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An Interactive Animated Display of Man-Controlled and Autonomous Robots

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ABSTRACT

An interactive computer graphics program has been developed which allows an operator to more readily control robot motions in two distinct modes, viz. man-controlled and autonomous. In man-controlled mode, the robot is guided by a joystick or similar device. As the robot moves, actual joint angle information is measured and supplied to a graphics system which accurately duplicates the robot motion. Obstacles are placed in the actual and animated workspace and the operator is warned of imminent collisions by sight and sound via the graphics system. In autonomous mode, a collision free path between specified points is obtained by previewing robot motions on the graphics system. Once a satisfactory path is selected, the path characteristics are transmitted to the actual robot and the motion is executed.

INTRODUCTION

There have been significant advances in the broad range of technologies associated with robot manipulators such as for example kinematics and dynamics, control, vision, pattern recognition, obstacle avoidance, and artificial intelligence (see for example [1-4]). A major objective is to apply these technologies to improve the precision of operation and the control of manipulators performing various tasks.

Further, when it is necessary to perform tasks remotely in a hazardous environment it is desirable to create a flexible man-machine interface. Applications of this technology occur for example in nuclear reactor maintenance, space station operations, and cargo handling stations (where one or more robot manipulators is handling a dangerous cargo). In such cases the geometry of the robot workspace is known. One method of avoiding accidents is to utilize the knowledge of the workspace in an interactive animated display of the robot and its environment. Such a system can be used to both plan and execute moves and operations. For example, the operator can select a path from numerous computer generated paths which move the manipulator from one target point to another while avoiding obstacles. During this selection phase the operator can halt the motion at any time, zoom in, and orient himself to check clearance with obstacles.

The same interactive animated display system could be used as an aid in designing workstations where two or more mobile robots are operating in parallel with other autonomous machines. Furthermore the system could prove to be useful to a robot manufacturer to display and compare workspace envelopes, dexterities, motion capabilities, and the effect of changing robot dimensions. Although it is clear that an animated display system is a useful and versatile tool, this paper is concerned solely with the application of the animated display to robot control and operation.

TELEPRESENCE CONCEPT

It is often necessary in a hazardous environment for an operator to effectively control the motion of a robot manipulator which he cannot observe directly. The manipulator may be either directly guided via use of a joystick or similar device, or it may be autonomously controlled in which case it is desirable to preview and monitor robot motions. The operator must be provided with an accurate picture of the workspace environment and of the robot motion, together with other sensory information such as touch and sound. These inputs will allow the operator to experience the motion and forces acting upon the distant robot. In this context, the word telepresence is used to describe the type of system which permits the operator to effectively control the motion of the remote robot manipulator.
The primary sensory feedback that an operator requires to control robot motion is vision. In many instances, vision alone will give the operator sufficient information in order to avoid obstacles and to manipulate objects as desired. Logically, this vision could be provided by video cameras which surround the workspace of the manipulator or which are attached to the manipulator itself. The ability of the video camera to zoom in and provide enlarged visualizations of the work area would also assist in the control of the manipulator. Use of other sensors such as force feedback devices together with the video equipment would supplement the system.

It should be noted that the use of video cameras to provide vision feedback does have certain disadvantages. Primarily, more than one camera must be used to provide sufficient viewing positions for the operator. Each of these cameras will most likely have two degrees of freedom in addition to the zooming capability thereby giving the operator numerous additional parameters to control. Secondly, environmental conditions may cause the video image to be blurred or poor lighting and contrast may make the image confusing and unclear. Because of these and other limitations, a system has been developed which replaces the video feedback with a realistic computer graphics representation of the robot and the workspace.

The use of a computer graphics system offers three distinct advantages. First, images are clear and sharp. The use of solid color representations of the robot and work area with hidden surface removal provides a clear image of the scene. Colors can be selected to provide obvious contrast and clarity for the operator. Secondly, the computer graphics system readily allows for viewing of the image from any desired vantage point. This ability removes the requirement for a multitude of video cameras and allows the operator to focus his attention on only one monitor screen. Lastly, the computer graphics system can provide additional feedback to the operator. For example, when the manipulator is moved close to an obstacle, an audio signal can be given and the color of the obstacle can be changed. This additional feedback to the operator can significantly improve performance. The remainder of this paper will describe a computer graphics based telepresence system which has been developed at the University of Florida.

**SYSTEM COMPONENTS**

Figure 1 illustrates the telepresence system as it exists in the laboratory. The system serves as a test bed to verify the feasibility of the concept and consists of four distinct technologies and components as follows:

1. **Robot manipulator** - The manipulator chosen for the telepresence system was an MBAssociates (MBA) robotic manipulator. The MBA manipulator is a hydraulic six degree of freedom device. The second and third joint axes are parallel and the final three axes intersect at a common point. The robot is controlled by a PDP 11/23 computer which regulates hydraulic fluid flow so as to minimize the error between the desired and actual joint angles. The MBA robot was selected for this study because of its simple geometry and versatile control system.

2. **Six degree of freedom universal joystick** - Two six degree of freedom joysticks were utilized in the telepresence system. These are shown in Figures 2 and 3. The gripper of each joystick can be translated and twisted in any desired manner thereby giving the operator six degrees of freedom. The controlling computer calculates the position of the joystick and then determines the desired position and orientation of the end effector of the manipulator.

3. **Obstacle detection vision system** - A vision system is used to identify obstacles and then transmit the position and orientation of each to the computer graphics system. For this study, cubes and spheres were the only items placed in the workspace of the robot.

4. **Computer graphics system** - A Silicon Graphics IRIS 2400 computer graphics workstation was selected to provide the interactive animation capability required for the system. The ability of this workstation to rapidly draw shaded polygons was essential in order to allow for real time interaction with the animated display.

**METHOD OF OPERATION**

Shown in Figure 4 is a drawing of the configuration of the telepresence system. This system configuration allows for the operation of the manipulator in two distinct modes, viz. man-controlled and automatic. In both modes the problem to be solved is to identify and pick up a cube in the workspace and then maneuver the object to a desired point without colliding with a sphere. For the purposes of this investigation, it was assumed that all objects in the workspace of the robot were located on a flat horizontal surface.

**Man-controlled Mode**: In man-controlled mode the operator must control the robot via use of a joystick while observing only the graphics display screen. The first task to be
accomplished is the determination of the position of the sphere and the position and orientation of the cube in the workspace. This is accomplished by activating a vision system which is located directly above the robot. The vision system establishes a threshold such that the objects of interest appear as white objects on a black background as shown in Figure 5. A spiral search pattern is initiated to locate all white objects in the field of view of the camera. Analysis of scan line data identifies each object as a sphere or a cube and determines all position and orientation data. This data is transmitted to the computer graphics system.

The objects in the workspace are displayed on the graphics system along with a solid color representation of the robot. The exact configuration of the robot is determined at each instant by converting voltages from potentiometers attached to each joint to numeric angular values. These values are then transmitted to the computer graphics system and the robot is displayed.

Clearly the operator must not allow the manipulator to collide with the sphere during motion. This can be accomplished in two ways. First the operator can zoom in on the obstacle and maneuver the manipulator carefully when it approaches close to the sphere. He can also adjust his viewpoint so as to take advantage of the best vantage point possible. Secondly, the graphics system itself can signal the operator when a collision is imminent. An audio signal is given and the color of the obstacle is changed when the manipulator approaches near the obstacle. The determination as to whether a collision is imminent is conducted in real time by utilizing the built in capabilities of the graphics system. Simply, a bounding box is positioned around the obstacle. This box is monitored to determine if the robot manipulator will intersect it. An intersection signals that the manipulator is in close proximity to the obstacle. An important advantage of this technique is that the entire robot can be checked for collision in real time as opposed to just checking for collision of the end effector with the obstacle. An example of operation of the MBA robot in man-controlled mode is shown in Figures 6 and 7.

Automatic Mode: The goal of operation in automatic mode is for the manipulator to autonomously maneuver between user specified points without colliding with any obstacle in the workspace. The first steps to accomplish this task are the same as for man-controlled mode. The vision system is activated to identify and locate all items in the workspace. Next these objects are displayed on the graphics display system.

At this point calculations are made to determine if straight line motion is possible between the specified positions and orientations. If motion on a straight line would intersect an obstacle, calculations are made to alter the path to avoid the obstacle. If for any reason the operator is not satisfied with the computer generated path, it can be modified as desired. For example, if the operator would prefer to go over an obstacle rather than under it he may so direct the system to generate a new path. Once a trajectory is selected the operator can observe the motion of the animated manipulator. The bounding box technique utilized in the man-controlled mode is again used to insure that no part of the manipulator will strike the obstacle. After the operator is satisfied that no collision will occur, joint angle data is transmitted from the graphics system to the robot controller and the manipulator executes the motion. In this manner the operator has previewed a move of the manipulator on the graphics system prior to the robot actually executing the motion. This verification step allows the operator to have an influence over autonomous motion if so desired.

CONCLUSIONS

The telepresence system developed at the University of Florida has been successful in demonstrating that the concept of controlling a robot manipulator with the aid of an interactive computer graphics system is feasible and practical. The clarity of images coupled with real time interaction and real time determination of imminent collision with obstacles has resulted in improved operator performance. Furthermore the ability for an operator to preview and supervise autonomous operations is a significant attribute when operating in a hazardous environment. Further advances in the four component technologies which comprise this telepresence system will greatly improve such man—machine productivity in the future.

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REFERENCES


Fig. 1 - Telepresence System

Fig. 2 - Nine String Universal Joystick
Fig. 3 - Universal Scissor Joystick

Fig. 4 - System Configuration

TOTAL SYSTEM INTEGRATION
FINAL DEMONSTRATION

Fig. 4 - System Configuration
Fig. 5 - Obstacle Locations
Determined by Vision System

Fig. 6 - Operation in
Man-controlled Mode
Fig. 7 - Animated Representation of MBA Manipulator