Robonaut 2 – Operations on the International Space Station

Ron Diftler
Robonaut Project Lead
Software, Robotics and Simulation Division
NASA/Johnson Space Center
myron.a.diftler@nasa.gov

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Overview

Robonaut Motivation
GM Relationship
Robonaut Evolution
Robonaut 2 (R2) Capabilities
Preparing for ISS
Journey to Space
On Board ISS
Future Activities
Spinoffs
Robonaut Motivation

Capable Tool for Crew
- Before, during and after activities
Share EVA Tools and Workspaces.
- Human Like Design
Increase IVA and EVA Efficiency
- Worksite Setup/Tear Down
- Robotic Assistant
- Contingency Roles
Surface Operations
- Near Earth Objects
- Moon/Mars
Interplanetary Vehicles
Telescopes

Astronaut Nancy Currie works with 2 Robonauts to build a truss structure during an experiment.
Robonaut Development History

1998
• Subsystem Development
• Testing of hand mechanism

1999
• Single Arm Integration
• Testing with teleoperator

2000
• Dual Arm Integration
• Testing with dual arm control

2001
• Waist and Vision Integration
• Testing under autonomous control

2002
• R1A Testing of Autonomous Learning
• R1B Integration

2003
• R1A Testing Multi Agent EVA Team
• R1B Segwanaut Integration

2004
• R1A Autonomous Manipulation
• R1B 0g Airbearing Development

2005
• DTO Flight Audit
• Begin Development of R1C

2006
• Centaur base
• Coordinated field demonstration
GM’s Motivation

Why did GM originally come to us?
• World wide search for experienced development partner
• Looking for a robot that could do work
• Identified Robonaut development at JSC as a good match in terms of common goals and maturity level

GM Goals
• Exploit “Humanoid Dexterity”
• Automate “Non Traditional” Applications
• Ergonomically difficult tasks
R2 – Successful Government-Industry Collaboration

NASA and GM came together

- In early 2007, GM and NASA began the R2 development
- GM embedded 7 engineers onsite at JSC, working with equal numbers of NASA and Oceaneering Space Systems (OSS) Engineers
- Formed a “Badgeless” team
Robonaut Series

Robonaut 1 (R1)  Excellent

Robonaut 2 (R2)  Better
Robonaut 2 Introduction

- 3 DOF Neck
- 7 DOF Upper Arm and Wrist
- Waist
- 12 DOF Hands

Superior Dexterity
Total of 42 Degrees of Freedom
Controlled by 54 Servo Motors
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Hand Dexterity

4 DOF Thumb
Dexterous fingers
Grasping fingers
Approaching human joint travel
High friction grip surface
Fine motion
Tendon Tension
Wide range of grasps

Human Like Grasps: Pen

Cutkosky Grasps
Finger Dexterity – Knob Turn
Finger Impedance Control
Tactile System
Extremely Small
Integrated Load Cells
6 Axis
Up to 14 per Hand
Serialized Data
Gram sensitive
US Patent 7,784,363 B2
Finger Haptics
Arm Control

Series Elastic Control

• Embedded Springs
• High resolution absolute position sensing
• Joint level torque control
  – 10Khz loop
• Variable compliance

Modular Joint Electronics

• Highly integrated
• Redundant processing
• Local A/D
  – Noise reduction
Workspace

Dual Arm Workspace

- Maximized through Arm Placement
- 15 degree shrug angle
- Increases workspace in front of Robot

Body Mobility

- Waist Degree of freedom
- Extend dual arm workspace over 360 degrees

No Shrug

Shrug
Strength

Minimum 20 lb lift capability

Exceeds human endurance at human strength

Differentiator
Neck/Head

Neck

• Three Degree of Freedom
• Inspired by Human Spine
  – Double pitch joints
• Enhanced viewing close to body

Head Sensor System

• Workspace visual data
• Mounted on Atlas of Neck
  – Stereo high resolution Cameras
  – Infrared camera for growth
  – Auxiliary lighting
Human Interaction

Size
- Smaller than R1
  - Internal wiring – 16 conductors
  - 32” wide
- Comparable to human
- Soft skin with padding

Safety
- Force limiting
- Unintentional Contact Sensing
- Multi-level Sensors
  - Position
  - Force/Torque
  - Cross checks
  - Heartbeats

Designed to Interact with People

Force Limited at Multiple Levels
Force Control
Human Interface - Controller

User Interface

- Menu based
- Startup with minimal typing
- Easy to use
  - Even I can run the robot
  - I have even built scripts

Skills toolbox

- Primitive Blocks
- Controller
  - Zero-g motion
  - Cartesian control
  - Stiffness control
- Predefined grasps
  - Drill
  - Multi-Layer Insulation
Human Interface - Teleoperation

Teleoperator Interface
- Intuitive
- Immersive (very)
- Investigative

Programming Tool

Flexible Interface
- Unstructured tasks

Washington DC Experience
Flexible Material Application

The Space Blanket
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R2 on Space Station

Putting A Robot On ISS-IVA Will Take Us A Long Way Towards Maturation

- Space Vehicle(s)
- Micro-gravity
- EMI/Radiation environment
- Crew Interaction

Earn Stripes

- Task board operations
- Low risk IVA crew tasks
- Beyond

Engage ISS Inspection and Maintenance Community

Education

Public Relations
R2 on Space Station – Working Near Crew

Safety System

- Triple Redundancy
- Fault containment Regions
- More restrictive safety limits
- Built in motion-stop

Checks, Checks, and More Checks

- Velocity, torque, jerk, position, comm, heartbeats
- Multiple levels
- Multiple sensor types

Brakes

- Released after 1 second
Two Fault Containment Region (FCR) Classes

Class 1
- Left Arm: JR3
- Right Arm: JR3
- Nominal Commanding (not FCR), Heartbeat

Class 2
- Left Elbow: S D
- Left Shoulder: S D
- Waist: S D
- Right Shoulder: S D
- Right Elbow: S D
- Neck: S D N
- Superdriver: APS In, APS Out
- Gate Driver Relay
- Body Motor Power Relay
- Backpack Enable
- Monitor Region
  - JR3 Control Board
  - I/O Processor
  - Serial I/O Board
  - PDMC
  - PD
  - AIG
  - PLZ

Heartbeat connection between JR3 data and Control Processor.
Preparing For Shuttle Launch and ISS

Audits

• Materials
• Vibration
• Acoustics
• Grounding
• Safeties
• Video/Comm

Development Testing

• Radiation
• EMI
• Power quality
• Acoustics
• Vibration
R2 on Space Station

ISS Modular Task Board
Practicing for ISS – Task Board Development

R2 Ground Unit
Crew Training – Teleoperation Training
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R2 Unpack Video
R2 Setup on ISS – Power Soak
First Humanoid Robot In Space - Motion
First Humanoid Robot In Space - Hello
First Humanoid Robot In Space – Human Interaction
First Humanoid Robot In Space – Power Panel
First Humanoid Robot In Space – Tool Use
First Humanoid Robot In Space – IVA Panel
First Humanoid Robot In Space: Housekeeping
ISS – Lessons Learned

Safety is Number 1 Priority
- Meticulous care taken to ensure safety systems are always verified
- Sensitive robot reflexes are doing their job
- Speed of on-board testing is limited
- Safety and control must be clearly separated

Communication is Challenging
- GUI can only send non-hazardous commands
- All safety systems local to robot

Crew Comfortable Around Robot
- Trust being built
- Predictable system
- Inadvertent contact always benign
- Cool robot – liked by crew
- Volunteered weekends to work with R2
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IVA Mobility

Need to learn more about climbing in zero-g
ISS IVA is the perfect laboratory
  • Buy down risk early
Gain experience for EVA
  • Forces
  • Gaits
  • Ops concepts
Assist crew with IVA tasks - payoff
  • Clean filters
  • Inside rack inspection
  • Inventory management
  • Instrument monitoring
  • New tasks are being presented
IVA Mobility

R2 ISS Climbing Legs
IVA Mobility – Node Transit
EVA – Big Payoff

Worksite prep/tear down (60-90 minutes on each end)
- APFR setup
- Configure EVA Tools
- Retrieve/Stow tools
- Visual inspection under the skin
- Inspection of hoses, flexible lines
- Remove/replace MLI

Assist SPDM
- Remove, replace MLI

Assist with big 12 tasks
- Work side by side with crew
- Provide temporary fixes
- Perform portions of task
EVA Mobility
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RoboGlove

Grasp Assist Device
- Reduce ergonomic Strain
- Reduce fatigue

R2 Hand Technology
- Tendon based actuation
- Hand drivetrain

Multiple modes
- Contact sensing for actuating
- Multiple contact sensors
- Programmable

Applications
- Spacesuits
- Assembly floor
- Rehabilitation
- Many more
Grasping Objects
**Exoskeleton**

**Wearable Robot**
- Help paraplegics
- Assist humans in walking

**R2 Limb Technology**
- Harmonic driver actuation
- Joint level electronics/safeties

**Multiple modes**
- Assistance
- Resistance
- Biometric data collection

**Applications**
- Exercise
- Dynamometry
- Rehabilitation
- Strength Augmentation
Exoskeleton
Backup
ROS Simulation – Publically Available
R2 on Space Station

Learn More About R2:  
http://robonaut.jsc.nasa.gov/
Planetary Capability – Supervised Geologist
Using Tools – Drill Training
Using Tools – Tightening Bolts
First Humanoid Robot In Space: Housekeeping