Robotic roles in transit
Uses of free flyers working with IVA Crew

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Exploration destinations

(one-way travel times)

International Space Station (2 days)

Earth

Moon 3-7 days

Libration Points and stable lunar orbits 8-10 days

Mars 6-9 months

Near-Earth Asteroid 3-12 months

Future missions will be longer, more complex, & require new technology

Robotics and Mobility
Deep Space Habitation
Advanced Spacesuits
Advanced Space Comm
Advanced Propulsion
Resource Utilization
Human-Robot Systems
Why do we need robots in transit?

Motivation
• Need to maintain human spacecraft
• Need to enhance crew productivity
• Need robots to do work before, in support of, and after humans

In-Flight Maintenance (IFM)
• Must perform IFM to keep spacecraft in a safe and habitable configuration
• Many IFM tasks are tedious, time-consuming, repetitive & routine
• Many IVA/EVA tasks cannot be done using only fixed sensors / actuators

Unmanned mission phases
• Setup spacecraft prior to human arrival (e.g., Mars exploration)
• Contingency situations (maintain vehicle when humans have to leave)
Extra-Vehicular Activity (EVA)

- Not enough crew time to do everything (only 1 EVA per year)
- Crew must always carry out “Big 12” contingency EVA’s
  - Maintain electrical power system
  - Maintain thermal control system
- Worksite prep & tear down requires 2-3 hr per EVA

Intra-Vehicular Activity (IVA)

- Crew spends a lot of IVA time on maintenance (40+ hr/month)
- Routine surveys require 12+ hr/month
  - Air quality, lighting, sound level, video safety, etc.
- Crew must always carry out contingency IVA surveys
  - Find and repair leaks, combustibles, etc.
Repetitive and Routine IVA Tasks on ISS

**Camera positioning**
- Many cameras are used for IVA work
- Crew has to manually reposition video cameras monitored by mission control
- Camera are essential for many tasks
  - Safety surveys
  - Equipment and payload inspections
  - Crew “over the shoulder” views during IVA activities

**Logistics**
- Crew must locate equipment and materials needed for IVA work
  - Crew spends **up to 1 hr per day** manually searching for items
  - **6,000+ “lost” items in ISS Inventory**
  - Automated logistics is a key HEOMD priority for ISS and future missions
Assistive Free-Flyers

What are AFF’s?

• Small free-flying robots that assist humans (Szafir, Mutlu, & Fong 2013)
• AFF’s perform exploration, surveillance, inspection, mapping, transport, etc.
• AFF’s are often co-located with human and operate in human environments

Key design issues

• Autonomy
• Ecological fit
• Human-robot interaction
• Morphology
• Navigation
• etc.
Assistive Free-Flyers

“Drones Wirelessly Automated to Retrieve Forensics” (D.W.A.R.F.)
Marvel’s Agents of S.H.I.E.L.D. (ABC Television)
Co-location
   • Humans and robots working in shared space, close proximity
   • Neither gets in the way, nor disturbs, the other

Interaction
   • Indirect – mediated by handheld user interface (tablet)
   • Direct signaling (blinders, light projection)

Social intelligence
   • AFF’s move “naturally”: smooth motions, gradual acceleration, curve/arcing flight paths
   • AFF’s aware of human intent – yields “right of way”
AFFs for Human Exploration Missions

Support crew
• Prepare for crew activity
• Display or prompt crew procedures
• Transport tools / equipment
• Transport material

Support ground control
• Perform logistics (inventory, etc.)
• Remotely operated mobile sensor
• Embodied communication device
• Remote presence (mobile camera)

Support spacecraft
• In-flight maintenance
• Monitor IVA environment
• Identify contingency situations
• Perform initial emergency response
Use Case: Mobile Camera

Before crew activity, ground controller starts free-flyer. Free flyer prepares for flight.

Free-flyer undocks and flies to module.

Free-flyer perches and waits for astronaut.

Ground controller controls camera position as astronaut moves around.

Free-flyer moves to new perch because astronaut is blocking the view.

After activity, free-flyer returns to dock to recharge.
Use Case: Environment Survey

Ground controller activates the Free-flyer, uploads an sound level measurement file, and initiates SURVEY.

Free-flyer undocks and autonomously heads to first survey point.

Free-flyer moves from point to point, taking measurements, and avoiding astronauts and equipment along the way.

Half way through the survey, battery requires recharge. Free-flyer returns to the dock.

Once recharged, the Free-flyer continues performing the survey.

Free-flyer returns to dock.
In advance of crew activity, ground controller activates the free flyer, uploads tool ID and expected location, and initiates SEARCH.

Free-flyer undocks and heads to expected location. Free-flyer avoids astronauts and equipment along the way.

Free-flyer scans the expected location with its RFID reader, but the tool is not there.

Free-flyer initiates automated search pattern.

Free-flyer locates tool at the other side of the module and updates logistics database.

Free-flyer returns to dock.
State-of-the-Art: Smart SPHERES

Mobility: SPHERES satellite
- IVA free-flyers (NASA / DARPA / MIT)
  - 22 cm diameter, 4 kg
  - Cold-gas propulsion + AA batteries
  - External sonar beacon localization
  - 3 units installed on ISS (2006)
    - 52+ test sessions, 340+ hr crew time

Computing: Google Nexus-S
- Android smartphone
  - 1GHz Cortex A8 (ARM) + GPU,
    512 MB RAM, 16 GB flash
  - 3-axis gyro, 3-axis accel.,
    two color cameras
  - 802.11 b/g/n (Wi-Fi)
- Robotics software
  - RAPID middleware
  - Basic teleop + command sequencing
  - Ground control user interface
IVA Survey with Smart SPHERES

December 12, 2012 (ISS Japanese Experiment Module)
Crew: Kevin Ford, Expedition 33 Commander
Questions?

Luca Parmitano working with Smart SPHERES in the ISS Japanese Experiment Module

**Safeguarded movement**
- 6-DOF navigation (computer vision & Wi-Fi localization)
- Static & dynamic obstacle detection
- Collision avoidance

**Automated operations**
- Automated task execution / notification (ground supervisory control)
- Automated health monitoring (self diagnostics / prognostics)
- Autonomous perching & station keeping
- Autonomous free-flyer docking / resupply

**Telerobotic sensor platform**
- 6-DOF localization (no beacons): Wi-Fi + structured light (Kinect) + stereo vision
- Environment sensors and monitoring algorithms (sound, light, radiation)
- RFID sensor for sparse area inventory (key component of automated logistics)

**Open and extensible platform**
- Expansion port (mechanical, data, & power) for new payloads
- High-level programming interface (protects safety critical functions)
- Support microgravity experiments and E/PO (robotic competitions)