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FY94 OFFICE OF TECHNOLOGY DEVELOPMENT MIXED WASTE OPERATIONS ROBOTICS DEMONSTRATION (U)

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EXECUTIVE SUMMARY

The Department of Energy (DOE) Office of Technology Development (OTD) develops technologies to help solve waste management and environmental problems at DOE sites. The OTD includes the Robotics Technology Development Program (RTDP) and the Mixed Waste Integrated Program (MWIP). Together these programs will provide technologies for DOE mixed waste cleanup projects. Mixed waste contains both radioactive and hazardous constituents. DOE sites currently store over 240,000 cubic meters of low level mixed waste and cleanup activities will generate several hundred thousand more cubic meters. Federal and state regulations require that this waste must be processed before final disposal.

The OTD RTDP Mixed Waste Operations (MWO) team held several robotic demonstrations at the Savannah River Site (SRS) during November of 1993. Over 330 representatives from DOE, Government Contractors, industry, and universities attended. The MWO team includes: Fernald Environmental Management Project (FEMP), Idaho National Engineering Laboratory (INEL), Lawrence Livermore National Laboratory (LLNL), Oak Ridge National Engineering Laboratory (ORNL), Sandia National Laboratory (SNL), and Savannah River Technology Center (SRTC). SRTC is the lead site for MWO and provides the technical coordinator. The primary demonstration objective was to show that robotic technologies can make DOE waste facilities run better, faster, more cost effective, and safer. To meet the primary objective, the demonstrations successfully showed the following remote waste drum processing activities: non-destructive drum examination, drum transportation, drum opening, removing waste from a drum, characterize and sort waste items, scarify metal waste, and inspect stored drums. To further meet the primary objective, the demonstrations successfully showed the following remote waste box processing activities: swing free crane control, workcell modeling, and torch standoff control.

INTRODUCTION

The DOE Weapons Complex sites produce special nuclear materials for military, space, and medical applications. Normal production and decommissioning operations generate radioactive and hazardous wastes. Sites typically store small solid waste items, like protective clothing, in 55 gallon drums and large solid waste items, like decommissioned equipment, in metal boxes. DOE sites currently store over 240,000 cubic meters of low level waste containing radioactive and hazardous constituents, or low level mixed waste. Cleanup activities will generate several hundred thousand more cubic meters of low level mixed waste over the next five years.

Federal and state regulations require that stored low level mixed waste must be reopened, characterized, processed, and repackaged for final disposal. Regulations also require that cleanup activities minimize: personnel radiation exposure, personnel safety risk, and waste generation. Personnel in protective clothing can perform these cleanup tasks, but there are the following disadvantages: 1) personnel will receive radiation exposure during routine operations, 2) manually size reducing and decontaminating large items will be a safety concern, and 3) operations will generate new waste in the form of protective clothing. The OTD RTDP develops robotic technologies to remotely process mixed waste. These robotic systems will reduce personnel exposure, minimize personnel safety risk, and generate less secondary waste compared to manual operations.

The SRS hosted the MWO Robotics Demonstrations during the first week in November of 1993. The MWO team included representatives from LLNL, SNL, ORNL, INEL, FEMP, and SRTC. The objectives were:

- Show that robotics can make DOE waste facilities run better, faster, more cost effective, and safer.
- Demonstrate available technologies to U. S. industries for possible technology transfers and partnerships.
- Involve universities in DOE projects and indicate future DOE research needs.
- Inform the public of DOE efforts in Environmental and Waste Management projects.

TECHNICAL DISCUSSION : DRUM PROCESSING

DOE sites temporarily store hazardous and radioactive solid wastes in various containers including metal drums. Many drums must be reopened to allow the waste to be processed and repackaged for final disposal. These operations must be performed remotely to reduce personnel exposure to hazardous and radioactive environments. The OTD demonstration included several drum processing operations in a non hazardous environment. The following sections describe the systems demonstrated.

Non Destructively Inspect Drum

LLNL developed a Drum Computed Tomography (CT) system that determines drum contents without opening the drum [1]. The system uses passive and active data acquisition techniques. The passive technique measures various energy gamma-rays emitted from a drum to identify the location and type of radioactive sources. The active technique uses a known x- or gamma-ray source to pass rays through the drum. The system records attenuated rays and uses this information to calculate the drum waste matrix density. The active data is also used to correct the passive results. The end result is an accurate three dimension representation of drum contents. Since the drum CT equipment is large and uses high energy waves, it was not sent to SRS for the demonstrations. Each demonstration included a video showing the system and sample results.

Transport Drum

The SRTC Telerobot used the INEL developed drum lifter to lift and transport drums [2]. The Telerobot is an 8 axis robot made by PaR Systems Inc. The Telerobot uses a bridge, trolley, and telescoping tubes to provide x, y, and z motions. A five axis robotic arm hangs from the telescoping tubes and it provides shoulder rotate, shoulder pivot, elbow pivot, wrist pivot, and wrist rotate motions. An Applied Robotics tool changer mounted on the wrist allows the Telerobot to pickup various tools. A second Applied Robotics tool changer mounted on the shoulder (directly under the telescoping tubes) allows the Telerobot to pick up heavier items like the drum lifter.

The drum lifter has four main parts: the mating plate, support structure, four belt supports, and an adjustable belt (see figure 1). The Telerobot uses the mating plate to pick the lifter up, the support structure anchors the belt supports and houses the electronics, the belt supports allow the belt to expand and contract, the belt changes circumference to grab or release the drum. When a drum is being grabbed, the computer system monitors force transducers on the belt to ensure proper gripping force is obtained. When a drum is being released, the computer system monitors position sensors to ensure the lifter is fully opened. The four belt supports are approximately 75 centimeters long to allow the lifter to grab a drum at the top, middle, or bottom.

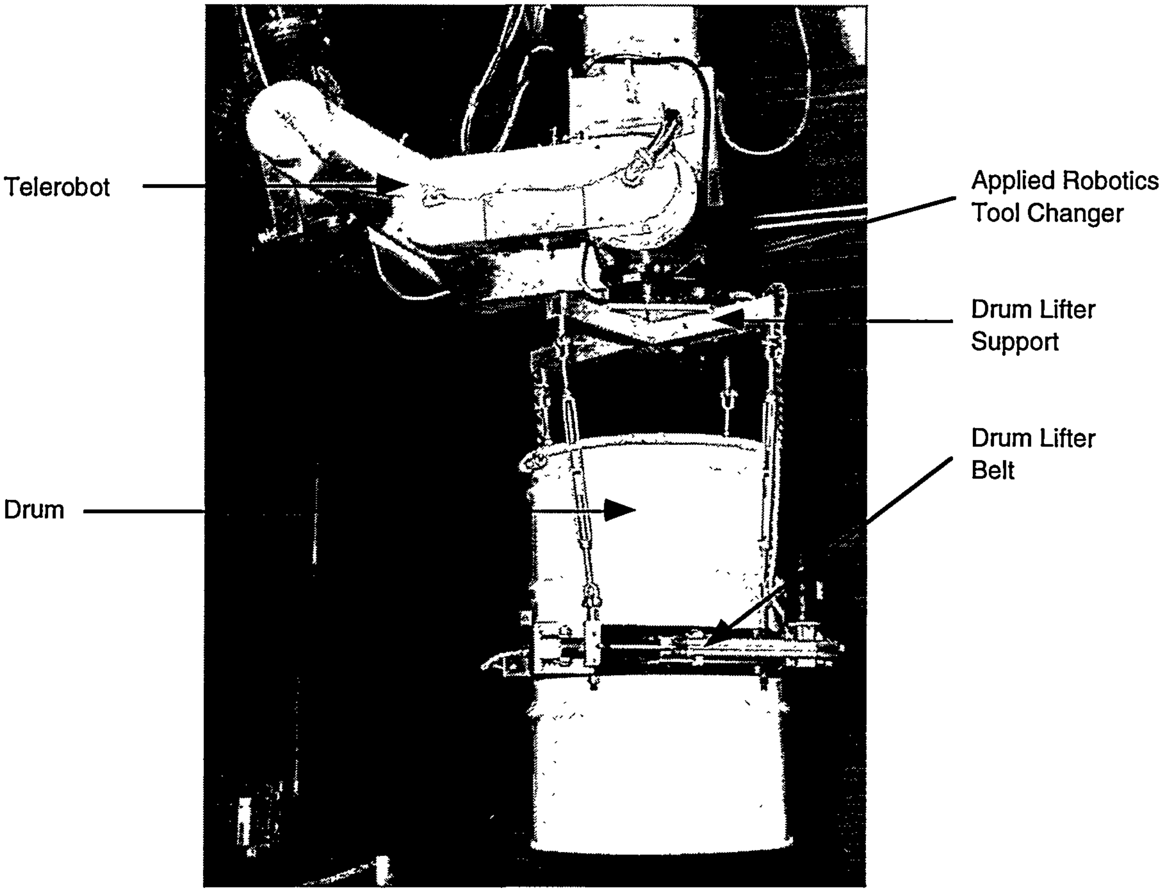


Figure 1 - Telerobot and Drum Lifter

Each demonstration included the Telerobot using the drum lifter to transport a drum from a conveyer to the drum opener and transporting cut drum parts from the opener to a storage area.

Open Drum

SRTC, with help from Merrick Inc., developed an automated drum opener (see Figure 2). The opener has three main parts: a turntable, two tool arms, and a computer based control system. The turntable is a large lathe style chuck capable of holding 30, 55, and 83 gallon drums and can rotate up to 60 rpm. Each tool arm can raise and apply follower wheels and a cutting tool to the drum being cut. Cameras mounted on the tool arms allow the operator to view the cutting progress. The Apple Macintosh computer based control system allows operators to manually operate the opener from a Labview™ environment, prevents operators from making mistakes (i.e. driving a tool into the chuck), and allows other computer systems to operate the system. Each demonstration included the drum opener cutting a 55 gallon drum with a cutting wheel and cutting a plastic drum liner with a parting tool.

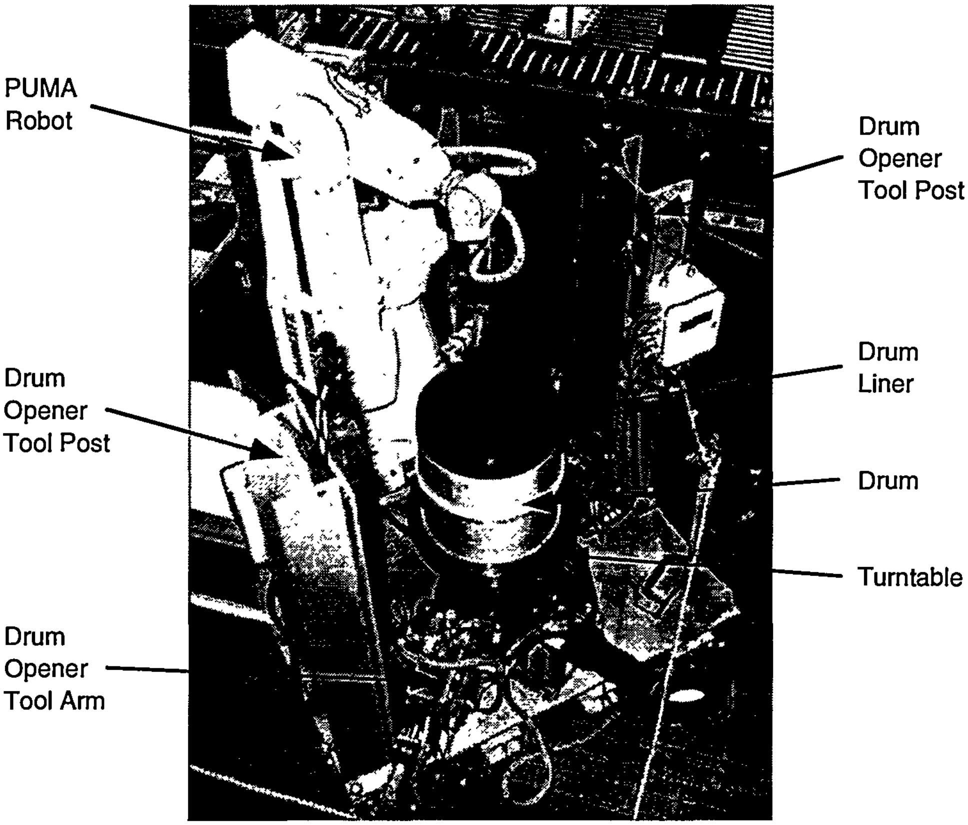


Figure 2 - Drum Opener and PUMA Robot

SRTC Supervisor

SRTC used a Silicon Graphics computer to run a Graphical User Interface (GUI), three dimensional (3D) workcell model, and control software [3]. The GUI is a menu set that allows an operator to program the devices in the workcell without writing software. The 3D workcell model accurately represents the workcell equipment and it allows the operator to preview operations from any perspective. The control system is based on the SNL Generic Intelligent System Controller (GISC) software and it ensures proper communications between all systems.

Each demonstration included the operator using the GUI, 3D model, and control software to preview, initiate, and monitor several operations. For example, when the operator wanted the PaR robot to pick up the drum lifter, he would open the PaR menu, select drum lifter, and select "get it." The Interactive Graphical Robot Instruction Program (IGRIP) model would show the PaR robot picking up the lifter. The GUI would pop-up a dialog box asking the operator if this is the desired operation. The operator would accept the operation, the GISC would transfer the user defined program to the robot controller, the robot would get the lifter, and IGRIP would track the robot motion in real-time. Looking at the previous example, assume a device is between the robot and the drum lifter. When IGRIP shows the robot moving to the lifter, it would detect the collision between the robot and the device. The GUI would tell the operator this move is invalid, and ask if it should find an alternate collision free path.

Remove Drum Contents

LLNL and SNL developed a singulation system that can remove waste items from a drum or waste pile [1]. The singulation system has three main parts: a PUMA robot, control system, and force ball. The PUMA-762 is a six axis robot with a JR3 Force/Moment sensor and Robohand tool changer mounted on the wrist (see Figure 3). The JR3 weighs items and the Robohand system allows fast automated tool changes. The control system included the standard PUMA robot controller and the GISC compatible Sequential Modular Architecture for Robotics and Teleoperation (SMART) system [4]. SMART is a software system that links input devices (i.e. force ball) to robots. The CIS Dimension 6 force ball is similar to a joystick except that it is a sphere and it doesn't move. The operator applies forces and moments on the ball and SMART converts these to robot motions in real-time. Each demonstration included singulating waste items from a waste pile. An operator used the force ball and remote cameras to position the PUMA gripper around a waste item. The control system closed the gripper, moved the PUMA over the conveyer tray, and released the waste item.

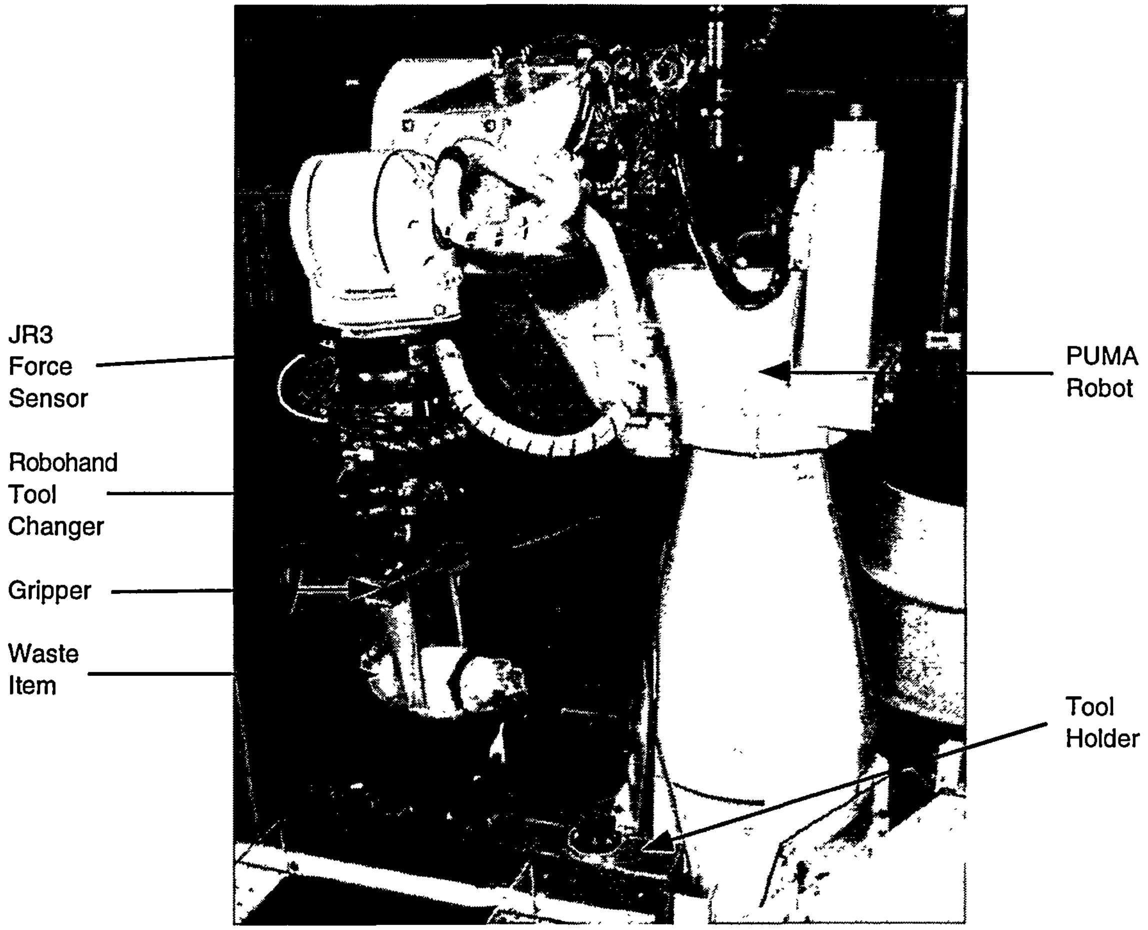


Figure 3 - PUMA Robot

Characterized Waste Items

LLNL developed a waste characterization system that efficiently and reliably determines the physical characteristics of waste items. The system has six main parts: a force sensor, conveyer, profile detector, metal detector, radiation detector, and control computer (see Figure 4). As the PUMA robot transports a waste item to the characterization conveyer, the JR3 force sensor on the PUMA wrist determines its weight. The conveyer uses a belt and trays to transport waste items to the various sensors. The belt and trays are plastic to reduce false readings from the metal detector. The profile detector is an archway over the conveyer that emits light from one side and detects light on the other. As an item passes through the arch, the light beam is broken for some time and the system approximates its volume.

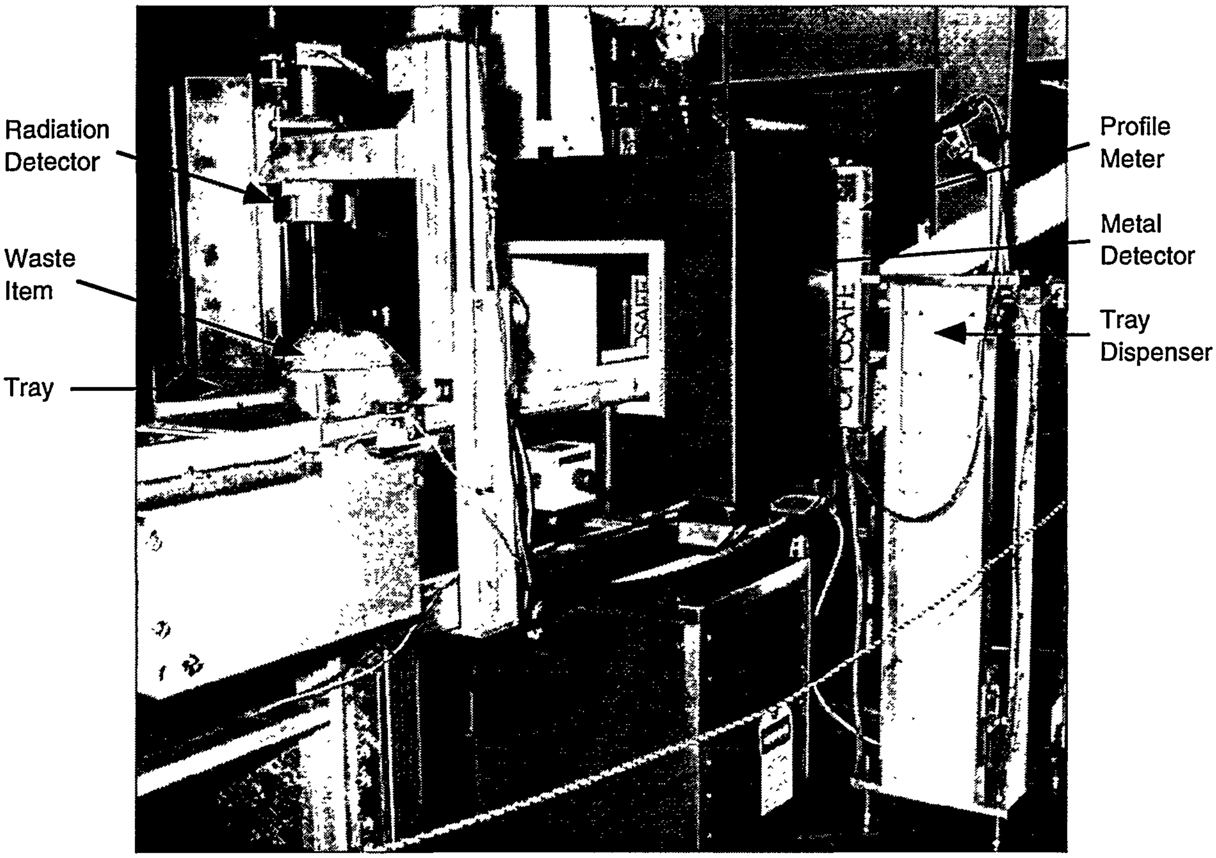
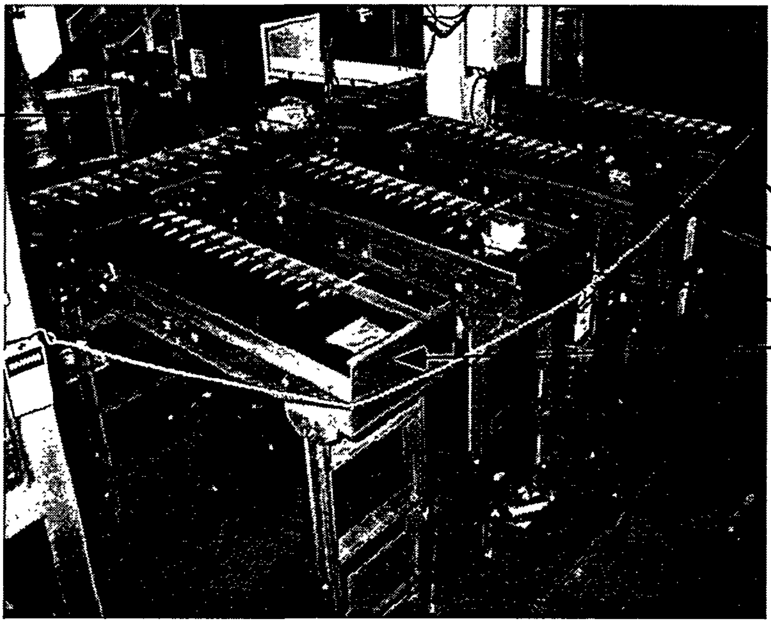


Figure 4 - Characterization System

The metal detector is also an archway over the conveyer and it creates a magnetic field around the conveyer. Metal items passing through the detector change the magnetic field and the approximate metal volume is calculated based on this change. A Sodium Iodide radiation detector over the conveyer determines if waste items contain radioactive sources. The control computer is a 68030 microprocessor running in a VME system and is linked to the hardware via serial and parallel ports. The VME Central Processing Unit (CPU) ran low level driver and server software for each major component. These servers link via Ethernet to supervisory clients running on the host computer. The supervisor will be discussed in a later section. Each demonstration included the characterization of several waste items.

Sort Items Into Waste Streams

LLNL developed a waste sorting system that determines the waste item type and sent the item to the proper processing system (see Figure 5). The sorting system uses data from the characterization sensors to determine the waste type. Since some data is approximate and some is graduated, a fuzzy logic algorithm decided the item type. The five waste types are: high radioactive content, non metal, homogenous metal, heterogeneous metals, and metal with non metal. A set of roller conveyers transported the waste items to the proper processing system. Each demonstration included the sorting of several waste items.



Waste Item On Tray

Conveyers To Various Processing Stations

Figure 5 - Sorting Conveyer

Process Waste Streams

Due to time and space limitations, the MWO demonstration only included the processing of a homogenous metal waste stream. LLNL developed a decontamination system that scarifies items with Carbon Dioxide (CO2) pellets, inspects items for contamination, and palletizes items.

The decontamination system has three main parts: a robot, CO2 blaster, and control system (see Figure 6). The robot is a 4' x 4' x 20' IBM six axis gantry robot and has a 50 pound lifting capacity. All six joints and the gripper are electrically driven. Operators use a CIS Dimension 6 force ball to manually control the International Business Machines (IBM) robot and the robot can be autonomously controlled. The Alpheus CO2 blaster, provided by SRTC, places frozen CO2 pellets into a high velocity air stream and discharges the mixture through a specially designed nozzle. The nozzle is mounted to a down draft chamber in the IBM robot workcell. The pellets hit the item being cleaned, remove surface contamination, and sublimate. The only waste product is debris removed from the item. The control system is a robot control software package called Robline by Cimetrix and a LLNL supervisor. Robline includes a 3D computer workcell model, off-line programming, and multitasking capabilities. The supervisor includes a GUI and state manager.

Figure 6 - IBM Robot and CO2 Blaster

Each demonstration included the processing of a homogeneous metal waste item. Painted Aluminum blocks simulated contaminated lead bricks for these demonstrations. The block entered the robot work envelope via the sorting conveyer. Operators manually picked up the block and instructed the robot to autonomously pass it back and forth in front of the CO2 nozzle. The Robline 3D model simulated this task and asked if this should be executed. The operator accepted the move and the supervisor downloaded the program to the controller. The robot cleaned four sides of the block, set it down, cleaned the gripper fingers, picked up the block, and cleaned the remaining sides.

Operators instructed the robot to perform the warm survey, Robline simulated this task, operators approved the task, and the robot passed the item in front of a non-contact radiation detector. The robot passed the item through a simulated airlock to the cold inspection area. Due to space limitations, the same robot performed the warm and cold inspection functions. The cold inspection included a non-contact and a swipe survey. The cold non-contact survey was identical to the warm non-contact survey. The robot picked up a swiping tool, slid it across the item, and placed the swiping tool in a simulated radiation counter. The robot then places the block on a 12" x 12" pallet and the pallet conveying system removed full pallets.

LLNL Supervisor

LLNL used five independent processes to control their equipment during the demonstration [1]. The first process is the Supervisory Control System (SCS) and it distributes control responsibilities, coordinates tasks, and dispatches information to the other processes. The SCS interfaces with the graphical robot simulation package

Robline, by Cimetrix. The second process is the menu manager and it maintains all interfacing to the SCS and provides a GUI for the operator. The third process is singulation and it controls the PUMA robot and associated sensors. The forth process is classification and it controls the tray dispenser, conveyers, sensors, and characterization algorithm. The fifth process is scarification and it controls the IBM robot and CO2 blasting system.

Communications between processes are requests for actions or requests for data. Each process incorporates an event driven finite state machine and communications are streamlined into single event queues for each task.

Each demonstration included an operator using the SCS and Robline simulation to preview, initiate, and monitor several operations. For example, when the operator wanted the IBM robot to scarify an item, he requested the operation from the SCS GUI, Robline previewed the operation, and asked the operator if this was acceptable. If the operator accepted the operation, the new generated motion program was transferred to the IBM robot controller and executed. Robline will not download a motion that includes a collision.

Inspect Drums During Interim Storage

SRTC developed a Stored Waste Autonomous Inspector (SWAMI) to survey floors and inspect stored drums [9]. SWAMI is a mobile robot with navigation, video, bar code, radioactive survey, data logging, and supervisory systems (see Figure 7). The navigation system monitors the SWAMI position and allows it to autonomously maneuver through drum storage areas collision free. The video system can capture and recall drum images for comparison. The bar code system locates and reads the drum bar code. The radioactive survey system inspects the floor in front of SWAMI for sources and stops motion before the vehicle enters the contamination. The data logging system stores all the information received about each drum, location, time, date, image, and bar code. This information is off loaded after each inspection to a host computer and can be recalled for comparison. The data logging system also combines date, time, location, and survey results to generate an updated radiation map of the storage area. The supervisory system integrates all the subsystems to complete complicated tasks.

Each demonstration included SWAMI autonomously navigating around a simulated drum warehouse, reading drum bar codes, storing drum images, and finding a simulated radioactive source on the floor.

TECHNICAL DISCUSSION : BOX PROCESSING

DOE sites temporarily store hazardous and radioactive solid wastes in various containers including boxes. Boxes are metal or wood and usually contain large items, like decommissioned process equipment. Many boxes must be reopened to allow the waste to be processed and repackaged for final disposal. These operations must be performed remotely to reduce personnel exposure to hazardous and radioactive environments. The OTD demo included several large waste item processing operations in a non hazardous environment. The following sections describe the systems demonstrated.

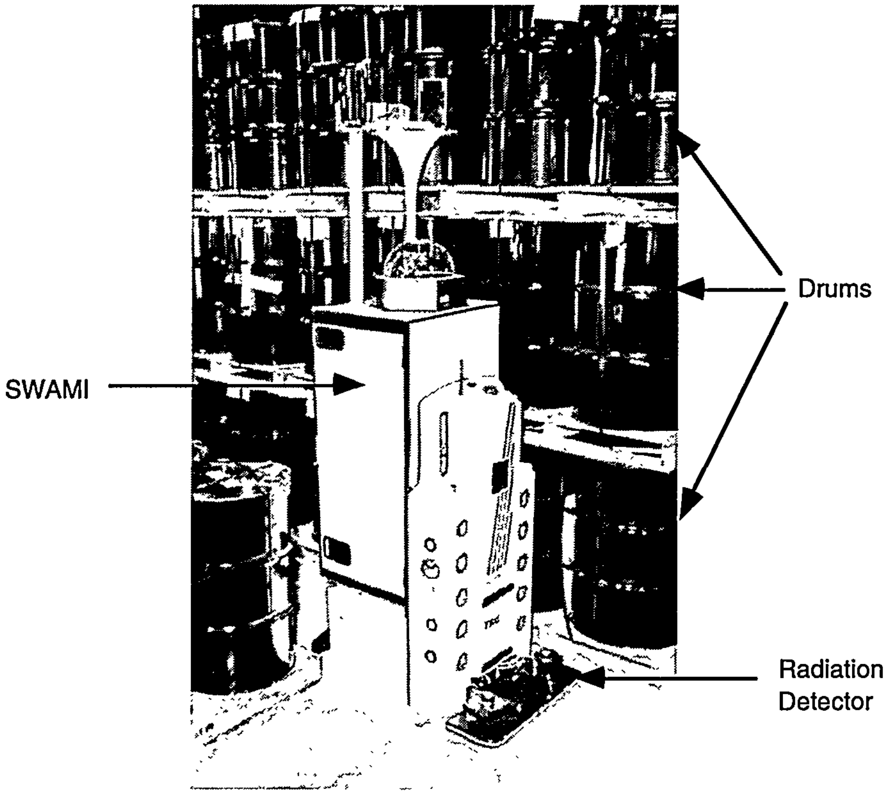


Figure 7 - Stored Waste Autonomous Mobile Inspector

Swing Free Crane Control

SNL and ORNL developed a crane control system that prevents the payload from swinging while the crane starts, moves, and stops. SNL patented the original technology, transferred it to ORNL, and ORNL revised it. The ORNL system uses a 30 ton crane with AC motors, commercially available motor drives, and a computer system. When the operator commands the crane to move, the computer system accelerates the motors so that the payload starts moving without any over-swing. When the operator commands the crane to stop, the computer decelerates the motors so that the payload stops without any over-swing. Each demonstration included a videotape showing the full size ORNL crane moving a drum without swinging. Also, each demonstration included the SNL table top swing free display moving a metal ball around obstacles collision free without swinging.

Workcell Modeling

SNL and Mechanical Technologies Inc. (MTI) developed a Structured Lighting System (SLS) that scans a workcell item, creates a 3D data file, and sends the data file to the IGRIP workcell model [5]. The SLS uses 4 stages and a control computer. The four stages are in a 20' x 20' square in the Telerobot workcell and each is 16' off the ground. Each stage consists of a camera, laser line projector, and a pan/tilt unit. The pan/tilt units accurately move the laser and camera and provide position data to the control computer. The control computer digitizes camera images, moves the pan/tilt units, and analyzes data.

The following procedure will import a new object into the IGRIP workcell. An operator defines an area to be scanned (i.e. an area containing a new object) and the stages to scan with. The SLS uses one stage to pass a laser line over the area while another stage camera views the laser line passing over the target object. The SLS repeatedly digitizes the camera view as the laser line passes over the target object. The camera threshold is adjusted to only show the laser line. Knowing the camera and laser orientation for each digitized image, the computer system calculates the target object height at many locations. The SLS compiles the height and location data in an IGRIP formatted file. IGRIP imports this data file as a new object in the simulated workcell.

Each demonstration included IGRIP importing a scanned object into the simulated workcell. The scanning operation takes approximately fifteen minutes, so operators scanned objects before the demonstration.

Torch Standoff

SRTC developed a torch control system that maintains the plasma torch standoff distance during robotic cutting operations [6]. The standoff system has four main components: Telerobot, torch, laser range finder, and computer (see Figure 8). The Telerobot uses the wrist Applied Robotics tool changer to hold the torch end effector. The torch is a Thermal Arc 45 Plasma Torch that uses a Hydrogen/Argon gas mixture and electricity to create the plasma. The plasma melts metal items to be cut and blows the molten material

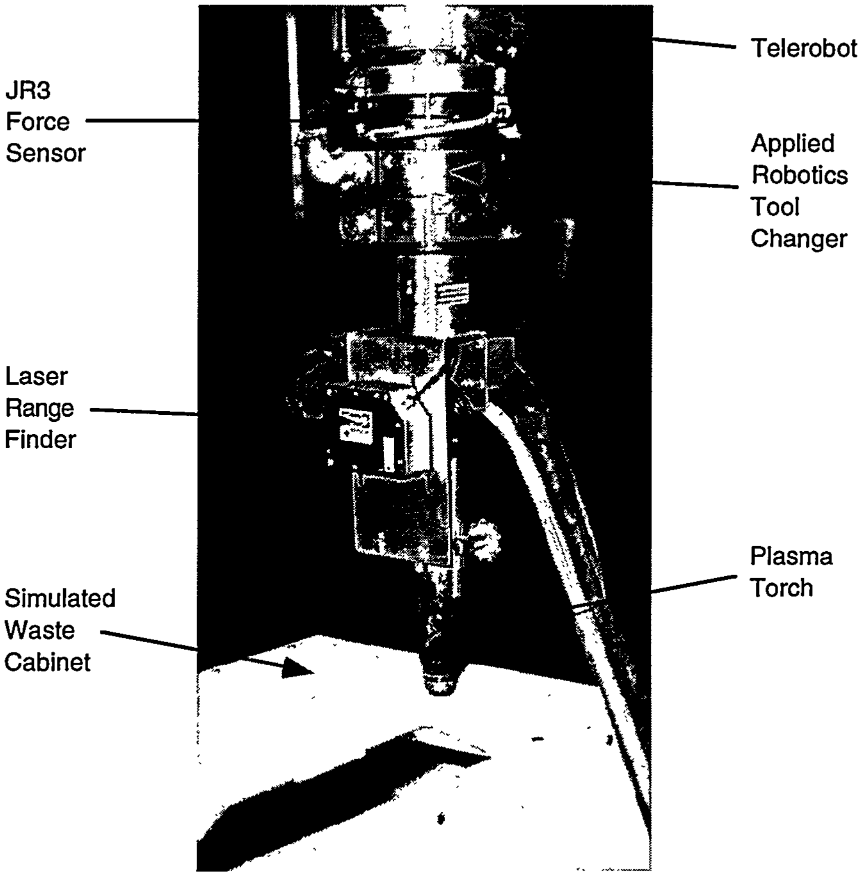


Figure 8 - Plasma Torch

away with Nitrogen gas. A laser range finder mounted next to the torch measures the distance between the torch and the item being cut. The laser is not effected when the torch operates because the laser uses an infrared beam and the torch emits visible and ultraviolet light. The computer system is an IBM-486 and it reads laser range data, calculates a desired robot position, and sends this desired position to the robot controller approximately twenty times a second.

Each demonstration included the Telerobot picking up the torch end effector and the control system moving the torch over a large waste item while maintaining the proper standoff distance, approximately half an inch. The torch didn't operate during the demonstrations because it emits strong ultraviolet light and spectators need eye protection to observe operations. This eye protection makes it difficult to view the robot moving.

CONCLUSION

DOE sites must process several hundred thousand cubic meters of mixed waste to meet federal and state regulations for permanent disposal. Regulations also require that these cleanup activities minimize personnel exposure to radiation and hazardous environments. The OTD MWO Robotics Demonstration successfully demonstrated that robotic technologies can open, characterize, process, and repackage simulated low level mixed waste. These technologies will allow DOE waste facilities to run better, faster, more cost effective, and safer. Representatives from several US companies attended the demonstrations and expressed interest in DOE technology transfer. At least one Cooperative Research and Development Agreement (CRADA) developed from this interest. Several university professors attended the demonstrations and are interested in working on future DOE projects.

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