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ROBOTIC CONTROL ARCHITECTURE DEVELOPMENT FOR AUTOMATED NUCLEAR MATERIAL HANDLING SYSTEMS*

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ABSTRACT

Lawrence Livermore National Laboratory (LLNL) is engaged in developing automated systems for handling materials for mixed waste treatment, nuclear pyrochemical processing, and weapon components disassembly (Ref. 1, 2). In support of these application areas there is an extensive robotic development program. This paper will describe the portion of this effort at LLNL devoted to control system architecture development, and review two applications currently being implemented which incorporate these technologies.

BACKGROUND

Generally, robotics automation in the above application areas are required to reduce worker exposure and radiation risks, minimize waste, and improve system reliability. To achieve these results it is necessary to build robot control systems that support a range of capabilities from telerobotics to automated task planning and execution in complex systems.

ARCHITECTURE DESIGN

The control design incorporates an open system architecture with functional capability and flexibility, platform portability, standardized interfaces, standardized operating systems, and adaptability to the robot types required for the range of nuclear materials handling applications.

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TECHNOLOGY DESCRIPTION

The core technologies required in support of the robot control system architecture for these applications are as follows:

- Graphical simulation and modeling: Workcell and robot modeling, and sensor and robot simulation which provide a means of designing, modeling and testing prototypes of prospective process implementations before actually building the design; for performing off-line programming in the modeled workcell environment; and for operator visualization of the workcell and robot during remote telerobotic control.

- Graphical users interface: A users interface for generating workcell and robot models; for specifying custom robot mechanism kinematics; as an interactive teach pendant, as a means for displaying sensor data and for initiating changes in shared control between autonomous and teleoperational robot control.

- Workcell supervisory control: A supervisory control platform which provides a cell control with multi-threaded, asynchronous event and error handling; a means of scheduling and controlling event sequences and insuring single point of control; and a client/server message handler for processes running on the supervisory platform, robot and hand control controllers, and other intelligent computing nodes.
- Telerobotics control: A telerobotics control system which provides a means of directing the robot with either an autonomous program or teleoperational input from a hand control; access to the user interface to accomplish seamlessly transferring between these two

modes of directing the robot; kinematic transformations by which the operator can direct the robot with either rate or position input in either the world, tool or joint space coordinate frame of reference; and a means of handling robot and workcell constraints, and robot singularities so that the operator can impart smooth robot direction.

- Surface modeling: The acquisition, reduction and interpretation of 3 dimensional surface data for control of tool paths, and material handling and inspection operations. Surface data are acquired using binocular machine vision, structured lighting, or laser range-finder systems. Surface mapping of objects is achieved by converting multiple range images into sets of adjoining planar polygonal surfaces that together represent each object. This representation lends itself to path and grasp planning, surface following and object recognition. These tools can also be applied to collision avoidance for teleoperation, workcell calibration for off-line programming, and geometry modeling for automatic workcell CAD updating.

- Data fusion: Acquisition, interpretation and visualization of data from complementary sensors to improve control by increasing both observer and machine understanding of a systems' state. Generally, fuzzy logic or neural nets can serve as the foundation for automated sensor interpretation.

- Sensor-based control: Advanced control methodology to facilitate control of complex systems with demanding feedback requirements. Included are embedded and distributed controls for modular electromechanical systems, telerobotic control with or without force reflection, and sensor-based motion control.

- Managing complex systems: Supervisory control architecture and API that are suitable for capturing and representing the state of a complex system, performing needed analysis, and automating the generation of program logic to accomplish tasks given high level instructions. Applications range from embedded error recovery and automated system analysis to programming of automated workcells. Generally, expert systems serve as the foundation for automated management of complex systems

TECHNOLOGY DEVELOPMENTS

At LLNL under the Mixed Waste Operations program of the Department of Energy Robotic Technology Development Program, a key emphasis has been to develop a total solution to the problem of characterizing, handling and treating complex and potentially unknown mixed waste objects. LLNL has been highly successful at looking at the problem from a system perspective and addressing some of the key issues including non-destructive evaluation of the waste stream prior to the materials entering the handling workcell, the level of automated material handling required for effective processing of the waste stream objects (both autonomous and teleoperational), and the required intelligent robotic control to carry out the characterization, segregation, and waste treating processes. These technologies were integrated and demonstrated in a prototypical surface decontamination workcell (Ref. 3).

The Department of Energy has a need for treating existing nuclear waste. Hazardous waste stored in old warehouses needs to be sorted and treated to meet environmental regulations. LLNL is currently experimenting with automated manipulations of unknown objects for sorting, treating, and detailed inspection. To accomplish these tasks, two existing technologies were expanded to meet the increasing requirements. First, a binocular vision range sensor was combined with a surface modeling system to make virtual images of unknown objects (Ref. 4). Then, using the surface model information, stable grasp of the unknown shaped objects were planned algorithmically utilizing a limited set of robotic grippers (Ref. 5).

OPERATIONAL APPLICATIONS

Tritium Legacy Waste Decontamination Facility:

Lawrence Livermore National Laboratory (LLNL) is developing a semi-automated system for handling, characterizing, processing, sorting, and repackaging hazardous wastes containing tritium (Ref. 6). The system combines a special glovebox designed to protect the workers and minimize the potential release of tritium to the atmosphere, and a special gantry robot developed to operate in a glovebox (Ref. 1). All hazardous waste handling and processing will be performed remotely using the robot in a teleoperational mode for one-of-a-kind functions and in an autonomous mode for repetitive type operations. The glovebox air handling ducts are interfaced with a portable gas treatment system designed to capture any gaseous phase tritium released into the glovebox.

The glovebox robot which is a 6-(3 prismatic and 3 resolute) degrees of freedom (DOF) gantry is being adapted for this application with a compound z (vertical) axis to reach down vertically 60 inches and operate in a glovebox with an internal height of 108 inches; configured to work in a space 48 inches wide and 282 inches long, and fitted with brushless dc servo motors to provide a lift and pitch-up capacity of 150 lbs, and 60 ft-lbs, respectively.

The robot controller is being upgraded to provide telerobotics functionality including interconnections to a graphics simulator, workcell supervisory controller, and user interface consoles; and master arm (hand control) controller as well as the robot servo amplifiers and position resolvers and other workcell sensors and effectors. An integral part of this capability will be a seamless mode transfer feature which will enable the operator to easily transfer between the teleoperational and autonomous control of the robot, and select from an ensemble of established robot programs to accomplish specific well defined pick and place operations. Typical among these would be tool changes, depositing objects to specific waste stream containers, and maintenance maneuvers such as wiping down the walls of the glovebox.

Mixed Waste Management Facility (MWMF):

LLNL is developing the MWMF, a national pilot-scale demonstration test bed for the evaluation of mixed (low level radioactive and hazardous) waste treatment processes that will provide an effective alternative treatment to incineration which meets EPA limits. The facility will have the capability to evaluate a variety of competing technologies on the same organic waste streams, and define the waste streams best suited for specific treatment processes. It will be operated in an integrated manner, demonstrating state-of-the-art waste characterization, sorting, and feed preparation technologies, the best mature treatment systems, and the immobilization of the treatment processes solid output into a final form. A networked instrumentation and control system covering process and supervisory control functions, monitoring and safety interlocks will be an integral part of the facility..

In the solid feed preparations (SFP) area of the facility the heterogeneous wastes must be segregated into appropriate feed streams for the primary treatment processes (Ref. 7). Two robotic systems will be used in the facility: a large 3-DOF gantry robot and a 6-DOF articulating robot on a rail. The gantry robot will span the SFP area and will lift, move and deposit 55 gallon drums from the receiving air-lock to the sampling and characterizing station, drum opening station, and drum dumping station. Similarly, the gantry will be used to transfer drums filled and sealed with material rejected for treatment from the fill station to the decontamination and inspection stations, and shipping air-lock. The gantry robot will be used to handle and transfer the 7A (nominally 42x48x84 inch steel) boxes in a like manner. It will also be used to move certain of the SFP machinery modules to and from maintenance and staging areas.

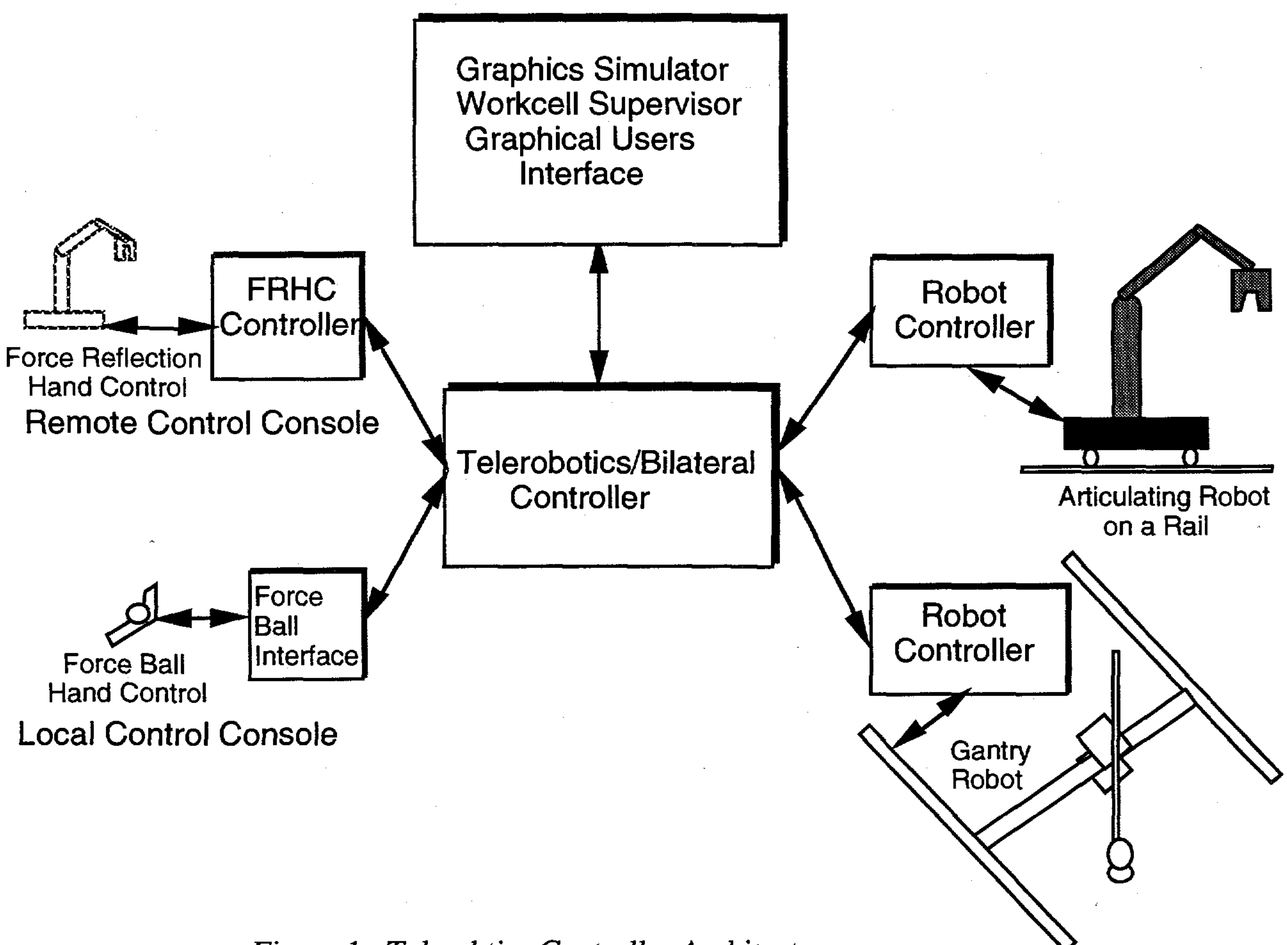

Figure 1. Telerobtics Controller Architecture

The articulating robot on a rail will be used to perform sorting of dumped waste into respective waste stream containers, removing untreatable objects for repackaging, and decontamination inspection. A special adaptation is being considered whereby the articulating robot could be disconnected from the rail mount and attached to a similar mount on the gantry for additional flexibility. The articulating robot controller would have the flexibility to coordinate 7-DOF robot motion with the rail servo drive in the former configuration and with the gantry z-arm servo drive in the later configuration.

The telerobot control system architecture is shown in Figure 1 with the force ball and force reflection hand controls interconnected to the gantry and articulating robot controllers via the telerobotics controller so that an operator has the option of controlling either robot from either of the hand control consoles. It embodies the telerobotic functionality required to provide means for performing seamless transfer between teleoperational and autonomous control of the robots. It embodies the world, tool and joint space transforms to accommodate dissimilar hand control-robot kinematics. It will utilize the telerobotics architecture of SMART to impart robot and workcell constraints, handle robot kinematic singularities, and impose virtual forces via the hand control force reflection to signal on set of these constraints and the path augmentation to circumvent impending singularities (Ref. 8).

SUMMARY

In summary, the development program at LLNL on a robot control system architecture for automated handling of nuclear materials is focusing on graphics simulation and users interface, workcell supervisory control, telerobotics, data fusion, sensor-based control and management of complex systems. The integration of these technology areas into a unified robot control system architecture is being applied to the development of automated systems that will reduce worker radiation exposure and risk, minimize waste, and improve operating reliability. Two applications are under development at LLNL embodying these technologies: the legacy tritium waste decontamination system, and the mixed waste management facility.

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