Combined Long Reach and Dexterous Manipulation for Waste Storage Tank Applications*

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Introduction

One of the highest priority environmental restoration tasks within the Department of Energy (DOE) is the remediation of single–shell waste storage tanks (WSTs), especially those suspected of, or documented as, leakers. Most currently proposed approaches for remediation of large underground WSTs require application of remotely operated long–reach (greater than 10 m), high–lift capacity (greater than 200 kg) manipulator systems. Because of the complexity of in–tank hardware, waste forms, remediation tasks, and variety of end–effector tools, these manipulator systems must also be capable of performing a diverse set of dexterous manipulations. Since no single commercially available system currently exists that exhibits the full range of performance capabilities required for retrieval of wastes from the largest of the DOE's WSTs, an effort is underway within the DOE Environmental Restoration and Waste Management Office of Technology Development (OTD) to develop this technology. A robotics technology testbed (RTT) for study and evaluation of WST remediation approaches was assembled during 1991 at DOE's Hanford site, Richland, Washington. Assembly of this testbed

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resulted from the combined efforts of personnel from four DOE national laboratories, Idaho National Engineering Laboratory (INEL), Oak Ridge National Laboratory (ORNL), Pacific Northwest Laboratories (PNL), and Sandia National Laboratories (SNL), along with the Westinghouse Hanford Company. In addition to this presentation, four other papers have been submitted[1-4] describing various aspects of the testbed and demonstrations planned in 1991. This presentation will describe the integration of a Spar RMS 2500 manipulator system, a Schilling Titan-7F manipulator, and control systems developed at ORNL and SNL to provide a combined long reach and dexterous manipulation system. The purpose of integrating these two manipulator systems was to study and demonstrate their combined performance, evaluate design requirements for a deployed system, and provide a testbed for control and end–effector technologies that might be applicable to remediation of WSTs.

System Description

There is not yet a consensus baseline concept accepted for a retrieval system for WSTs like those found at the Hanford site and elsewhere throughout the DOE complex. Design parameters such as the length of reach, link configurations, number of degrees of freedom (DOF), payloads, and overall system performance requirements are not well defined. In an effort to move ahead with technology development while awaiting waste characterization data and system design requirements, the OTD initiated integration of the RTT by pooling available national laboratory robotics expertise and leveraging prior commercial systems development. ORNL was tasked with providing a long–reach, high–strength positioning system while SNL is providing a smaller dexterous manipulator. The two laboratories were required to develop and integrate control systems that would permit operation of the two systems from a single operator control station. A description of this graphical model-based control station is provided in a separate submission[2].

Long Reach Manipulation

During the 1980s, Spar Aerospace Limited developed a pair of manipulator systems for Ontario Hydro to be used for reactor maintenance tasks. These manipulator systems, Spar RMS 2500, were developed for operation in highly radioactive environments and included radiation-hardened electronics and CPUs, fully redundant actuators, and extensive safety systems to prevent runaway conditions due to either hardware or software failure. The manipulator has five DOF, shoulder yaw, shoulder pitch, elbow pitch, wrist yaw, and linear wrist extension, and was originally mounted on a linear track, adding a sixth DOF. The positioning resolution and repeatability of the system are each 1.27 mm. At full extension, the arm reaches 8.5 m and can lift 1134 kg, with reduced performance the payload can be extended to 2268 kg. Maximum velocity of the end-effector is 610 mm/sec. The system is hydraulically powered.

In a cooperative arrangement, Ontario Hydro made one of the manipulators available to ORNL and DOE for use in the 1991 RTT demonstration. ORNL developed an interface box that allows switchable control between the Spar controller and an ORNL developed VME-based controller running the VxWorks multitasking realtime operating system. ORNL developed a Sun Unix-based graphical operator interface. In order to structure the controller in an efficient manner to handle both synchronous and asynchronous control loops, the ORNL-developed Modular Integrated Control Architecture[5] (MICA) was ported to VxWorks and implemented. The control system has five major internal modules that interact synchronously with the Spar RMS 2500 manipulator system at a 50 ms loop rate. These modules include a planner module, kinematics module, control module, follower module, and input/output module. Interface to the master control station is through a series of function calls that can be executed at the remote master control station or through the local ORNL controller.

Dexterous Manipulation

The Schilling Titan series was initially developed for undersea applications and has become increasingly popular for deployment in other hazardous environments because of its reliability and high strength. The Schilling Titan series is hydraulically powered, weighs about 70 kg and has a lift capacity of between 290 and 530 kg, depending upon configuration. At full extension, the arm can reach 2.4 m. The manipulator has 6 DOF. For the past several years, SNL has worked on controller improvements incorporating the Knowledge-based Review and Intervention To Impose Constraints (KRITIC) controller that makes the Schilling Titan manipulator also capable of high performance in robotic (computer control) mode. Control of the Schilling Titan manipulator is integrated into the graphical model based master control system[2]. The Schilling Titan has been outfitted with a JR3 force sensor to provide force feedback. Information from the force sensor is used by the KRITIC controller to modify the trajectory of the Titan.

For development of the RTT, the three finger gripper of the Spar RMS 2500 manipulator was removed and an interface plate mounted that would support the Schilling Titan manipulator and a variety of end–effectors for waste retrieval tasks or removal of in–tank hardware. The end–effectors planned for use in the 1991 demonstration include a jaws-of-life hydraulic cutting tool, a scraper tool, a vacuum beater bar, a vacuum nozzle, and a pneumatic scaler. These five end–effectors were selected primarily because of convenience. Operation of the manipulator system with more relevant end–effectors will be tested as these become available. In addition, the Schilling Titan manipulator will, at times, deploy various mapping or inspection sensors using a self contained sensor package.

Results

The Spar RMS 2500 manipulator system was installed at Hanford in May of 1991; the Schilling Titan manipulator was mounted on the Spar wrist interface plate in June. During June, the local control systems for the Spar manipulator were integrated with the master control system and the Schilling Titan controller. Combined operation of the two systems commenced in July with a series of demonstrations using the end–effector tools described previously and integrating the manipulation efforts with sensing, inspection, mapping, and control technologies[1-4]. Following initial operation of the RTT; modifications and enhancements are planned for 1992 that will greatly assist in the generation of technical performance specifications required for eventual design and deployment of a waste retrieval system. The RTT will continue to operate as a testbed for robotics and remote operations technology related to remediation of WSTs and for technologies such as sensing and control that are cross cutting in nature and impact a wide variety of characterization and remediation needs.

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