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
Ground-Crew Daily Operations
Frequent Resupply Spacecraft

Timelapse Video of Cygnus Release: http://youtu.be/-dtOS-oavGg
Special Purpose Dexterous Manipulator (SPDM)

- **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

future missions

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 fed-back 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.

Credit: MIT Instrumentation Laboratory Report (circa 1960s)
### Wondering since 1950s …Fitt’s List

<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

Applications
- 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
No Magic Bullet/Solution

• 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.
QUESTIONS?

http://humanresearchroadmap.nasa.gov/evidence/reports/HARI.pdf