Robot Teleoperation and Perception Assistance with a Virtual Holographic Display

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Abstract

Teleoperation of robots in space from Earth has historically been difficult. Speed of light delays make direct joystick-type control infeasible, so it is desirable to command a robot in a very high-level fashion. However, in order to provide such an interface, knowledge of what objects are in the robot's environment and how they can be interacted with is required. In addition, many tasks that would be desirable to perform are highly spatial, requiring some form of six degree of freedom input. These two issues can be combined, allowing the user to assist the robot's perception by identifying the locations of objects in the scene. The zSpace system, a virtual holographic environment, provides a virtual 3D space superimposed over real space and a stylus tracking position and rotation inside of it. Using this system, a possible interface for this sort of robot control is proposed.

Contents

1 Introduction and Background

NASA has produced many sophisticated and capable robots, such as Robonaut and ATHLETE. They offer the potential to carry out tasks that otherwise must be performed by humans in dangerous or inaccessible areas. Robonaut, for example, has the dexterity to perform many tasks that would otherwise require human hands. Dangerous repairs aboard the International Space Station could be carried out without any risk to astronauts. However, despite their mechanical capabilities, they are utilized infrequently and poorly.

ATHLETE is a robot under development by the NASA Jet Propulsion Laboratory, originally designed for lunar missions[3] but now being repurposed for future asteroid missions. Currently, when ATHLETE engineers want to position a tool such as a drill, they have a person stand next to the robot and call out how to move it. This would be unacceptable on any sort of space mission. Operators can use predefined sequences to get to certain leg positions, but this is not useful for any sort of new location. This situation is typical of potentially space-bound robots.

In many situations in which these robots would be used, a significant speed-of-light delay would be present. This adds another layer of difficulty to commanding these robots. Even small delays make direct joystick-type control of joints infeasible[2]. This effectively rules out any sort of servo-level control or one-to-one mapping to human actions on the controlling side. It becomes desirable to command at a higher level, telling the robot to perform an action upon an object rather than how to perform it.

Figure 1: ATHLETE

This presents another problem. In order to act upon such high-level commands, the robot must be able to identify objects around itself and their relative pose. In uncluttered environments with preexisting models of objects, this is an all-but-solved computer vision problem[1]. However, as shown in Figure 2, environments like the International Space Station are anything but uncluttered. A system for commanding robots in space must be able to contend with densely packed, noisy, downright confusing environments.

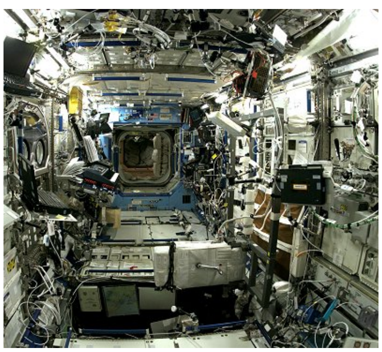

Figure 2: Onboard the International Space Station.

Given a good way to input 6DOF pose information, the object identification problem can be trivially solved. Rather than attempting to programmatically extract object information from sensor data, the user can be used. Humans have no trouble identifying objects in cluttered environments. The operator of a commanding interface can simply tell the robot what is around it. Such human-aided perception would deliver excellent results in otherwise impossible conditions.

The zSpace[4] system, shown in Figure 3, is a virtual holographic workstation produced by Infinite Z. It provides a stereoscopic display, head tracking, and a stylus tracking position and rotation. These allow the user to see a scene in full 3D and look around it easily and naturally. This system offers the potential to assist in solving the problems. With zSpace's very natural 6DOF stylus input, the user can easily specify a pose in 3-space. This makes it trivial to identify objects and their poses for the robot.

2 Objectives

The objectives of this project were twofold. The overarching goal was to investigate these problems, and deliver a prototype of an interface that addresses them in a more natural and intuitive way than existing interfaces. A secondary goal was to demonstrate the viability of the zSpace system for use in JPL operations.

One goal was to produce a prototype interface for commanding Robonaut in cluttered, unstructured environments. The user would identify objects that could be interacted with by dragging wireframe models into the scene. Using this information, the user would be able to construct high-level command sequences and send them to the robot. An example of the proposed interface, taken

Figure 3: The zSpace device, including 3D display, polarized glasses, and stylus

from a low fidelity prototype, is shown in Figure 4.

As a simpler task to demonstrate the viability of zSpace, an application for controlling ATHLETE while drilling in an asteroid mission scenario was created. The zSpace stylus is used to position the end effector of a limb.

3 Approach

Two prototype interfaces were developed in the Unity 3D game engine. Development was done in the C# language.

The majority of development time was invested in the ATHLETE drilling demonstration. In this application, ATHLETE's end effector moves to exactly match the position and orientation of the stylus. Figure 5 shows the application in use.

Much effort was spent on the integration of the zSpace system with Unity. For the majority of the project's duration, the interfaces were developed in 2D due to lack of integration. Infinite Z provided an early preview of their plugin for the Unity engine in the seventh week. Although the plugin was functional, little to no documentation was provided and many of its behaviors were unexpected and unintuitive.

In order to move ATHLETE's end effector to match the position and orientation of the zSpace

Figure 4: Low Fidelity Interface Prototype

stylus, inverse kinematics routines were needed. A previous implementation was available, based on a numeric cyclic coordinate descent method. Though this worked quite well for positioning, there was no support for orientation. In order to solve this, sections of ATHLETE's flight software pertaining to inverse kinematics were ported to C# on the Unity engine. The flight software implemented an analytic solution for position and orientation, giving instant and perfectly accurate results.

Though this solved the orientation problem, it introduced problems of its own. ATHLETE's flight software uses a number of different coordinate frames, none of which are native to Unity. Converting position vectors between these frames was relatively trivial. However, rotation was more difficult. In addition to the axes of rotation being different, the flight software expected Tait-Bryan angles as an input for orientation. Unity operates solely on quaternions. Conversion routines were needed.

4 Results

Though two interface prototypes were under development, only one was finished. The significant delay in obtaining the zSpace Unity plugin caused most development effort to be condensed into the last two or three weeks. Though 2D mockups of the Robonaut interface were completed, the zSpace-enabled prototype is not yet complete.

The ATHLETE drilling application was completed and user testing was performed. The user testing garnered universally positive results. Users were excited about the prospect of operating ATHLETE without a tape measure.

Though the Robonaut interface was not completed, a solid foundation for working with zSpace

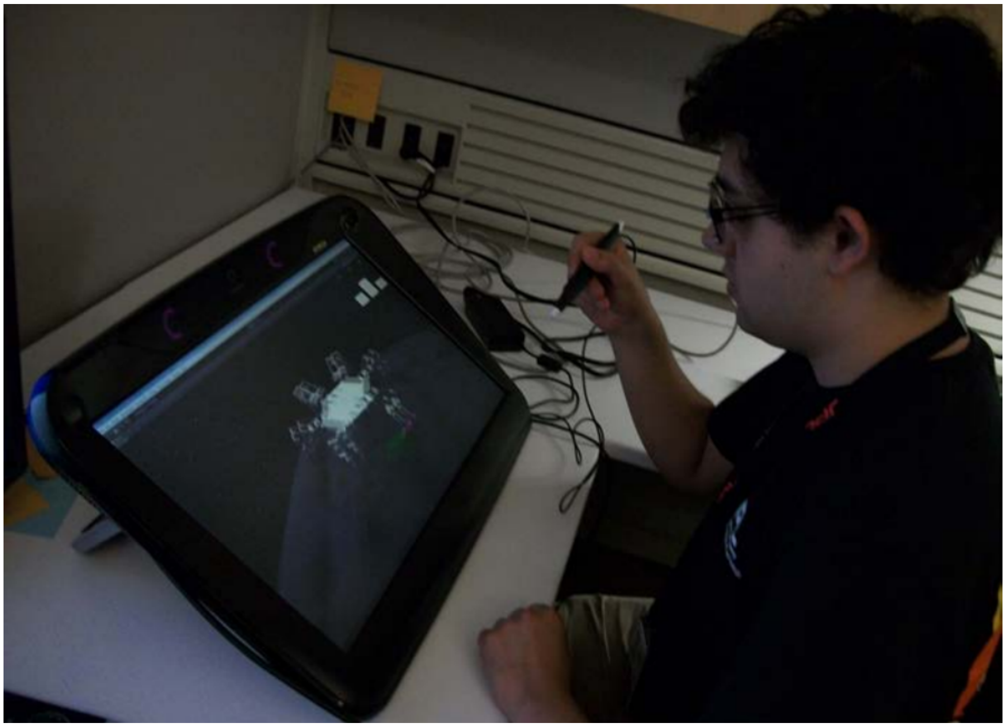

Figure 5: ATHLETE drilling application in use

in Unity in the future has been laid.

5 Acknowledgements

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