Geophex Airborne Unmanned Survey System

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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 non-intrusive system will provide "stand-off" capability to conduct surveys and detect buried objects, structures, and conditions of interest at hazardous locations.

This system permits rapid 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 geophysical anomalies can be detected.

System Approach

Geophysical surveys provide a non-intrusive means of evaluating subsurface conditions, but geophysical characterization of many environmental sites is difficult or impractical due to hazardous conditions. Ground-based surveys place personnel at risk due to 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. These inherent problems of ground-based surveys are minimized by the use of a remotely operated geophysical survey system.

The Geophex Airborne Unmanned Survey System (GAUSS) is designed to detect and locate small-scale 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 model GAUSS survey scenario in which a pilot maneuvers the radio-controlled model helicopter over a survey site. The helicopter traverses the site and positions magnetic or electromagnetic sensors close to the Earth without making contact.

Geophysical data, position data, and flight status information are telemetered from the helicopter 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 transmits a geophysical measurement, the
data is displayed as a color-coded region at the location corresponding to the helicopter position. Operators receive instant feedback regarding data content and quality via the graphical video display. Anomalies are detected, located, and characterized in real-time allowing modification of the survey to produce optimal results. For example, the survey can be modified on-the-fly to switch between a high-speed mode suitable for target detection, and a slow-speed, high data density acquisition mode for detailed target characterization.

Project Description

Goals

This project is a feasibility study to determine the applicability of RCH carried sensor systems for stand-off geophysical surveying. The emphasis is on development and demonstration of technologies for use in the airborne system.

The project is divided into two phases. The first phase requires design, construction, and testing of a hand-held pre-prototype sensor system. Specific tasks during the first phase are:
- Develop light-weight geophysical sensors with digital output.

- Develop or acquire a light-weight, two-way digital telemetry system that incorporates a communications protocol featuring error detection and correction capability.

- Develop or acquire a light-weight, real-time automatic positioning system.

- Develop software for remote instruments and for the base-station to accomplish communications, data recording, error detection, data processing and display functions.

- Integrate the components to produce a fully functional hand-carried version of the GAUSS system.

- Test and evaluate the hand-held system.

During the second phase of the project, the technology developed in the pre-prototype is applied to the airborne prototype. Tasks associated with the second phase include:

- Modify subsystems developed in phase one to maximize performance and minimize weight and size.

- Convert subsystems for use with RCH.

- Acquire a helicopter autopilot system to reduce complications during flight.

- Integrate the RCH-based survey system.

- Evaluate the efficacy of the system for geophysical surveying of environmental sites.

**Project Participants**

Work for this project is led by Dr. I. J. Won. Dr. Won contributes his experience and expertise to the theoretical formulation and hardware specification of geophysical sensors and flight systems. Dr. Dean Keiswetter, Deputy Program Manager of Geophysics at Geophex, Ltd. manages the daily operations and contributes in the collection, processing and analysis of geophysical data. Engineering design and development are completed by Mr. David Burgess, Mr. Joseph Seibert, and Mr. Alex Gladkov. Mr. Burgess, the Hardware Manager at Geophex, has a strong background in analog electronic systems and over twenty years experience in the field. Mr. Seibert is an electrical engineer with over eighteen years of industry experience in design and construction of custom electronics systems. Mr. Gladkov, an electrical engineer, contributes to the hardware construction.

**Results**

**System Operation**

The hand-held, pre-prototype survey system has been designed, constructed, and tested. An understanding of the acquisition system is best described by following the sequence of events that 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 data and the multivalue data set is written to the base-station fixed disk. The data is scaled and displayed in color on the base-station monitor. The spatial location of the data sample is mapped to a representative location on the screen. The numerical value of the data sample determines the color.

As the survey progresses, a colored survey map is constructed on the video display. Because the geophysical map is produced in real time, anomalous areas can be re-occupied to either support, enhance, or correct suspicious results.

GAUSS Subsystems

Base-Station. A 50 MHz 80486 personal computer running DOS with VGA color display is used as the GAUSS base station. This system has sufficient power for the GAUSS software and is readily available. A pentium laptop with two serial ports and an active matrix screen is being tested as a possible replacement.

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). Individual software tasks are indicated by rectangular borders in Figure 2, and hardware tasks are identified by an oval border. Each task is an independent programs which run simultaneously with all other tasks. The scheduler determines which task is running based upon the task’s priority (indicated below each rectangular border in Figure 2), the status of the computer hardware interrupts, and software semaphores which accomplish intertask communication.

Any task has the capability to access the hardware through the associated driver, or can access the global data structure. Inter-task communication for 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.
Figure 2. Software structure of the multitasking GAUSS survey module.

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 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. The magnetometer computer then passes field magnitude data to the remote radio modem for transmission to the base station.

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.

A block diagram of the GAUSS electromagnetic (EM) induction sensor system is shown in Figure 3. The system is comprised of electronics and a monostatic coil assembly. The custom electronics reside on a single printed circuit board which requires 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's 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 also monitors the relative gain of the receive and reference channels and compensate for thermally induced electronic drift. Figure 4 is a plot of the monostatic response of this sensor system in the vicinity of a nonferrous anomaly.

Figure 3. Block diagram of major components of the GAUSS electromagnetic sensor
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 information is acquired using a laser tracking system. Differential global positioning systems (DGPS) have been considered, but current DGPS technology does not provide sufficiently accurate real-time position data at an acceptable update rate.

Pre-prototype Test Surveys

Test surveys have been conducted using the hand-held GAUSS system with both the electromagnetic sensor and the magnetometer. Figure 5 is an eight-shade grayscale screen dump of a magnetic survey conducted over a 70 by 60 ft area located near our Raleigh Office. 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 anomalies in the presence of a background field of 4,845 nT. The large anomaly marked with a "+" in Figure 5 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.

Figure 6 shows a screen dump of an electromagnetic survey of a 16 by 16 ft site. Data were collected on a regular two foot grid. The

Figure 4. Monostatic response of the GAUSS electromagnetic induction sensor in the vicinity of a conductive nonferrous object
Figure 5. Screen dump of a GAUSS magnetic survey map

Figure 6. Screen dump of a GAUSS electromagnetic survey map
circular anomaly, marked with a "+" is caused by a vertically oriented, 5-ft steel pipe. The shallow end of the pipe is buried beneath six inches of soil.

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 to detect weak anomalies without direct contact with the near-surface materials. 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 typically cannot detect and locate the small-scale anomalies caused by ordnance items, explosive waste, or buried drums due to minimum sensor-height limitations. It is necessary to position sensors very 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.

GAUSS provides automated data collection, processing, and display capabilities. A color map of the survey data is displayed in real time. This reduces 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 results in a cost and time savings as well as improved survey quality. This technology is applicable to surveys using any type of survey platform (e.g. ground based, model boat, etc.).

GAUSS has been designed using off-the-shelf subsystems wherever possible. As a result, costs associated with the GAUSS are minimized and maintenance is standardized.

Future Activities

We are currently completing the prototype design and have started the construction of critical subsystems. An automatic electronic positioning system has been located and is being integrated into the prototype system.

Although prototype work has begun, we continue to test the pre-prototype GAUSS system. The emphasis of these tests is the refinement of design and construction criteria necessary for the final helicopter-towed systems.

During the next year, we will complete the design, construction, and testing of the RCH-based system. Specific tasks are to 1) finalize the miniaturization of the geophysical sensor systems, 2) test the helicopter altitude autopilot system, and 3) enhance the base-station software.

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