GEOPHEX AIRBORNE UNMANNED SURVEY SYSTEM

AUTHORS:

I. J. Won
David W. A. Taylor

CONTRACTORS:

Geophex, Ltd.
605 Mercury Street
Raleigh, NC 27603

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3.5 Geophex Airborne Unmanned Survey System

CONTRACT INFORMATION

Contract Number
DE-AR21-93MC30358

Contractor
Geophex, Ltd.
605 Mercury St.
Raleigh, NC 27603
(919) 839-8515

Contractor Project Manager
I.J. Won

Principle Investigators
I.J. Won
David W.A. Taylor

METC Project Manager
V.P. Kothari

Period of Performance
September 30, 1993 to September 29, 1996

Schedule and Milestones

Program Schedule

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- Pre-prototype Design
- Pre-prototype Construction
- Pre-prototype Test/Evaluation
- Prototype Design
- Prototype Construction
- Prototype Test/Evaluation

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OBJECTIVES

The purpose of this effort is to design, construct, and evaluate a portable, remotely-piloted, airborne, geophysical survey system. This nonintrusive system will provide "stand-off" capability to conduct surveys and detect buried objects, structures, and conditions of interest at hazardous locations.

This system permits two operators to rapidly conduct geophysical characterization of hazardous environmental sites. During a survey, the operators remain remote from, but within visual distance of, the site. The sensor system never contacts the Earth, but can be positioned near the ground so that weak anomalies can be detected.

BACKGROUND INFORMATION

System Concept

Geophysical surveys provide a nonintrusive means of evaluating subsurface conditions, but geophysical characterization of many environmental sites is difficult or impractical due to hazardous conditions. Personnel are placed at risk by the proximity of buried unexploded ordnance (UXO) items, or by exposure to radioactive materials and hazardous chemicals. Use of elaborate personal protective equipment increases cost and decreases efficiency of a site characterization. The problems of health and safety as well as efficiency can be solved by use of a remotely operated geophysical survey system.

The Geophex Airborne Unmanned Survey System (GAUSS) is designed to detect and locate small-scale and weak anomalies at hazardous sites using magnetic and electromagnetic survey techniques. The system consists of a remotely-piloted, radio-controlled, model helicopter (RCH) with flight computer, light-weight geophysical sensors, an electronic positioning system, a data telemetry system, and a computer base-station.

Figure 1 depicts a typical GAUSS survey scenario in which a pilot maneuvers the radio controlled model helicopter over a survey site. The helicopter traverses the site and can position magnetic or electromagnetic sensors close to the Earth without making contact.

Geophysical data, position data, and flight status information are telemetered from the helicopter flight computer to a base-station computer via a digital radio communications link. The base station records and processes the data. A cursor on the real-time graphical video display indicates the position of the moving helicopter. Each time a sensor performs a geophysical measurement, the data is displayed as a color coded region at the location corresponding to the helicopter position.

Operators get instant feedback regarding data content and quality via the graphical video display. Anomalies are detected, located, and characterized in real-time allowing the operators to modify a search to produce optimal results.

Commands are telemetered from the base station to the flight computer which modify the sensor configuration. The system configuration can be modified on-the-fly to switch between a high speed target seeking mode, and a high accuracy data acquisition mode which produces data suitable for detailed target characterization.

Applications and Benefits

GAUSS allows operators to conduct geophysical surveys of hazardous environmental sites at stand-off distances which decreases the risk to personnel. The GAUSS system hovers
near the ground which positions sensors to detect weak anomalies without making contact with the Earth. This capability is desirable in UXO remediation efforts and also mitigates the need for decontamination of equipment and personnel.

Survey systems for hazardous sites based on robotic or remotely guided ground based vehicles have difficulty negotiating uneven terrain which can result in reduced survey speed or vehicle incapacitation. GAUSS can be used to characterize such sites (e.g. open pits or steep terrain). GAUSS can also be deployed for surveys over surf-zones, and shallow water areas where land-based or hydrographic surveys are not possible.

Existing airborne technologies cannot detect and locate the small-scale anomalies caused by objects such as small ordnance items, explosive waste, or buried drums. It is necessary to position sensors close to the ground to detect and accurately locate weak anomalies. In many instances, it is not practical to attempt this with a full sized airborne system.

Due to rapid data acquisition capability, GAUSS necessarily provides automated data collection, processing, and display capabilities. Each geophysical datum is automatically associated with position coordinates. A color map of the survey data is displayed in real time. This eliminates the need for costly and time consuming post processing. The "answer" is known at the
conclusion of the survey as opposed to a post processing scenario in which data quality may not be known until days after a site is abandoned. Automated data processing technology will result in cost and time saving as well as improved survey quality. This technology is applicable to surveys using any type of survey platform.

GAUSS has been designed using off-the-shelf subsystems wherever possible. As a result, GAUSS is inexpensive and easy to maintain. Due to survey efficiency and low cost, GAUSS provides an attractive alternative to traditional survey methods.

PROJECT DESCRIPTION

Goals

This project is a feasibility study to determine the applicability of RCH carried sensor systems for stand-off geophysical surveying. This goal is to be accomplished in two phases. The first phase requires design, construction, and testing of a hand-held pre-prototype sensor system. The emphasis is on development and demonstration of technologies for use in the airborne system. Specific tasks during the first phase are;

1. Develop or acquire light-weight geophysical sensors with digital output.
2. Develop or acquire a light-weight, two-way digital telemetry system. Incorporate a communications protocol featuring error detection and correction capability.
3. Develop or acquire a light-weight, real-time automatic positioning system.
4. Develop software for remote instruments and for the base-station to accomplish communications, data recording, error detection, data processing and display functions.
5. Integrate the components to produce a fully functional hand-carried version of the GAUSS system.
6. Test and evaluate the hand-held system.

During the second phase of the project, the technology used in the pre-prototype will be applied to development of an airborne prototype. Tasks to be accomplished include;

1. Modify systems to improve performance as needed based on results of pre-prototype testing.
2. Modify systems for use with RCH.
3. Develop or acquire helicopter altitude autopilot system.
4. Integrate the RCH based survey system.
5. Evaluate the efficacy of the system for geophysical surveying of environmental sites.

Project Participants

Work for this project is led by the project manager, Dr. I. J. Won. Dr. Won, a principle investigator, contributes his experience in geophysical sensors and flight systems and also provides overall project guidance. Dr. David W. A. Taylor, the second principle investigator, is the Special Programs Manager at Geophex, Ltd. Dr. Taylor contributes his experience in geophysical sensor systems as well as data collection, processing and analysis.

Engineering design and development are accomplished by Dr. Patrick Heron and Mr.
Joseph Seibert. Dr. Heron has a strong background in analog electronic systems and applied electromagnetics. Mr. Seibert is an electrical engineer with over eighteen years of industry experience in design and construction of custom electronics systems.

RESULTS

System Operation

The hand-held, pre-prototype survey system has been designed, constructed, and tested. The function of the system can best be understood by following the sequence of events which occur when a single measurement is made during a survey. A remote operator carries a geophysical sensor and the remote radio modem into the field. The base-station running GAUSS software and a local radio modem are located less than one mile from the survey site and have a clear view of the survey.

The remote operator occupies a survey location and depresses the fire button on the instrument. The instrument then makes a measurement, performs necessary calculations, and passes the datum to the remote radio modem. The remote modem packetizes the datum, affixes error correction information to the packet, then transmits this information. The local modem receives the packet and checks for data integrity. If the information has been corrupted, the local modem discards the packet and the remote modem re-transmits the data packet. If the data packet is deemed to be uncorrupted, the local modem broadcasts confirmation to the remote modem, then makes the datum available to the base-station computer via a serial port.

The base station captures the datum from the serial port, translates to binary format, and appends it to a global data list. An error flag is attached to the data if internal errors are detected by the software. If no error condition is detected, the base-station broadcasts confirmation to the remote instrument. Radio transmission error checking is also in effect during the confirmation transmission.

Position coordinates are associated with the geophysical datum and the data set is written to the base-station fixed disk. The data is scaled, then displayed on the base-station color graphics display as a colored region. The location of the colored region on the display corresponds to the position of the geophysical instrument at the survey site. The numerical value of the geophysical datum determines the color of the display region.

As the survey progresses, a colored survey map is painted on the video display representing data gathered while the remote operator traverses the site. Locations of interest can be re-occupied on directions from the local operator.

GAUSS Subsystems

The sub-systems which comprise the hand-held pre-prototype have been selected or designed so that they may easily be modified for use in the airborne prototype.

Base-Station. A 50 Mhz 80486 personal computer running DOS with VGA color display is used as the GAUSS base station. This machine has sufficient power for the GAUSS system and is a common machine which provides a large number of systems on which GAUSS can operate. This selection allows the use of readily available DOS laptop computers in the field.

GAUSS base-station software is comprised of a suite of independent programs tied together by menu-driven DOS batch programs. These programs provide facilities to conduct automated surveys, post-process survey images, and translate the format of the survey datafiles.
The survey programs collect, record, interpret, and display sensor data in real-time; providing the functionality described in the System Operation Section. These programs have been written using the C language in conjunction with a real time supervisory kernel (task scheduler). The kernel utilizes interrupt driven preemptive task switching to prioritize numerous simultaneous tasks. Figure 2 shows the structure of the software, individual tasks are indicated by the rectangular borders. Each task is an independent programs which run simultaneously with all other tasks. The scheduler determines which task is running at any given instant based upon the task's priority (indicated below each rectangular border), the status of the computer hardware interrupts, and software semaphores which accomplish intertask communication. Most tasks involve the control of computer hardware which is identified by an oval border.

Any task has the capability to access the hardware through the associated driver, or can access the global data structure. Inter-task communication for the nominal software configuration is indicated by the arrows in Figure 2. The modular structure of this software allows flexibility during development stages and provides good performance. The magnetometer survey program has been used to receive, record, process and display magnetometer data at rates up to 75 samples per second.

Sensors. GAUSS presently uses static magnetic field and induction electromagnetic sensor systems. These sensing techniques are proven, and widely applicable for environmental site characterization.

The magnetic field technique is very effective at detecting magnetically permeable objects or geological formations by measuring perturbations in the Earth's natural magnetic field.

The induction electromagnetic survey technique detects discontinuities in the Earth's conductivity which can be caused by buried objects, contaminant plumes, groundwater, and other conditions of interest.

The GAUSS magnetometer subsystem uses an off-the-shelf, low noise, three axis, fluxgate magnetometer. This compact unit weighs 100 g and produces three output voltages, each proportional to the magnetic field strength in the direction of a fluxgate axis. A custom analog circuit board buffers and filters each of the three voltage signals. Three synchronized 20-bit analog to digital (A/D) converters sample the filtered signals over 9000 times per second.

A modified off-the-shelf CMOS computer controls the A/D converters and receives the vector magnetic field data at rates up to 240 data sets per second. This computer has a 2.5 by 3 inch footprint and weighs less than 50 g. The computer processes the vector data to determine magnetic field magnitude. A tensor correction formula is used which compensates for non-orthogonality of the fluxgates and for gain differences in each of the three analog channels. Figure 3 shows that the correction formula reduces the sensor heading error to less than 5 nT. The magnetometer computer then passes field magnitude data to the remote radio modem for transmission to the base station.

A block diagram of the GAUSS electromagnetic (EM) induction sensor system is shown in Figure 4. The system is comprised of electronics and a monostatic coil assembly. The custom electronics reside on a single printed circuit board which requires only a unipolar supply voltage. The computer is based on the Motorola 56001 and performs control and signal processing tasks. The system functions by transmitting a trinary pulse-width modulation (PWM) bitstream to a high efficiency coil driver. The transmitter signal strength is monitored by a
reference coil. The Earth response is detected by a high gain receiver coil. The reference and receive signals are amplified and filtered by low noise analog electronics and then digitized by a stereo A/D converter at a rate exceeding 72 k samples/second. The computer cross correlates the receive signal with the transmitted signal to determine magnitude and phase of the anomaly response. The computer can also monitor the relative gain of the receive and reference channels and compensate for thermally induced electronic drift. Figure 5 is a plot of the monostatic response of this sensor system in the vicinity of a nonferrous anomaly.

Telemetry System. Radio modems are used for system telemetry. These off-the-shelf components operate at rates to 19.2 kBAUD and use checksums with handshaking to provide error free data transmission. The radios broadcast a spread spectrum signal which can be used at any location without a radio license and allows full duplex communication. A compact OEM version is available which occupies a single printed circuit board.

Positioning System. At present, position during a GAUSS survey is based on an implied rectangular grid. Both laser tracking systems and differential global positioning systems (DGPS) are being considered for electronic positioning.
Present, DGPS technology does not provide sufficiently accurate real-time position data at an acceptable update rate using compact receivers. Laser tracking systems provide excellent performance but at a cost in conflict with the goal of producing an inexpensive survey system.

Laser positioning may provide an interim solution during the rapid maturation of DGPS technology. GAUSS software can accommodate either positioning system.

Test Surveys

Test surveys are being conducted using the hand-held GAUSS system with both the electromagnetic sensor and the magnetometer. The GAUSS base station is typically located inside the Geophex building. Various sites around the building at ranges up to 500 feet have been surveyed. Figure 6 is an eight shade grayscale screen dump of a magnetic survey conducted over a 70 by 60 ft area. Magnetic data were collected on a regular 2.5 ft grid and interpolated. Filtering was used to remove the large scale effects of a metal building located seven feet south of the site and a storage shed located just off the northeast corner. Use of the data filtering capability of the GAUSS software has allowed us to detect 30 nT field anomalies caused by buried objects in the presence of the 4845 nT field variation due to the metal structures. The large anomaly marked with a "+" in Figure 6 is due to an exposed electrical conduit. Using this data, ferrous objects have been recovered from excavations at three locations east and north of the conduit. The locations south of the conduit have not yet been investigated.

Figure 7 shows a screen dump of an electromagnetic survey of a 16 by 16 ft site. Data
were collected on a regular two foot grid, then interpolated. The circular anomaly, marked with a "+", is caused by a buried, vertically oriented, 5 ft length of steel pipe. The top end of the earth-filled pipe is located six inches below the surface and covered with red clay.

**FUTURE WORK**

Testing of the hand-held GAUSS system will continue. A 1/4 acre geophysical test site has been constructed in which ferrous and nonferrous targets have been buried at known depths and orientations. These will be used to benchmark system performance.

An automatic electronic positioning system will be integrated into the pre-prototype system which removes the constraint of surveying using a rectangular grid.

The base-station graphics display will be updated from the present VGA mode display. The capability to display many color shades is needed so that small scale anomalies can be detected in surveys where large anomalies also exist.

Design, construction, and testing of the RCH based system will be initiated. Areas of focus are: miniaturization of the electromagnetic coil assembly, addition of a helicopter altitude autopilot system, and electrical power systems for airborne instruments.
Figure 5. Monostatic Response of the GAUSS Electromagnetic Induction Sensor in the Vicinity of a Conductive Nonferrous Object

Figure 6. Screen Dump of a GAUSS Magnetic Survey Map
Figure 7. Screen Dump of a GAUSS Electromagnetic Survey Map