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DEVELOPMENT OF ROBOTICS TECHNOLOGY FOR REMOTE CHARACTERIZATION AND REMEDIATION OF BURIED WASTE*

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ABSTRACT

Detection, characterization, and excavation of buried objects and materials are important steps in the restoration of subsurface disposal sites. The U.S. Department of Energy (DOE), through its Buried Waste Robotics Program, is developing a Remote Characterization System (RCS) to address the needs of remote subsurface characterization and, in a joint program with the U.S. Army, is developing a teleoperated excavator. Development of the RCS is based on recent DOE remote characterization testing and demonstrations performed at Oak Ridge National Laboratory and Idaho National Engineering Laboratory. The RCS, which will be developed and refined over a two- to three-year period, is designed to (1) increase safety by removing on-site personnel from hazardous areas, (2) remotely acquire real-time data from multiple sensors, (3) increase cost-effectiveness and productivity by partial automation of the data collection process and by gathering and evaluating data from multiple sensors in real time, and (4) reduce costs for other waste-related development programs through joint development efforts and reusable standardized subsystems. For retrieval of characterized waste, the Small Emplacement Excavator, an existing U.S. Army backhoe that is being converted to teleoperated control, will be used to demonstrate the feasibility of retrofitting commercial equipment for high-performance remote operations.

INTRODUCTION

Across the U.S. Department of Energy (DOE) complex are hundreds of acres of landfill waste storage areas, many of which will require remediation during the coming decades. These waste storage areas contain millions of cubic feet of radioactively contaminated materials and hazardous substances. Mixed in with the low-level radioactive waste from production and research facilities are hazardous chemicals, pyrophorics, explosives, and high-level radioactive waste. Though many drums and box containers were buried in orderly stacks, a large volume of unpackaged materials and many large, heavy pieces of equipment also were buried. Most of the packages have been buried for periods that exceed the design life of the packages. Natural phenomena such as floods and terrain subsidence have moved buried materials and shifted trench boundaries. The result is a number of waste storage areas containing a wide range of potential hazards, with little information on the specific location of particular items. Because of the potential hazard levels for the buried materials, remote performance of characterization and remediation operations is highly desirable. Also, because of the large volumes of waste that must be processed, introduction of automated remote operations wherever practical is desirable. The application of robotic systems to remediation of landfill buried waste offers opportunities for safer, faster, and cheaper solutions over the duration of these massive cleanup projects.

A team composed of members from five DOE laboratories has participated in the development of this technology which addresses the needs of buried waste remediation including: Idaho National Engineering Laboratory (INEL), Oak Ridge National Laboratory (ORNL), Lawrence Livermore National Laboratories, Pacific Northwest Laboratories, and Sandia National Laboratories. The specific objective has been to identify, develop, and demonstrate robotic technologies that support environmental remediation of buried waste, including all forms of subsurface contamination—waste disposed of in pits and trenches, waste stored on pads and covered with soil, contaminated soil, and underground piping. The technology developed is designed to allow operations personnel to perform their work functions away from the hazardous environment, and the technology is expected to be applicable to multiple sites, resulting in lower life-cycle costs.

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The activities addressed in this paper include buried waste characterization by noninvasive subsurface mapping, waste excavation, and waste retrieval. The Remote Characterization System (RCS) is the evolved result of several years of effort by the various labs to provide DOE with reliable, high-performance subsurface mapping. The Small Emplacement Excavator (SEE) combines military and DOE excavation goals into a single project to examine the feasibility of converting commercial equipment for remote operation.

CHARACTERIZATION

As part of the buried waste remediation efforts, ORNL has undertaken the development and demonstration of technology to remotely perform geophysical surveys of buried waste sites. Current noninvasive subsurface mapping techniques are labor intensive and time consuming. The emphasis of this activity has been the study of current state-of-the-art robotic technologies to reduce the time required to perform subsurface mapping and site characterization. The applied technologies provide improved data quality through automated data acquisition at a rate higher than that by typical manual operations. The technology demonstrated through this task will be applicable to various buried waste sites for both DOE and the U.S. Department of Defense.

Initial demonstration of remote buried waste characterization was performed in 1990 at ORNL.[1,2] That demonstration used the U.S. Army's Soldier Robot Interface Project (SRIP) robotic testbed to examine the feasibility of remote characterization. The SRIP vehicle (Fig. 1), developed jointly by the U.S. Army's Human Engineering Laboratory, ORNL, and Tooele Army Depot, was configured as a research testbed used for studying mobile manipulation with respect to military applications. The SRIP robot platform consists of an eight-wheeled, skid-steered utility vehicle powered by a 15-hp diesel engine with significant modifications and enhancements for remote computer control. Initial results of that demonstration showed that remote characterization was indeed feasible and that further development was merited. A series of tests and demonstrations were then performed during the summer of 1991 on actual buried waste pits at INEL and underground piping at the Idaho Chemical Processing Plant (ICPP), again using the SRIP platform.[3] The focus of these tests was the integration of multiple sensors on a single platform to provide input for program direction and further development. The objective of using multiple sensors in a remote operation was to obtain better data safer, faster, and, ultimately, cheaper. This testing represented the first attempt to remotely deploy an array of multiple sensors for subsurface characterization.

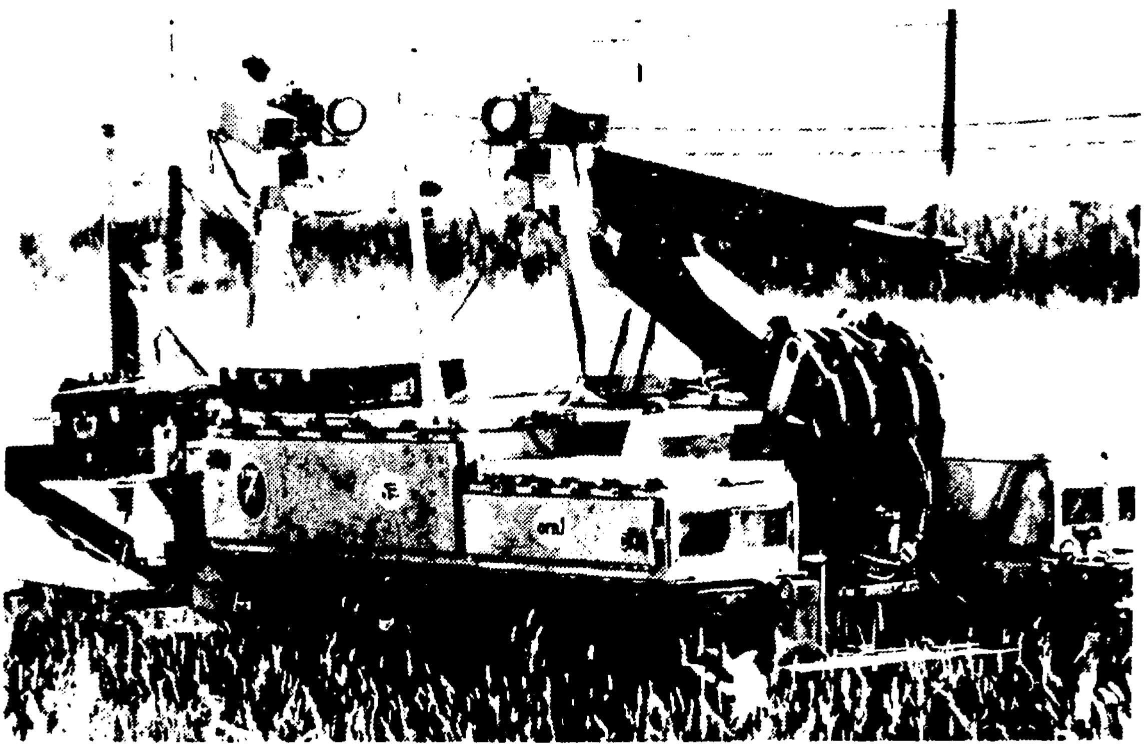

Fig. 1. SRIP vehicle with instrumentation at Idaho National Engineering Laboratory

The vehicle was equipped with subsurface geophysical sensors and sensors for detecting surface radiation and organic vapors. The sensor data and x-y position obtained from the mapping demonstration were displayed in real time on an operator's monitor and recorded for postprocessing and future reference. The display indicated areas of increased interest, thus allowing the operator to slow the platform or return to the area of interest for more detailed surveying. The specific sensors used included ground-penetrating radar, a terrain conductivity meter (EM-31), a magnetometer, a sodium-iodide gamma nucleonics detector, and a photoionization organic vapor detector. After integration of the components, the system was deployed at several locations within INEL: the Cold Test Pit and Pit 9 of the Subsurface Disposal Area, both of which were located at the Radioactive Waste Management Complex, and the ICPP construction areas where the underground piping was located.

The results of the INEL testing and demonstration directly affected the design of the RCS which has been under development starting this fiscal year. Specific recommendations based on experience gained at INEL included using a vehicle that is more appropriate for the specific site survey task. Vehicles for this application should have a low magnetic signature and be easily transportable, highly reliable, and mobile. Additional work also has been required in improving sensor response time and integration. Improved integrated real-time display of data from all the sensors has allowed for on-the-fly identification of regions of interest for further evaluation. The current RCS design features multiple sensor deployment on a platform design that minimizes effects on sensor performance. Operator control station, navigation, and communications subsystems have been designed that will be reusable in other remote vehicle applications in the DOE Office of Technology Development (OTD) Robotics Technology Development Program (RTDP). Real-time display of integrated data has been incorporated into the control station design. The RCS will be used for future buried waste site characterization studies at various sites throughout the DOE complex.

The RCS low-signature vehicle (LSV) is a relatively small six-wheeled robotic platform roughly 4 by 7 ft weighing several hundred pounds. (By comparison, SRIP weighs 5000 lb.) A small-scale prototype model is shown in Fig. 2. Actual LSV size and weight specifications will depend on several design issues that are being finalized at this time. The LSV is designed with a flexible suspension system that permits smooth transitioning over rough terrain stabilizing height-dependent sensor performance. Low-power embedded control computers keep the required power consumption to a minimum and provide a thermal tolerance higher than that of normal

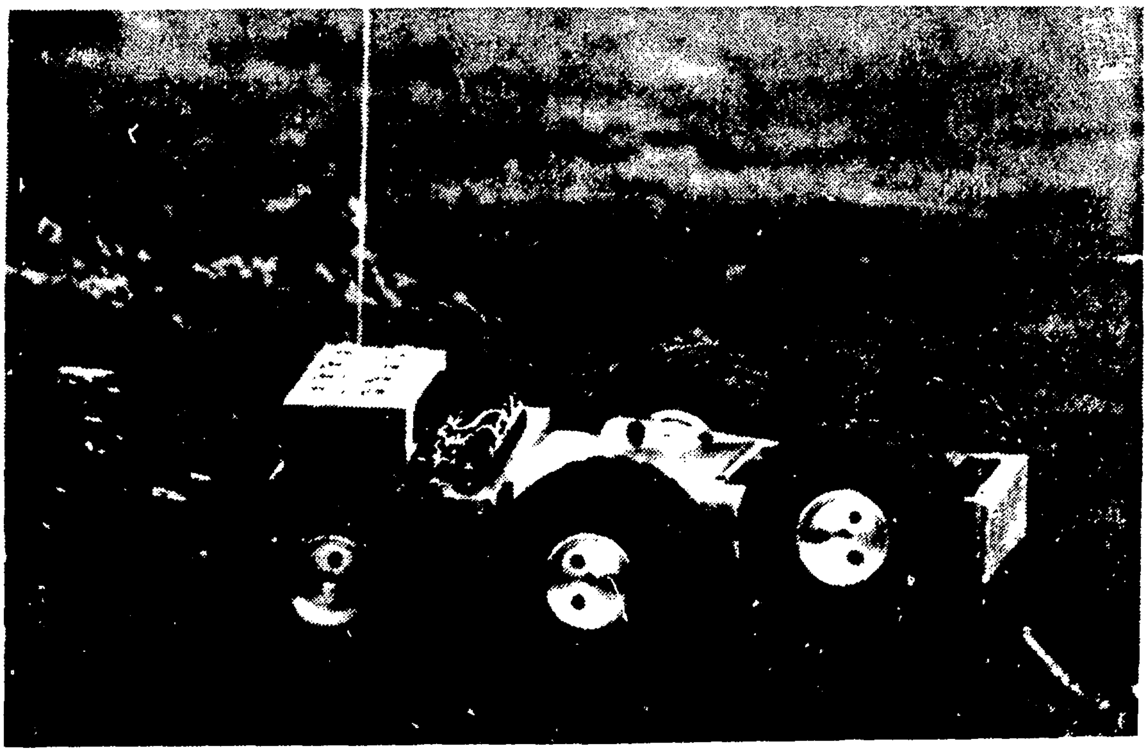

Fig. 2. Remote Characterization System prototype model

computing components. These advantages facilitate environmental sealing of the control packages and minimize the size of the power generation equipment on the vehicle. Individual sensor packages are designed to be modular, each with its own control computer; installation requires only that the sensor package be plugged into vehicle power and the computer network. Control software recognizes which instruments are on-line, configures the data acquisition system, and initiates data collection from the operator's control station. Communication from vehicle to operator control station is completed via a radio frequency link for both data collection and vehicle control. On-board cameras provide viewing for remote driving. The x-y positioning is determined by geopositioning satellite hardware.

The operator interfaces to the vehicle and survey instruments at the high-level control station (HLCS) located in a base station vehicle safely out of the hazardous environment. The HLCS provides simple function control including camera positioning, remote driving (or teleoperation), and real-time data display as well as higher level functions including supervisory and semiautonomous vehicle control and advanced data analysis (real-time and postprocessing). Simple teleoperation and real-time data display are meant to be an evolution of the previous work done at the ORNL and INEL test sites. The advanced control features emphasize as much automated survey capabilities as possible to relieve the operator from information overload. Intelligent path planning of a mapped region and automated path following are the key elements of this feature. Multiple vehicle control by one station with occasional operator input during problem resolution is one ultimate extension.

The physical configuration of the HLCS revolves around a control chair which provides the operator with ergonomic vehicle joystick controls and a keyboard and cursor interface for command inputs to the graphics-based operator interface. The viewing console is designed as a separate modular set of racks. Past remote driving station configurations have typically integrated controls directly into the remote viewing console. The operator chair was then added as a necessary but nonintegral afterthought. While this worked well in laboratory situations, it did not create a well-integrated field system. Modifications were tedious and costly. With the HLCS configuration under construction, controls on the chair can be changed readily, and remote viewing hardware can be radically altered, individually without affecting the other components in the system. The primary operator sits in the control chair driving the remote vehicle and controlling cameras with joysticks and fingertip controls. Remote viewing and a graphical interface to the control computer are mounted in the displays in front of the operator. The operator also controls sensor selection, configuration, 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. A significant key feature of the HLCS is that it has been designed in collaboration with other remotely driven vehicle projects in the OTD Buried Waste Robotics Program to help produce a standardized interface that can be used for several vehicles.

Initial testing is planned for early fiscal year 1993. After testing and enhancements, coordinated demonstrations at actual buried waste sites are planned at INEL and at the Fernald Environmental Management Project (FEMP) in Ohio later in 1993. Further testing and enhancements are expected to lead to a final deployable system by the end of 1994.

EXCAVATION

Remote excavation is the second major area under investigation in the ORNL buried waste remediation efforts. As previously stated, DOE will be required to retrieve large amounts of hazardous buried waste in the future. Because of the potential hazards and uncertainty concerning waste contents and container integrity, excavation and retrieval of these wastes using remotely operated equipment is highly desirable.

The SEE, a U.S. Army backhoe, was chosen as the development vehicle for this project because it is a commercially available system already supported as an inventory vehicle by the U.S. Army with hundreds of manually operated units in service throughout the world. The goal of this particular project is to demonstrate the feasibility of retrofitting commercial equipment to achieve high-performance remote operations. The controls technology developed for the SEE is intended to be readily portable to other hydraulically actuated vehicles for conversion to remote operation.

The SEE has a backhoe and a front-end loader as shown in Fig. 3. The vehicle was developed by Freightliner for the U.S. Army for multipurpose use including unexploded ordinance retrieval. ORNL alterations to the vehicle center around modifying the hydraulic systems for computer control. The backhoe and front-end loader will be outfitted with position encoders for use in robotic operations. Remote viewing will be provided by two color television cameras with pan-and-tilt mechanisms mounted on the truck body and a camera mounted on the backhoe boom. The vehicle drive system will be modified for remote driving. Additional sensors such as metal

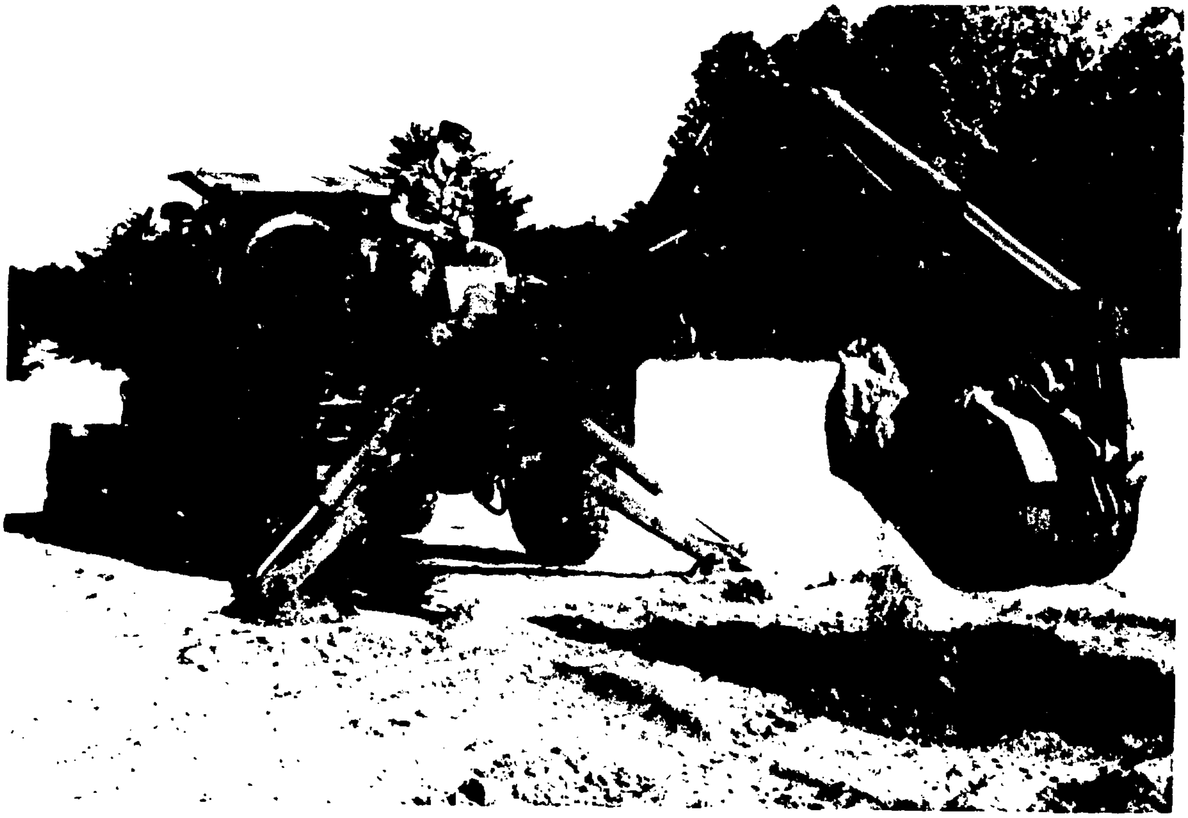

Fig. 3. Small Emplacement Excavator

detectors, radiation meters, and chemical gas samplers are being considered for improving excavation operations.

The computer system is an adaptation of an industrial design commonly used for the OTD RTDP projects. The basic system is composed of a Sun workstation host networked to a VME-based Motorola 68040 target computer running the VxWorks operating system. This technology is essentially the same as that used for the RCS control hardware. The communications system between the vehicle and base station consists of two microwave video channels and an Ethernet data radio. For U.S. Army applications where a secure communication channel may be required, a fiber-optic bundle will be used.

Three major concerns for future consideration include robotic operation, improved graphics displays, and advanced radio communications. One envisioned operator improvement is an automatic "empty bucket" procedure that will empty the backhoe's load at a preset location. This feature will eliminate the need for the operator to reposition the television cameras for each dumping operation. Another desired feature is gradual robotic excavation of a specified area. This feature would provide excavation to a precise depth as well as provide overall higher task throughput. An additional benefit of robotic excavation would be automatic digging in areas that are identified as contaminated by other robotic sensors. With such a direct method, the operator would not need to interpret the sensor data map while operating the backhoe. Graphical aids can be used to describe to the operator the existing situations with respect to vehicle position, area contamination, and excavated areas. Maps of contaminated areas can show the operator where digging operations are needed. Alternate radio communication methods are being investigated because of specific problems associated with previous communications schemes. Current microwave video systems perform well but are susceptible to multipath distortion and are poor in over-the-hill performance.

The fiscal year 1993 demonstrations planned at both INEL and FEMP are part of the OTD Integrated Demonstrations. Both demonstrations would provide a coordinated RCS/SEE effort where an area would be characterized first and then excavated. Characterization and excavation would be integrated such that they could be alternately applied as layers were removed, providing a realistic remediation scenario.

SUMMARY

The RCS and SEE remote vehicles provide a previously unavailable coordinated package capable of meeting remote characterization and remote excavation needs for remediation of buried hazardous waste. The controls architecture has been specifically designed to facilitate operation of similar vehicles and even coordinated operation. The RCS fills a technology gap in geophysical characterization. SEE capabilities may be expanded to other and larger platforms in the future. Development and testing will continue through 1994, at which point, the technology should be ready for use by the various DOE facilities.

REFERENCES

1. Richardson, B. S., Killough, S. M., Emery, M. S., Herndon, J. N., Hamel, W. R., and Burks, B. L., *Remote Site Survey and Characterization for the National ER&WM Program Using the SRIP Vehicle,* from the proceedings of the 1990 Annual Meeting of the American Nuclear Society, Nashville, Tenn., June 10–14, 1990.

2. Richardson, B. S., Killough, S. M., Emery, M. S., Herndon, J. N., Hamel, W. R., and Burks, B. L., *Remote Survey and Land Characterization Using the SRIP Vehicle*, Unmanned Systems, **8**(5), 22–24 (Fall 1990).

3. Richardson, B. S., Noakes, M. W., Griebenow, B. E., and Josten, N. E., *Buried Waste Remote Survey of the Idaho National Engineering Laboratory Subsurface Disposal Area,* from the proceedings of the 1991 Winter Meeting of the American Nuclear Society, San Francisco, Calif., November 10–14, 1991.

4. Burks, B. L., Killough, S. M., and Thompson, D. H., *Development of a Teleoperated Backhoe for Buried Waste Excavation,* Spectrum '92 Nuclear and Waste Management International Topical Meeting, Boise, Idaho, August 23–27, 1992.