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A TELEOPERATED SYSTEM FOR REMOTE SITE CHARACTERIZATION

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ABSTRACT

The detection and characterization of buried objects and materials is an important step in the restoration of burial sites containing chemical and radioactive waste materials at Department of Energy (DOE) and Department of Defense (DOD) facilities. By performing these tasks with remotely controlled sensors, it is possible to obtain improved data quality and consistency as well as enhanced safety for on-site workers. Therefore, the DOE Office of Technology Development and the US Army Environmental Center have jointly supported the development of the Remote Characterization System (RCS). One of the main components of the RCS is a small remotely driven survey vehicle that can transport various combinations of geophysical and radiological sensors. Currently implemented sensors include ground-penetrating radar, magnetometers, an electromagnetic induction sensor, and a sodium iodide radiation detector. The survey vehicle was constructed predominantly of non-metallic materials to minimize its effect on the operation of its geophysical sensors. The system operator controls the vehicle from a remote, truck-mounted, base station. Video images are transmitted to the base station by a radio link to give the operator necessary visual information. Vehicle control commands, tracking information, and sensor data are transmitted between the survey vehicle and the base station by means of a radio ethernet link. Precise vehicle tracking coordinates are provided by a differential Global Positioning System (GPS).

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The sensors are environmentally protected, internally cooled, and interchangeable based on mission requirements. To date, the RCS has been successfully tested at the Oak Ridge National Laboratory and the Idaho National Engineering Laboratory.

INTRODUCTION

The detection and characterization of waste burial sites require surveys that involve non-intrusive geophysical, radiological, and chemical sensors. Such surveys, performed with manually operated sensors or vehicle-mounted sensors can often detect and map buried objects, materials, contaminants, and geological features to depths of several meters in the earth. Vehicle-based surveys are more efficient than those which involve manual methods, but they have generally suffered from poor vehicle maneuverability and from degraded sensor performance due to interactions with the vehicle. The benefits of vehicle-based sensing can be most fully realized if the survey vehicle is specifically designed to be a sensor platform. Further, a remotely controlled survey system can enhance efficiency and provide a means of safely dealing with sites where it may be undesirable to perform site characterization surveys in which human operators must traverse the site either on foot or on board a survey vehicle.

In Fiscal Year 1992, the U.S. Department of Energy's Office of Technology Development (OTD) initiated the development of the Remote Characterization System (RCS). The primary objective of this continuing project is to develop a remotely controlled system that can perform site characterization surveys that will be safer and more cost effective than those that are being performed by other available methods. At the same time, it is expected that the data sets produced by the RCS should be at least as accurate and complete as those produced by other survey systems. The remote-control capabilities of the RCS will improve safety at hazardous sites by reducing on-site manpower requirements and by minimizing the exposure of personnel to unnecessary risks. It is also expected that RCS subsystems will be utilized in other DOE telerobotic applications to achieve time and cost savings in other phases of site cleanup. The vehicle tracking capability of the RCS has already been transferred to a teleoperated excavation system that has been developed at the Oak Ridge National Laboratory.

The major hardware and software components of the prototype system have now been developed and assembled. Initial system tests have been performed at test sites at the Oak Ridge National Laboratory and at the Idaho National Engineering Laboratory. Additional tests at waste burial sites and technology transfer of the RCS are planned for FY 1994.

Joint support for this work has been provided by the U.S. Army Environmental Center. The project is a collaborative effort involving the Pacific Northwest Laboratory, the Oak Ridge National Laboratory, the Sandia National Laboratory, the Lawrence Livermore National Laboratory, and the Idaho National Engineering Laboratory.

SYSTEM OVERVIEW

The RCS design philosophy required that the remotely controlled survey vehicle and its instrumentation be small, light, and relatively inexpensive. Another requirement was that the vehicle must be constructed predominantly of non-metallic materials so that it will have a minimal effect on the operation of on-board geophysical sensors. The suite of sensors supported by the vehicle and its instrument package currently includes ground-penetrating radar (GPR), a metal detector, a magnetometer, a magnetic gradiometer, an induction-type ground conductivity sensor, and a radiological sensor.

Figure 1 is a drawing of the system in a field application. Although the picture differs from the actual system in certain details, it illustrates the basic system configuration. The vehicle is self-propelled and is guided by an operator located at a remote base station. Telemetered video signals give the operator the visual information needed to control the vehicle. Digital commands for vehicle and instrument control are transmitted to the vehicle. Data produced by the on-board sensors are transmitted from the vehicle to the base station where they are recorded, processed, and displayed.

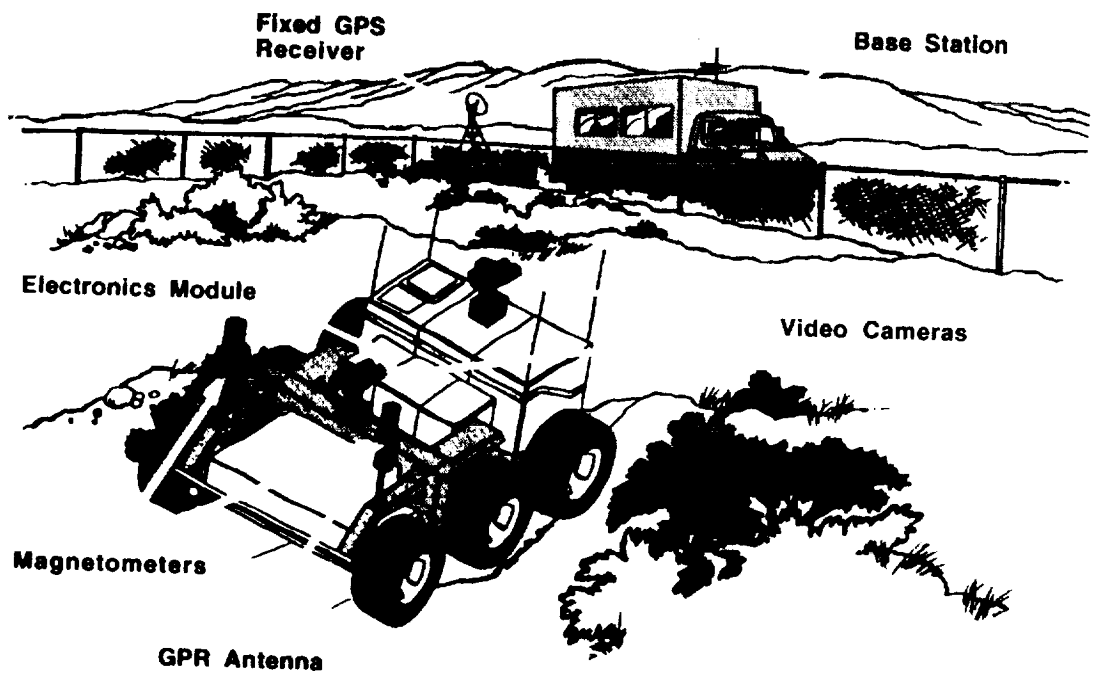

Figure 1. Drawing of the RCS.

THE SURVEY VEHICLE (LSV)

The construction of a sensor-compatible low-signature vehicle (LSV) required the use of a minimum amount of metallic material. The current prototype vehicle contains approximately 130 lbs of metal, but this material is distributed so that it has only a small effect on the on-board geophysical sensors. The most critical part of this effort was to reduce the amount of magnetic material (steel) on the vehicle and to locate unavoidable steel components as far from the magnetometers as possible.

A typical site for a geophysical field survey exhibits surface features such as bushes, trees, fences, buildings, parked vehicles or other machinery, open holes, depressions, ditches, hills, berms, rocks, and miscellaneous debris (wire, cable, 55-gal drums, concrete blocks, etc). To obtain the maneuverability needed to operate the LSV among these kinds of obstructions, we adopted two additional design requirements. First, the LSV must be able to turn in place. Second, all sensors and other vehicle components must be contained within the perimeter of the vehicle as defined by its wheels and bumpers. These requirements eliminated the possibility of transporting sensors on a trailer or a boom. In particular, the large size of a ground-penetrating radar antenna and the necessity of coupling it to the ground virtually dictated that the vehicle be designed around it. Thus, as illustrated in Figure 1, the front part of the chassis is an open structure that permits the GPR antenna to be suspended between the front wheels.

Figure 2 is a photograph of the prototype LSV that has been constructed at the Pacific Northwest Laboratory. This vehicle is approximately 7 ft long and 5 ft wide. Its weight is approximately 800 lbs, including a payload of approximately 150 lbs. Its major components include the chassis, the engine, the drive train, and an electrical power generator. They also include an on-board digital controller and peripheral devices to monitor vehicle status and to provide low-level control inputs to the vehicle.

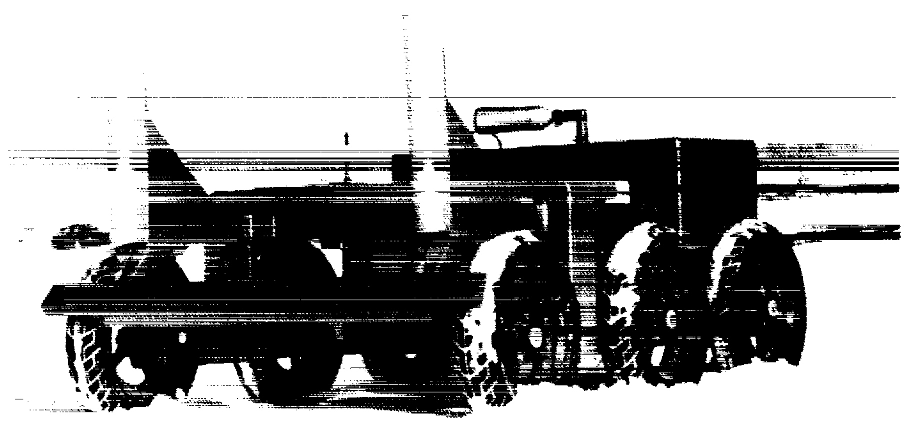

Figure 2. The RCS Low-Signature Vehicle.

The LSV is based on a six-wheeled design with modified skid steering. To equalize wheel loading and to minimize the vertical movement of the instrument platform in response to the roughness of the ground surface, we developed a simple articulated chassis that has proven to be very effective. It consists of two main sections that form the rear third and the forward two-thirds of the vehicle, respectively. A pivot located on the vehicle's longitudinal axis allows the the front and rear sections of the chassis to rotate relative to each other. Additional articulation is provided at the front end of the chassis. The two wheels on each side of the front section of the vehicle are mounted at the ends of a horizontal arm. Each of the two arms is connected by a bearing to the ends of a yoke, or inverted U-shaped member, that straddles the front part of the chassis. Each arm is free to pivot about a transverse axis located at the center of the arm.

A 20-hp, gasoline-powered, 2-cylinder engine is mounted on the rear section of the chassis. A 12-V, 50-amp alternator mounted on the engine provides electrical power for the sensors, control modules, and other electronic devices on the vehicle. A hydraulic pump, electronically controlled hydraulic valves, and four hydraulic motors provide power at the front and rear wheels.

The LSV has been designed to climb and traverse 35° slopes, to have a ground clearance of 8 in. (except for the GPR antenna), and to operate at speeds up to 5 ft/s. These features permit operations on most of the terrain present at DOE and DOD waste burial sites.

NAVIGATION SUBSYSTEM

A differential kinematic implementation of the satellite-based Global Positioning System (GPS) is the primary means of tracking the LSV. The differential configuration involves the use of two NovAtel (Calgary, Alberta, Canada) GPSCard Model 951R receiver modules. The first, mounted on the LSV, computes its location and transmits that information to a dedicated computer in the RCS base station using an embedded computer and telemetry unit. The second module is mounted on the base-station truck. It is fixed in position for a given survey and provides error-correction information that is transmitted to the LSV's GPS receiver. Coordinates accurate to ±50 cm (typically) are calculated in real time at a rate of 5 measurements/s. Coordinates accurate to ±15 cm (typically) are obtained by post-processing the recorded GPS data.

COMMUNICATIONS SUBSYSTEM

A digital, radio-frequency (RF), command/data link provides ethernet communications between the vehicle and the base station. Signals transmitted to the LSV control the direction and speed of the vehicle, the orientation of the video cameras, and the setup and operation of the on-board sensors. Vehicle status information and sensor output data are transmitted from the LSV to the base station. Setup commands are transmitted to each sensor prior to the initiation of a survey, and parameter update commands can be transmitted to the sensors at any time. After data collection has been initiated, the sensor data are transmitted at predetermined intervals without intervention or commands from the base station. This approach permits data to be transmitted at 25 kbytes/s, a rate sufficient to handle the 17-kbyte/s output of the GPR sensor together with the output of all of the other sensors. Two separate analog RF channels handle video transmissions.

HIGH-LEVEL CONTROL STATION (HLCS)

The operator interface to the LSV is called the High-Level Control Station (HLCS). It is contained in the base-station vehicle and communicates with the LSV via the RF telemetry link described above. The components of the HLCS are housed in the truck shown in Figure 3. The cargo box was custom

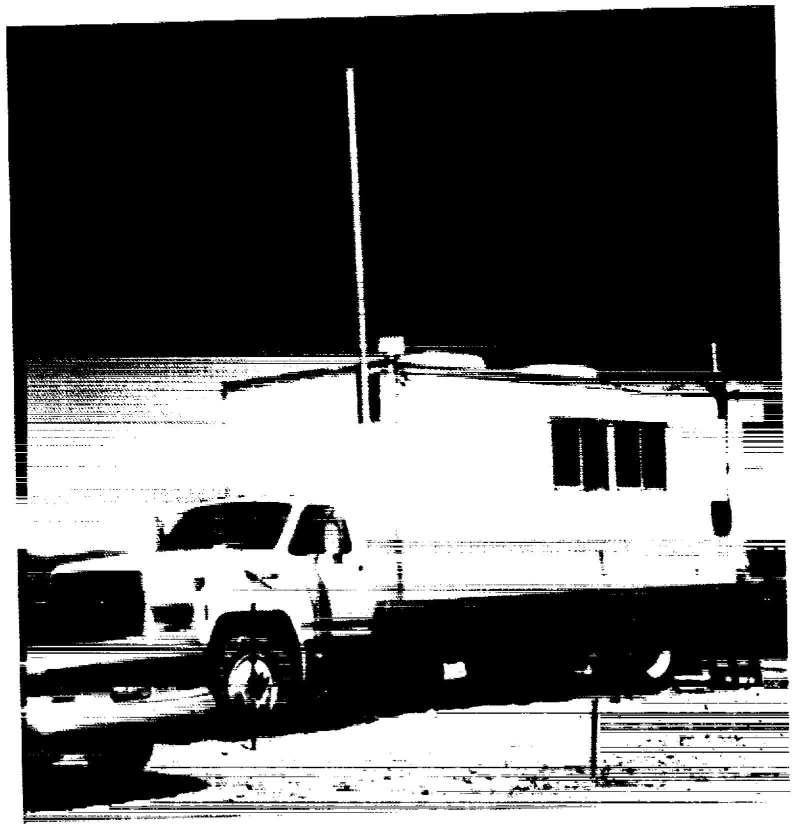

Figure 3. The truck housing the RCS base station.

built to provide equipment mounting space, electrical power, lighting, heating, air conditioning, windows, counter space, and storage cabinets.

The HLCS provides the hardware and software for remote driving (teleoperation), camera positioning, and data displays. A central feature is a control chair with vehicle joystick controls and a keyboard/trackball interface for command inputs to the graphics-based operator interface (Figure 4). The system operator sits in the control chair, driving the remote vehicle and controlling the video cameras with joysticks and fingertip controls. The remote video images and a graphical interface to the control computer are presented on video displays located in front of the operator. The operator also controls sensor selection, sensor operation, and data acquisition through the graphical operator interface. A secondary graphical data display station is provided to allow a geophysicist or observer to examine real-time data. Planned extensions of the control features emphasize automated and semi-automated survey capabilities that will reduce he burden on the operator. An additional potential extension would provide multiple vehicle control by one station with occasional operator input during problem resolution.

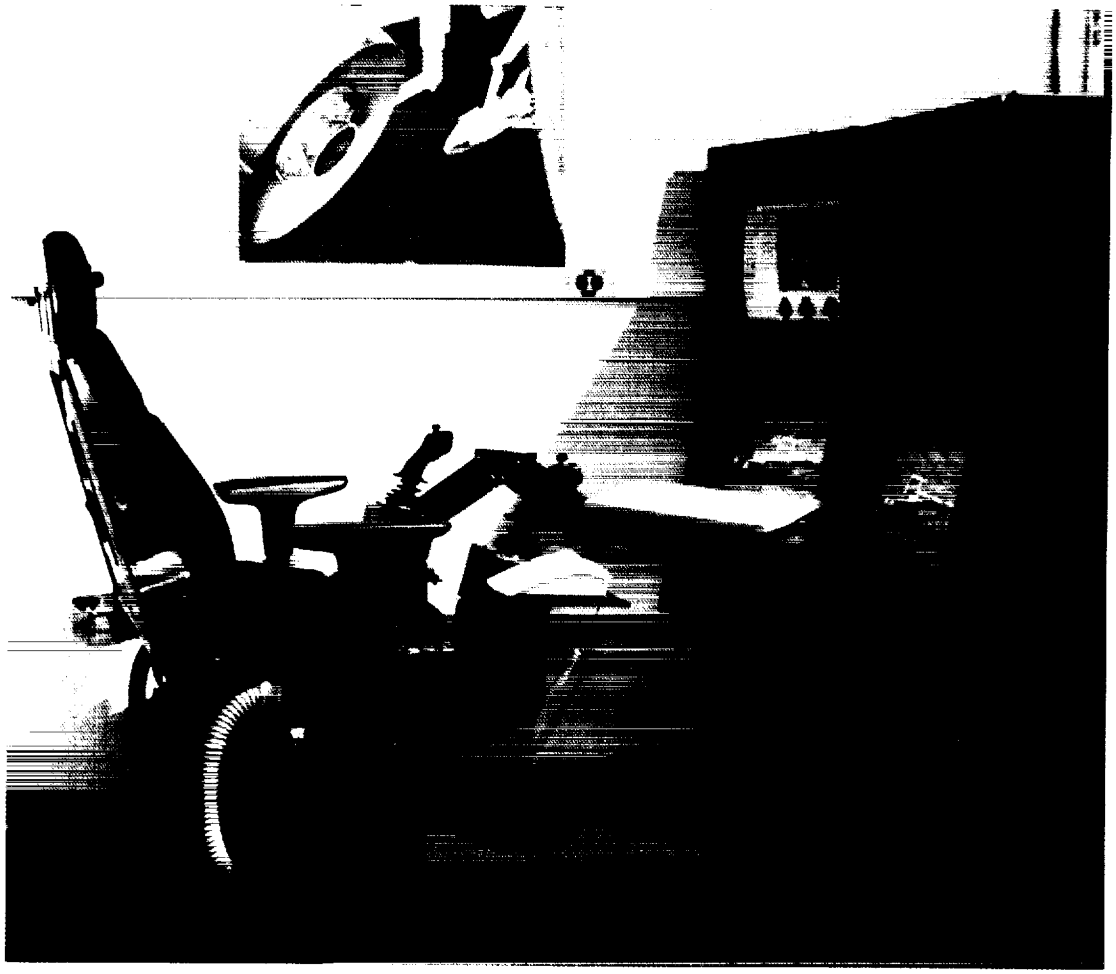

Figure 4. The operator's control station.

VIDEO SUBSYSTEM

The system operator must receive visual information from the LSV so that he can recognize hazards and obstructions and can guide the vehicle around them. It is vital that the information available to the operator be sufficiently detailed that he can make on-the-fly decisions regarding the risks associated with anomalous features that the LSV will encounter in the field. A stereo video subsystem is planned to provide the necessary detailed visual information, but the current configuration provides two monoscopic channels that are set up for viewing in the forward and backward directions. The current system includes the cameras, camera control components (pan/tilt), and the associated telemetry links needed for stereo viewing, but does not include the necessary stereo display and head-tracking components. These, together with a data compression technique that will permit both video channels to be transmitted on a single RF link, represent goals for system improvement.

SENSORS

To date, the following sensing instruments have been mounted on the LSV for testing:

- Fluxgate magnetic gradiometers (Model APS-511, Applied Physics Systems, 897 Independence Avenue, Mountain View, CA 94043)

- Cesium vapor magnetometers (Model G822A, EG&G Geometrics, 395 Java Drive, Sunnyvale, CA 94089)

- Sodium iodide gamma detector (2-in. thick, 5-in. diameter crystal, Harshaw/Filtrol, 6801 Cochran Road, Solon, OH 44139).

- Ground-penetrating radar (Model SIR 3, Geophysical Survey Systems, Inc., 13 Klein Drive, North Salem, NH 03073-0097)

- Electromagnetic induction ground conductivity sensor (Modified Model EM31, Geonics Ltd., 1745 Meyerside Drive, Unit 8, Mississauga, Ontario, Canada L5T 1C5)

It has been proposed that a portable mass spectrometer under development at the Lawrence Livermore National Laboratory be added to this package to provide a chemical sensing capability. Not all of the sensors will be mounted on the vehicle at any given time. This is partly due to inherent differences in operating requirements or operating modes. In particular, for radiological and chemical sensing, the vehicle will probably be operated at a low speed or in a slow start-stop mode rather than the fast continuous-motion mode that is appropriate for the geophysical sensors.

The test data sets that have been collected to date, are currently being processed, but initial results are available for the magnetic and radiation sensors. Figure 5 is a contour map that illustrates the data produced by the cesium vapor total-field magnetometer. This data set was recorded at an uncontaminated (cold) test pit at the Idaho National Engineering Laboratory. It compares favorably to equivalent data sets collected by manual methods. The locations of the magnetic anomalies shown in this figure correspond well to known locations of buried objects. Repeated measurements over the same sets of test objects have shown that the data produced by the LSV-mounted magnetic sensors and the GPS tracking subsystem are both stable and repeatable. Figure 6 shows an orthographic projection of radiation intensity data produced by the sodium iodide gamma ray sensor. The radiation source for this test survey was a small packet of lantern mantles buried just below the ground surface.

A project is currently underway at the Pacific Northwest Laboratory to develop a compact, rugged, high-performance, ground-penetrating radar system that can be operated in a remotely controlled mode. However, the sensors currently deployed on the LSV are commercially available instruments. Modifications are being made to minimize their size, weight, and electrical power requirements and to improve their ruggedness. Each sensor includes a small embedded computer that provides interfacing to the RCS communications network.

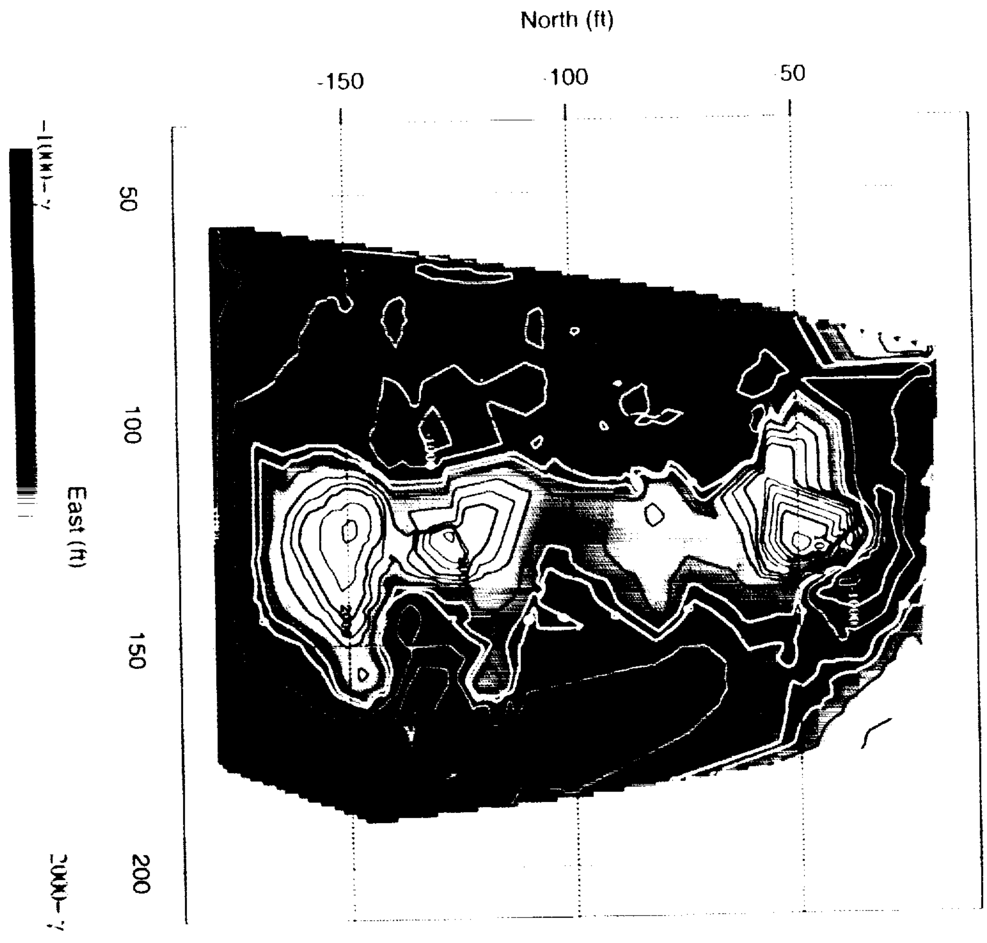

Figure 5. Total-field magnetic contour map.

CONCLUSIONS

Initial tests of the prototype system have shown that the system will provide the desired benefits of enhanced safety, efficiency, and data quality in site characterization operations. The ability of the GPS subsystem to provide accurate vehicle and sensor coordinates is particularly significant because automated tracking is a crucial factor in telerobotic operations at hazardous sites. The display of video, compass heading, and real-time GPS tracking data on the operator's console allows the operator to drive the survey vehicle accurately along desired survey paths. In addition, the real-time display of sensor output on a data display monitor allows the operator to identify features of particular interest and to ensure that the track spacing adequately delineates those features. The efficiency of the survey operation and subsequent data processing procedures is enhanced by the ability of the RCS to acquire multiple data sets simultaneously and to attach time stamps and geographical coordinates to each datum.

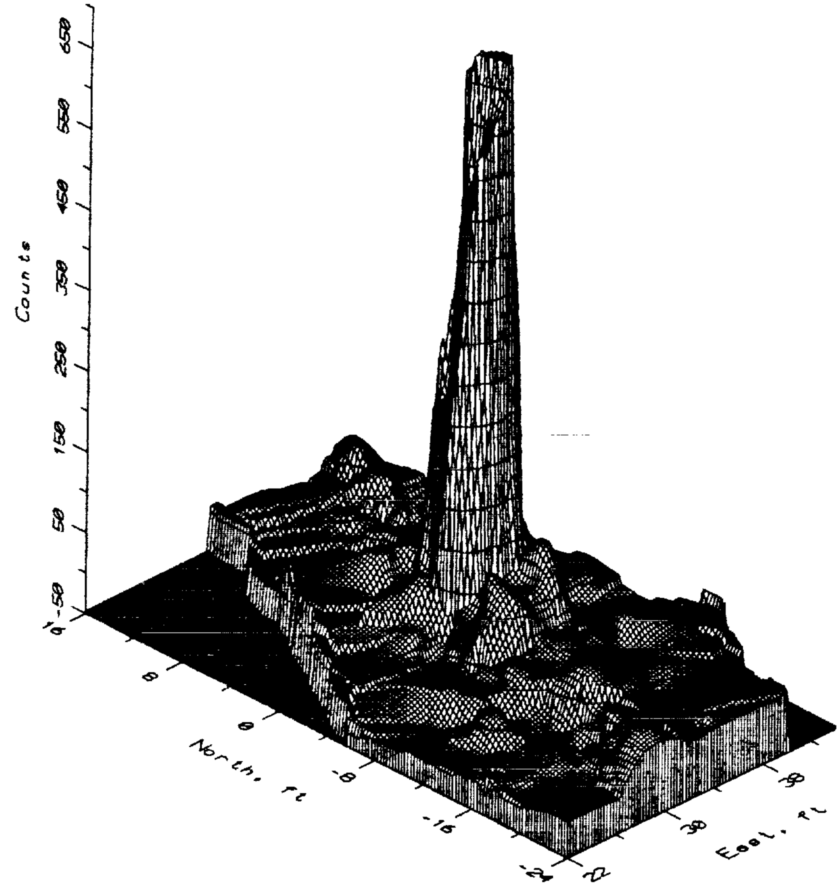

Figure 6. Orthographic projection of gamma radiation intensity from a localized source.

Although the metallic content of the LSV has not yet been reduced to the desired minimum level, the vehicle has proven to be an effective low-signature platform for the magnetic, radiological, and GPR sensors. The principal effect of the LSV's engine and the other metallic drive train components has been a reduction in the stability and effective sensitivity of the EM31 electromagnetic induction sensor. Efforts are currently underway to improve the performance of that sensor. A continuing objective of the RCS project is to further reduce the number of metallic components on the vehicle.

One of the proposed operational functions of the RCS is to work in parallel with waste site excavation equipment in what is called the "scratch and sniff" mode. This mode involves repetitive site characterization surveys as layers of overburden are removed from the waste deposit. As the chemical and/or radiological contaminants are progressively exposed, the RCS will be able to define and characterize the waste materials with increasing levels of detail and accuracy without exposing human operators to the hazards associated with proximity to the waste materials. In this mode, data relating to the distribution of waste materials and contamination levels will be used to formulate and refine excavation strategies.