Robonaut/Centaur

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Advancing robotic mobility and manipulation technology is an important step in preparing for NASA's planned lunar and martian missions. To address this challenge, engineers in the Robotic Systems Technology Branch at the Johnson Space Center (JSC) have combined the highly dexterous Robonaut upper body with a rugged and versatile four-wheeled base to yield the Centaur. Centaur's anatomy allows the robot to perform human-scale tasks away from the laboratory, in unstructured environments that simulate the lunar or martian surfaces where the robot would eventually work. Centaur, under both teleoperated and supervised autonomous control, completed testing with other NASA robots and suited crew members in recent field trials, demonstrating its utility as part of a lunar human/robot team.

Robonaut's most important feature is its ability to help astronauts perform tasks that currently only humans can perform. These tasks range from working with tools designed specifically for space-suited hands to assisting with the assembly and maintenance of habitats with human interfaces. These capabilities are realized through the human-scaled anatomy of Robonaut's upper body. With both dexterous arms and hands and a wide range of sensing capabilities, Robonaut is an excellent astronaut assistant that can work both alongside a suited crew person or be remotely supervised to perform tasks while the crew is attending to more important scientific and exploration activities.

Robonaut has multiple control modes. Teleoperation is the simplest. It allows a human operator in close proximity to control the robot's arms, hands, and neck directly using a collection of virtual-reality gear. The human's motions are picked up by the position sensors embedded in the virtual-reality gear and drive the robot's limbs and fingers to match the human's positions. Video screens in the virtual-reality helmet display the views from the robot's head-mounted cameras, allowing for very intuitive control. A second control mode, Shared Control, reduces operator workload by handing off certain motions to the robot. For example, the robot uses internal sensors to correct for lateral misalignments while the operator directs the robot's hand to insert a utility box into a receptacle. The final mode is Supervised Autonomy. In this mode, a remote operator sends high-level commands and then verifies that the robot has completed a subtask before going on to the next step in the sequence.

Robonaut has demonstrated its capability to assist crews under all three control modes over several years. As shown in figures 1 through 7, multiple teleoperated Robonauts have worked as direct helpers, providing parts to a suited crew person as that crew person assembled a prototype

Fig. 1. *Centaur with human/robot teammates, Meteor Crater, Ariz.*

Space Truss Structure in the Dexterous Robotics Laboratory at JSC. Later, Robonaut, in one of its early mobile configurations, graduated to the level where it could mate the truss couplers using its own hands while under shared control by a human operator. Working at the NASA Ames Research Center, Robonaut acted as part of a larger human/robot team, autonomously performing simulated welds on habitat panels handled by humans. Mostly recently, in its Centaur configuration, Robonaut moved outdoors to assist in higher-fidelity planetary exploration scenarios.

Robonaut/Centaur

continued

In the Centaur configuration, Robonaut has impressive body mobility. Not only can the entire unit traverse moderate to rough terrain, the built-in waist degrees of freedom allow the upper body to interact directly with the ground and the rear-mounted utility tray. During testing at Meteor Crater, Ariz., Centaur, under teleoperated control, bent close to the ground, scooped soil, and examined rocks. Under Supervised Autonomy, Centaur approached the back of a Crew Rover testbed; used machine vision, force, and position sensors to acquire a geological sample box; and then rotated 180 deg around to place this box on its utility tray for transport to an analysis station. A local

Fig. 2. *Two Robonauts assisting a suited astronaut.*

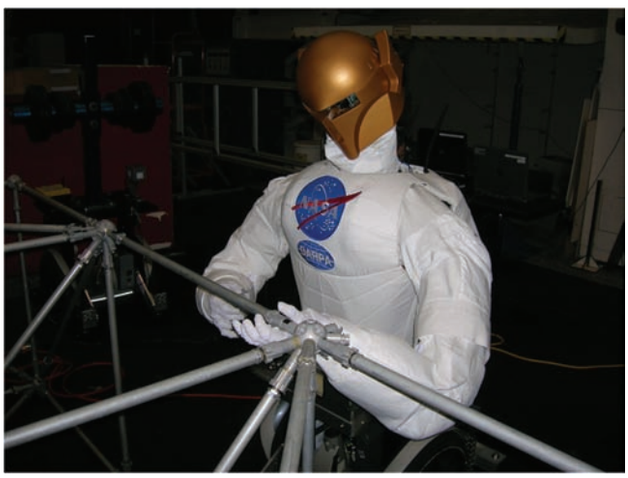

Fig. 3. *Robonaut manipulating truss couplers.*

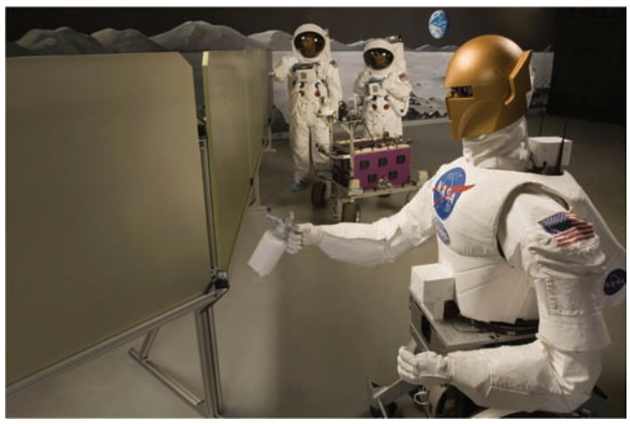

Fig. 4. *Robonaut preparing to weld.*

Fig. 5. *Centaur acquiring sample box from crew rover testbed.*

Fig. 6. *Centaur stowing sample box.*

operator and an operator located in Houston supervised this task, providing the same commands over a time delay that simulated Earth-to-moon communication.

Fig. 7. *Centaur bending over and acquiring a sample.*

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