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Presenter Information

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ADVANCED VISION AND ROBOTIC SYSTEMS FOR HAZARDOUS ENVIRONMENTS

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This paper describes work performed at the Rockwell Space Division, Downey, California, and at Fluor Daniel Inc. Irvine, California, related to task performance in remote hazardous environments through advanced robotic and vision systems. These environments could be in space, for example related to the Space Shuttle, Space Station and outer space and planetary environments. In addition, the environments could be on earth, for example areas contaminated by chemical or radioactive waste. In both instances, the task is most efficiently performed when the environment has been designed from the very beginning for remote task performance. While this is often not the case, much is being done in the development of two important related remote technologies: environmental characterization and inspection; and remote handling and manipulation.

Important work has already taken place in developing robust systems for remote characterization, inspection and manipulation, for example, at the facilities of NASA and the Department of Energy. NASA is already integrating and testing a mobile robot system for inspection and re-waterproofing of thermal protection system tiles on the Space Shuttle. Other NASA efforts include micro-rovers, robotic devices for ground emergency responses, robots with local autonomy for ground characterization, and small, highly dexterous robots for visual inspection. In addition, the Department of Energy has many efforts to develop characterization, inspection and robotic systems for radiation areas. Notable examples include mobile systems for inspection of exterior and interior acreage sites, reactor vessels, pipes, drums, and various devices and special end-effectors for waste excavation, size reduction, manipulation, decontamination, and decommissioning. To support these activities, we have taken a systematic approach to developing some of the basic technologies necessary for remote operations in hostile environments. Our major thrust has been to develop a modular, re-configurable robotics laboratory test bed, and then to use this test bed to support advances in the following areas: simulation and engineering analysis for development and verification of

remote tasks; special vision systems; and vibration isolation to stabilize and enhance remote manipulators.

Laboratory Test Bed

A block diagram of the Rockwell Robotics test bed is shown in Figure 1. It contains 4 different industrial robot systems, each with its own controller: Unimation Puma 560, Adept 1, Remotec RM-10A dual-arm system and a Cybermotion Mobile Platform. We have a variety of different input devices, including a six-degree-of-freedom tracker sensor, 3-D mouse, keyboards, computer screen inputs, voice and robot-specific teach pendants. Computer architectures include Virtual Memory Environment (VME)-bus systems, Personal Computer (PC)-bus systems, and Sun and Silicon Graphics workstation computers. The vision system section of the test bed consists of the following equipment: vision cameras, high resolution cameras in a remote area, ITI Image Processing System Hardware, VME bus and video patch panel for image processing, and an operator interface system for display of the processed images. To complete our laboratory integration, we have developed a graphical front end as an operator aid, using the Deneb Robotics IGRIP 3D solid graphical kinematic and dynamic modeling package.

Simulation and Engineering Analysis for Development and Verification of Remote Tasks

In planning a task in a remote environment, for example the moving of a drum of high level waste by a robot device or hoist, or moving of a fragile payload in space, it is important to rehearse and preview the task in simulation. This enhances task safety as it allows a check of safety features like clearances, reach and so on and also serves as a training aid. Our graphic modeling feature allows development and practice of robot actions, and prediction of outcome before an actual hardware device is moved. The operator can be helped with on screen cues such as collision/near miss detection and joint position/speed/acceleration/torque limits. Paths can be revised or completely replanned accordingly. The graphical system can include a complete CAD-based model of a facility/environment and all robotic systems in that facility. The model of the robotics can include kinematics, rigid body dynamics, flexible body dynamics based on finite element analysis, and control systems. As well as commanding the robot motion, the system is designed to receive sensor data, and can update the models in real time based on these sensor data. This minimizes any error between the model and real environment. Additionally, operators can superimpose video of a remote hazardous environment and a CAD based 3-D solid model of that remote environment. Comparisons can then be made of the present scene with the "as designed" environment. Changes in the real remote environment would then be immediately obvious, and could signal the need for corrective action. Capabilities of this type are widely used today in many Department of Energy laboratories developing technology for future remote decontamination and decommissioning activities.

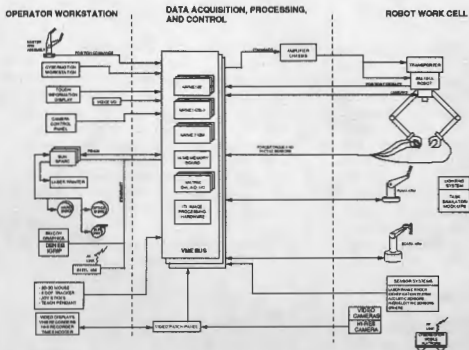


Figure 1. Laboratory Test Bed

Verifying Design of Remote Maintenance Systems Through Simulation

Verifying compatibility with remote maintenance is ideally conducted in the initial design stages of a project. Changes can then be made without expensive retrofit. We have used the above graphic system to develop and verify robotic systems for remote inspection and maintenance at the initial stages of a program. The particular facility involved is expected to be hot both as regards radiation and temperature. Concepts for remotely controlled mechanisms and robots to perform maintenance tasks in that facility have been added to 3-D CAD models of the facility. All reaches, clearances, weight tolerances and viewing angles have been verified so that the optimal inspection or maintenance device can be developed at the earliest stages of the facility design. Using the techniques discussed above, the 3D model can also be used for planning remote tasks, for predictive displays of these tasks, and for controlling the actual task through the model. In the latter instance, commands are downloaded from the model to the mechanisms in the real world, thus adding a high degree of safety to the task performance. For example, the system would be used to plan and then control tasks to remotely reduce contaminated waste to rubble, and then to bag and dispose of it.

Vision Systems

Remote tasks are often performed without the aid of direct human vision. In many instances the distance is too great or the environment too hostile to allow direct vision. For example the task may be shielded by a concrete wall, or may be far away. Environments, for example the interior of waste tanks, may have unknown visual characteristics in which case finding and identifying objects is important. Or the contents of the environment may be known and need inspection. For example pipes and ducts may be inspected for damage, discoloration, missing parts and so on. Both object identification and inspection have been addressed in our vision system test bed. We have developed unique tracking algorithms to identify and track several "points of interest" on arbitrary objects. As long as most of the points remain in view, those points which are lost are automatically replaced by new points of interest, and the algorithm is able to adapt and keep tracking. We also developed a detection algorithm which automatically identifies damaged areas and shows them in high relief on the screen. The test case used metal panels with fine honeycomb texture. The damage of interest was very difficult for the human eye to detect but was successfully detected and displayed by the system.

Vibration isolation

Remote task performance, particularly by robots, cranes and other mobile devices, often demands that account be taken of vibration of the arm itself. This may be very important if the arm is handling a heavy load or if the task must be done quickly. Task time may lengthen as the operator waits for an arm to stabilize after movement. In addition there is the safety aspect of a swinging arm hitting an object in that remote environment. We therefore addressed the problem by developing an active compliance, vibration isolation system, which we named the "end point control unit" or EPCU. Various control algorithms were then developed to accommodate a variety of vibration isolation requirements. The EPCU uses force as its primary feedback for control. It is composed of four sub components: drive mechanism; linear motion constraints; feedback sensors; and digital control hardware and software. A variety of control laws were developed to accommodate variations in system linearity and vibration characteristics. When integrated to a remote handling system, the unit could have many advantages for decreasing time and enhancing safety of manipulation in a variety of remote hostile environments.

Conclusions

We are advancing the technology of machine vision and robotics which will help ensure the safety and efficiency of remote tasks in hazardous environments. We have developed a test bed, and put in place unique vision capabilities, demonstrated techniques for design audit for remote maintainability, and developed and demonstrated techniques for enhancing and improving performance of remote manipulator systems.

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