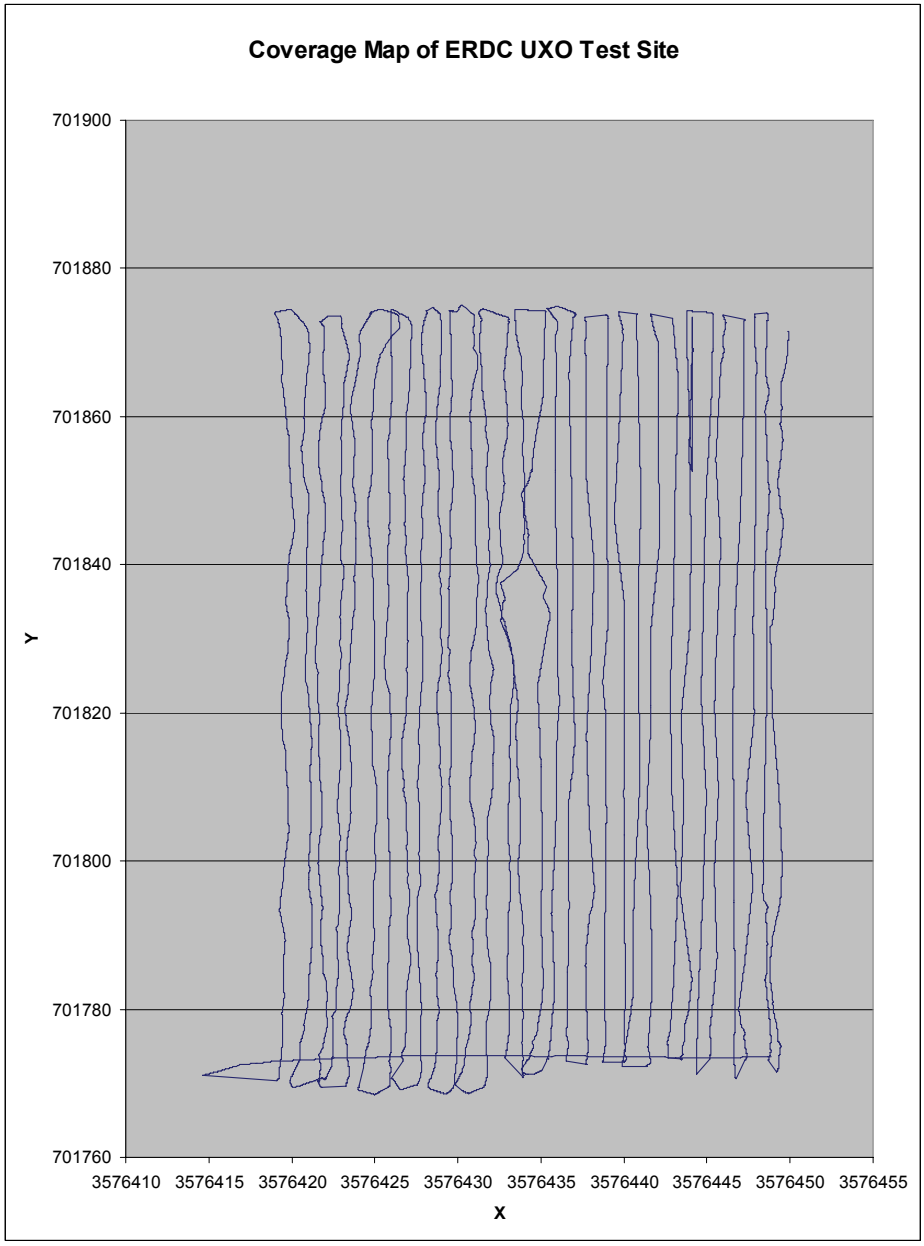

Figure 5. MSS for the 100- by 30-m line path.

GPS corrections

GPS was collected using a NavCom SF-2050 series rover with a Starfire subscription for DGPS. In this configuration, the accuracy is between 10 and 30 cm.

Due to an internal lag between the synchronization of the input port on the sensor systems and the output of the DGPS system, it was necessary to correct the merged data stream to ensure that the position data and the measured electro-magnetic data were correctly collocated. Values observed for the magnitude of this drift typically range from 0.5 to 1.5 sec, which is believed to be caused by either the initial states of the buffers in the two instruments or in the overhead requirements for their processing of the raw data. Observation of the data showed that once a correction value was found, it continued to be corrected until the instruments were restarted.

Each data collection run began with a calibration and synchronization procedure so that the length of the lag could be determined. The instrument was placed on a steel calibration item with the DGPS streaming position data and the data acquisition on the data collection started. The instrument was moved forward a few meters and stopped. After a brief hesitation, it was rolled back across the item to a distance of approximately a couple of meters behind the item and stopped. Finally, the sensor was moved back across the item and into the grid to begin the collection run.

Figure 6 shows an idealized data set from which the speed of the sensor and the sensor response are normalized and plotted on the same graph. The initial speed of the sensor is at zero and the sensor response is at a maximum. As the sensor is pushed off the item, the sensor response declines and the sensor speed rises.

For this example, the change in speed from the sensor lags the decrease in sensor response. Measurement along the time axis will give the value of the lag, and this can be used to shift the data so that the two streams are synchronized as in Figure 7.

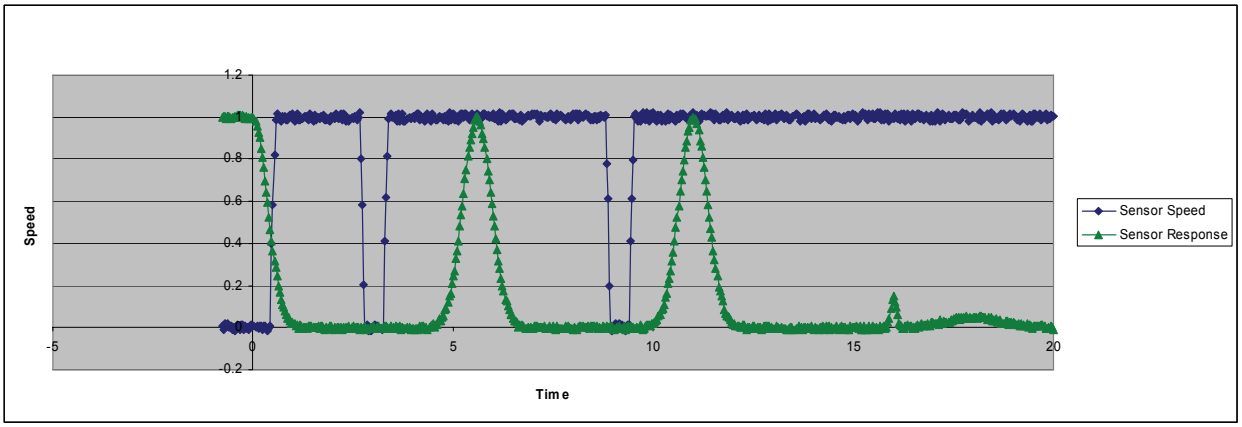

Figure 6. Idealized uncorrected sensor speed and sensor response versus time.

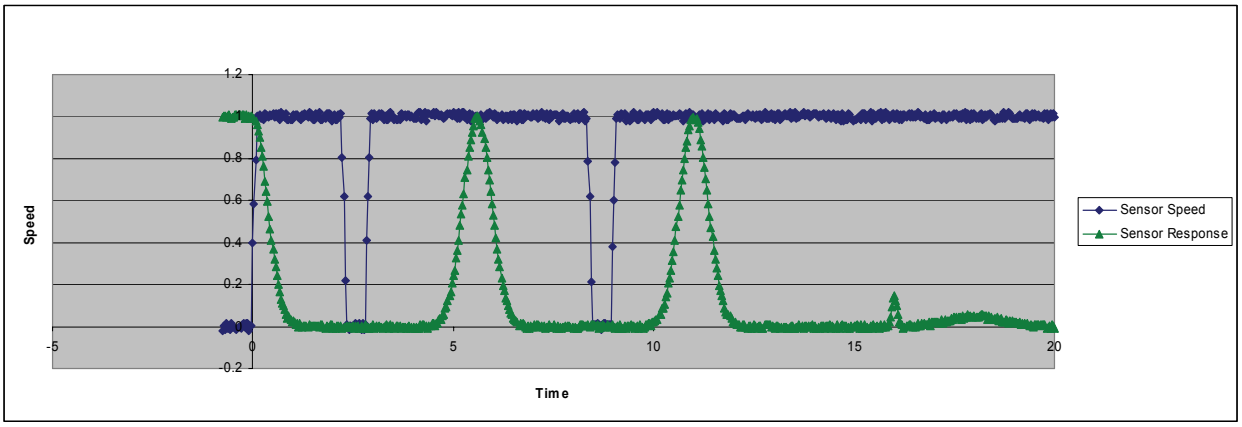

Figure 7. Idealized corrected sensor speed and sensor response versus time.

Once the data are synchronized, an additional check ensures the correctness of the drift. If the data are plotted on a surface map with x and y being the color of the point as sensor response, and with the drift corrected, then all three passes over the item will appear as a single anomaly on the graph. Incorrectly synchronized data will shift anomalies and appear larger than the actual item. An example of raw data for the passes over an item can be seen in Figure 8. After the correction, the seemingly multiple targets converge into larger features as shown in Figure 9. This represents a truer picture of detection.

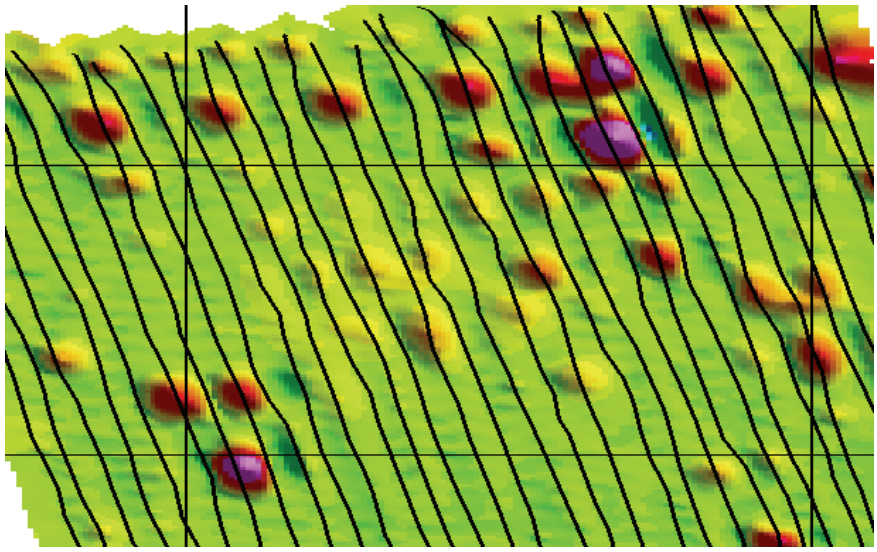

Figure 8. Raw data for passes before lag correction.

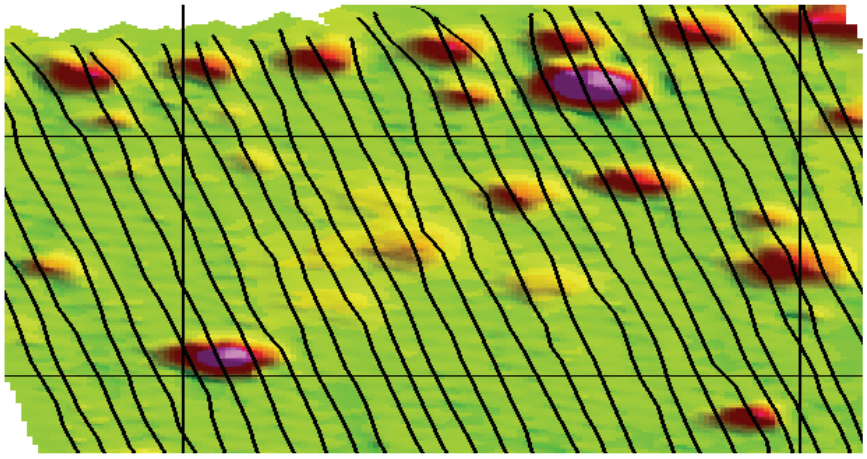

Figure 9. Data for passes after lag correction.

Drift correction

A common problem encountered when collecting geophysical data is sensor drift. The GEM-3's signal level varies with time during data collection due to changes in temperature and power output from the batteries. The Geosoft UX-Detect drift correction algorithm was applied to the data collected with the GEM-3 system to compensate for this drift. This algorithm calculates the average value for each block of data of a user-specified size and subtracts the average from all the points in the block. A user-specified percentage of points at the high and/or low end of the range of values is excluded from the calculation of the average so that the presence of targets in the data block does not skew the average. Ideally, only background points will be included in the average calculation; however, this can be

difficult to achieve in areas where targets are densely located. Figure 10 shows a single channel of data for one survey line before and after drift correction. The uncorrected data, shown in red, have a significant downward drift, which is no longer present in the corrected data shown in green. Drift correction is performed on each data channel independently.

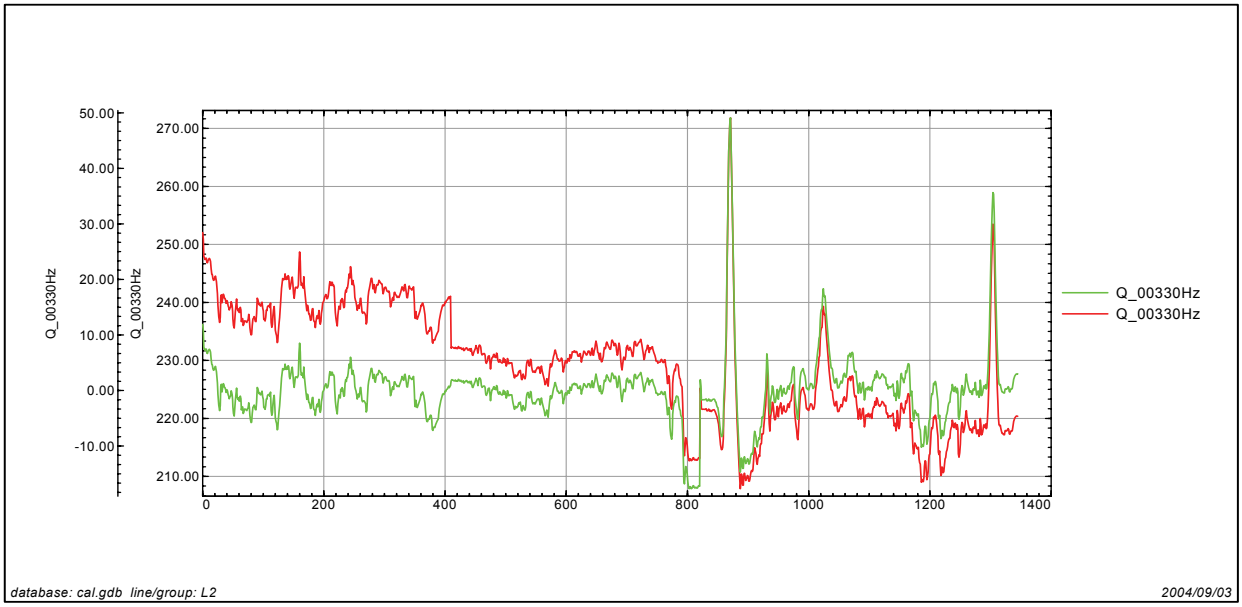

Figure 10. Corrected (green) and uncorrected (red) signal level.

5 Data Collection and Analysis at UXO/CM Test Stand

Test stand location and description

The UXO/CM test stand (ERDC, Vicksburg) (Figure 11) is 3 m (10 ft) tall with an area of 5.5 by 6.1 m (18 by 20 ft). The test stand was completed in September 2003 and is constructed from nonmetallic material. The test stand allows for open-air evaluations of sensor systems used for UXO/CM detection applications. Use of the test stand by the UXO/CM community aids in the development and evaluation of new sensor systems and new discrimination algorithms. The test stand is used to collect signatures on items in open air and at multiple angles and distances. A greater measurement density can be obtained from this facility as compared to those produced in the field or in most laboratory situations with position repeatability to within an average 2 cm accuracy.

The test stand has two automated systems. One system controls the positioning of the sensor system, and the second controls the positioning of the inert UXO, mines, clutter, and/or background materials. The test stand has a positioning information data stream available for input into a sensor system's positioning data port. The test stand can record data streams from the sensor system through hard-wired or wireless communication techniques. The data collection area gives a nominal 4- by 4-m data acquisition grid and the item holder has a 1.25-m travel giving up to 2 m of depth.

Data collection procedure

The sensor system was attached to the shuttle of the test stand and positioned over the origin. The sensor system was started to allow it to "warm up." The test stand was started (which produced a pseudo-GPS string) to feed into the sensor system over a wireless serial link and stored in a text file on the test stand computer to allow for data integration if there is no serial input on the sensor system. Data were collected and stored on the data console. During some data acquisition runs the system was controlled over a separate wireless link.

Figure 11. ERDC UXO/CM test stand.

At the end of every data collection, the data were downloaded and viewed to determine if the data were "good" or "corrupted" and if the data collection needed to be re-collected. A background (no-target) data collection was performed at the beginning of every day before the data were collected over the standardized UXO targets. The data grid was varied from a 1- by 1-m to a 2- by 2-m grid with data taken every 12.5 cm. Data were collected for 3 to 10 sec over each grid position to facilitate the acquisition of data sufficient to average. Averaging reduced the noise inherent in the system and allowed for any noise introduced by the test stand to be filtered out.

Data collection with the GEM-3-E

Data download

Two systems were used to store data, either the data acquisition module or on the computer. Data stored on the data acquisition module were downloaded to the computer using the WinGEM2K software. The serial port of the GEM-3-E was attached to the serial port on the computer, the data acquisition module was powered on, and the WinGEM2K software was started. Download data were selected from the tool bar, the file was named, and the file download location was selected.

When data were stored on the computer, the interface and data storage location were downloaded differently. The GEM-3-E was connected to the computer by the wireless connection. The WinGEM2K program was activated and the files were automatically saved to the hard drive as the file was created. These files were copied to a new directory for further analysis (Geophex, Ltd. 1998).

GPS sensor data integration

The GEM-3-E has an input port for the GPS stream which makes the task of data integration relatively simple for this system. However, some care must be taken to synchronize the data streams to remove the lag discussed previously in "QA/QC and Data Analysis Procedures" in Chapter 4.

Data collection with the EM-63

Data download

Data stored on the data acquisition module were downloaded to the computer using LYNX software. The serial port of the EM-63 was attached to the serial port on the computer, the data acquisition module was powered on, and the PS program on the data acquisition module was started. The LYNX software was started on the computer, and a file was selected and downloaded. The file download location was selected, and the file transfer button was pushed. These files were copied to a new directory for further analysis (Juniper Systems 1999).

GPS sensor data integration

The EM-63 has an input port for the GPS stream, and the task of data integration is relatively simple. However, care must be taken to the synchronize the data streams to remove the lag, discussed previously in "QA/QC and data analysis procedures," Chapter 4.

Data collection with the GSMP-40

Data download

Data stored on the data acquisition module were downloaded via serial port to the computer using GEMLinkW software. The data acquisition module was powered on, the GEMLinkW software was initiated on the computer, and a file was selected and downloaded. Next, the file

download location was selected, the file transfer button was pushed, and the files were copied to a new directory for further analysis.

GPS sensor data integration

Because the GSMP-40 has an input port for the GPS stream, the task of data integration is relatively simple. However, care must be taken to the synchronize the data streams to remove the lag, discussed previously in "QA/QC and data analysis procedures," Chapter 4.

EM-63 and GSMP-40 magnetometer data comparison

The information that follows was taken from the June-July 2003 Geophysical Solutions monthly progress report to show the data correlation between the EM-63 and the GSMP-40 magnetometer. The graphs in Figure 12 indicate that both instruments show an anomaly in the same place. The multi-sensor geophysical data were collected over a 355-mL aluminum soda can and a 60-mm A49A4 target. Figure 12(a) shows total magnetic field intensity data, and Figure 12(b) shows EM-63 data. Note that only the odd gates are shown for the EM-63 instrument to simplify the diagram. The collection of collocated data with multiple instruments was shown in this data set to increase the probability of detection.

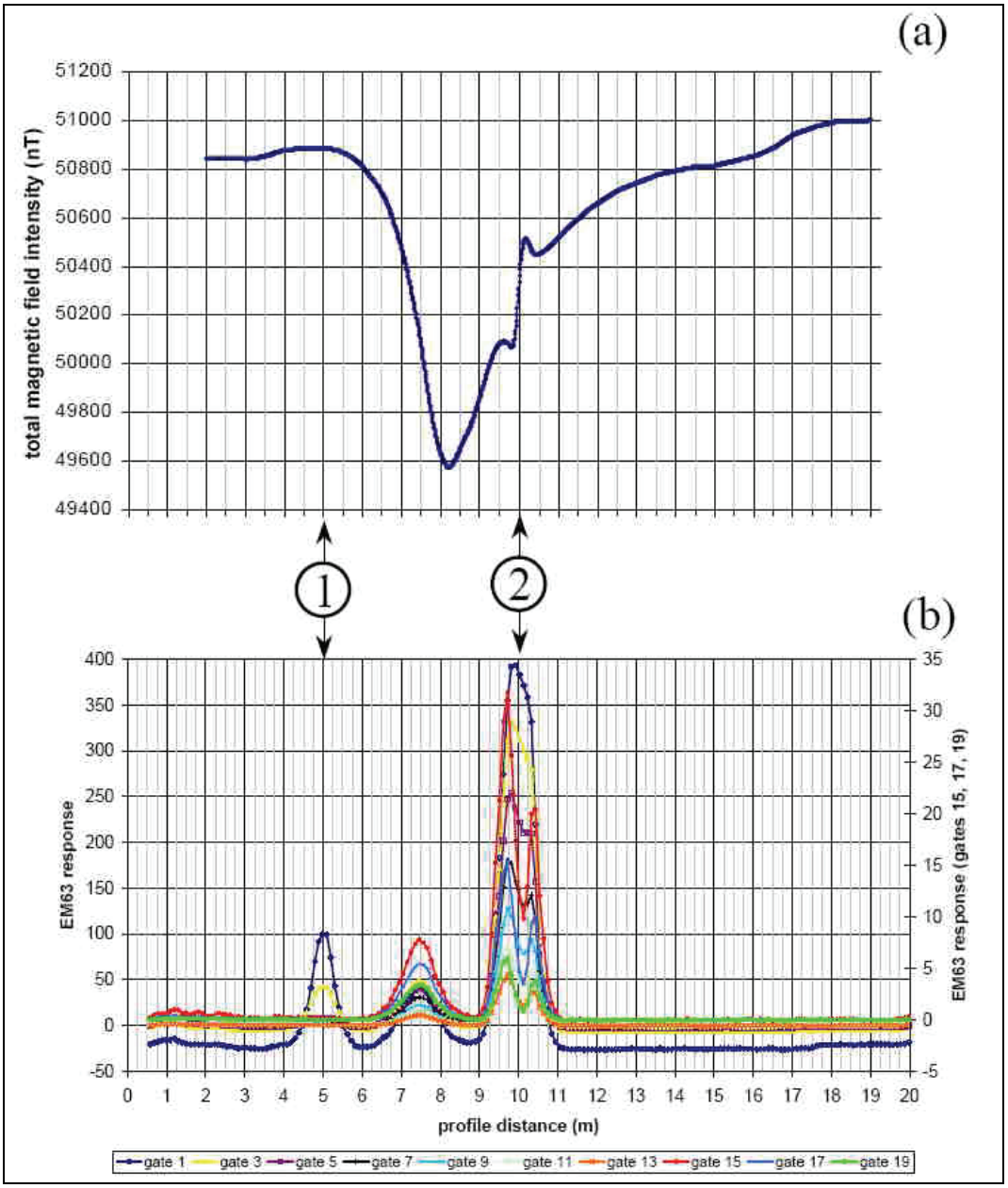

Figure 12. Multi-sensor EM-63 and GSMP-40 magnetometer geophysical data.

6 System Evaluation

GEM-3-E

Due to problems with the system when it was tested at the ERDC UXO test site, the system was returned to the manufacturer for repair. Upon arrival back at ERDC after repair the system was evaluated using the ERDC UXO/CM test stand. The data from the test stand showed a minor drift in the signal due to power drop over time. Due to the drift of the GEM-3-E electronics, data required normalization or leveling to obtain consistent, repeatable results. A new power supply is being investigated to replace the battery and allow operation of the system at a constant voltage and current to determine if a new power supply will minimize power drift.

The signal produced by the GEM-3-E did not appear to introduce any noise into the magnetometer system when both were used together (no bucking coil was needed).

The GEM-3-E data produced similar results as those obtained from other GEM-3 instruments used by ERDC personnel. The results were repeatable on the UXO/CM test stand (Figure 13).

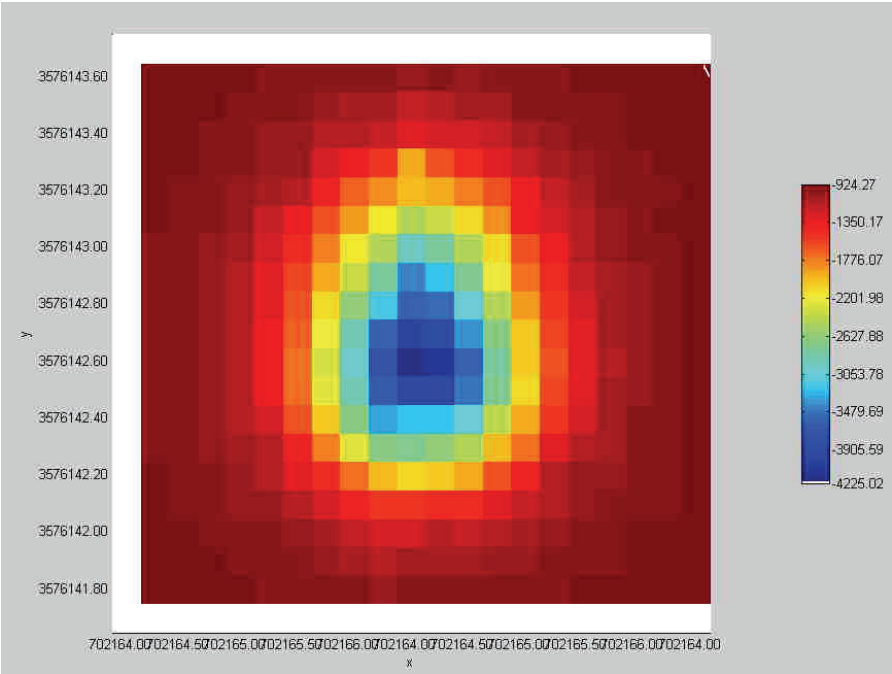

Figure 13. Data taken on the UXO/CM test stand using the GEM-3-E.

EM-63

Due to problems with the system when it was tested at the UXO test site, the EM-63 was returned to the manufacturer for repair. Upon arrival back at ERDC after repair, the system was evaluated using the ERDC UXO/CM test stand. The signal produced by the EM-63 did introduce noise into the magnetometer system when both were used together (a bucking coil was needed as a result).

A problem arose during data collection using the Geophysical Solutions breakout box. The breakout box only allowed the system to save channels of data with the rest of the system data. The data collector on the EM-63 saves the other channels but they must be downloaded after the fact and synched with GPS data, since the only serial port on the system is being used to collect data on the computer.

The EM-63 data produced results similar to those obtained from other EM-63 instruments used by ERDC personnel. The results were repeatable on the UXO/CM test stand (Figure 14).

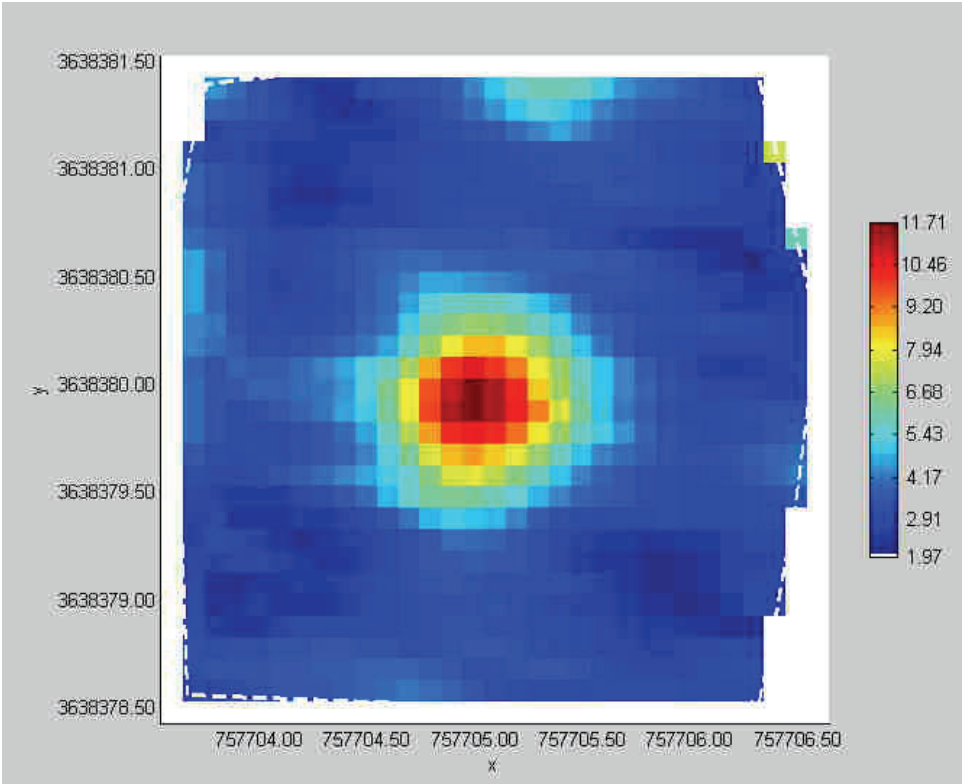

Figure 14. Data taken on the UXO/CM test stand using the EM-63.

GSMP-40

Due to time constraints, this system was not fully evaluated. The data that were collected by Geophysical Solutions personnel were consistent with other magnetometer data and therefore were not evaluated beyond the initial investigations.

7 Conclusions and Recommendations

The key points of this study and recommendations are summarized below.

Conclusions

The following conclusions can be drawn:

- The project focused on evaluating the Geophysical Solutions MSS for the UXO Multi-Sensor Design Work Unit. Geophysical Solutions and ERDC personnel utilized the ERDC UXO test site and the UXO/CM test stand, which are located at ERDC, Vicksburg, MS.

- The MSS includes two sensor systems, the Geophex GEM-3-E and Geonics EM-63, as well as the Gem Systems GSMP-40 magnetometer and the NavCom SF-2050 series rover using the Starfire DGPS. The MSS was tested first with the EM-63 since it came already assembled with the pushcart on 11-12 March 2004. The GEM-3-E was attached to the pushcart and demonstrated on 12 March. The total area (100 by 30 m) was covered on 11 March with the magnetometer and EM-63. The magnetometer and GEM-3-E were used to cover the 30- by 30-m grid on 12 March.

- The positioning system for the cart lacked expected accuracy. With the GPS positioned near one of the pivot points, the arc of the other sensors can be moved through without any change in the GPS recording.

- The Starfire GPS had some flaws in deployment. For some undetermined reason, the Starfire GPS failed on several occasions to maintain a lock on the DGPS signal, thus decreasing its accuracy. For several sections collected, the GPS positioning accuracy was much less than the advertised 10-cm accuracy. The accuracy of the system was more in line with the 1-m accuracy of a standard GPS unit.

- The MSS was heavy and extreme in its length, which made it difficult for operators to move the MSS along a straight line. Geophysical Solutions manufactured the front and rear wheels like casters so

the system could turn easily. However, this made it more difficult to keep the system going down a straight line. The cart was made primarily of nonferrous, nonmetallic materials, which reduced any interference from the cart into the sensors. The materials used resulted in a very sturdy cart, thus allowing the system to be towed by a vehicle. Towing the MSS would remove many of the directional problems by forcing the MSS to follow a selected path.

- The system did not allow for more than five data channels to be saved from the EM-63, which does not allow for adequate information to run the standard identification and discrimination routines that have been developed.

- The bucking coil was only necessary when the EM-63 was used. The EM-63 induces a large signal in the magnetometer that must be removed before useful data can be collected. Because a bucking coil must be used in this configuration, an array of magnetometer detectors cannot be used. If multiple bucking coils are used, then the magnetometer detectors can be used in the null points of the bucking coil/EM-63 field, but those null points will move depending on the local magnetic field.

Recommendations

The following recommendations can be made:

- Tilt and angles should be recorded or three GPS receivers should be positioned in a rough triangle shape (one front, two back) to provide a better idea as to the actual position of the sensors.

- The GPS positioning system should be upgraded to a real-time kinetic system to obtain sub-decimeter accuracy.

- The system should be towed behind a vehicle with a sufficiently long tow arm to reduce the signal from the vehicle. This would decrease the number of individuals needed to operate and manually tow the heavy system.

- The complete raw data files should be collected on the controller computer and saved there during the data collection runs rather

than only on the data loggers and only partial sets of the raw data on the controller computer.

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14. ABSTRACT

The Multi-Sensor System (MSS) developed by Geophysical Solutions was tested and evaluated in March 2004 at the unexploded ordnance (UXO) test site and the UXO/countermine test stand located at the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. The MSS includes two sensor systems, the Geophex GEM-3-E and Geonics EM-63, as well as the Gem Systems GSMP-40 magnetometer and the NavCom SF-2050 series rover using the Starfire differential global positioning system (GPS).

The MSS was found to be heavy and extreme in its length, thus making it difficult to move the MSS along a straight line. The positioning system for the cart lacked expected accuracy. With the GPS positioned near one of the pivot points, the arc of the other sensors could be moved through without any change in the GPS recording. Also, the GPS occasionally failed to keep a lock on the differential GPS signal, thus decreasing its accuracy.

With the EM-63, the system did not allow for adequate channels to be saved. The EM-63 induced a large signal in the magnetometer that had to be removed. The EM-63 and GEM-3-E both produced data with similar results as those obtained from other GEM-3's and EM-63's used by ERDC.

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15. SUBJECT TERMS (Concluded)

MSS
Multi-sensor system
Geophysical Solutions
Unexploded ordnance
UXO
UXO test site
UXO test stand
EM-63
GEM-3-E
Starfire GPS
GSMP-40 magnetometer
Electromagnetic
Frequency domain electromagnetic
Time domain electromagnetic