Astrobee: A New Tool for ISS Operations

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SpaceOps: May 29, 2018
Current IVA Free Flyers

- SPHERES (NASA) – launched 2006
  - Highly successful research platform used for many guest science experiments
  - Astrobot will replace SPHERES, managed by the same facility team
- Int-Ball (JAXA) – launched 2017
  - Successful experiment in building an IVA free flyer with a rapid development cycle (18 months)
  - Small size (15 cm diameter) enabled by JAXA’s miniaturized all-in-one CPU / IMU / 3-axis reaction wheel module
  - Joint activities between Int-Ball and Astrobot may be possible
- CIMON (DLR) – to launch later this year
  - Enable research on AI for human-robot interaction
  - International cooperation – CIMON will share from the pool of batteries that Astrobot qualified for ISS
Project Objectives

• Provide a microgravity robotic research facility in the ISS US Orbital Segment (USOS), which will replace the existing SPHERES facility

• Provide remotely operated mobile camera views of the ISS USOS to enhance the situation awareness of mission control

• Perform mobile sensor tasks in the ISS USOS
Sensing on the ISS

- Monitor the environment
  - Ensure crew health and safety
  - Maintain vehicle health and longevity
  - Sound levels, radiation, air quality
- Automate logistics
  - Increase efficiency of on-orbit operations
  - RFID localization
- Currently collected by fixed location sensors or by crew-conducted sensor surveys

Localizing signal sources by analyzing RSS spatial variation (e.g. RFID, acoustics)

Habitat thermal mapping
Basic Conops

- When an Astrobee is idle, it charges in its dock
- Astrobees can execute complex plans with full autonomy and no astronauts present
  - Including undock, traverse multiple modules, return to dock
- However, Astrobees run with ground operator oversight
  - When an anomaly occurs, an Astrobee generally stops and waits for operator intervention
  - It can continue operating during communication outages until it encounters an anomaly
- The operator can always take over and teleoperate
- Astronauts can also be operators, but this is rare (minimize crew time)
https://www.nasa.gov/astrobée/videos
System Description: Sensors & HRI

Speaker/Microphone
Laser Pointer
HazCam
Touch Screen
Power Switch
Forward Flashlight
Wake Button
Status LEDs
SciCam
NavCam
Nozzle
Signal Lights
Impeller
Terminate Button
Battery
Arm
DockCam
Aft Flashlight
PerchCam

8/23/2017
SPHERES/Astrobee Working Group

SciCam
NavCam
Nozzle
SpeedCam

May 29, 2018
Astrobee - SpaceOps 2018
System Description: Communications

- Communicates through ISS WiFi when flying
- Single telemetry/video stream to ground
- Multiple ground stations can connect through server
- Large file transfers and software updates through Ethernet on the dock
System Description: Position Estimation

• Vision-based navigation
  • Compares features with on-board a priori map
  • Incorporates inertial measurements

• Fiducials used for autonomous docking
  • Requires approximately 1 cm position accuracy

• Visual odometry
  • Robot can continue to navigate where no map features are recognized

Feature map of the JEM-PM
System Description: Perching Arm

- Designed to grasp handrails
- Stows completely in payload bay
- Acts as a pan-tilt unit while perched
- Flexible and back-drivable
- May be perched manually
System Description: Docking Station

- 85 cm x 38 cm x 28 cm
- Berths for 2 free flyers
- Provides power and Ethernet
- Fiducials used for visual servoing to autonomously dock
- Magnets provide retention force
System Description: Ground Data System

- Astrobot Control Station
  - Sortie planning tool
  - Execution monitoring
    - Live telemetry
    - Image and video streams
    - 3D virtual display
  - Supervisory control (run plans or single commands)
  - Typically used by ground operators
- Crew Control Station (used rarely) runs on an EXPRESS Laptop Computer (ELC)
- Server for archiving and distributing Astrobot data
- Suite of engineering tools to support maintenance and software upgrades
Astrobee Control Station
Control Centers

- Astrobee can be operated from almost anywhere
  - Flight controllers at Mission Control Center (JSC)
  - Payload controllers at Payload Operations Integration Center (MSFC)
  - Guest scientists at Multi-Mission Operations Center (ARC) or home institutions

- Provides operators with a mobile camera for improved ground situation awareness during crew activities
  - Optimize viewing angles using the pan/tilt or by relocating Astrobee

- Supervisory control means 100% of operator’s attention is not required
Camera Scenario: OSO observes crew maintenance task

• Schedule Astrobee activity
• Use Plan Editor to create 1) a plan that moves Astrobee to crew activity site, and 2) a plan that returns Astrobee to the Dock
• Shortly before crew activity, execute 1\textsuperscript{st} plan
• At start of crew activity, switch to Teleoperate to begin streaming HD video and adjust pan and tilt
• If crew blocks camera view, teleoperate Astrobee to unperch, fly to new handrail, re-perch.
• During LOS, Astrobee will continue to record video
• At conclusion of crew activity, end HD video streaming and execute 2\textsuperscript{nd} plan to return to dock
• Once Astrobee is docked, if desired, downlink recorded video file.
Other Operational Considerations

• 3 Astrobees will be on orbit, but only 2 Docking Station berths are available
  • Third free flyer will be stowed and will require crew to charge and install batteries before use

• Multiple free flyer operations
  • Each Astrobee accepts commands from only one Control Station at a time
  • Any Control Station may monitor telemetry from multiple Astrobees
  • Allows operators to watch for interference between multiple Astrobee activities

• ISS operators must schedule use of Astrobee with the Astrobee Facility
Challenges: Safety

• Unique collision hazards: Crew can move faster than Astrobee can move out of the way

• Mitigations
  • Light (low mass, ~10 kg)
  • Slow (max speed 0.5 m/s)
  • Soft (corner bumpers and foam padding)
  • Signal lights/noise when entering hatchway
  • Keep crew aware through operational techniques
    • Daily Plan
    • Daily conferences
    • CapCom calls as needed

• Screens cover intakes
• Grills cover nozzle flaps
Challenges: Privacy

• Some cameras always on whenever Astrobee is operating
  • Privacy status LEDs on forward and aft faces indicate when cameras or mic are on and/or streaming

• Crew actually most concerned about live audio
  • In addition to privacy status LEDs, signal lights on left/right Prop Modules will shine blue when mic is on

• Keep-Out Zones (KOZ) can be used to keep Astrobee out of areas where:
  • A crew member is exercising
  • A medical experiment is in progress
  • A sensitive payload is operating
  • An exhaust vent creates fast-moving air that might blow Astrobee off course
Challenges: Placement

• Difficult to find a “permanent” location for the Docking Station
  • Occupies significant space
  • Want to avoid high traffic areas
  • Anticipated service life until 2024, will last through many changes to ISS

• Lesson learned: expect to be moved, and be flexible
  • Dock design now has many mounting configurations with adjustable brackets, based on both seat track and hook-and-loop
  • Accommodates many possible mounting locations

• Initial location: JAXA has agreed to host the Astrobee dock in the JEM-Pressurized Module Port Endcone, Aft

Initial dock location in red, JPM1A7
Status: First ISS Activity (Pre-Launch)

ISS CDR Bresnik taking photos, 2017/11/06
Panorama stitched from 9 photos
Resulting 3D map of visual landmarks

JEM Mapping: Locations of 14 panoramas
Status: Integration in Progress

- Propulsion Module Plenum
- Core Avionics Burn-In
- Nozzle Mechanism
- Propulsion Impeller
- Fit Check – Free Flyer Core with Dock
Future Applications

• Astrobee will help prove out the concept of “Caretaker Robots” for future exploration architectures

• Allows monitoring, maintenance and repair of a facility before and between crews
  • Gateway may be crewed just six weeks per year!
  • Critical need to care for spacecraft when crew are not present

• Inspection functions can include:
  • Spot checks
  • Surveys
  • Automated change detection and trending
  • Localizing problems

• With dexterous robotic manipulation capabilities, future tasks could include:
  • Maintenance
  • Repair
  • Cargo transfer
Conclusion

• Increases efficiency of flight and payload operations
• Improves crew safety
• Mobility caused unique operational challenges
• Launch: November 2018
• Commissioned: mid-2019
• Current status: Integration
Acknowledgments

• Funded by:
  • NASA Game Changing Development Program (Space Technology Mission Directorate)
  • ISS SPHERES Facility (Human Exploration and Operations Mission Directorate)

• Thanks go to:
  • ISS SPHERES Team
  • ISS Payloads Office
  • JSC Flight Operations Directorate
  • ISS Avionics and Software
  • Advanced Exploration Systems Program
Questions?

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