(Preprint) AAS XX-XXX

ADVANCING ROBOTIC CONTROL FOR SPACE EXPLORATION USING ROBONAUT 2

Julia Badger[*], Myron Diftler[†], Stephen Hart[‡], and Charles Joyce[§]

Robonaut 2, or R2, arrived on the International Space Station (ISS) in February 2011 and is currently being tested in preparation for its role initially as an Intra-Vehicular Activity (IVA) tool and eventually as a robot that performs Extra-Vehicular Activities (EVA). Robonaut 2, shown in Figure 1, is a state of the art dexterous anthropomorphic robotic torso designed for assisting astronauts. R2 features increased force sensing, greater range of motion, higher bandwidth, and improved dexterity over its predecessor.[1] Robonaut 2 is unique in its ability to safely allow humans in its workspace and to perform significant tasks in a workspace designed for humans.

The current operational paradigm involves either the crew or the ground control team running semi-autonomous scripts on the robot as both the astronaut and the ground team monitor R2 and the data it produces. While this is appropriate for the check-out phase of operations, the future plans for R2 will stress the current operational framework. The approach described here will outline a suite of operational modes that will be developed for Robonaut 2. These operational modes include teleoperation, shared control, directed autonomy, and supervised autonomy, and they cover a spectrum of human involvement in controlling R2.

Many technology demonstrations and tasks are planned for Robonaut 2. During the check-out

Figure 1: Robonaut 2

---

[*] NASA-Johnson Space Center

[†] NASA-Johnson Space Center

[‡] General Motors

[§] Oceaneering Space Systems

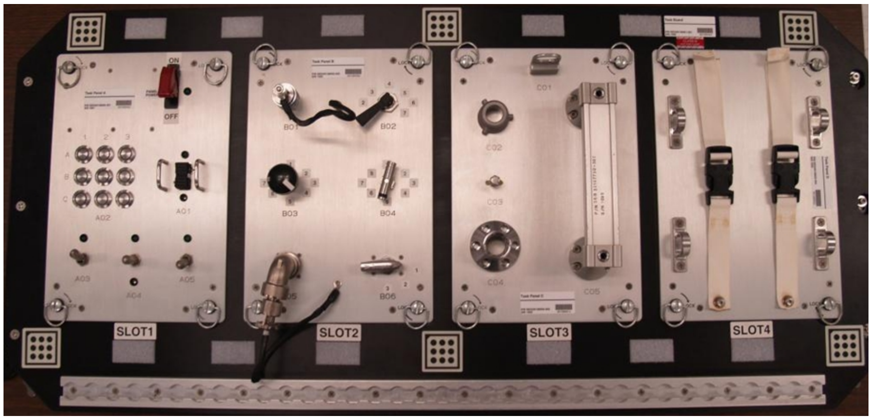

Figure 2: Reconfigurable task board for R2 check-out operations

phase, R2 will be tested using a specially-designed task board that was sent to the ISS along with the robot.[2] The task board, shown in Figure 2, consists of many common manipulation tasks performed by the crew both inside and outside of the ISS, such as pushing buttons, actuating switches and valves, and handling fasteners. After the task board testing has been completed, R2 will be integrated with legs and a battery backpack for mobility. Suggested tasks for IVA include general cleaning and vacuuming, tools and parts inventory, tool calibration, equipment relocation, food preparation and clean up, general inspection, and air and water testing. Robonaut 2 is expected to help on EVA by setting up and tearing down work stations. By having R2 do this work in support of the EVA, the astronauts will be able to spend less time on simple maintenance tasks and have more time to spend on important and complex activities.

The breadth of tasks that R2 is slated to perform drives the spectrum of control modes to be implemented. Many of the IVA tasks mentioned are chores currently performed by astronauts. For many of these tasks, such as cleaning or inventory, it is important that R2 can complete its job with minimal crew involvement. If R2 can perform these tasks autonomously and supervised only by the ground control team, precious on-orbit time can be saved, allowing astronauts to complete more important scientific activities. For EVA tasks, R2 will likely be operated by a combination of modes. The ground will direct the translation of the robot along the outside of the ISS while the crew members would either teleoperate R2 or closely monitor and direct semi-autonomous functionality to complete the more intricate tasks. Understanding how to distribute function, supervision, and autonomy in an environment where safety is paramount is an interesting and important challenge. Furthermore, learning how to operate R2 in IVA and EVA will apply directly to robotic operations during long duration exploration missions.

Technology advances in controlling R2 will take a progressive approach along the spectrum from constant supervision towards autonomy. After the check-out phase, one of the operational modes that will be explored is teleoperation. The crew will teleoperate R2 by donning special equipment, including a virtual reality immersion helmet, as depicted in Figure 3. The crew member will articulate commands to “thaw” and “freeze” the robot’s hands and arms. The crew member’s movements will be sent to R2 as position commands. Shared control is another operational mode that will be used. The operator will have an interface that allows him or her to pick a path for the robot to follow, validate the path using simulation, then approve and monitor the movement. Simple commands, such as “open hand,” may be used by the operator. Operation over time delay is also a

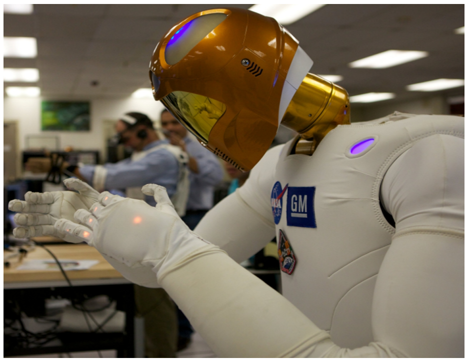

Figure 3: Astronaut Don Pettit teleoperating R2

current research topic,[3] and this will essentially allow shared control of R2 by ground controllers. However, since the robot will need extra autonomous functionality to work safely during the time delay, this sort of control is referred to here as directed autonomy.

The development of teleoperation, shared control, and directed autonomy will allow R2 to become extremely effective for EVA and some IVA tasks. However, a greater degree of autonomy is necessary for tasks such as taking inventory of tools or objects. For this sort of activity, a potential operational scenario could be as follows. First, an operator (either crew or ground-based) checks out R2 and configures it for the inventory task. A ground operator will then monitor as R2 works. R2 will autonomously move through the specified lab or area, counting and logging the item or items it has been assigned to inventory. Whenever R2 has a question (i.e., "is this a rubber glove?" or "where is the next handrail?"), the ground controller will be available to give input to R2. If R2 has a more serious problem, such as a hardware issue with a drawer or an issue with the robot itself, the ground operator will troubleshoot the problem, and if necessary, a crew member would be called in to support the task.

Many advances will be needed for this operational scenario, including vision processing for identifying the tool or object being inventoried, map development for efficient traversal of the specified area of the ISS, and intelligent planning and learning functions to allow the robot to handle contingencies appropriately. Research efforts are currently underway in all these areas in preparation for operations using supervised autonomy.

Finally, robotic assistants on long duration missions will likely need to be programmed to complete new tasks in situ. Allowing the ISS crew the ability to train R2 to accomplish new tasks is an important feature which will further demonstrate the utility of service robots on long duration missions. In order for this to be possible, a new robust set of core functionalities that can integrate effectively with one another must be added to R2's control toolbox.

In conclusion, Robonaut 2 will serve as an excellent platform for understanding how best to operate service robots in future exploration missions. As R2 moves along a spectrum of control from direct teleoperation to supervised autonomy, robotics technology will be pushed to provide the degree of reliability and intelligence needed to make robotic operations effective and efficient. The different tasks planned for Robonaut 2 are representative of what will be needed on long duration missions, and the ISS is an incredible test bed on which to conduct this research.

REFERENCES

[1] M. A. Diftler *et al.*, “Robonaut 2- the first humanoid robot in space,” in *Proc. of the IEEE International Conference on Robotics and Automation*, 2011.

[2] M. A. Diftler *et al.*, “Robonaut 2- initial activities on-board the ISS,” in *Proc. of IEEE Aerospace Conference*, 2012.

[3] R. Burridge and K. Hambuchen, “Using prediction to enhance remote robot supervision across time delay,” in *Proc. of the IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 5628 –5634, Oct. 2009.