Smart SPHERES

A Telerobotic Free-Flyer for Intravehicular Activities in Space

www.nasa.gov/telerobotics

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Smart SPHERES

Enhance & Enable Human Missions

Motivation

- Maintain human spacecraft
- Enhance crew productivity
- Need robots to do work before, in support of, and after humans

In-Flight Maintenance (IFM)

- Keep spacecraft in a **safe** and **habitable** configuration
- Many IFM tasks are **tedious**, **repetitive** and **routine**
- Many tasks cannot be done using only fixed sensors

Unmanned mission phases

- Setup prior to human arrival
- Contingency situations (decrew due to fire, etc.)

International Space Station (ISS)

- Increment 35/36 = 260 hr of planned IFM activities
- 44 hr/month average

IVA Free-Flyer can off-load IFM tasks on ISS from astronauts

- Air sampling (5 hr/month)
- Sound survey (3 hr/month)
- Camera positioning (3+ hr/month)
- Video safety survey (1 hr/month)

IVA Free-Flyer Use Cases

Off-load work from crew

- Perform interior **environmental surveys** (air quality, sound levels, radiation)
- Support **post-fire recovery** by assessing smoke, combustibles, etc. (potential replacement for CSA-CP instrument)
- Support **Automated Logistics Management** (ALM) (inventory and missing item searches)
- Ground controllable **mobile camera** to support IVA activities, safety fly-through video, and E/PO products
- Provide mission control, payload scientists, public with **telepresence** ("free-flying Skype")

Support Crew

- Function as **floating microphone**
- Function as **free-flying computer** (display/speak procedures to crew)
- **Transfer items** from one crew member to another (e.g., transport tool needed to complete an IVA crew activity)

IVA Free-Flyer Roadmap

ARC Laboratory	ISS Laboratory	ISS Core System
		
SPHERES development and lab testing Upgrade existing SPHERES platform Telerobotic free-flyer prototypes	Demonstrate IFM tasks Demonstrate ground control ops Demonstrate crew control ops	Environment surveys Inventory and missing item searches Mobile ground support (camera, procedure prompt, etc.)

NASA, DARPA → *ISS Program*

TRL ***4*** ***5*** ***6*** ***8*** ***9***

SPHERES

Synchronized Position Hold Engage Reorient Experimental Satellites

- IVA free-flyers developed at MIT with DARPA funding
  - 22 cm diameter, 4 kg
  - Cold-gas (CO_2) propulsion
  - Sonar beacon localization
  - Powered by 16 AA batteries
- Testbed for distributed satellite & free-flying control algorithms
- 3 units installed on ISS in 2006
- ISS Facility managed by ARC
  - Coordination & scheduling
  - Flight operations
  - Sustaining engineering

Scott Kelly working with SPHERES on the ISS

SPHERES ISS Facility

- **Program Executive:** J. Crusan (HQ / HEOMD)
- **Program Manager:** A. Martinez (ARC / R)
- **Operations Lead:** S. Ormsby (ARC / PX)
- **Engineering Lead:** J. Benavides (ARC / TI)
- **Payload Integration:** M. Boyer (JSC/OZ)

SPHERES

Smart SPHERES

Smartphone Upgrade

- Convert SPHERES from satellite testbed to free-flying robot

Google Nexus-S

- Android-OS smartphone
- Hardware
  - 1GHz Cortex A8 (ARM) + GPU, 512 MB RAM, 16 GB flash
  - 3-axis gyro, 3-axis accel., two color cameras (still/video)
  - 480x800 touchscreen
- Connectivity
  - 802.11 b/g/n (Wi-Fi)
  - MicroUSB
- Physical
  - 63x124x11 mm, 129 g

Smart SPHERES Team

- **Team Lead:** C. Provencher (ARC / TI)
- **Engineering Lead:** DW Wheeler (ARC / TI)
- **User Interfaces:** T. Cohen (ARC / TI)
- **Smartphone Software:** T. Morse (ARC / TI)
- **ISS Certification:** M. Bualat (ARC / TI)

Putting a Smartphone on ISS …

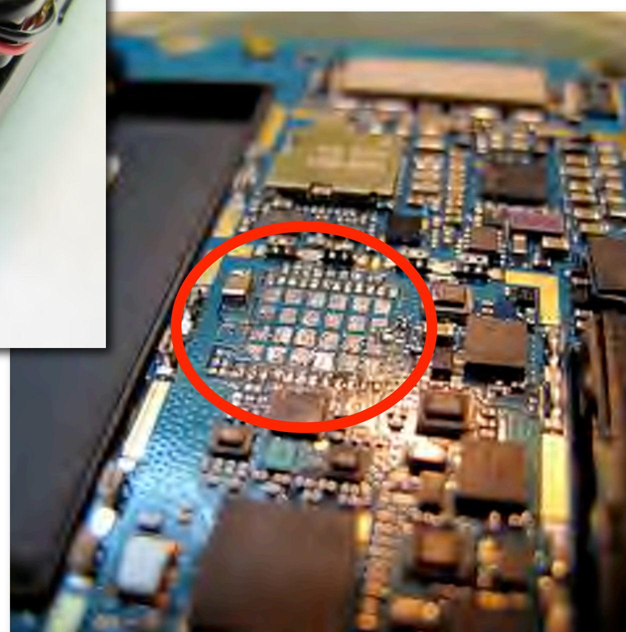
Certification Challenges

- **GSM 850Mhz frequencies** are not safe for ISS
- Cell phone **lithium-polymer** batteries are not flight certified
- **Alkaline batteries are preferred** and shipped (upmassed) on regular 6-month basis
- **Glass breakage** is a safety critical problem (free-flying shards)
- **Procurement** and certificates of conformance (prove that this is a "smartphone")
- **Mechanical drawings** and assembly procedure
- **Windows XP SP3** with new device and no driver support

Putting a Smartphone on ISS …

Modifications for ISS Certification

- Replaced Lithium polymer battery with Alkaline (AA “six-pack”)
- Removed GSM chip (transmitter front-end module)
- Added teflon tape to contain glass in case of breakage



Smart SPHERES on ISS

Smartphone Upgrade

- Delivered to ISS on STS-135
- Provides low-cost, COTS avionics upgrade for SPHERES
- Activiated and initial check-out on November 1, 2011

Key Points

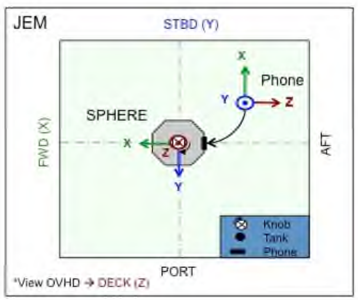
- Smartphone was the first COTS smartphone (with open-source software) certified for use on ISS
- Smartphone enables remote operation of SPHERES by crew and ground control
- Smartphone provides modern CPU, Wi-Fi, and sensors (camera, magnetometer, etc)

Checkout Test (Nov 1, 2011)

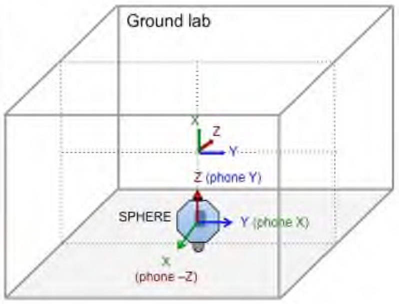
Verify performance in space

- SPHERES translated 1m in +X, +Y, +Z directions
- SPHERES made full rotations about the X, Y, Z axes.
- Ran same test on ISS and in SPHERES Lab (ARC) to compare and assess the results
- Logger app (Android Market) recorded all available sensor data
  - Gyroscope
  - Magnetometer
  - Gravity
  - Linear Accelerometer
  - No GPS
  - No battery temperature

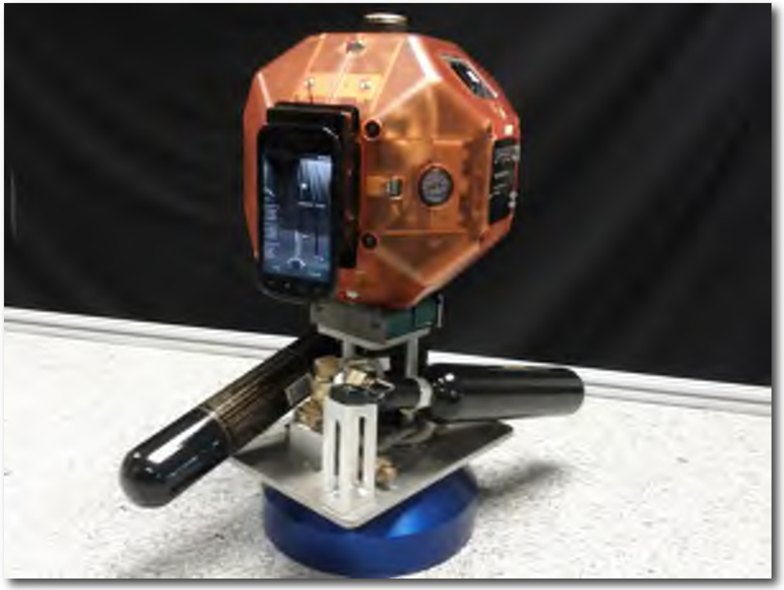
Coordinate Systems



ISS



Ground



Smart SPHERES Checkout

Smartphone Sensors

Raw video from smartphone

Exposure balanced

Smartphone Sensors

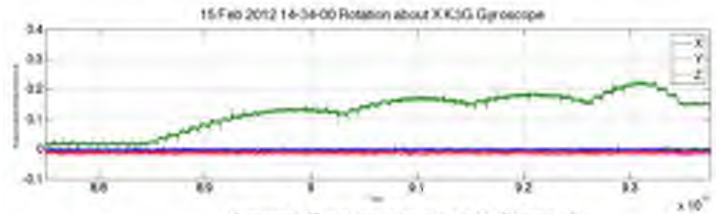
Gryoscope

- Four 90 degree turns (with pauses in between)
- Total duration was faster on orbit (less mass & no friction)
- On-orbit “stair steps” due to thrusters firing
- On-orbit has oscillations in X & Z axes (ground unit sits in a pallet which keeps it stable)

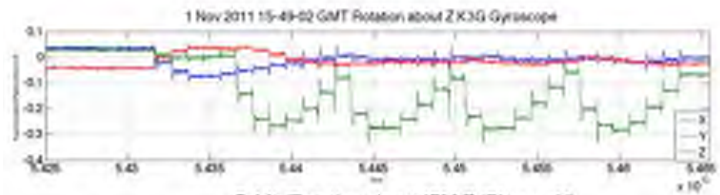
Magnetometer

- No significant difference
- Field is stronger on Earth
- Neither were calibrated

Gyroscope - Rotation about Y

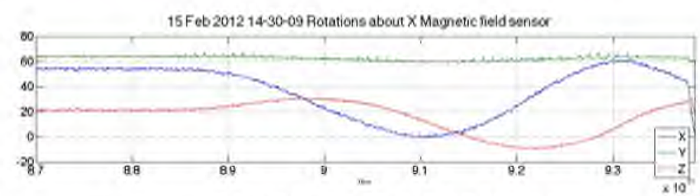


Ground (Rotation about Lab X (Phone Y)



Orbit (Rotation about JEM Z (Phone –Y)

Magnetometer - Rotation about Y



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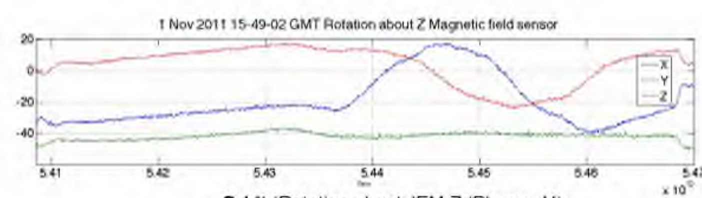


Orbit (Rotation about JEM Z (Phone –Y)

Smartphone Sensors

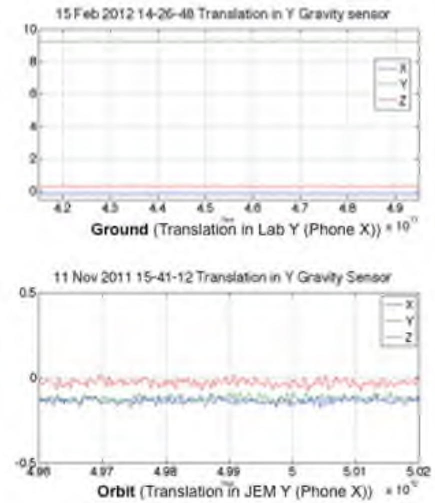
Gravity

- Results - as expected (confirmed microgravity…)

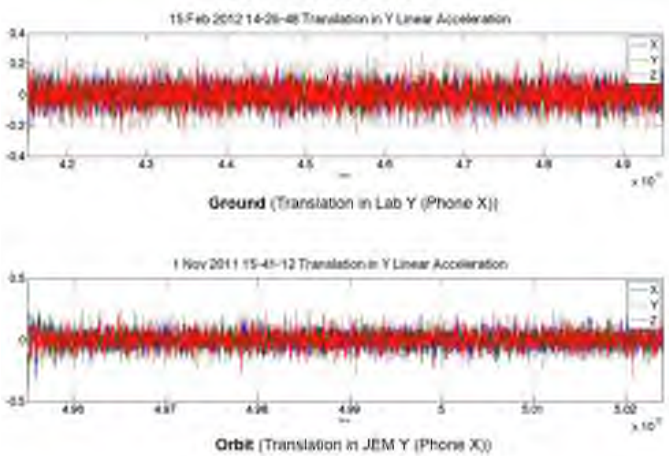
Linear Accelerometer

- Movement does not register with the sensor on ground or in orbit
- SPHERES mass = 4Kg
- Twelve thrusters with 0.1N each

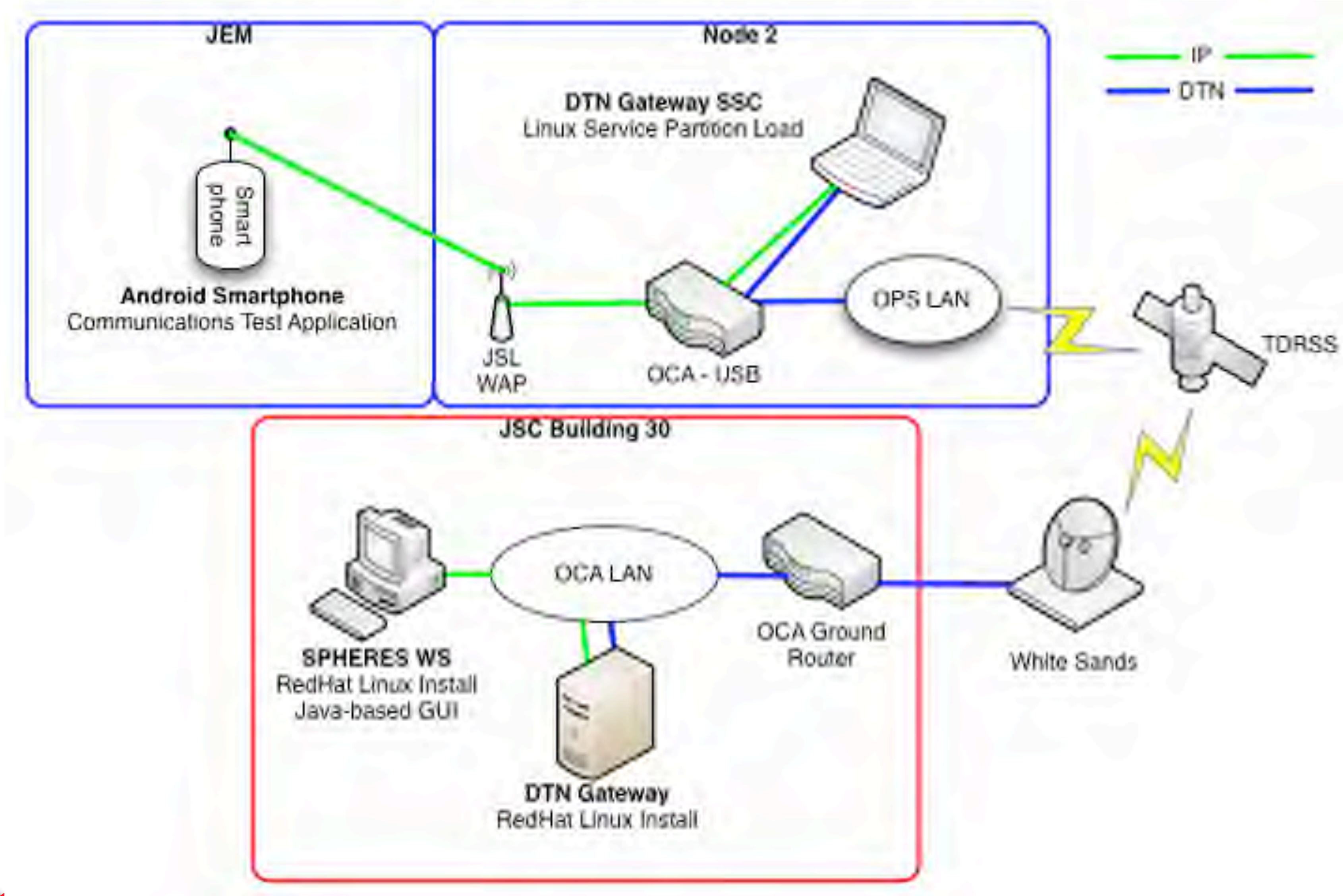
Gravity Sensor - X Translation



Linear Accelerometer - X Translation



Smart SPHERES Network Config



Data Comm Test (July 2, 2012)

Nominal conditions

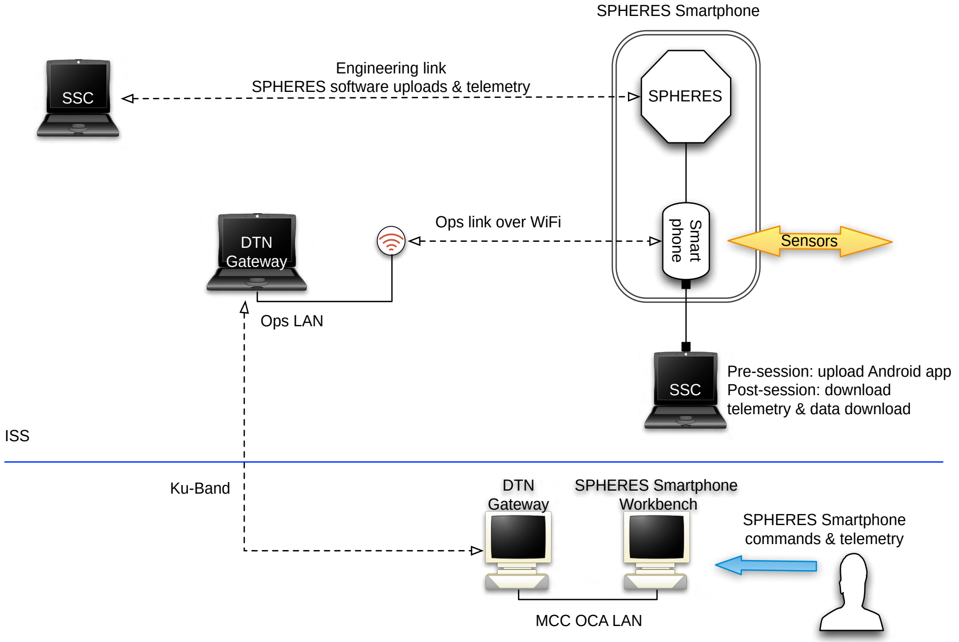
- 10 minutes of video downlink
- 11 no-op commands
- Tested greater than the normal Wi-Fi range

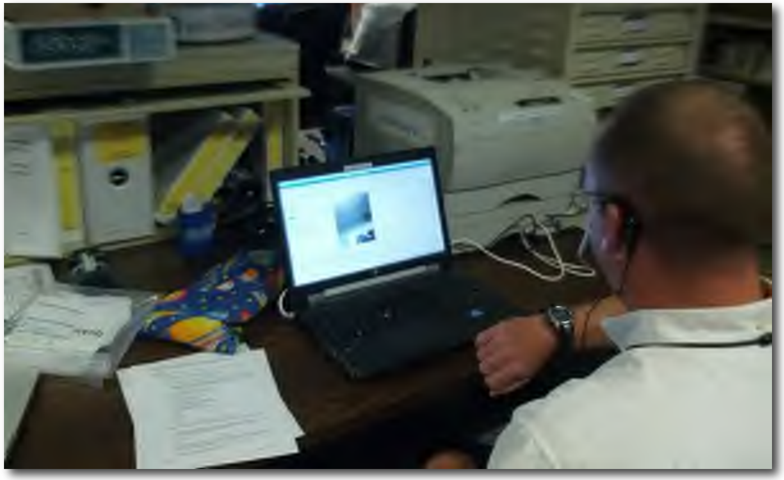
Off-nominal conditions

- Loss of signal
- ISS network error

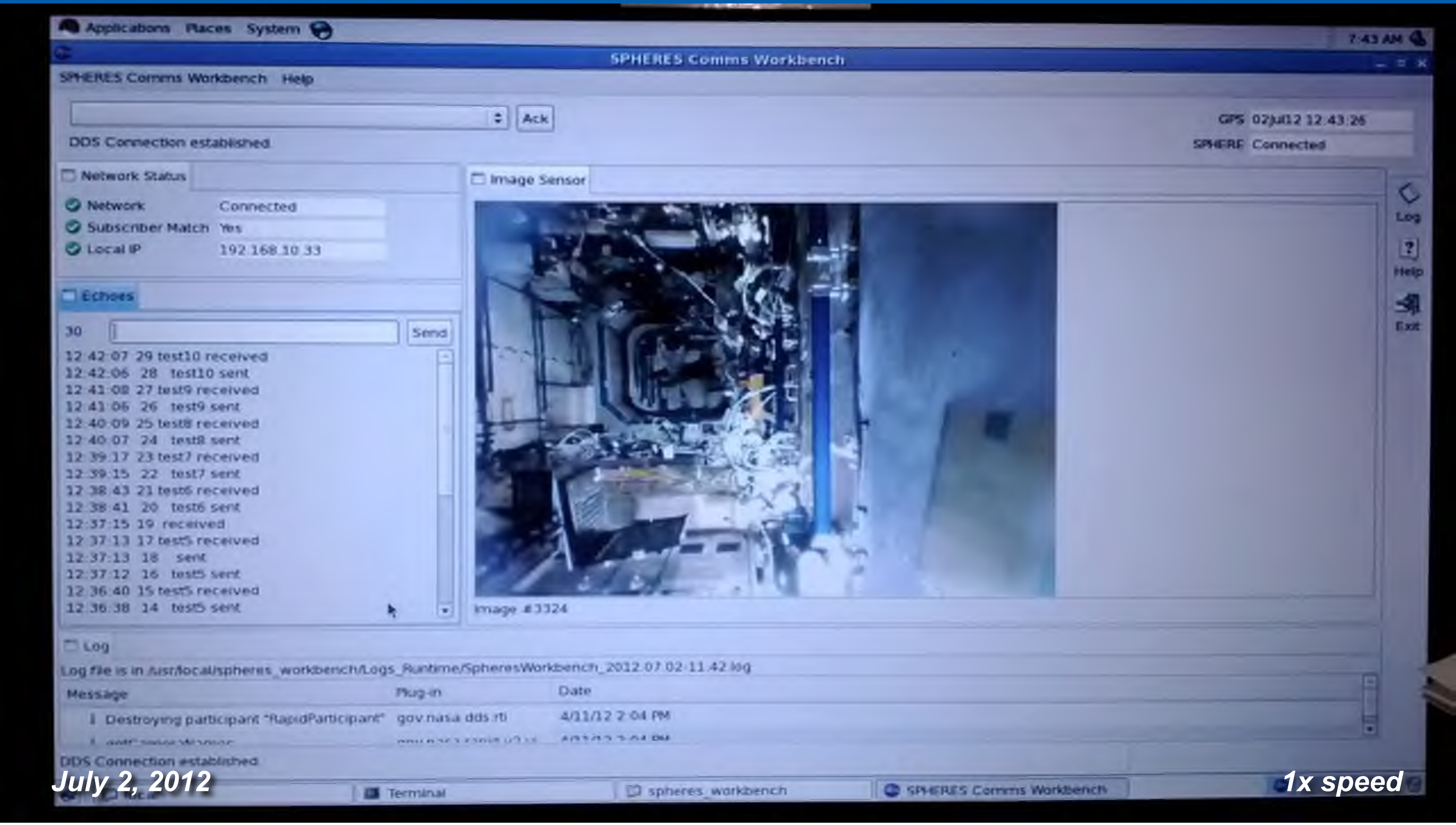
Protocols

- NASA “RAPID” (messaging) **http://rapid.nasa.gov**
- Data Distribution Service (DDS) middleware
- Disruption Tolerant Networking (DTN) transport





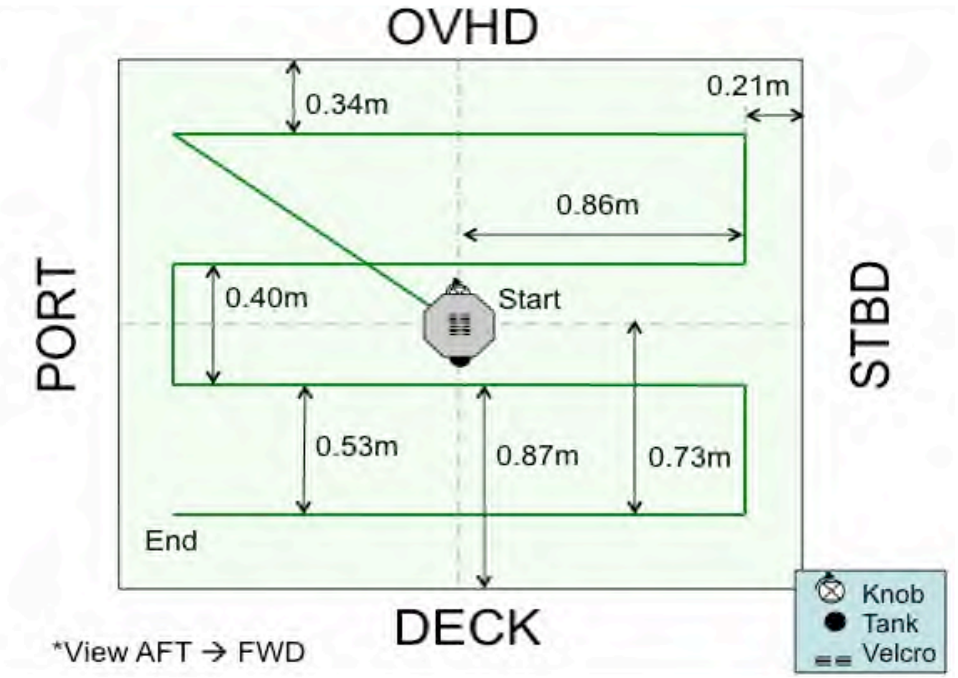
Data Communications Test



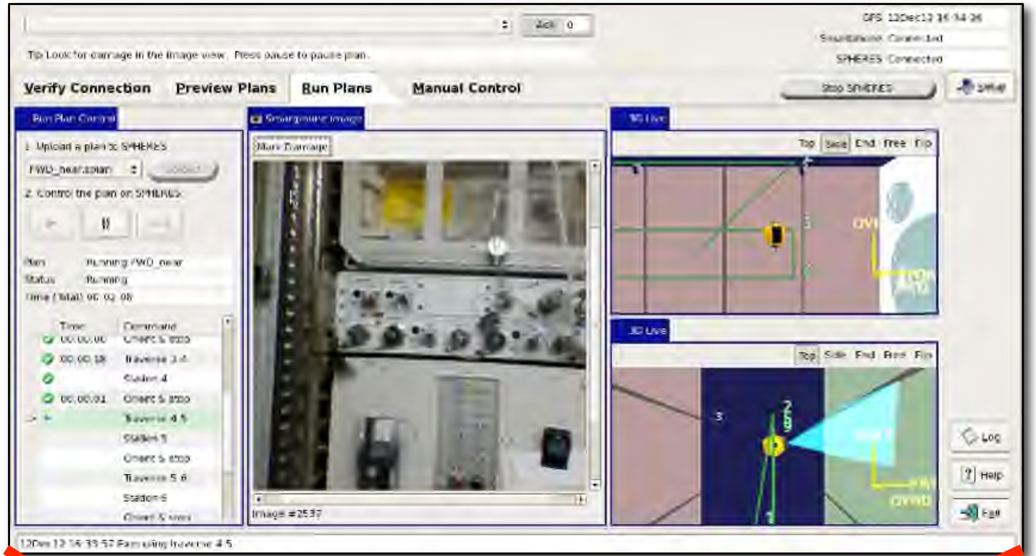
Ground Control Test (Dec 12, 2012)

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



IVA Survey


December 12, 2012
Crew: Kevin Ford, Expedition 33 Commander
2x speed

IVA Survey


December 12, 2012
Crew: Kevin Ford, Expedition 33 Commander
1x speed

Future Work

Hardware Improvements

- New propulsion system
- Longer run-time
- Docking mechanism
- “Manipulator” (perhaps just a stick!)
- IFM specific sensors (RFID, miniature gas, etc)

Software Improvements

- Navigation: localization and hazard detection
- Crew detection and tracking
- Auto-docking and recharge
- Integration with ISS telemetry and databases
- Upgraded avionics and core flight software

Questions ?

Luca Parmitano working with Smart SPHERES