THE DOE OFFICE OF TECHNOLOGY DEVELOPMENT ROBOTICS PROGRAM

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ABSTRACT

The objective of the Robotics Technology Development Program (RTDP) is to develop and apply technologies for environmental restoration and waste management that will be applicable through- out the U.S. Department of Energy (DOE) complex. These efforts are aimed at: (1) reducing worker exposure and increasing safety through remote operation and control of equipment; (2) increasing productivity through enhanced capabilities and automation; and (3) reducing costs by faster completion of remediation activities, that in turn will reduce life-cycle costs.

INTRODUCTION

Robotics spans a broad range of technologies which include master-slave, electromechanical, and servo- manipulators; remotely operated heavy equipment; special remote tooling; industrial-type programmable and autonomous robots; mobile platforms and transporters; and sensing and control systems.

The existing robotics program is based on a DOE site needs and requirements assessment. From this, a detailed applied research and development and demonstration plan was assembled to develop and deploy robotic systems to meet site needs. This program addresses:

- Waste storage tank inspection, waste characterization and retrieval,
- Buried waste characterization, down-sizing, and remediation,
- Waste facility remote and automated inspection of interim stored waste, and automated opening, repackaging, loading, and unloading systems,
- Contaminant analysis automation to increase sample throughput, decrease personnel exposure, and enhance Quality Assurance
- Decontamination and decommissioning operations including facility surveys, mobile decontamination platforms, and size reduction systems,
- Waste minimization to reduce need for storage and remediation, and
- Advanced technology for enhancing robot/automated systems.

ROBOTICS PROGRAM UNDERGROUND STORAGE TANKS - WEST

The UST Robotics West Program is focused on robotics technology support to the Underground Storage Tank Integrated Demonstration (USD-ID). Selected robotics technology development is pursued and demonstrated where the current state of the art in industry is not adequate to meet UST environmental restoration and waste management challenges. Technologies are demonstrated in a UST Robotics West Test Bed, then transferred to industry for implementation. As a first step in the technology transfer process, UST Robotics West technologists will contribute to a functional specification for a prototype waste retrieval system.

Investment in UST Robotics West provides the technology basis to perform environmental restoration and waste management operations faster, with higher productivity and associated cost benefits, and safer, through focused development on operational safety and reliability of man-machine systems. Sensor-based methods of characterizing the condition and configuration of waste tank internals, along with characterization of the waste itself, are being addressed. Through UST West Robotics developments, sensors interfaced with manipulator controls provide collision avoidance ability, preventing human operators from damaging tank internals or waste retrieval equipment. Sensors and autonomous sensor data transfer approaches to perform these functions are being developed and demonstrated in the Test Bed as increments of an integrated UST waste characterization and retrieval system.

Tools and methods for excavation of UST waste are being addressed. Methods to retrieve sludges, liquids and crystallized salt cake are being investigated. Developments are based on physical principles and on adaptations of commercially available equipment.

The useful technology envelope is extended for high weight capacity, long reach manipulators applied to highly productive retrieval of waste from USTs. Since the size of openings in the USTs is limited, effort is being applied to produce high capacity, long reach manipulators with minimal cross-section.

The UST environment in which robotic characterization and retrieval systems must operate requires special consideration by equipment developers. High radiation levels limit materials selection. Radioactive contamination of equipment creates the need for specialized decontamination and maintenance approaches. These constraints are being identified and evaluated as an integral part of the work of UST - West.

STORAGE TANKS - EAST

An initial demonstration in FY 1991 included remote contour surface mapping in an empty silo at the Fernald Environmental Management Project (FEMP). This technology has since been integrated into an actual CERCLA Removal Action, one month after the Silo 4 field demonstration.

Approaches for waste retrieval, remote mapping of waste surfaces, and enhancing an existing testbed structure will be pursued during FY 1992 and beyond. With stored wastes being both homogeneous at location such as Fernald, Idaho, Oak Ridge, and heterogenous (Hanford), prototypic retrieval devices must include a spectrum of capabilities in their design. Waste properties and storage configurations will both impact hardware component and software data processing design requirements. ST-East designs will exploit the many similarities between the tank and silo geometries and waste forms throughout the DOE complex to provide generic technology systems.

ST-East will also enhance an existing in-field testbed for RTDP and Underground Storage Tanks Integrated Demonstration (UST-ID) projects to support time-critical remediation milestones at multiple sites.

BURIED WASTE

Planning the remediation of buried waste across the DOE complex requires consideration of several factors. These include public acceptance of proposed actions, cost effectiveness, technical feasibility, health risks to workers involved in the cleanup effort, and risks to the environment from remobilizing disposed waste.

The mission of the Buried Waste Robotics (BWR) is to identify, integrate, demonstrate, and evaluate robotic technology solutions for comprehensive, cradle-to-grave buried waste remediation efforts that lower life-cycle costs and personnel radiation exposure, while increasing safety, productivity, and speed of operations.

Characterization

The BWR will develop Remote Characterization System(s) (RCS) to provide remote subsurface mapping of buried waste materials. The RCS will incorporate state-of-the-art robotic vehicle, remote controls, data interpretation, and geophysical sensor technologies into an integrated system for characterizing waste buried under various depths of soil. The technologies developed for this system will continue to be enhanced for testing and employment on site-specific RCS models. Remote characterization sensors, vehicle control, and navigation technologies can be transferred to the development of buried waste remote retrieval platforms, as well as other areas of the RTDP.

Short-term plans include the development of a remotely-controlled sensor platform with a minimal amount of metal components that may interfere with sensor signals, a control station with advanced navigation and data links for radio frequency (rf) communication of sensors and platform controls, an enhanced suite of geophysical sensors, state-of-the-art data interpretation systems for each sensor, and sensor fusion to overlay all sensor data of a mapped area.

Remote Retrieval System

The BWR will develop Remote Excavation/Retrieval Systems to test remote techniques for waste retrieval and soil excavation on a buried waste site. Methods for remediation of buried waste from site to site, and even within different areas of the same site, are dependent upon the materials handled. With the majority of buried waste being radioactive, contaminated, and hazardous in other ways, remote handling and robotics is desirable and necessary for retrieval activities. The development of remote retrieval systems will be pursued in parallel with that of the RCS, in order to maintain design continuity between the remote platforms and their associated equipment.

Activities include the remotization of an existing, hardened excavation vehicle; development of a remote control station and additional end effectors-beyond existing buckets of backhoes-for removal of various types of waste forms; preparation and demonstration of the remote retrieval system in a cold test area, and enhancements of this system for actual remediation of a hot buried waste site.

Remote Sizing System

The BWR will develop a Remote Sizing System for operation at the dig face of a buried waste site. A large percentage of waste buried in pits and trenches throughout the DOE complex is too massive for disposal in its present configuration. Therefore, volume reduction of this waste form is required to secure it into packages sized for proper disposal. This function should be performed remotely and at the dig face, rather than transferring waste to a reduction facility, in order to save time and reduce personnel exposure and cost to the overall program.

Short-term remote sizing activities for the BWR include the addition of force-based control and safety features to enhance the remote sizing manipulator developed in FY 1991, and development of a dig face delivery system for the remote sizing operations.

WASTE FACILITIES *OPERATIONS* (WFO)

DOE has waste facilities in operation at many sites, and many more of these facilities are planned as part of the site cleanup effort. As the cleanup continues, existing facilities and new facilities will be taxed with an increasing volume of waste, more varied waste streams, more complex processing requirements, more stringent waste form criteria and more challenging waste characteristics, i.e., mixed waste. The goals of robotic technology development are: to remove humans from both radiologically and physically dangerous environments in waste facilities, improve the quality and quality assurance of operations, increase the throughput of operations, increase the flexibility of facilities, reduce the manpower requirements for operations and meet federal, state and local regulations. There are four subareas within the WFO area; Stored Waste Inspection, the Mixed Waste Treatment Project, the Waste Isolation Pilot Plant (WIPP) and Remote Size Reduction.

Stored Waste Inspection

A mobile robot for remote inspection in typical stored waste facilities will be developed. Cost considerations demand the minimum width for aisles in these facilities to provide the highest facility utilization. Most of the waste stored at the facilities is in drums. Technology to be developed will aim at navigation and data collection in the narrow aisles expected in these new facilities. The robot will provide a video image of drums stacked several levels high, and store the images in a computer system to meet weekly inspection and documentation requirements for mixed waste with minimum exposure to personnel. The robot will warn of high levels of alpha particles and beta/gamma radiation, and generate a map of alpha contamination and radiation levels. This will allow early detection of spills and other problems to enable early remediation. This mobile robot will be applicable to proposed new waste storage facilities for waste drums.

Mixed Waste Treatment

In support of the Mixed Waste Treatment, this program will install a graphical interface on the Telerobot gantry robot in the Savannah River TRU Waste Demonstration Facility. This will demonstrate collision avoidance, task planning and improved operator perception for the Mixed Waste Treatment Project and other remotely-operated facilities for increased throughput and decreased maintenance. Remote sensors will be developed to allow characterization of waste items without exposure to personnel. These sensors will also provide faster and more reliable results than manual methods.

Swing-free control of a standard AC crane will be developed. Swing-free control eliminates swinging of the load induced by movement with standard cranes. This not only reduces potential damage caused by swinging loads, but offers significant reduction in the time required for movement of loads in waste facilities. This technology has been demonstrated on a special DC driven crane under programmed control and will be extended to standard AC cranes. Technology for swing-free operations under typical manual control will also be developed.

Opening and Repackaging System

The design and development of a remote drum opening and emptying system will be completed. The system will remotely open a 55 gallon drum and liner, and remove the contents. This project will demonstrate technology that will isolate personnel from the radiological and physical hazards of manual opening and emptying of waste drums.

WIPP Robotic/Automated Systems

The Waste Isolation Pilot Plant (WIPP) requires systems for TRUPACT handling operations, remote tunnel inspection and emergency response equipment. Technology for dramatically increasing throughput of TRUPACT handling operations and reducing radiation exposure during radiological surveys will be developed. Technology for the WIPP remote tunnel inspection mobile robot will be developed for improved quality and documentation of data and increased reliability. Specifications will be developed for an emergency response vehicle, for use in initial deployment for situation evaluation in an emergency at the WIPP facility.

Remote Size Reduction System

Plasma arc cutting is the leading process for size reduction of metal equipment and components. This program will continue the development of technology for automatic parameter control of plasma arc cutting. Force control and sensor-based control will be developed for automatic control of standoff distance. Sensor-based control to provide optimum cutting speed will also be developed. This technology will provide increased process reliability and increased speed of operation while ensuring complete cut-through of material.

LABORATORY AUTOMATION

DOE has significant amounts of radioactive and hazardous wastes stored, buried, and still being produced at many sites associated with its activities. Historic waste disposal and storage manifests have been found to be incomplete or missing at many sites. Moreover, for much of the waste, prolonged storage or burial has caused leaching-induced migration of the material into the surrounding environments. Therefore, stored and buried wastes need to be analyzed for element, isotope, and compound content. Contaminant analysis must occur before site remediation can occur.

The requirements for sampling and analysis will increase sharply as DOE is required to devise and defend environmentally- sound site remediation plans. Analysis needs are projected to increase from the current 2-3 million samples per year to 10 million samples per year by 1995.

Due to the unique characteristics of the DOE waste (i.e., the presence of radionuclides), most commercial analytical laboratories are not equipped to perform the remote analytical processes. The projected work load far exceeds the current capacity of certified DOE and commercial laboratories. Productivity in the analytical laboratories must be increased while the cost of analyses are reduced.

Intelligent systems must be developed for analytical laboratories that essentially automate the time, risk, and cost intensive steps required to take a sample and produce interpreted results. The approach to laboratory automation recommended by a DOE Laboratory automation study group calls for the development of automated laboratory systems to perform standard analysis methods (SAMs) according to rigorous specifications. The system performing a SAM would receive a sample and produce interpreted analytical data as output while automatically maintaining necessary records for quality assurance and quality control. The automated laboratories would be assembled from SAMs together with a Laboratory Information Management System or LIMS.

The long-term goal is the full automation of required analytical characterization techniques to allow complete instrumentation packages to be delivered to the waste sites for on-site characterization.

Two EPA Methods have been selected for implementation of the SAM technology. The first method identified for automation is EPA Method 3550, sonication extraction. Method 3550 extracts nonvolatile and semi-volatile organic compounds from solids such as soils, sludges, and other waste forms. In addition, it includes some cleanup steps common to many extraction protocols. Identification of this protocol as a candidate for early automation was based on the fact that it is widely used, employs several common laboratory unit operations, and represents a significant part of the overall analysis cost. EPA Method 3540, soxhlet extraction, is the next protocol to be automated within the SAM formalism. Similar to EPA 3550, it is time-consuming and performed very often. This method also uses many of the SAMs developed for Method 3550.

A second long-term goal of the program is to develop SAMs in an unconventional setting. These settings include on-site locations, so that transport of potentially hazardous samples is avoided. SAMs will also be developed within the confines of a silicon wafer, in essence making a SAM on a chip for in situ measurements and data reduction.

DECONTAMINATION AND DECOMMISSIONING

Present and advanced technology robotic systems are required to characterize, decontaminate, dismantle, and decommission hazardous and/or contaminated facilities safely and cost- effectively.

Nearly every DOE site has contaminated facilities that must be decontaminated and decommissioned over the next three decades. Because of the diversity of the DOE activities, there is a wide variety of facilities and contaminates to be addressed. The objective of a decontamination and decommissioning (D&D) activity can range from removing old processing equipment and replacing it with new equipment to full restoration of the landscape.

Hazards associated with D&D are the radiation, contamination, and hazardous chemicals associated with the processes performed at the facilities. Many of the D&D activities must be performed remotely. Characterization must be performed using remote means to protect personnel from undefined hazards. This will include radiation mapping, swipes for contamination, facility mapping for 3-D world models, and samples for chemical containment analysis. D&D operations include disassembly of process equipment, size reduction of equipment to be removed, transport out of the hot cells, decontamination of some equipment before removal from a facility, and decontamination of walls and remaining equipment in facilities to be refurbished. Robotics may also be needed for the dismantlement of the facility structure itself. Hardened robotic systems for D&D can provide capabilities to allow reliable operations with workers in a safe environment away from the work site. Programmable, sensor-based robots can reduce the time required for repetitive D&D operations.

ROBOTICS WASTE MINIMIZATION

The objective of automating plutonium processing is to remove the operator from the glove box environment. This specifically supports the DOE program goal to eliminate or greatly reduce, through design materials and process changes, both current and future waste streams associated with the production of nuclear weapons.

The focus of these tasks is to apply proven commercial and advanced robotics and automation technologies to the existing waste generation problems identified by the production plants and the DOE laboratories, and to anticipate projected future waste handling needs involving applications of the technologies in potential DOE facility modernizations.

Four task areas for robotics applications to Pu processing have been identified. These can impact both the direct chemical processing waste and the combustible waste *generation* by reducing operator-associated waste and improving processing efficiency and yield. These areas are:

- Automation of Pu processing furnace operations with robotic assistance,
- Bagless transfers of Pu-related materials in and out of glove boxes and linked lines,
- Automated handling of Pu oxide and dust control, and
- Robotically-assisted Pu product button breakout and cleaning.

CROSSCUTTING AND ADVANCED TECHNOLOGY (CC&AT)

The Crosscutting and Advanced Technology (CC&AT) task of the Robotics Technology Development Program develops needs-based generic and advanced technology which holds significant promise to provide faster, safer, and cheaper robotic systems for application to DOE's Office of Environmental Restoration and Waste Management (ER&WM) problems as outlined in the ER&WM Five-Year Plan.(1) Although ER&WM applications vary widely, much of the underlying technology is generic, and can be applied to many ER&WM robotic systems. This subtask reduces the overall cost of technology development by fostering the development of general technologies and supporting their broad application. In particular, modular mechanism, control, and sensing technologies can be applied to many ER&WM application. As advances occur in the computing, material and other sciences, this task integrates those advances into new mechanical, control, and sensory subsystems capable of further reducing the time and cost of ER&WM operations while providing greater environmental and operator safety. CC&AT depends heavily on coordinating the talents in DOE, industry, university, and other governmental laboratories into a focused technology development effort.

CC&AT carries out activities in three areas:

- Advanced Robot System Controls

  This activity builds upon the Generic Intelligent System Controller (GISC) development supported in other tasks, to incorporate advanced error detection and recovery technologies and extend the development of modular software architectures. The concept of an Intelligent Robot Operating Environment in which the communication software requirements specific to model-directed robotic systems operating in a multiprocessor computing architecture are formally defined, is applied to GISC.

- Environmental Sensing Systems

  This technology development effort addresses continuation of the systems development of the minilab. The minilab incorporates an environmental sensing package into an existing robot system to provide in-situ automated environmental characterization. Miniaturized, complementary, sensing technologies developed for specialized applications such as weapons monitoring have been integrated into a sensing subsystem for the gas phase detection of volatile organic compounds, hydrogen, radiation, temperature, pressure, and moisture. In addition, gamma spectroscopy has been integrated into a sensor ensemble.

An important result of integrating multiple sensing modalities into a single sensory subsystem is that characterization, such as flammability, which can not be measured directly, can be assessed. The minilab in-situ sensor laboratory will be expanded to incorporate additional sensing modalities and development of advanced sensor fusion technologies. The main product of this environmental sensing development laboratory will be integrated micro-sensor systems suitable for robotic deployment. This work will serve as a basis for further micro-miniature sensor systems development in subsequent years.

- Mechanisms

  The environmental hardening of robot mechanisms has been identified as an important technology development area. Sandia National Laboratories will initiate development into environmental hardening of robot manipulator mechanisms with particular emphasis on the development of highly modular mechanisms which facilitate maintenance. The initial application area for such technology is in underground storage tanks where significant robot maintenance is anticipated.

REFERENCES

1. U.S. Department of Energy, Environmental Restoration and Waste Management Five-Year Plan, Fiscal Years 1993- 1997; Washington, D.C., August, 1991.