The Effectiveness of Real-Time Graphic Simulation in Telerobotics

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Abstract - An experimental telerobotic system has been developed which uses graphic simulation support. The operator may select from a variety of display methods including the overlay of the simulation aligned with live video images from the remote site. The robot may also be directly controlled from the simulation, using a six degree-of-feedom hand controller. An experiment has been carried out to determine the effect that having perspective control of simulation has upon the performance of a teleoperation task. The experiment also compared the effectiveness of different display methods.

I. INTRODUCTION

The development of useful teleoperational robotic systems (telerobots) requires an effective subsystem for remote perception of the robot's workspace. Such systems in use today usually consist of remote video cameras, perhaps equipped with capabilities to permit the operator to alter the orientation and zoom of the cameras, and it is also common to use a camera fixed to a link of the manipulator. Despite these video sources, it may still be the case that a desired view of the workspace is unavailable or obstructed. Lighting conditions may be inadequate, preventing the operator from attaining a clear understanding of the workspace. The lack of depth cues from fixed position video sources may also hamper effective operation [1,2].

As high speed graphics becomes more widely available, the use of graphic-enhanced video images, or complete graphic substitution of video images is gaining favour as a method for enabling telerobotic perception. One approach is to superimpose a grid upon the video image corresponding to the base horizontal plane of the workspace. This grid can then be marked to indicate the position, and even orientation, of objects and items of interest to the telerobotic task [1]. This approach can eliminate some of the problems of poor lighting and limited perspective, but it is still subject to many forms of perceptual degredation.

Another approach is to utilize wire frame or solid rendered images of the robot and objects in its environment [3]. This approach has the additional advantage of offering any desired perspective or zoom under operator control. Providing that sensors are capable of determining position and motion of objects, such graphic enhancements can also become predictive displays capable of reducing the limitataions introduced by time delays.

We have been developing a real-time graphic simulation as a part of our experimental telerobotic system, which also includes bilateral force reflection, integration of tactile and force sensed data, and computational perception support.

This paper describes the graphic simulation and outlines experimentation carried out to determine the simulation configuration which will offer the greatest enhancement to operator performance.

II. GRAPHICS SIMULATION

Our graphic simulation is of a CRS-Plus M1A 5 axis small industrial robot, carried out on a Silicon Graphics 4D-85GT workstation. Depending on the number of active features, the simaluation can operate up to 30 frames per second. Four different display modes are provided: wire frame, wire frame with hidden line removal, solid, and transparent (see Figures 1-4). Control of the perspective parameters of the viewpoint to the simulated robot and

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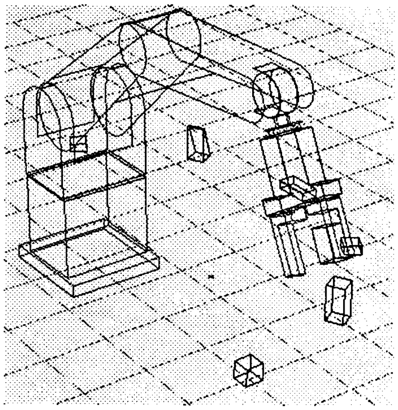

Figure 1: Wire-frame display

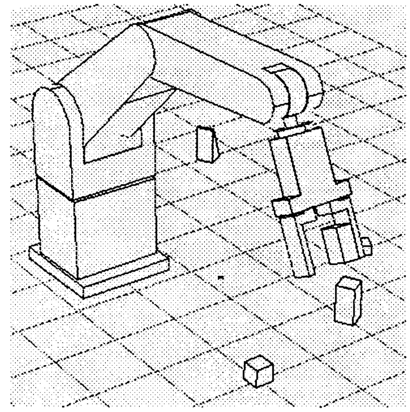

Figure 2: Wire-frame with hidden line removal

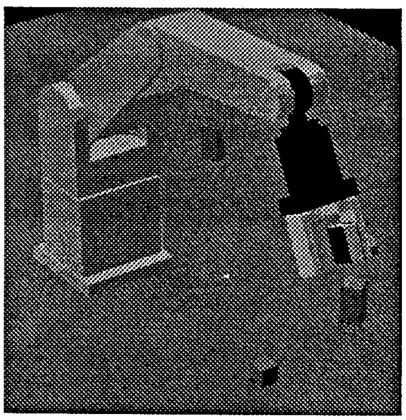

Figure 3: Solid display

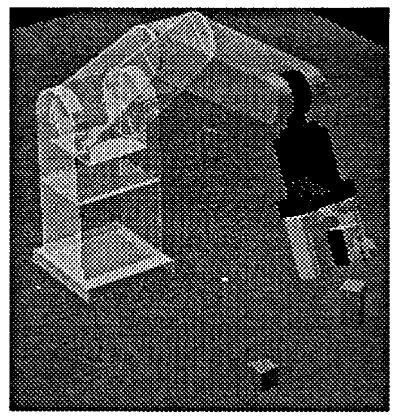

Figure 4: Transparent display

environment is achieved by assigning the parameters to the workstation's mouse buttons or through the use of a six degree of freedom hand controller. In addition, the simulation may operate in conjunction with a video camera which is set to view the manipulator site, feeding its output to a live-video digitizer on the Silicon Graphics workstation. After the camera parameters are established through calibration, the simulation is assigned to the same viewpoint parameters as that of the video camera. The video image and the simulation are then mixed under software control to appear on the screen as a composite aligned image. This not only confirms the accuracy of the simulation for the operator, but it also permits the operator to adjust and alternate between live and simulation views of the robot in operation.

The simulation of the robot and its parallel-axis servo gripper can be controlled in a variety of ways. In *joint-angle* the simulation can be operated from any of a variety of screen-based methods, including for example, a set of sliders representing the robot joint angles. In *animation mode* a predesignated list of joint angles is interpolated to obtain smooth movement at speeds that can be adjusted within the simulation. In *mimic mode* the joint angles are obtained through a serial link from the robot controller, and thus the simulation will carry out the same movements as the robot does, and it is possible to operate the actual robot with the teach pendent while viewing the simulation alone. In *effector mode* the operator utilizes the six degree of freedom hand controller to specify gripper locations and orientations within the simulation. The simulation moves in accordance with this specification, and the data link from the workstation to the robot is used to have the actual robot carry out the same movements. Perspective and zoom control are available at the same time through the operation of the workstation's mouse.

It is clear that the avilability of real-time simulations offers a variety of possible telerobotic perceptual enhancements from which it may be difficult to select an appropriate, or even optimal configuration. As a first step towards this selection, it is necessary to answer certain empirical questions:

1. Which of the many possible mappings from the workstation's mouse and hand controller to the simulation viewpoint provides the greatest enhancement of performance in telerobotic tasks?

2. Which of the simulation display modes, mixed or alone provides the operator with the most effective perceptual?

3. Which method of controlling the robot through the simulation can be best used simultaneously with viewpoint control?

We have embarked on a program of experimentation designed to answer these questions. We report here an experiment which asks the more fundamental question of the extent of performance enhancement that accompanies the availability of viewpoint control.

III. EXPERIMENT

Method

The experiment was composed of trials which displayed an animation sequence of the robot moving the gripper toward a block placed in the scene. The subjects' task was to predict whether or not a collision would occur between the gripper and the block. There were four conditions: *wire-frame with viewpoint-control*, *wire-frame without viewpoint-control*, *solid-model with viewpoint-control*, *solid-model without viewpoint-control*. Each condition consisted of twelve trials, six in which collision occured, and six in which it did not. All animation sequences were of comparable difficulty, and they were assigned randomly to the conditions. Ten subjects participated in the study.

Results

The error rate for both of the conditions *with viewpoint-control* was 43% of the error rate for the conditions *without viewpoint-control*. This result was found to be significant using an analysis of variance ($F(1,76) = 8.49$, $p < 0.005$). This supports other findings of the effects of various other display techniques in telerobotic tasks [1]. The greatest performance enhancement was in detecting actual collisions, for which the conditions *with viewpoint-control* exhibited only 18% of the errors found in the conditions *without viewpoint-control*. The amount of time taken to respond was also significantly less in the conditions *with viewpoint-control* ($F(1,72) = 4.58$, $p < 0.04$).

IV. CONCLUSIONS

Given the obvious ability of the experimental technique to detect performance differences, it was surprising that no significant differences were found between the two display modes that were used. Recent results in aircraft simulation studies suggest that there should be an effect of these different display types [4]. However, our results are more consistent with psychological studies which have shown that subjects are no faster to recognize objects in full colour photographs than they are to recognize the same objects in line drawings [5].

In future studies we intend to provide a choice of display modes so that the subject may select the most appropriate alternative for each trial. We also have planned a study which will investigate the effectiveness of the various viewpoint control methods. Incorporation of the bilateral force reflection will also permit us to operate the robot more effectively in *control mode*, which will open the door to experimentation using trials which are more similar to actual telerobotic tasks.

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