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Virtual Reality and Telepresence Control of Robots Used in Hazardous Environments

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Abstract

This is the final report of a one-year, Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). The purpose of this project was to explore the application of teleoperation and telepresence control to robots in hazardous environments at Los Alamos. The primary use of this technology would be in a glove-box type operation potentially allowing operators to work on hazardous materials while being completely removed from the danger of exposure in situations that are difficult to completely automate due to the highly unstructured environments or off-normal conditions. This project focused on determining the most appropriate tools and methods that could be applied in the near future resulting in a reasonably inexpensive working teleoperation or telepresence control system for industrial robots used in the handling of hazardous materials. Several topics had to be addressed to perform this task including input devices, control systems, robot manipulators, and simulation techniques or packages. Much of the work is still in the developmental stage and hardware will follow—providing a usable tool for glove box robot control.

1. Background and Research Objectives

This paper presents the application of a teleoperation or telepresence controller to an existing robot manipulator used in hazardous environments. The primary use of this technology will be glove box applications where the high levels of radiation that are possible and the large quantity of material handled make automation of the tasks necessary. Use of automation and control of the robot in this fashion offers several advantages. One of the most significant benefits is the reduction or elimination of exposure of the technicians to radioactive material by allowing them to perform the same work while being removed from the hostile

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environment. Although it is not always possible to be completely removed from the situation, it is often possible to reduce the time at, or increase the distance from, the glove box. Another problem with working in glove boxes is operator fatigue. In general, it is difficult to reach all the areas and perform the required tasks over long periods as often needed in these operations. The addition of a robot to the system allows the operator to perform the repetitive motions with pre-programmed routines. In addition, by allowing for teleoperation with off-normal and infrequent tasks or just providing a "third hand" with the robot, the operator is able to perform in this harsh condition without fatigue and danger of becoming careless. Many of the nondestructive tests such as calorimetry require repeatable handling and are very susceptible to slight perturbations that would be introduced by human operators. Therefore, the system will also be able to handle material more reliably and repeatably providing for more accurate test results performed on the samples. It should be noted that some of the work discussed below requires problem solving and hardware will follow as the need to get the system going and resources become available.

2. Importance to LANL's Science and Technology Base and National R&D Needs

This project supports Los Alamos core competencies in theory, modeling, and high-performance computing; complex experimentation and measurement; and nuclear and advanced materials. It enhances the Laboratory's visibility in robotics and increases LANL's ability to respond to initiatives in that area.

3. Scientific Approach and Results to Date

A gantry robot designed at LANL will be fitted into a glove box allowing for the automation of certain tasks dealing with hazardous materials. This will easily facilitate the automation of repetitive tasks using common pick and place routines that can be anticipated and programmed in advance. However, in an off-normal situation or a highly unstructured environment, some sort of human interaction will be necessary. This will allow for potentially harmful exposure unless the technician has the capability to operate the robot from a distance via teleoperation or telepresence. Here, teleoperation usually consists of a vision system and a joystick type input device that allows the operator to control the robot. Although this will reduce exposure time to some extent, there will still be instances in which more input is required from the glove box environment to complete a task. This input may be in the form of additional visual data such as video capability or tactile data such as feeling the forces encountered at the robot end-effector. It was proposed therefore that the use of virtual reality and telepresence would allow the operator to process this additional data while still being removed from the task.

One of the first ideas considered was a telepresence system allowing the operator complete submersion in the working environment [1]. This would involve both arms and hands for input, some method of giving the operator a sense of feel, augmented stereo vision and sound as well as some torso and head motion to allow for easy video tracking. Force feedback through a seven-degree-of-freedom (DOF) arm and up to twenty-DOF for each hand could be required for this type of system to match that of the operator. This would allow for the natural manipulation techniques humans possess to be duplicated on the robot side and would include the natural redundancy resolution for obstacle avoidance we posses as well as the inherent dexterity humans have developed. Although this deserves consideration in the future, it is beyond the scope of what is necessary for the current LDRD project. In addition, the technology does not currently exist to feed forces back to a twenty-DOF hand sufficiently and is not achievable with the funding or time allotted. This project therefore focused on determining the most appropriate tools and methods, which can be applied in the near future resulting in a reasonably inexpensive working telepresence control system for industrial robots used in the handling of hazardous materials.

Robot and Controller Hardware

A key restriction in considering some of the teleoperation or telepresence potential for a project is the hardware/software combination that must be used. In the case of the glove box robot, industrial quality hardware is needed as it is very important to have a functional, reliable, and maintainable system. The robot will be at most a six-DOF system, depending on the application, and any redundancy in the system will not be available for the user. This type of system can be seen in the current gantry prototype where a three-DOF robot system is made up of five actuators. This gantry style robot has the first axis redundantly actuated with separate motors located on two parallel rails. The next axis spans the first two rails and the last axis is perpendicular to the first two as well as the floor of the glove box. The last axis consists of two prismatic joints in line with each other but the redundancy is eliminated by splitting the desired motion equally between the two. The controller chosen will most likely continue to be an Adept industrial controller as used on the current prototype with a few changes such as the introduction of a VME bus. The VME bus provides a high speed back plane required for this sort of computation and processor communication. In addition, the processor may be upgraded from a single Motorola 68040 chip to multiple chips allowing better computational performance needed to run multiple robots or master/slave combinations. Note that in the case of a telepresence controller, the master may be seen effectively as another robot that is run simultaneously with the slave robot where the master is driven according to the forces read at the slave robot's end-effector force sensor. This is a unique approach, but the Adept controller is capable of this operation. The hardware has been extensively tested in factory as well as laboratory settings and has proven itself functional and reliable. Although there are some restrictions encountered when applying this type of commercial hardware, it is also one of the most reliable and robust systems available and the trade off is easily justifiable when considering the ultimate goals for the robot system. We met with Adept and determined that while offering the industrial quality needed for reliability, they are also able to provide many of the advanced programming and control tools needed to implement this type of system. The gantry robot is currently up and running, which has been a major milestone and is proving to be a useful tool in sorting out some of the teleoperation issues for the next device.

Teleoperation Control

The first level of control allowing human interaction will be robot teleoperation. This is defined here as the position control of the robot end-effector with some sort of joy-stick input device. A number of input devices were considered consisting of position and rotation measurement capability. One version of the glove box is only a three-DOF machine and only requires a three-degree joystick but a six-degree input device capable of measuring three-degree position and three-degree rotation is needed for the more advanced robot. There are a wide variety of choices available for position measurement ranging from a two-degree mouse to a six-degree Spaceball. One consideration in choosing an input device is reducing the amount of computing (thinking) the human operator must perform while operating the device. This basically means trying to match the motion of the robot end-effector and the motion of the input device and may be easily achieved by matching the kinematic motion of the two devices as much as possible. Another criteria here is the ergonomics in considering how well it feels to hold, move, etc. The Logitech Magellan three-degree (actually six-degree in operation) input device was chosen as it seemed to best fulfill all the requirements. It has an advantage over the Spaceball in that it provides a small amount of displacement in measuring the desired input and it is an inexpensive alternative to some to the other devices considered. In addition, the robot camera will be needed. This is existing technology and is easy to implement if provided for in the design of the robot and glove box systems.

Environment Simulation

The simulated environment will have the opportunity to provide visual input supplementing the live video as well as providing a means for other training and programming aids. Again, much work has been done in advancing the state of the art [3], however the goal here is to apply hardware and software that has been in the field for some time and proven itself reliable. This system should provide a method of training teleoperators for use of the glove box robot system. This will allow a new user to get up to speed quickly and easily as they are allowed to make their mistakes in a simulated environment or allow experienced users to train for a particularly difficult task. In addition, new automation tasks that are programmed for the robot may be test run in the simulated environment before they are executed on the actual system to check for collisions and other programming errors. There are currently several packages that are available that can provide some or all of the tools required including packages available from Deneb and Silma. Most are run on a high end graphics workstation such as a Silicon Graphics machine in order to get the type of high speed rendering required.

Conclusions

In general, the system must be simple, functional, and reliable. It must be easy to turn on and intuitive to operate in order for it to be used rather than the technicians using the glove ports as a default. A number of input devices were considered including position as well as force-reflexive devices. Much of this technology is well established and the devices are robust and reasonable in cost. The control system technology is largely driven by industry and, therefore, very reliable but lacking in the technical sophistication available in some experimental systems. Simulation techniques are only recently at a usable stage partly due to the increase in CPU power over the past few years. Several robot simulation packages are available and being reviewed for consideration in this type of control. Some of the information given above is still conceptual or still in the design phases, but hardware will follow as the resources become available. The existing technology will be easy to implement and if done correctly, will provide a powerful system capable of performing most glove box operations. This will ease operator fatigue, reduce exposure, improve test results by providing reliable and repeatable material handling, as well as possibly improving system throughput and easing operation.

References

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Telepresence Control

The second level of control involves a type of input device that is capable of providing force feedback to the operator reflecting the forces encountered by the robot at the end-effector. This allows for a sense-of-feel, which is particularly important in many operations involving material handling, assembly, or disassembly of parts. In addition, this type of system might attempt to provide more information to the user such as better vision or audio capabilities. Although there are a number of manufacturers involved with this type of device, they are not as developed as the position input devices discussed above. As a result, the technology is not nearly as evolved and integration with existing robot systems is more difficult. There are, however, some robot systems that focus primarily on this type of robot control. In particular, the Schilling line of manipulators, which are almost entirely teleoperated, have shown themselves to be functional and reliable devices capable of working in harsh environments. They do not currently make a system capable of performing the required tasks in a glove box, but rather give a good example of what can be achieved with this type of technology. Part of their product line are the two types of input discussed above. In testing some of the existing products and methods of operation, the Schilling product line was considered and although it proved to be a good tool, the application of the product line would be too difficult, if not impossible, to implement with the existing gantry robot glove box system. It was determined that a kinematic similarity between the master and the slave devices was even more critical with a telepresence system than that required for simple teleoperation making it necessary to find an input device that matched the glove box system to some degree. It may even prove necessary to construct a dedicated master controller for the kind of performance required to perform the necessary work with this robot system. As part of the investigation into existing technologies, we studied some of the techniques used at Sandia National Labs with SMART [2] as well as others and came to the conclusion that in general, many of these systems are too complex to provide the simple and reliable control needed for our glove box device.

After the input device has been chosen, some sort of visual capabilities should be provided to augment what may be seen through the glove box windows. This may involve two basic types, which are live video and computer generated simulations where these may be used independently or simultaneously as needed. Note that in general the live video will provide the most accurate and reliable source of input and a variety of options are available to supply this. A camera will most likely be needed at the wrist to provide close up views as well as views into the deeper wells of the box. In many cases, the operator may look through the glove box ports and obtain a good overview, but a camera set off some distance may also be needed to give a wide angle system view to complement that obtained by looking through windows. In particular, when it is desired to operate the system from a distance an additional