Progress Report

Project Title: Remote Manipulation for D&D Exhibiting Teleautonomy and Telecollaboration
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Research Objective: The purpose of the work is to enhance remote operations of robotic systems for D&D tasks by extending teleoperation with semi-autonomous functions. The work leverages the $1.2M dual-arm work platform (DAWP) developed with broad participation for the CP5 D&D, as well as 2,000 hr DAWP D&D operational experience. We propose to develop a reactive, agent-based control architecture well suited to unstructured and unpredictable environments, and *cobot* control technology, which implements a virtual fixture that can be used to guide the application of tools with force-feedback control. Developed methodologies will be implemented using a structured light sensor and cobot hand controller on the dual-arm system.

Research Progress and Implications: This report summarizes work completed after two years under the three-year project. This first two years of work focused on the system design and implementation of component technologies. Argonne National Laboratory and Northwestern University conducted the work jointly.

<u>Design and test of reactive behaviors</u>: The focus of our work has been on implementing motor behaviors for the reactive control of hydraulic manipulator systems. In particular, motor agents - *teleoperation*, *dock*, *move-along-path*, *maintain-attitude*, *escape*, and *open/close gripper* - were devised as constituents of a large grain behavior, *apply_tool* (Figure 1). A demonstration for the pipe-cutting tasks revealed that the behavior-based teleoperation can be very effective in relieving the operator from the burden of aligning and constraining the tool to the desired path, thereby enhancing the system efficiency by decreasing the operation time.

A PC based control system has been developed with a new master subsystem that uses a 6 DOF position tracking sensor to replace the existing hand controller. This controller benefits from an open structure which makes it easy to implement and extend. The control scheme has been tested on a teleoperation test bed consisting of a hydraulic manipulator, circular cutting tool, and mockup pipes. For communications with external sensor nodes, a distributed object scheme based on Java virtual machines and a native interface was implemented and tested. To enhance the user interface, the robot motion and environment is updated on-line through a solid graphics display.

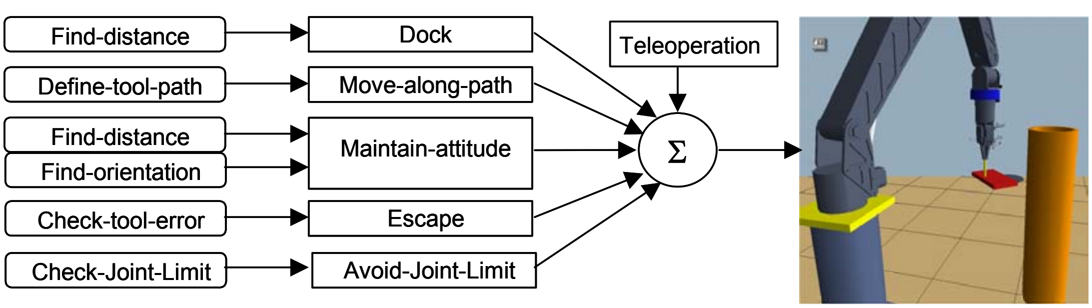


Figure 1. Reactive Robotic Architecture for *apply_tool* behavior

<u>Development of perceptual basis</u>: A structured light system has been used for the sensory device that consists of a patterned laser beam projector and camera. Perceptual behaviors are implemented that analyze the locations and distortion of the beam to determine position and orientation of the environmental

objects. Since structured light systems are known to be ineffective in the presence of occlusion, we implemented a perceptual basis that utilizes multiple sensory modules (Figure 2). To establish parallax among multiple sensory devices and perform range measurement, an on-line camera-projector calibration method has been implemented which consists of camera intrinsic calibration, camera-projector extrinsic calibration and camera-manipulator calibration.

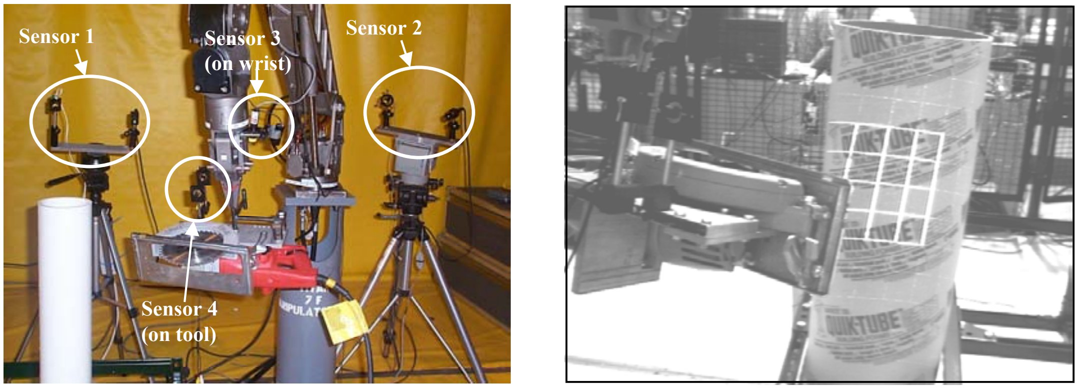
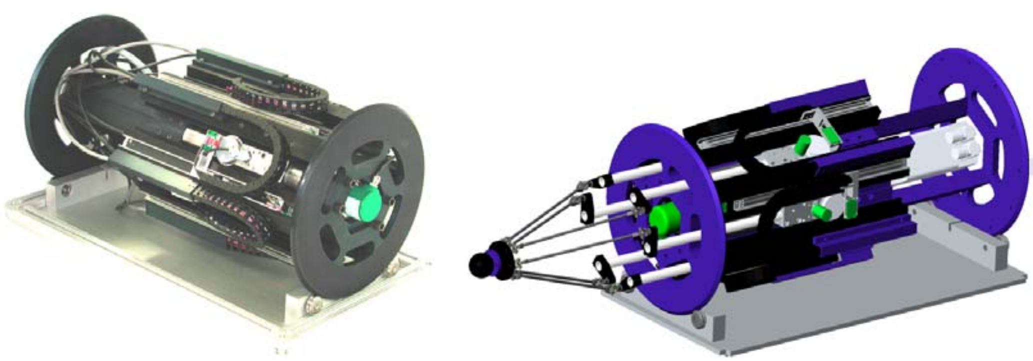


Figure 2. Sensory Modules based on Structured Light System

Cobotic Hand Controller Development: A major part of this project entails the design, construction and testing of a new cobotic hand controller for the operator's remote control of a slave robot when involved in teleoperation tasks. The new hand controller will be capable of providing force feedback and presenting virtual surfaces that constrain operator motions in useful ways. It will be tested with the Dual Arm Work Platform (DAWP) which decommissioned the CP-5 test reactor at Argonne National Laboratory as part of a demonstration project.

The cobotic hand controller is based on a parallel mechanism design similar to a Stewart Platform, and offers motion in six degrees-of-freedom (Figure 3). At present, electrical and mechanical assembly has been completed and all sensor and actuator operation has been verified. Code has been written under the QNX real-time operating system for device drivers, control system infrastructure, data logging, and user interface. The design and implementation of "free-mode," "path-mode" and virtual surface controllers is underway. A combination of these modes will provide an interface capable of numerous haptic cues.



(a) Photograph of partially assembled hand controller (b) Solid model of hand controller

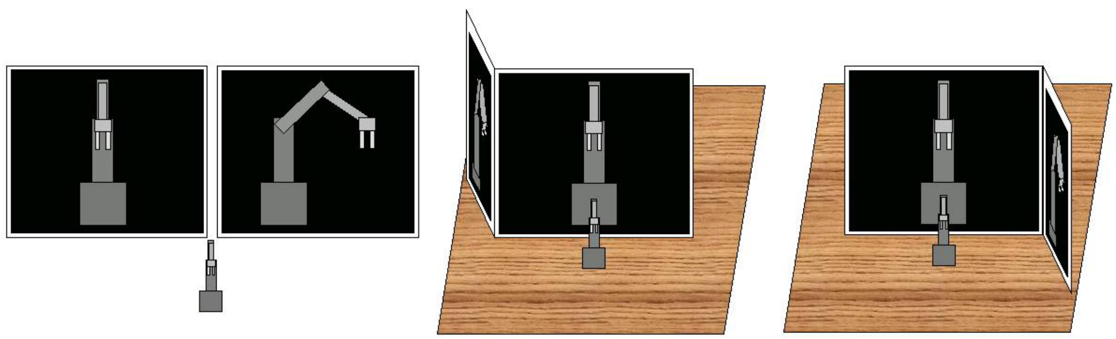
Figure 3. Cobotic Hand Controller

Thinking "Inside the Box" – An Intuitive Telemanipulation Interface: This R&D effort investigates techniques for improving the intuitiveness of teleoperation interfaces, especially those that present the operator with multiple camera views. It is motivated by experience with the Dual Arm Work Platform (DAWP) at Argonne National Laboratory. Operation of the DAWP showed that training time for users was extensive, setting up to do tasks took much longer than actually performing them, and users complained of difficulty perceiving spatial relationships from the camera views. We hope to devise new interface designs that alleviate these difficulties.

We have accomplished the following. First, a teleoperation test bed has been established at Northwestern University for testing various interface techniques. This test bed involves a 6-DOF arm-robot, a 6-DOF input device, flexible in-house software, multiple cameras, and multiple monitors. It has the capability to implement augmented reality (overlaying computer graphics onto live video) and virtual surfaces/constraints, and it allows for physical rearrangement of the monitors.

Figure 4. Teleoperation test-bed at Northwestern University

Second, the technique of *Inside the Box* (and Outside the Box) has been proposed, examined, and found to be beneficial. The *Inside* and *Outside the Box* techniques involve the physical arrangement of the monitors so that each monitor's configuration relative to the input device matches that of its camera relative to the robot. This approach eliminates the tiring mental transformations between input device and camera views. It also naturally leads to monitors arranged not on a plane, but at odd angles to one another. One might imagine the monitors being on the faces of a box. The box can either be a small one in front of the user (called *Outside the Box*) or a larger one around the user (called *Inside the Box*). An experiment testing teleoperation performance for three monitor/image setups, including *Inside the Box*, was performed. The results show that *Inside the Box* improves task time and is considered by users to be intuitive and easy.



Unrotated, Misaligned Setup　　Outside the Box　　Inside the Box

Figure 5. Concept of "outside the box" and "inside the box" monitor configurations.

<u>Implementation of integrated control system for dual-arm robot</u>: Ultimately, enhanced teleoperation will be demonstrated with the dual-arm work platform (DAWP). Substantial effort has been devoted to establish to integrate of various component technologies: slave robot controller on VME bus, motor behavior computer, machine vision system and the hand controller system. The integration is done with EPICS (Experimental Physics Instrumentation Control System), which enables soft realtime control of equipments over the network. The tasks entail development of real-time control programs, event driven control and network, and graphical user interface. It is expected that the network-based control will reduce system complexity of integration between multiple control systems platforms.

Planned Activities:

- Complete prototype development of sensor module (September, 2003)
- Develop and demonstrate more motor behaviors: *grasp_ tool*, *inspection*, and tooling behaviors other than circular saw (October, 2003)
- Complete assembly and programming of Cobot hand controller, and demonstrate generation of virtual fixtures (November, 2003)

- Enhance intuitive teleoperator interface (Jan, 2004)
- Demonstrate motor behaviors with dual-arm manipulator (March, 2004)
- Interface Cobot with dual-arm system, and demonstrate virtual fixture (May, 2004)
- Develop meta behaviors by combining virtual fixture and motor behaviors (August, 2004)
- Prepare final Report (September, 2004)

Information Access:

http://www.td.anl.gov/Programs/ti/robots/index.html
http://www.mech.northwestern.edu/dept/research/lims.html