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Advanced Robotics Technology Applied to Mixed Waste Characterization, Sorting and Treatment

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Advanced Robotics Technology Applied to Mixed Waste Characterization, Sorting and Treatment*

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ABSTRACT

There are over one million cubic meters of radioactively contaminted hazardous waste, known as mixed waste, stored at Department of Energy facilities. Researchers at Lawrence Livermore National Laboratory (LLNL) are developing methods to safely and efficiently treat this type of waste. LLNL has automated and demonstrated a means of segregating items in a mixed waste stream. This capability incorporates robotics and automation with advanced multi-sensor information for autonomous and tele-operational handling of mixed waste items with previously unknown characteristics. The first phase of remote waste stream handling was item singulation; the ability to remove individual items of heterogeneous waste directly from a drum, box, bin, or pile. Once objects were singulated, additional multi-sensory information was used for object classification and segregation. In addition, autonomous and teleoperational surface cleaning and decontamination of homogeneous metals has been demonstrated in processing mixed waste streams.

The LLNL waste stream demonstration includes advanced technology such as object classification algorithms, identification of various metal types using active and passive gamma scans and RF signatures, and improved teleoperational and autonomous grasping of waste objects. The workcell control program used an off-line programming system as a server to perform both simulation control as well as actual hardware control of the workcell. This paper will discuss the motivation for remote mixed waste stream handling, the overall workcell layout, sensor specifications, workcell supervisory control, 3D vision based automated grasp planning and object classification algorithms.

Introduction

This past year, the LLNL Environmental Restoration and Waste Management Applied Technology(ER/WM-AT) Robotics Program had a key focus on developing automation and robotics technology for hazardous waste handling and processing in support of the Department of Energy Office of Technology Development and the Robotics Technology Development Program (DOE/OTD/RTDP) Mixed Waste Operations Program. The primary emphasis has been technology development for sensor interpretation and decision making, advanced robot and supervisory control, and advanced telemanipulation. The feasibility and advantages of automation and robotics technology for waste material handling and processing applications were demonstrated .

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During the fall of 1993, this technology was deployed at Savannah River Technology Center (SRTC) and demonstrated as part of the Mixed Waste Operation (MWO) Robotics Demonstration on November 2-4, 1993. The technology development provided by LLNL for the FY93 MWO demonstration supports several mixed waste material handling and waste processing thrusts. They are :

- Non destructive evaluation of whole drums and waste stream objects using computed tomography NDE technology
- Mixed waste singulation (separation of a collection of items into idividual pieces) into easily characterized packages using structured-lighting based object characterization and automated grasp planning technology.
- Waste characterization and segregation using commercially available sensor packages and advanced machine intelligence decision algorithms.
- Waste processing of homogeneous metal objects using surface decontamination.

The control and monitoring of the multiple process systems was demonstrated using a supervisory controller with the flexibility of shared control between the operator and the automated systems.

Overview of Robotic Application

The technical demonstration consisted of a sequence of processing steps. Initially, objects were singulated from a pile or from a barrel and placed in a transport tray. The transport tray moved through various sensors to classify the objects and to determine the treatment needs. Homogenous metals were delivered, via conveyor system, into the waste treatment glove box. The metal object was then grasped by the glove box robot and moved to the surface decontamination enclosure. After the cleaning process, the waste object was moved to a warm inspection station. Upon determination of an acceptable warm inspection radiation threshold, the object was transported to a cold inspection station. Once the object successfully passed through the cold inspection, it was placed on the pallet conveyor for transport out of the glove box.

Computed Tomography

Computed tomography (CT) was used for nondestructive evaluation of drums and waste objects. Conventional x- and gamma -ray computed tomography imaging measures the effect of an object on an incident beam or ray that travels in a straight path. The data measured are photon intensities of the incident beam and the transmitted beam that is attenuated by the object. This is true to first order, ignoring the effects of x- or gamma-ray scattering. The incident beam is partially absorbed and scattered in the object of interest with the remaining transmitted photons traveling in straight lines to the detector plane where they are recorded. The quantity that is recorded at each x, y coordinate of the detector plane is the digitized radiographic images of the object. These radiographs or projections are recorded at many different angles around the object. Using these projections, the internal structure of the object is reconstructed with a computer. The quantity that is reconstructed is the attenuation value for some volume element, or voxel, at location x, y, z within the object. The voxel size and clarity are defined by scan and image reconstruction parameters. The reconstruction algorithms require line integrals, also called ray sums, for many ray paths through the object. Each ray sum is recorded at each individual x, y detector element at different angles around the object. It is useful to note that the CT ray sum acquired at a single energy is analogous to a simple gamma-ray transmission gauge.

The whole drum characterization data was represented in video and presentation format for the formal demonstration, while the actual object data was coupled into the waste stream segregation algorithms as part of the sensory data set. The computer data reduction and interpretation, coupled with 3-D graphics displays was used to render the data in a more understandable format to the operator.

Singulation and Automated Grasp Planning

For the formal MWO Demonstration, robust and reliable singulation was performed in a shared mode of control (autonmous and teleoperational). This capability enabled singulation of waste objects from the collective pile of objects and from the waste drum teleoperationally. The process was completed autonomously with the robot placing the waste objects into the characterization line.

Using structured lighting-based object range sencing developed by ORNL (SCOPE) and automated grasp planning developed by LLNL Engineering Research Division (ERD), waste singulation was completed as an integrated system in December 1993. Although the structured lighting system was not reliably integrated for the formal MWO Demonstration, the grasp planning algorithms necessary to calculate a valid grasp from the 3-D structured lighting data were fully developed and tested.

The singulation system used a PUMA 762 robot with a payload of approximately 40 pounds. A JR3 force sensor was attached to the wrist and a Robohand tool changer allowed the use of many different end effectors. Robline, by Cimetrix, provided a graphical operator interface and generated all the commands for autonomous operations, i.e., object placement and tool changeouts. For teleoperation, an interface was developed using a Generic Intelligent System Controller (GISC) compatible software module called SMART (Sequential Modular Architecture for Robotics and Teleoperation) developed by Sandia National Laboratory, Albuquerque, (SNLA). SMART allows the use of many different master input devices for teleoperation. However, a Dimension 6 force ball by CIS was used to manipulate the PUMA. This device was used by the operator to remotely control the PUMA robot, using remote cameras to assist in locating the objects. SMART also used the force sensor to prevent excessive force from being applied during singulation, which could damage the robot, the waste items, or surrounding equipment.

To control the singulation robot for autonomous tasks it was necessary to develop interfacing software between the high level graphical simulation and control side and the low-level controls side which used SMART software developed by SNLA. The software for both ends was written to use libraries and protocols of the GENISAS communications architecture developed by SNLA. Autonomous grasping used the ORNL range scanner (SCOPE)[1]. The scope system used a structured light source and CCD camera to develop a range image of the object to be grasped. From this range image, several possible grasp positions and locations were simulated and ranked with a fuzzy logic algorithm. The ranking of grasps was achieved through the weighted combination of grasp features[3]. These features include the distance from the center of mass of the object, the parallelness of the surfaces to be grasped, the smoothness of the surfaces to be grasped, the distance across the object versus the optimum gripper width, and the distance to collision with other objects[3](see Figure 1).

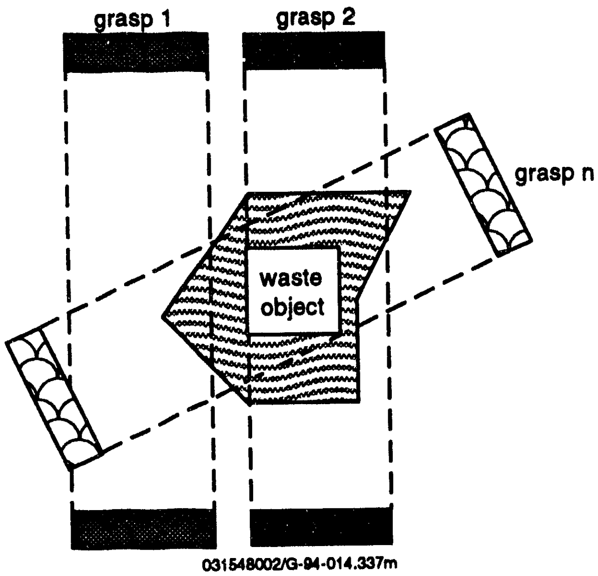

Figure 1. Possible Parallel Grasp Orientations using the Fuzzy Logic Ranking Algorithm.

Waste Characterization

Waste characterization and segregation used commercially-based sensor systems to demonstrate the ability to integrate an array of diverse sensors. Based on the sensor data, intelligent automated decisions were made for the sorting and segregation of the waste objects into appropriate streams[2]. The waste stream objects were classified into the appropriate treatment lines based on material type, radiation signature, special handling requirements, and basic object geometric data (such as size, shape, and volume) using an advanced fuzzy logic-based segregation algorithm. This effort was a significant step forward in the data interpretation and machine intelligence technology development arena.

The sensors used to determine the waste processing line were an x-ray gauge, sodium iodine radiation detector, commercial metal detector, JR3 force/torque sensor and profile detector. Since procuring a x-ray gauge system was beyond the scope of this project, x-ray absorption information was obtained by performing computed tomography (CT) scans on each of the waste objects and then by processing this information to get simulated x-ray gauge data. This data was stored in the supervisory system to be recalled when the x-ray data was required.

Once the data was collected from the sensor system it was assessed so that the correct processing line for the object was chosen. The different properties needed by the processing lines to assure that an object belongs in that line is given in Table 1. This information was assessed by an algorithm that employed fuzzy logic to help codify the sensor results since much of the sensors information was approximate[2].

Treatment line	Properties needed
Radioactive	Counts of gamma radiation
Non-metal	Volume of metal object
Mixed metal/non metal	volume of the metal object volume of the object
Heterogeneous metal	volume of metal object volume of object x-ray absorption variations
Homogenous lead	volume of metal object volume of object x-ray absorption variations Approximate metal conductivity

Table 1 : Information needed by the different treatment lines

Scarifying

LLNL developed and demonstrated autonomous and teleoperational surface cleaning and scarifying in a glove-box processing system for feed preparation and treatment of radioactive contaminated metals. Surrogates were used to avoid generation of mixed wastes during technology development. The automated cleaning of easily characterized geometries (bricks) was performed along with teleoperated cleaning of complex shapes. This application made technological advances in the robotics controller system by using a commercially-based open architecture controller as the platform. Software algorithms were developed to include remote and sensor-based operation in both a teleoperational mode and an autonomous mode.

For scarifying, a commercially available frozen CO_2 pellet abrasive cleaning system was integrated for surface decontamination of homogeneous metal objects. Several options for the cleaning process were available, but strong industrial support from ALPHEUS and the absence of waste byproduct dictated CO_2 abrasive cleaning. CO_2 pellets of approximately 4 cubic millimeters are inserted and accelerated with compressed air. The impact of the CO_2 pellet against the metal drives solid CO_2 under contaminating surfaces and spalls contaminated material off the metal. As contaminated material was removed, the CO_2 pellet sublimated and allowed the contaminated material to be pulled through a down draft exhaust system. For the MWO demonstration, the CO_2 was vented into the air. In an actual facility, the CO_2 would be passed through a high energy particulate air (HEPA) filter to separate the contaminates from the evaporated CO_2.

Supervisory Control

The Supervisor Control System, designed and developed for the SRTC demonstration contains valuable advanced technologies; the event-driven finite state machine for multiple processes and the independent menu manager process. The supervisory controller demonstrated that an operator, with a single user interface, could control multiple processing systems. The operator performed mixed waste handling, characterization, and waste minimization tasks. The independent nature of these tasks allowed for concurrent processing, with the Supervisor providing the exchange of information for resource sharing.

In addition to the supervisor controller, a Graphical User Interface (GUI) was developed to allow the operator access to all functions of the sub-system (i.e. open/close gripper, scan object, calculate grasp, read JR3 etc.) in a teleoperational mode. This interface included data readouts as well as action selections for the operator. All software conformed to the X windows and Motif presentation standards. This was thoroughly tested with the supervisory software in a simulation mode prior to hardware integration.

Conclusion

The formal MWO demonstration was an excellent avenue for the technologies to be developed and integrated. The opportunity to identify prominent issues and significant problems was provided by the demonstration. The integration of technologies, both established and emerging, revealed areas of future development. The feasibility of automation and robotics was articulated in a manner that provided a baseline of technology. The demonstration not only provided visualization tools of the fundamental technical issues for the technical arena, but also provided a conceptual framework of mixed waste handling to potential users and sponsons.

Acknowledgments

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