Workshop on Autonomy for Future SMD Missions

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Overview

First SMD autonomy workshop

- 75 attendees
- Scientists from astrophysics, heliophysics, earth science, planetary science
- Mission designers, engineers, and technologists

Keynote talks

- SMD technology focus & plans
- Autonomy & NASA tech roadmaps
- Self-driving cars & space exploration

Sessions

- Lightning talks
- Mission pull (breakout groups)
- Technology push (breakout groups)

Key Findings

Broad interest in understanding and realizing the potential of autonomy for breakthrough science missions

Identified 6 mission applications that require autonomy

- Mercury / the Moon
- Ocean worlds
- Venus
- The Heliosphere
- Earth
- Small Bodies

Autonomy technology would enable these missions and/or reduce the risk of mission failure

Identified cross-cutting mission capabilities needs

Need to conduct additional studies, workshops, & engagement

Motivation for 2017 Autonomy Workshop

Autonomy is changing the world

- Massive commercial investment in autonomy technology
- Drones, robots, self-driving cars, etc.
- NASA is falling behind in the use of autonomy in space

NASA science missions need to do more

- New destinations and measurements
- More ambitious and complex mission constraints
- Constrained budgets and staffing (particularly mission ops)

First SMD autonomy workshop

- Discuss autonomy for future SMD missions
- **Scientists**: learn about what is possible with autonomy
- **Technologists**: learn about missions that need autonomy technology
- Help SMD plan for studies, technology development, partnerships

Focus of 2017 Autonomy Workshop

Key questions

- Can autonomy increase science mission capabilities?
- Can autonomy increase science return?
- Can autonomy make high-priority missions more affordable?
- How can we design and carry out missions with increased autonomy?
- How can we better understand risk associated with autonomy?

Desired outcomes

- Identify new mission concepts that **can only** be accomplished with autonomy (to be considered for inclusion in future decadal surveys)
- Identify mission concepts that could be made cheaper, or less risky with autonomy as an option.
- New ideas, topics, etc. (autonomy technology, analog activities, etc.) for future R&D and study activities, RFIs, solicitations, etc.

Automation and Autonomy

Automation

- **Automation is the automatically-controlled operation of an apparatus, process, or system using pre-planned instructions**
- Automation is a tool that enables (supports) autonomy
- Current deep-space robot missions rely on automation
- Example: command sequence execution (LCROSS, MER, MSL, etc)

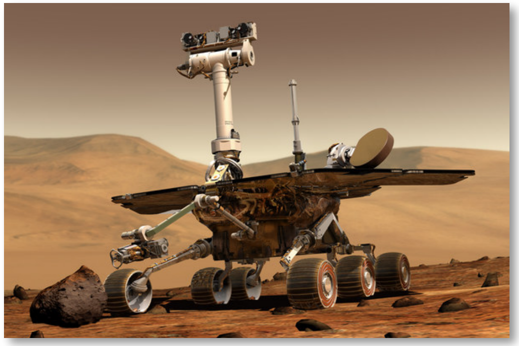
Autonomy

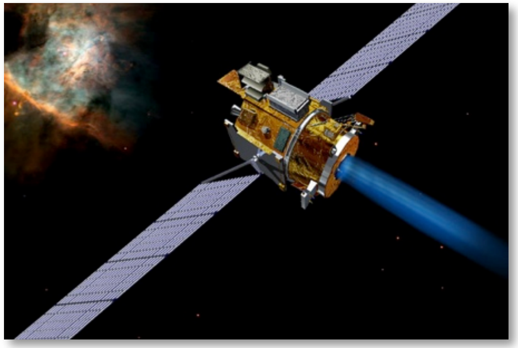
- **Autonomy is the ability to achieve goals while operating independently from external control**
- Autonomy is a relative term: from who? for what? and when?
- Both humans and systems can function autonomously
- Very limited use of autonomy in space missions today
- Examples: Remote Agent (1998 Deep Space 1 mission),
  AutoNav (MER and MSL rovers)

Autonomy Considerations

Autonomy is needed …

1. When the cadence of decision making exceeds **communication constraints** (delays, bandwidth, and communication windows)
2. When **time-critical decisions** (control, health, life-support, etc) must be made on-board the system, vehicle, etc.
3. When decisions can be better made using **rich on-board data** compared to limited downlinked data (e.g., adaptive science)
4. When local decisions **improve robustness** & **reduces complexity** of system architecture
5. When autonomous decision making can **reduce system cost** or **improve performance**
6. When **variability in training, proficiency**, etc. associated with manual control is unacceptable





Identified Applications for Autonomy

Mercury / the Moon (1, 4, 5, 6)

- Mobility in permanently-shadowed regions' crater terrain – enables inter-crater mobility
- Robotic arms or set of arms for sample manipulation
- Decision-making for mother-daughter rover combinations

Ocean Worlds (1, 2, 3, 4, 5, 6)

- Proactively execute mission activities in an unknown in situ environment
- Mobility in subsurface ocean
- Intelligent sampling mechanism

Venus (1, 2, 3, 4, 5, 6)

- Balloons or other airships
  - Platform coordination
  - Altitude dwell and re-plan
  - Chemical detection feedback to altitude profile

Autonomy Considerations

1. comm constraints
2. time-critical decisions
3. rich on-board data
4. local decision making
5. reduce mission cost
6. avoid manual control

Identified Applications for Autonomy

The Heliosphere (1, 3, 4, 5, 6)

- Coordinated constellations of satellites to achieve unprecedented spatial and temporal resolution
- Inter-satellite communication and coordination in response to short-lived events, synchronous pointing to transient signals

Earth (3, 4, 5, 6)

- Autonomous identification of anomalous features
- Adaptive, dynamic targeting of key measurements
- Model-directed ID of sensitive observing areas in the atmosphere
- Analysis of impact of model-observation feedback loop

Small Bodies (1, 2, 3, 4, 5, 6)

- Dynamic mobility for exploration (motion planning, targeting, etc.)

Autonomy Considerations

1. comm constraints
2. time-critical decisions
3. rich on-board data
4. local decision making
5. reduce mission cost
6. avoid manual control

Identified Cross-Cutting Capabilities

These capabilities are highly relevant to all missions that make significant use of autonomy:

- Active fault recovery
- Active power management
- Functional redundancy
- Self-aware systems
- Inter-asset communications
- Autonomous maneuvering of surface rovers

Summary

NASA is operating far from the state-of-the-art in autonomy

- Large gap between commercial applications and SMD missions
- NASA is falling behind in adopting and benefitting from autonomy

Numerous autonomy technologies are at mid-TRL already

- Automated planners, schedulers, and reasoners
- Diagnostics, prognostics, and state estimators

Must design missions for autonomy

- Adaptive and reactive science
- Function-level and system-level
- Systematic handling of uncertainty

Barriers to mission autonomy

- **Computing** – need higher performance, possibly new types
- **Culture** – need to change how SMD assesses and manages mission risk
- **Integration** – need architecture and tools to add autonomy to missions
- **Sensors** – need to adapt terrestrial systems (e.g., lidar for planetary rovers)
- **V&V** – need analytical and empirical methods

Next steps

Explore the potential of autonomy for achieving breakthrough science missions

- Increase engagement of mission stakeholders (engineers, scientists, mission planners, etc.)
- Initiate RFI or funded studies of mission concepts that would benefit from autonomy
- Conduct a second autonomy workshop in 2018

Engage the technology community and development

- Ensure that SMD mission needs are well understood by the Autonomy Systems Capability Leadership Team (AS-CLT)
- Adapt / expand upcoming SMD solicitations to include autonomy technology development, infusion, and testing
- Encourage HEOMD & STMD to develop and mature autonomy technology that is relevant for SMD
- Engage other communities (non-space commercial, other agencies, etc) that could contribute autonomy technology to SMD missions