ROBOT TASK SPACE ANALYZER INTEGRATION AND TESTING

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ABSTRACT

A percentage of Department of Energy (DOE) deactivation and decommissioning (D&D) tasks are too hazardous to permit direct human contact and must be completed remotely. Such remote work has typically been performed using purely teleoperated systems. However teleoperation has typically been shown to be about an order of magnitude slower than direct hands-on task execution, and remote systems are also typically expensive. This problem grieves the cost conscious D&D community and must be resolved to permit efficient cost-effective remediation of the more difficult sites in the DOE complex. One possible solution to this problem is to greatly improve the efficiency of remote operation by adding automation to the existing teleoperated capability. The D&D Focus Area has funded multiple industry and university contracts to develop new robotics techniques to address these needs. One commission of the DOE Robotics Crosscutting Program D&D Product Line is to integrate and test these various capabilities to see if they are viable for field deployment. This paper outlines progress on the first such integration and demonstration, which involves the University of Tennessee at Knoxville Robot Task Space Analyzer.

TELEROBOTIC CONTROL TEST BED

The Robotics Crosscutting Program (Rbx) deactivation and decommissioning (D&D) Product Line has set up a telerobotic control test bed at the Department of Energy (DOE) Oak Ridge National Laboratory (ORNL). This test bed, referred to as the telerobotic manipulation system (TMS) is based on a compact remote operator console (CRC) enhanced with significant computing capability and arranged in a modular fashion to make the difficult task of integrating multiple organizations' software as simple as possible. The Rbx D&D telerobotic control architecture is shown in Fig. 1. The general idea is that integration occurs by building the research and development of multiple organizations into a high level telerobotic controller (TrC) which can be installed onto the TMS by installing the developed software algorithms onto dedicated personal computers and attaching the relevant computers to the TMS network. Communication between a TrC and the low-level manipulator controller (arm level controller or ALC) is managed through a high level controller (HLC) focusing on "traffic control." Actual control of the arm can be passed to any TrC attached via Ethernet or to a master controller for pure teleoperation. While not the most tightly integrated hardware/software approach, this architecture does allow a TrC to be packaged separately (hardware and software) and then tied into the test bed for evaluation. Custom communications software does have to be written for each application to meet the required telerobotic control communications interfaces, but Windows, Unix, and linux code has been completed to support this requirement.

In order to verify the approach while providing added value to the DOE D&D community, an initial TrC was developed, implemented, and tested under Rbx activities at ORNL. This controller is based on plasma torch cutting tasks and was initially tested by cutting flat plates, as shown in Fig. 2, and structural angle iron typically found in process racks. In order to finish out the capability, testing will be completed on a structural I-beam as well. One characteristic of this particular controller is that it borrows the central theme from the behavior-based robotics community that "the world is its own best model." No a priori graphical world modeling of the task is completed. The operator and robotic system work directly with the object to be cut to quickly establish cut points and to execute the task. Motion planning is completed in teleoperation mode; actually cutting is completed in a fully robotic mode [1].

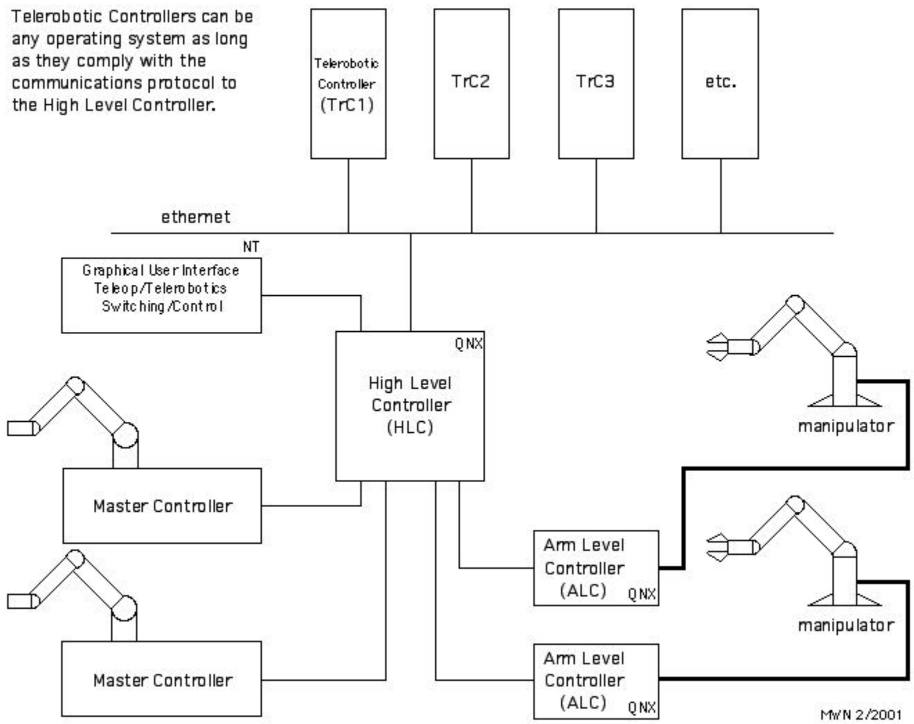

Fig. 1. Telerobotic control architecture block diagram.

Fig. 2. Demonstration of the plasma torch telerobotic controller. Inset shows remote viewing of cutting of a flat plate.

ROBOT TASK SPACE ANALYZER

Automated dismantlement tasks involve reasoning about the 3D structure of the task environment and planning the motion of robots and tools. It therefore requires quantitative position, size, and shape information about equipment to be dismantled and other objects surrounding it that the robot needs to have knowledge of. The Robot Task Space Analyzer (RTSA) developed under DOE contract by the University of Tennessee at Knoxville (UTK) is one system by which the necessary geometric data is acquired, processed, and integrated [2,3]. The position of the equipment is also needed to plan collision-free robot motions, though it may not be necessary to make a detailed analysis of their geometry (i.e., the existence/absence of solid matter at a point in space is all that is necessary). RTSA results, or models, must be complete and accurate to the extent dictated by the specific tool being used: positioning of a shear demands less accuracy than maintaining the proper standoff for a plasma arc torch. Once an appropriate model is available, algorithms to plan manipulator trajectories and tooling motions can be applied, and the cutting can be automatically executed.

The RTSA has three major scene analysis components (i.e., manual, stereo auto-scanning and range auto-scanning) as shown in Fig. 3. The manual modeling utilities allow the operator to select three-dimensional coordinate points with the laser range finder on the sensor head to define part positions. To use either the stereo AutoScan or the range AutoScan module, the operator first selects a region of interest (ROI) from a panoramic view (PV) of the task scene. Using the graphical user interface, one of the AutoScan modules is then selected, and then one or more classes of objects to be found in the ROI is specified in the catalog of object primitives or object of interest (OOI). In its current implementation, RTSA contains object classes for standardized process piping components (valves and elbows, Tees and other unions) and a custom object tool. The operator must also specify the schedule and size of the object and whether it is welded, flanged, or bolted.

The structure of the RTSA combines interactive analysis of objects that can be modeled with relatively simple descriptions and operator specifications (e.g., pipe sections and elbows) with automatic analysis of scene objects that have more complicated descriptions (e.g., valves). With three paths available for the analysis of the task space, the operator is both an administrator and an active participant. Regardless of the method used to locate a particular object in the scene, the operator makes final approval of the object placement. He also has the option to make small adjustments in translation and rotation of the object as it appears in the task space model.

Once the objects to be removed have been identified and modeled, a task script is generated and a path planned for download to the robot controller. Tasks demonstrated to date at UTK have primarily focused on the use of a manipulator held portable bandsaw to remove sections of process piping from a mockup.

RTSA HARDWARE

Excluding sensor systems and support, the RTSA controls reside on two PC-compatible personal computers. The first is a Windows-based dual processor machine that is used for the RTSA front end and the associated image processing (each run on a separate processor). Additional commercial cards required include an image processing card and 4-port serial card (due to a large number of serial-based peripherals used in the RTSA external support hardware). The second computer system in the UTK RTSA system is a linux-based machine that runs the Real-Time Innovations, Inc., ControlShell software development environment and run-time architecture. The linux machine provides all of UTK's low-level control and robotics functions. The linux machine connects to a Schilling Titan 2 hydraulic manipulator via a bus repeater, VME interface rack, and Schilling's VME controller interface. All Schilling hardware is on loan from ORNL in support of this task.

INTEGRATION PLAN

Integrating software components that were not developed together and written from scratch to work with each other is a particularly difficult task and was known to be nontrivial from the start. Given that a major component of the purpose of the TMS is to integrate and test other organization's developed capability, the architectural decision was to use a network-based approach so that software could be installed on separate machines and tied into the TMS network as a separate module. The two

RTSA computers fit this paradigm well. It was determined that two Rbx computers would be supplied to UTK so that their original installation would not be disassembled. Rbx would outfit the computers in as similar a configuration as possible. UTK would then install their software, and the UTK sensors and Rbx computers would be moved to ORNL for testing. After testing, the UTK sensors would be returned to UTK, and the Rbx computers would stay installed on the TMS. A complete sensor system for permanent installation on the TMS is under development. This activity was scheduled to be completed in the first half of FY 2002.

INTEGRATION STATUS

At the time of this writing, which is half way through the fiscal year, the project is nearing the final integration phase but is not yet complete. Repeated difficulties have been encountered.

The primary difficulty, which has occurred repeatedly, is incompatibility between commercial hardware and its descendents, software device drivers, commercial software packages, and the software that UTK wrote to work with the original software/hardware configuration that they procured. Universities typically have a restricted equipment budget and abound in cheap student labor. They are likely to stick with existing hardware and software packages as long as possible. The image processing hardware and software was several years old; old enough that the original hardware was no longer available or supported by the vendor. The new hardware that the vendor sold would not work with the old software or device drivers. No other vendor's hardware would work without even greater modifications. Adaptation of the new hardware, software libraries, and device drivers to the UTK RTSA software was a major modification and debugging effort that has caused much of the delay. A similar but much less painful exercise has occurred with a required software upgrade for the ControlShell software on the linux computer; minor modifications were also required in the UTK RTSA software to accommodate these upgrades.

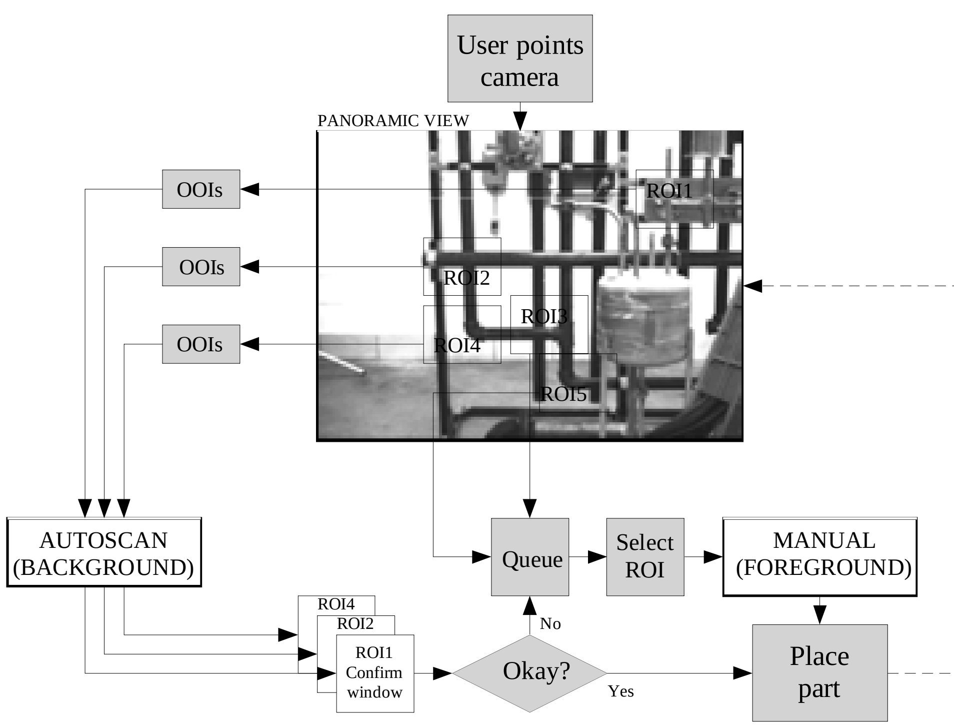

Fig. 3. RTSA operational flow.

The original UTK RTSA Windows-based computer was a dual processor workstation version. UTK had not intentionally partitioned their software tasks to run on both processors, so they were not aware that Windows was automatically managing the partitioning of the RTSA graphical user interface and the image processing software tasks (i.e., making full use of the dual processor capability of the machine). Therefore, when specifying a computer to support the Rbx version of the RTSA computer, there was no requirement for workstation grade multi-processor capability. Only after the Rbx system was up and running with the image processing boards, commercial software, and the RTSA code was it made evident that the “new” system was running much more slowly than the original UTK RTSA computer. Analysis and debugging revealed the multiprocessor factor. A new multiprocessor computer was procured and delivered to UTK so that the hardware and software could be installed.

Other problems included a hacker attack on the UTK linux box that has required rebuilding that system, which also revealed the difficulties of maintaining and reproducing all the backups made by various students over multiple years of university research. At the time of this writing, the UTK linux box is nearly put back together, and the Rbx RTSA computer is up and running at UTK. It is still necessary to finish repair of the UTK linux box, test the Rbx RTSA computer and the UTK linux box at UTK on the UTK RTSA system, then move to the Rbx linux box and integrate and verify it at UTK. Finally the Rbx RTSA and linux computers and the UTK sensor system will be moved to ORNL for installation and testing on the TMS. At this point some installation of TMS-based software modifications will be required so that the RTSA software will work with the TMS. The communications software has already been written but is waiting assembly of the full system for final debugging and verification. It is hoped that integration and testing will be complete before the final presentation is made.

RESULTS

Integration of the UTK-developed RTSA capabilities with the DOE Rbx capabilities at ORNL is occurring in FY 2002; however, preliminary testing was completed at UTK and those results are referenced here. The demonstration at UTK consisted of a mockup of processing piping and a task to remove sections of pipe in the telerobotic mode. The task included in situ modeling of the task (10 minutes), task planning (5 minutes), and task execution (18 minutes). The task execution itself consisted of tool acquisition (a “hand” held bandsaw), making 5 piping cuts with the bandsaw, and then stowing the tool. Total task execution time was 33 minutes. Since this was done in a university environment, there were no expert remote systems operators on hand for comparison. Experience level is an important component since D&D workers are typically not highly experienced remote systems operators. Within the integration and test activities performed in FY 2002 at ORNL, testing comparison will include novice and experienced operators.

CONCLUSION

The D&D Focus Area (DDFA) has funded the Rbx D&D Product Line to examine, integrate, and test various technologies developed by their university and industry research and development programs. A telerobotics test bed was developed at ORNL to provide the means of conducting these tests. The UTK-developed RTSA, which is the first DDFA-funded technology chosen for integration, is a promising technology for field deployment. Integration and testing will be conducted at ORNL by the Rbx in FY 2002 to verify its usefulness and to choose possible deployments.

REFERENCES

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