SPHERES National Lab Facility

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July 16, 2014
Synchronized Position Hold Engage Reorient Experimental Satellites - SPHERES

• A Facility of the ISS National Laboratory with three IVA nano-satellites designed and delivered by MIT to research estimation, control, and autonomy algorithms
• Installed on ISS in 2006
• Managed by ARC since Fall 2010
• By working aboard ISS under crew supervision, it provides a risk tolerant Testbed Environment for Distributed Satellite & Free-flying Control Algorithms
  ▪ Formation flight,
  ▪ Docking,
  ▪ Close proximity operations
• If anything goes wrong, reset and try again!
• The satellites can be reused
  ✓ Replenishable consumables
  ✓ Multiple test sessions assigned per year

If you can’t bring the space environment to the laboratory, take the laboratory to space!

Scott Kelly working with SPHERES in the Kibo lab

SPHERES ISS National Lab Facility
• Program Executive: Jason Crusan (HQ)
• Program Manager: Andres Martinez (ARC / R)
• Chief Engineer: Jose Benavides (ARC / TI)
• Operations Lead: Aric Katterhagen (ARC / PX)
SPHERES Platform Capabilities

Sensors
- Accelerometers, Gyroscopes, Ultrasonic ranging
- Smartphone Camera

Actuator
- CO2 Propulsion, 0.2N of force possible

C&DH
- 115kbps downlink to laptop
- Real-time interface to laptop Matlab runtime
- 400kbps real-time downlink to Mission Operations Center

Expansion Port
- Provides an interface for integration with additional technologies
- Well documented ICD
- Currently used by several Payloads

<table>
<thead>
<tr>
<th>Diameter</th>
<th>8.3 in (0.2 m)</th>
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<tr>
<td>Mass</td>
<td>7.8 lb (3.5 kg)</td>
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<tr>
<td>Thrust (single thruster)</td>
<td>&lt;1 oz (0.2 N)</td>
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<tr>
<td>CO₂ Capacity</td>
<td>6 oz (170g)</td>
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SPHERES Nat Lab Facility

3 SPHERES

Expansion Port Enabled

Smartphone

Vision Based Navigation

Electro-magnetic Actuation (RINGS)

Fluid SLOSH
SPHERES Facility Labs

Flight Lab

Engineering Evaluation Lab (EEL)

International Space Station

Granite Lab

Mission Operations Center

Micro Gravity Test Facility (MGTF) Lab: Cradle/Gimbal and Robotic ARM
- Emulate space-to-ground end-to-end communication
- Collect real-time telemetry
- Send commands
- Matlab integration
Guest Scientist Program (GSP)

Technical Aspects

1. Download GSP from Sourceforge, including simulator
2. Dev and Test your software on the simulator
3. Test in Ames SPHERES Lab
4. Deliver Software and planning products to SPHERES Operations
5. Conduct test session aboard ISS

Operational Planning Aspects

1. Deliver proposed investigation – one pager
2. SPHERES initiates request to schedule ISS Test Session
3. Generate all planning items required by ISS (e.g. Test Plan, )
SPHERES Simulator Capabilities

Simulator Features

1. ISS-validated dynamics model
2. Matlab/Simulink & C programming environment
3. Full embedded architecture fidelity
   a) Same C-code developed for Simulator can be re-compiled for SPHERES hardware un-modified
4. Integration with Simulink 3D Animation toolbox
5. Cross-platform compatibility (Windows/Mac OS X)
6. Publicly Available:
   a) http://sourceforge.net/projects/issspHERES/
Research & Benefits of SPHERES

- Demonstrated key close-proximity formation flight, rendezvous and docking maneuvers, fault diagnosis and recovery
- Supported human telerobotic operation and control investigations
- Conducted experimental evaluation of algorithms and sensing for autonomous docking, Satellite servicing, Re-supply, Upgrade of space systems
- **Crew-based teleoperation and time-delayed ground control experiments for future crew-assistant robots.**
- Evaluation of COTS technologies such as smartphones for rapid prototyping and deployment in space environments.
- Lessons learned on ISS have significant impact on ground robotics, mapping, localization, and sensing in 3D.
- Developed a platform to demonstrate and validate metrology, control, autonomy, and artificial intelligence algorithms for distributed satellite systems (DSS)
- **Evaluation of Autonomous Inspection operations, damage inspection & characterization**

Over 80 Test Sessions (400+ hrs. of Facility Console activities involving crew), 62 Crew training sessions (Over 100 hrs.).

**One of the most used and popular ISS National Lab Facilities**
Smartphone Overview

**Smartphone**
- Converts SPHERES from satellite test-bed to free-flying robot

**Demonstrate use cases**
- Environmental surveys
- Mobile camera inspections

**Technology development & risk reduction**
- Ground/crew control & communication paths
- Control modes (supervisory vs. manual)
- User interfaces
- Wi-Fi localization
- Vision based navigation

**Team Lead: Chris Provencher**
Ground Control Test (Dec 12, 2012)

Space Station Free-Flying IVA Survey

- Demonstrate video survey within ISS (Kibo Laboratory module)
- Smart SPHERES remotely operated by ISS Mission Control (Houston)
- **Manual control** (discrete commanding) and **supervisory control** (command sequences)
Remote Ops from MCC-Houston

Robot operator in "PLUTO" Multi-Purpose Support Room
December 12, 2012
Crew: Kevin Ford, Expedition 33 Commander
September 5, 2013
Crew: Luca Parmitano and Chris Cassidy

4x speed
"Plus Orbits" Translation

- Position data logged by smartphone (from SPHERES beacon system)
- Blue = target waypoints
- Red = measured path
Plus Orbits Orientation

Plus Orbits, Smartphone Data

- Red = target waypoints
- Blue = measured path
- Blue lines = orientation of smartphone camera
Image-based 3D reconstruction

- Reconstructed using only camera images
- Shows position of camera for each image taken
- Shows inspection coverage
Modified Google “Project Tango” prototype smartphone
(scheduled for delivery to ISS on Orbital-2)
Smartphone flight unit
Smartphone parabolic flight test
Smartphone-MM Localization

- Dynamics & Thruster Model
- Visual & Gyro Measurements
- Kalman Filter
- ICP Updates using Depth Sensor

- Sparse Mapping
- AR Marker (Smartphone Target)

Output State
Smartphone Mapping Activity

OVHD

DECK

Smartphone ISS Nav Demo

- First run remains in SPHERES beacon volume
- Subsequent runs to Node 2 and US Lab
- Limited to 20 mins of actual runs (data downlink constraints)
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Questions?