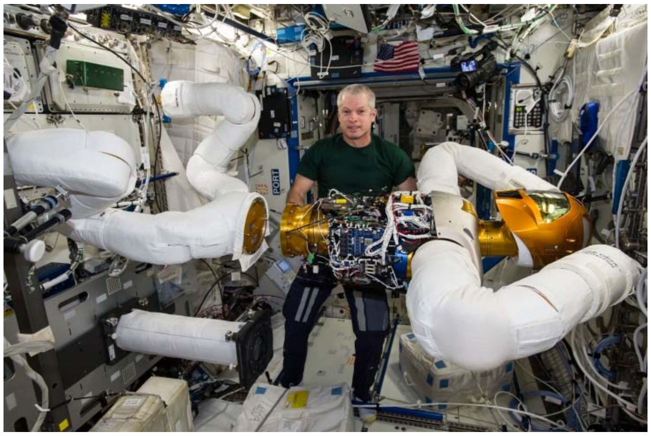
ROBONAUT 2 – BUILDING A ROBOT ON THE INTERNATIONAL SPACE STATION

Charles Joyce[1]; Julia Badger[2]; Myron Diftler[3]; Elliott Potter[4]; Leah Pike[5]

In 2010, the Robonaut Project embarked on a multi-phase mission to perform technology demonstrations on-board the International Space Station (ISS), showcasing state of the art robotics technologies through the use of Robonaut 2 (R2). This phased approach implements a strategy that allows for the use of ISS as a test bed during early development to both demonstrate capability and test technology while still making advancements in the earth based laboratories for future testing and operations in space. While R2 was performing experimental trials onboard the ISS during the first phase, engineers were actively designing for Phase 2, Intra-Vehicular Activity (IVA) Mobility, that utilizes a set of zero-g climbing legs outfitted with grippers to grasp handrails and seat tracks. In addition to affixing the new climbing legs to the existing R2 torso, it became clear that upgrades to the torso to both physically accommodate the climbing legs and to expand processing power and capabilities of the robot were required. In addition to these upgrades, a new safety architecture was also implemented in order to account for the expanded capabilities of the robot.

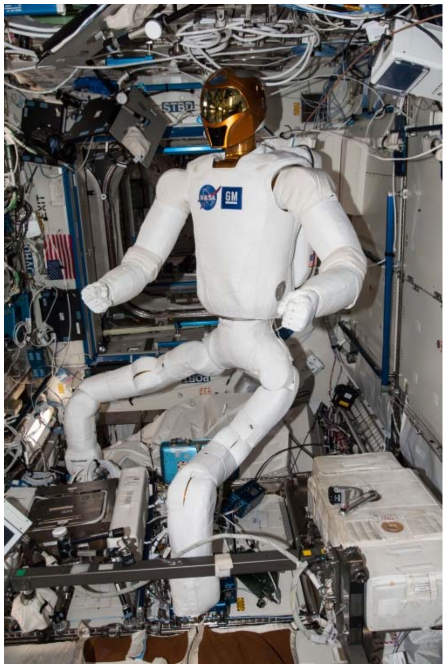


The IVA climbing legs not only needed to attach structurally to the R2 torso on ISS, but also required power and data connections that did not exist in the upper body. The climbing legs were outfitted with a blind mate adapter and coarse alignment guides for easy installation, but the upper body required extensive rewiring to accommodate the power and data connections. This was achieved by mounting a custom adapter plate to the torso and routing the additional wiring through the waist joint to connect to the new set of processors. In addition to the power and data channels, the integrated unit also required updated electronics boards, additional sensors and updated processors to accommodate a new operating system, software platform, and custom control system.

In order to perform the unprecedented task of building a robot in space, extensive practice sessions and meticulous procedures were required. Since crew training time is at a premium, the R2 team took a skills-based training approach to ensure the astronauts were proficient with a basic skill set while refining the detailed procedures over several practice sessions and simulations. In addition to the crew activities, meticulous ground procedures were required in order to upgrade firmware on the upper body motor drivers. The new firmware for the IVA mobility unit needed to be deployed using the old

1 Oceaneering Space Systems
2 NASA-Johnson Space Center
3 NASA-Johnson Space Center
4 Rethink Motion
5 formerly Oceaneering Space Systems

software system. This also provided an opportunity to upgrade the upper body joints with new software and allowed for limited insight into the success of the updates. Complete verification that the updated firmware was successfully loaded was not confirmed until the rewiring of the upper body torso was complete.



In conjunction with upgraded firmware, a new control system has been developed to account for the increases in degrees of freedom, mobility capability, and increased performance demands for the system. The control system features a model-based coordinated controller that allows for seamless commanding in joint and task space, a large range of user-specifiable joint dynamics, and embedded impedance control. To compliment this new control system and increase in capability, a custom safety system has been certified as two-fault tolerant in excessive force protections, as well as single fault-tolerant against inadvertent release of the R2 Mobility grippers. The safety system includes monitors and controls for static, dynamic, and crushing forces and controls for inadvertent gripper release. Static forces are sensed with load cells and the series elastic joints; dynamic forces are limited using momentum instead of velocity to allow higher limb speeds. An elaborate health monitoring system was deployed that checks over 100 sensors and 30 software components on four main processors over eight lines of communication.

Utilizing state-of-the-art software and controls also requires a high data rate connection to accommodate the high bandwidth requirements and communication protocols. To accomplish this, the R2 Team conceived and implemented a plan for a Ku-band data connection to a remote control center outside of the Mission Control Center in Houston (MCC-H), pioneering the first control center of its kind. A custom command verification system was also developed to ensure that no hazardous commands may be sent from the new control center. This allows the R2 team to maintain control of all commanding and maximizes development flexibility of software and applications while meeting all safety requirements.

The success of the R2 upgrades for IVA Mobility marks the completion of a unique and daunting task – building a robot in space. With the transformation from an experimental R2 torso into an integrated IVA Mobility unit complete, R2 will now begin its climbing trials inside the ISS after thorough testing in the JSC development labs. During this phase, R2 will continue to utilize the ISS as a test bed, demonstrating and proving out capabilities while influencing designs and upgrades applicable to future human-robotic exploration.