Moving NASA Beyond Low Earth Orbit: Future Human-Automation-Robotic Integration Challenges

Jessica Marquez, Ph.D. | Research Engineer | NASA Ames Research Center
Overview

• Current NASA Human Spaceflight Mission Operations
  – Mission Control Center
  – Automation & Robotics

• Planetary/Mars Human Missions
  – Game Changers
  – Evolution of Automation and Robotics

• Future Integration Challenges
  – Avoiding pitfalls
  – Key future research
CURRENT HUMAN SPACEFLIGHT
International Space Station (ISS)
Basic Facts: ISS

- ~150 miles above
- 8 buses wide (1 football field)
- Solar powered

- Flying for 15 years
- Construction for 10 years
- Orbiting Earth every 90 min
Continuously Inhabited by Six International Astronauts
To and From the Space Station
Mission Control Center
Ground-Crew Daily Operations
Frequent Resupply Spacecraft

- Dextre
- Visiting Vehicles
- EVA
- ISS Robotics Workstation (RWS)

Timelapse Video of Cygnus Release: http://youtu.be/-dtOS-oavGg
• **Dextre (SPDM)**
  – Two, seven-jointed robotic arms
  – Arrived on ISS in 2008, EVA astronauts assembled.
  – First operational task: 2011

• **Choreographed from ground.**
  – Designed & implemented knowing that timelines would be excessive and beyond available crew resources.
  – Uses automated sequences commands.
  – Has limited ability to respond to real-time anomalies, requiring day/s to re-plan.

BEYOND LOW EARTH ORBIT
How will human spaceflight operations evolve?
Missions will be more complex
Many required space assets

• Before ever launching people
  – Launching space assets
  – In-situ propellant generator
  – Ascent vehicle
  – Surface habitat
  – Robots
  – Power supply
  – Communication Infrastructure

• Sending astronauts
  – Spacecraft to launch from Earth
  – On-orbit transit spaceship
  – Descent vehicle
  – Mars-orbiting spacecraft
  – Spacesuits
  – Rovers
  – Spacecraft to return to Earth
Communication Limitations

~ 4 – 24 min one-way latency
when Sun not in the way!
Deep Space Network

Credits: NASA JPL
What does the future hold?

Ground team working under these constraints

With smaller astronaut teams to do work

With more complex space assets than before!
What does the future hold?

- Game-changers:
  - Fewer crewmembers
  - Farther away destinations
  - Longer duration missions
  - Variant, intermittent communication delays
  - Crew autonomy
  - Less ground support

More automation & robotics
Enabling Crew Autonomy

• How to do enable crew to work and problem-solve autonomously from ground support?

• Advanced training and procedure execution support
  – Internet of things?
  – Augmented reality?
  – Motion tracking?

• Crew self-scheduling
  – Current work, includes providing astronauts flexibility to manage own schedule.
Advanced Automation and Robotics

• How do we enable monitoring and commanding of different types of robot agents, at different distances/latencies, with varying levels of capabilities?

• Advanced Automation & Robotics must:
  – Enable safety
  – Increase capabilities
  – Increase crew efficiency
• **Rovers/Landers on Mars**
  - “Operations are open-loop, where the human must send sequences of commands rather than act on feedback information in real-time due to the long signal time delays between Earth and Mars”

• **Commands to ISS**
  - Space Station is monitored & commanded by a team of flight controllers, each with their specialization.
  - Everything from power management to attitude control.
How do we know that human and automation/robotics integration is challenging?

Introducing new automation/robotics is not as easy or simple as it sounds.
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Machine</th>
<th>Human</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>Superior</td>
<td>Comparatively slow</td>
</tr>
<tr>
<td>Power output</td>
<td>Superior in level in consistency</td>
<td>Comparatively weak</td>
</tr>
<tr>
<td>Consistency</td>
<td>Ideal for consistent, repetitive action</td>
<td>Unreliable, learning &amp; fatigue a factor</td>
</tr>
<tr>
<td>Information Capacity</td>
<td>Multi-channel</td>
<td>Primarily single channel</td>
</tr>
<tr>
<td>Memory</td>
<td>Ideal for literal reproduction, access restricted and formal</td>
<td>Better for principles &amp; strategies, access versatile &amp; innovative</td>
</tr>
<tr>
<td>Reasoning Computation</td>
<td>Deductive, tedious to program, fast &amp; accurate, poor error correction</td>
<td>Inductive, easier to program, slow, accurate, good error correction</td>
</tr>
<tr>
<td>Sensing</td>
<td>Good at quantitative assessment, poor at pattern recognition</td>
<td>Wide ranges, multi-function, judgment</td>
</tr>
<tr>
<td>Perceiving</td>
<td>Copes with variation poorly, susceptible to noise</td>
<td>Copes with variation better, susceptible to noise</td>
</tr>
</tbody>
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Hollnagel, 2000
Benefits and Consequences of Automation & Robotics

Benefits
- Increased capabilities
- Increased efficiency
- Lower workload

Consequences
- Changing nature of work
- Unexpected vulnerabilities

Fields:
- Aeronautics
- Military
- Nuclear Power
- Space
Evidence from Research

What We Imagine

Reality Check

• Using Automation may lead to:
  – Inability to maintain mode awareness
  – Decreased situation awareness
  – Mode-related errors
  – Skill degradation
  – Inappropriate knowledge acquisition
  – Lack of trust (disuse of automation)
  – Complacency and system overreliance
  – Errors of omission and commission
  – Decision/automation bias

Credit: Marvel Studios, Iron Man & The Avengers
• Balancing Act: increase needs for capabilities that automation and robotics affords while mitigating consequences.
  – Better recovery from automation failures when the level of automation during the task involved human interaction. (Endsley & Kiris, 1995)
  – Increasing amount of automation supports routine system performance and workload, but negatively affects failure system performance and situation awareness. (Onnasch et al., 2013)

• “New technology does not remove human error. It changes it.” (Dekker, 2006)

• Automation is only as good as we build it.
  – It inherently is imperfect and incomplete, because our knowledge of complex, new system behavior & extraterrestrial environments is incomplete.

• Humans are often considered the primary backup.
Human-Automation-Robotic Integration Challenges

- Under time-delayed, intermittent, limited bandwidth communication:
  - Tele-operations and autonomous commanding of robotic agents at variant distances
  - Supervisory control of complex, automated vehicle systems
  - Commanding variety of mixed-agents, different types of automation & robotic agents

- Enabling crew autonomy:
  - Human-robot team coordination
  - Flexible scheduling and planning
  - Training and procedure support
Future Exploration Missions

• Game-changers will shift the way we do human spaceflight operations.

• NASA will have to build upon & go beyond its existing human spaceflight operational experience, which has heavily relied on ground control support.

• NASA will have to infuse existing automation/robotic technology, which need to be validated in safety-critical context.

• Future human spaceflight will be more than developing automation/robotic technology – it will have to be about integrating these technologies with people.