Teleoperation of Robonaut Using Finger Tracking

Rachel G. Champoux
University of Southern Maine

Mentor: Victor Luo
Jet Propulsion Laboratory, California Institute of Technology

Abstract

With the advent of new finger tracking systems, the idea of a more expressive and intuitive user interface is being explored and implemented. One practical application for this new kind of interface is that of teleoperating a robot. For humanoid robots, a finger tracking interface is required due to the level of complexity in a human-like hand, where a joystick isn't accurate. Moreover, for some tasks, using one's own hands allows the user to communicate their intentions more effectively than other input. The purpose of this project was to develop a natural user interface for someone to teleoperate a robot that is elsewhere. Specifically, this was designed to control Robonaut on the international space station to do tasks too dangerous and/or too trivial for human astronauts. This interface was developed by integrating and modifying 3Gear's software, which includes a library of gestures and the ability to track hands. The end result is an interface in which the user can manipulate objects in real time in the user interface. Then, the information is relayed to a simulator, the stand in for Robonaut, at a slight delay.

Introduction and Background

What are computers good at? How can robots be used to help humans, particularly in outer space? These questions have been considered for years and are still being discussed today. Computers are good at doing what they're told, within reason, but not good at thinking for themselves. Most humans are the exact opposite. Moreover, humans are experts at analyzing their environments and basing conclusions on that analysis. So, how do we combine these two systems to maximize productivity? It may be possible to make a system completely autonomous, equipping it with enough information and code to do tasks. But, is this efficient use of time? What if, instead of a software programmer developing ways to get a robot to "understand" something, there is a human operator telling the robot what to do? In this way, the human can do what he or she does best – analyze the situation, develop a plan of action, and instruct the robot. Finally, humans are far more adept at making decisions when presented with new situations. A robot can only do what it is told to do in a certain situation, but a human can analyze a new situation and present new instructions to the robot to execute.

Robonaut, a humanoid robot was created to bridge the gap between humans and robots. Created by NASA's Johnson Space Center, Robonaut has near human-like dexterity in the hands, "which allows it to use the same tools as Astronauts currently use" [6]. Not completely autonomous, Robonaut requires input from humans in order to take full advantage of its capabilities. Not only could Robonaut eliminate the need for humans to do dangerous tasks, but it allows astronauts to make better use of their valuable time. Instructing Robonaut to do tasks does not need expert training, especially for tasks such as cleaning or basic maintenance. This project was developed with the goal of creating a user interface in order for an earthbound teleoperator to control Robonaut.

Finding a way to communicate between the user and the robot can be difficult. Originally, the simulator used a Kinect for body tracking and used certain hand movements to mean certain things for the system to understand. Unfortunately, the system is rather unintuitive as one has to learn the gestures, figure out how to operate the system, and then remember the hand movements. The most natural thing for a user to do would be to act as if they were picking up an object as they would do every day – reach out and grab it. Just using a Kinect is not enough to get that intricate information though. Instead, a finger tracking system is used, with information about what the hands are doing. A company called 3Gear happened to create such a finger tracking system, which was used for this project after integrating with the Robonaut Simulator and interface.

Although haptic devices such as joysticks, mice, and even arrow keys can generally be used for most robots, they do not map well to a robot with humanoid dexterity, particularly to motion degrees of freedom [2]. Robonaut has 14 degrees of freedom just in the hand. Angles can be more easily expressed by having the robot copy a hand movement, rather than using a joystick to try to tweak the robot's hand into a certain orientation. With the amount of complexity, a haptic device quickly becomes outmoded. Not only can it be more expressive, but finger tracking allows the operator to immerse themselves into the environment, as opposed to having an extra implement like a joystick to work with. As Graves and Czarnecki said in their paper "if the operator has the freedom to perform actions in the remote environment naturally, they will experience a feeling of projection into that remote environment, therefore teleoperation will involve no cognitive overhead" [3].

Method

This project used 3Gear's finger tracking software as the starting point. In addition, this system makes use of a robonaut simulator created prior to this project by the JPL conductor team. Taking the code from one of 3Gear's demos, the very first step was to integrate the code with the Robonaut simulator. Once the 3Gear software was connected to the Robonaut simulator in Unity, the simulator code needed to change so that one could control Robonaut using 3Gear's software. This was made possible by utilizing the simulator's functions and 3Gear's hand position information. Then, the system just needed tweaking due to differences between the two.

Once the simulator worked, the interface then had to be created. This was done by taking the Natural User Interface (NUI) previously created by the Conductor Team, and adapting it to suit the needs of the new system. The interface provides the user with an image of Robonaut that the user can control, as well as an image in the background of the position the simulator is in. The NUI works almost as it would if it were connected to the real Robonaut as it does now connected to the simulator, with a built in time delay. Point cloud data of Robonaut's environment, such as the items on the table, are passed from the Simulator to the NUI through the use of a RAPID sever. RAPID, Robot Application Programming Interface Delegate is a language for communication between robots. In our case, the server passes the commands from the Simulator to the NUI. Data can also be passed from the NUI to the simulator, such as when the NUI has grabbed an object, moved an arm, etc. In this way, the simulator state can be updated at controlled intervals with a time delay. Meanwhile, the user can look at what the NUI is doing and understand how their actions are controlling Robonaut.

In order to test out the system, two simulation scenes were used. One consists of a table with 3 items on – a drill, an oil can, and a flashlight. In addition, there are also 3 different colored squares which are used as "targets". The idea is to see if one can get the objects on the targets using the new interface controlled by finger tracking. The other scene was modeled after Robonaut's taskboard. So far, the taskboard only consists of wires and sockets - the goal being to plug the wires into the sockets without getting them tangled or grabbing the wrong wire.

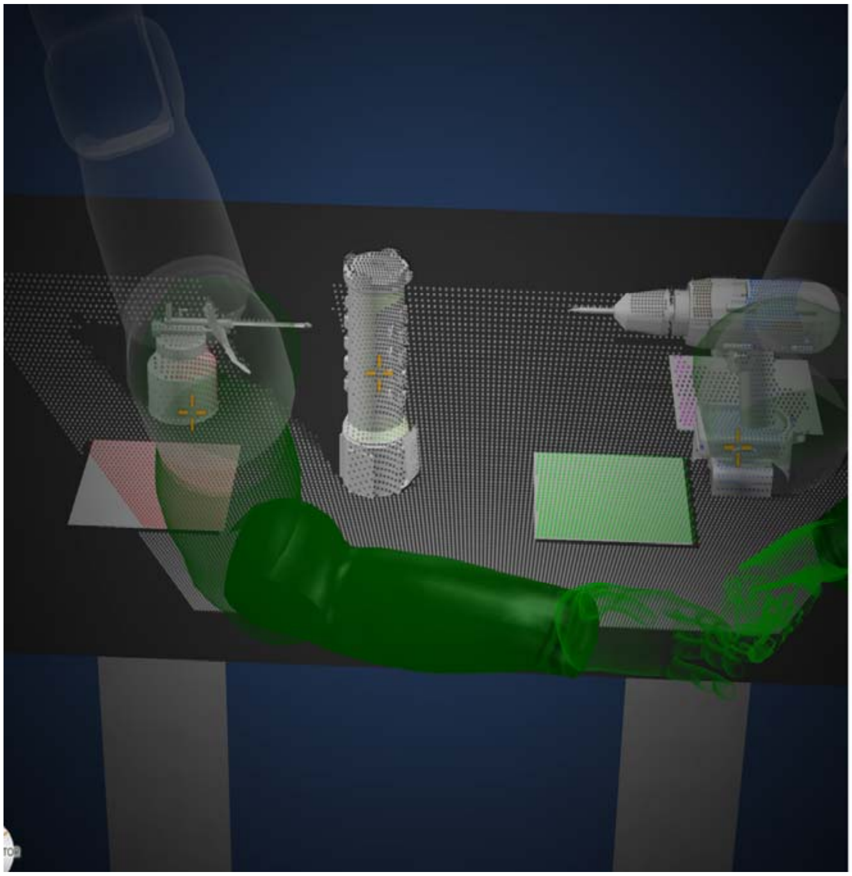

Figure 1: An image of the NUI with pointcloud data from the simulator table scene. The white arms coincide with the simulator's position and the green arms are controlled by the user.

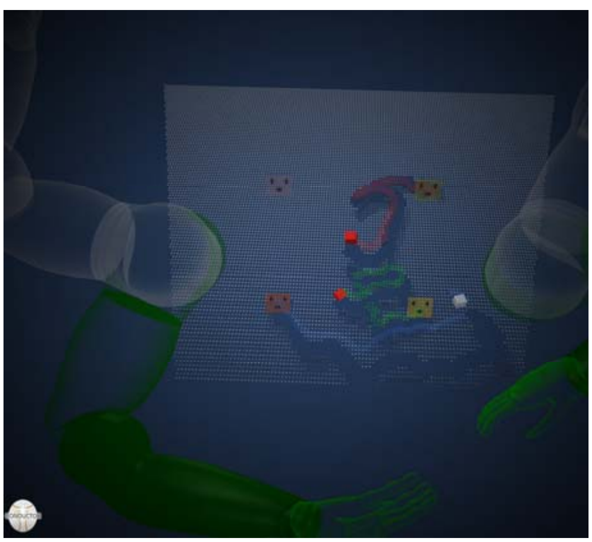

Figure 2: An image of the NUI with pointcloud data from the simulator taskboard scene. Models have been placed over the "plugs" and "sockets".

Both the table scene and taskboard scene are really just stepping stones to more complex tasks. It might not be extraordinarily helpful to an astronaut for a random wire to be plugged it, but this is just testing fine motor control. Not only is the goal to have Robonaut work on more complex tasks, but the wires scene comes in handy for another aspect as well - the space station is extremely messy. Most tasks require the ability to maneuver around objects in the environment. The wire scene allows experiments on object avoidance.

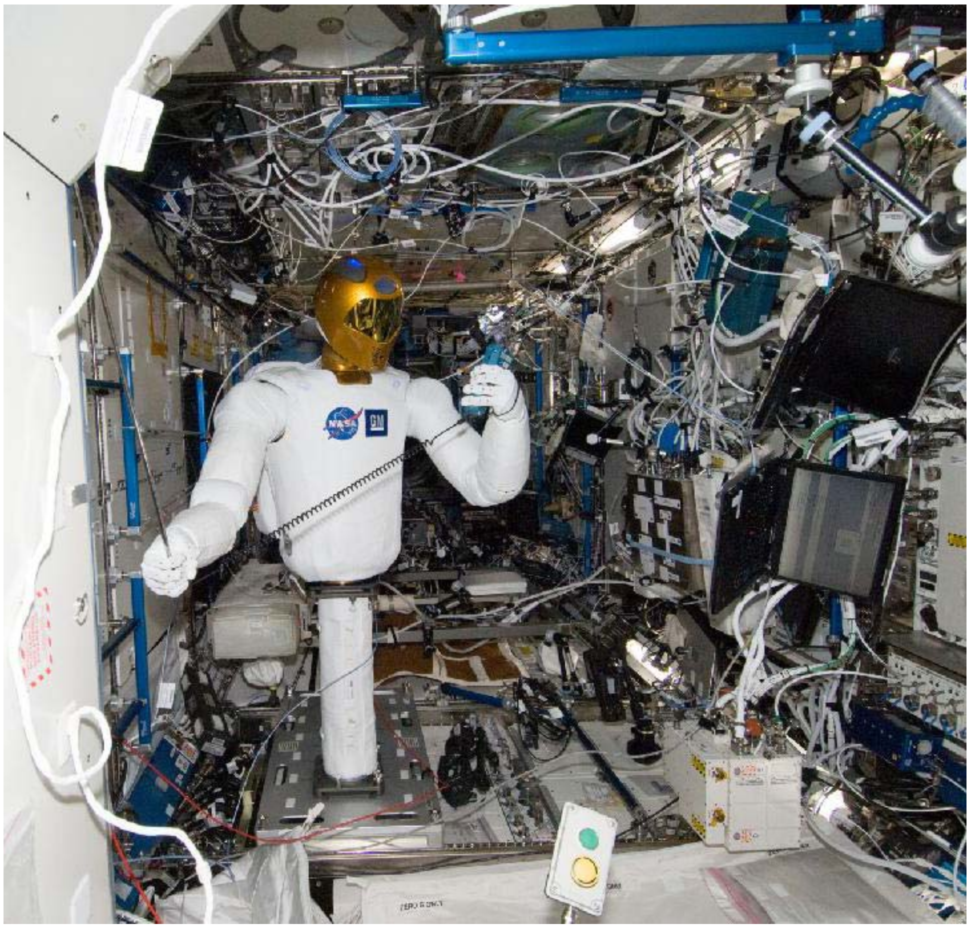

Figure 3: Robonaut's home – the messy International Space Station

Even if one knew all the items and exactly where they were in the space around Robonaut, there would be so many options that the user could quickly get overwhelmed. Plus, there may be a multitude of steps to do the exact right action, which would be hard to remember and require extra time. This system makes use of the idea that the human operator can quickly take in the scene and analyze the objects. Then, instead of needing to tell the system to grab a particular object at a certain point in space, which would need to already be in the program, the user can just reach out and grab it. In this way, the hope is that this is a far more intuitive and less frustrating system for the user than previous Robonaut interfaces.

Instead of making up a bunch of gestures that map to certain things the robot does, this system employs direct mapping. Meaning, if one holds an arm up, Robonaut's NUI arm will go up as well. In order to grab an object, the user must simply reach out and grab it. This way feels the most intuitive for the user and is much easier to remember than a bunch of disjointed gestures. In this way, the system strives to "[p]rovide devices and techniques which enable the human operator to convey control commands to and receive control feedback from the remotely operated robot in comprehensive, integrated and task-level terms and formats" [1].

However, other challenges present themselves when working with this technology. It is extremely irritating to try to pick up an object, when that object is presented on a flat computer screen with no information about where one's arms are in relation to the objects. While Robonaut can move in 3D space, the user is only seeing a camera feed and can't tell depth or even distance very well. The 3D image is converted into a flat 2D image, but the user must then be able to somehow convert the image back into 3D in their head. Because of this, consideration was put into the interface to give the user a sense of that depth information. When the user moves the green Robonaut hand close enough to grab an object, the hand turns blue. Not only does this tell the user instantly that the object is within reach to pick up, but it also gives the user a sense of where the objects are. In addition, when the user grabs an object, a blue toned ghost image of the item appears in the hand, so that the user know the object has actually been grabbed. For the Taskboard scene, an indication was needed both when the item had been grabbed and when the hand was near enough a socket to plug the wire in. Because the little ghost image of the plug would get lost in the hand when it was blue, the ghost image was colored red instead. Then, when the hand/plug combination was close enough, the plug would also turn red.

With the operator on earth and Robonaut on the International Space Station, the speed of light time delay adds another layer to teleoperation. Instead of creating a system that has the robot immediately mirror the human, the robot must only move when it is necessary and has the information to complete the task. Thus, it was decided that the robot would move only when the user had indicated that the robot should pick up an object. Then the robot follows the user to determine where to place the object.
In addition, a command was added so that the arms would mirror the NUI in the event that a certain button was pushed. In this way, one can move the arms if needed outside the programmed limits.

Conclusion and Future Work

The idea of this system is to take boring, repetitive, or dangerous tasks out of the Astronauts' hands (of which there are few) and into earthbound hands (of which there are many). In order to exploit Robonaut's human-like dexterity, we need only a way to communicate instructions to him. The system discussed here attempts to be that bridge between human operator and space robot. Because of Robonaut's dexterity, the system implements finger tracking since haptic devices may not be complex enough to communicate all the necessary information. User testing will continue to help refine the interface.

Upon user testing the system, it was revealed that there is quite a lot more to do with this system. For one thing, this system need not only control Robonaut, but any humanoid robot. Although the system is calibrated for Robonaut, it would be simple to tweak it for a similar, humanoid robot. This is especially true for robots that have human-like dexterity, as that is what this project will continue to focus on. The hope is that in the future, Robonaut would be able to do highly complex tasks that required the use of human-like fingers. For example, with the help of a teleoperator on earth, Robonaut could go outside the ISS and fix a solar panel. Moreover, other features could be added into the system in the future; such as additional bodily input. For instance, one user tester mentioned using foot pedals to move the camera around in order to get a better sense of the environment. Or instead of pressing a button to get Robonaut's arms to mirror the NUI's, voice commands could be utilized instead.
Finally, as more user testing is done, effort should continue in making the interface of this system as intuitive as possible.

Acknowledgements

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration. This project was advised by Victor Luo, Scott Davidoff, and Heather Justice. Charles Goddard collaborated on the development of this project. Sabrina Billinghurst gave input and conducted user testing.

Resources

1. Beiczv, Dr. Anta1 K. "Challenges of Human-Robot Communication In Telerobotics". BEACON eSpace. http://hdl.handle.net/2014/26477 November 1996.

2. Guo, Shengpeng, Dongxu Li, and Caizhi Fan. "Space Operation Based on Human-in-the-Loop." *Advances in Physical Ergonomics and Safety*. Ed. Tareq Z. Ahram and Waldemar Karwowski. N.p.: CRC, 2012. 332-41. Print.

3. Graves, A.R.; Czarnecki, C.A.; , "A man-machine interface for an AI-based telerobotic system," *Human Interfaces in Control Rooms, Cockpits and Command Centres, 1999. International Conference on* , vol., no., pp.302-307, 21-23 Jun 1999
   doi: 10.1049/cp:19990205
   URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=787726&isnumber=17061

4. Graves, A.R.; Czarnecki, C.; , "Distributed generic control for multiple types of telerobot," *Robotics and Automation, 1999. Proceedings. 1999 IEEE International Conference on* , vol.3, no., pp.2209-2214 vol.3, 1999
   doi: 10.1109/ROBOT.1999.770434
   URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=770434&isnumber=16696

5. Fong, T., Provencher, C., Micire , M., Diftler, M., Berka, R., Bluethmann, B., and Mittman, D. 2012. "The Human Exploration Telerobotics project: objectives, approach, and testing". IEEE Aerospace Conference.

6. "R2 ISS Update." *Robonaut: Home*. N.p., n.d. Web. 21 Aug. 2012. <http://robonaut.jsc.nasa.gov/default.asp>.