2018 Workshop on Autonomy for Future NASA Science Missions

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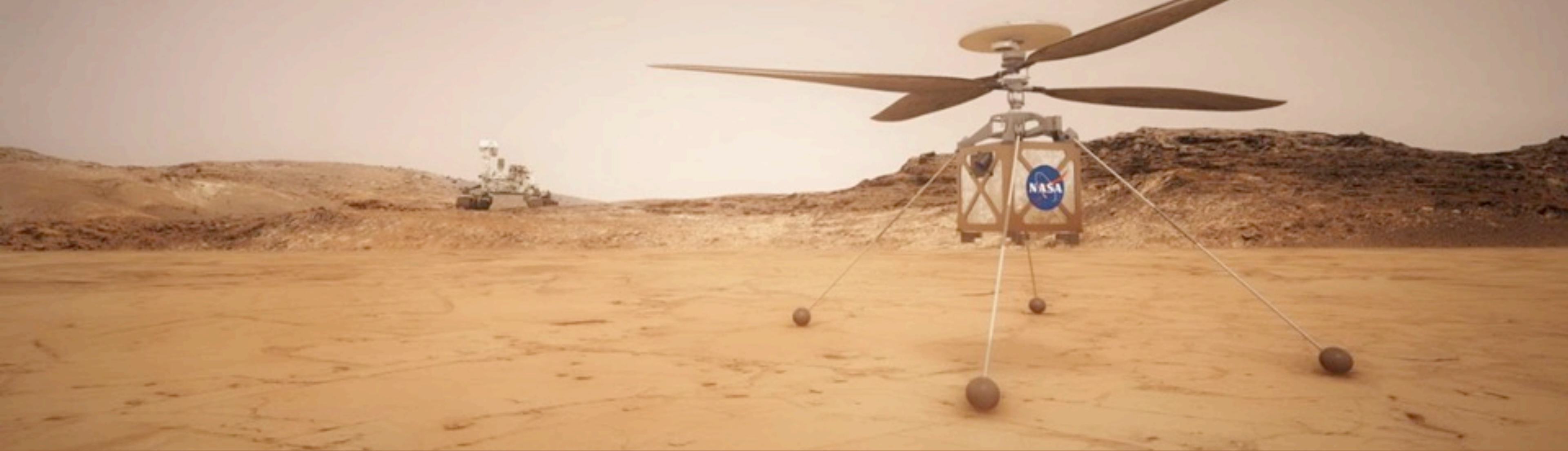

DRM Breakout Report

Mars

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Science Mission Objectives

- Corroborate remote sensing maps of near-surface (5 m, TBR) water ice
  - Water ice, ice/regolith, or mineral hydration?
- Is the presence of water related to geologic features?
  - What is the nature of the water reservoir?
  - What processes and sources are responsible for water detected?
  - Does it reveal anything about changes in climate with respect to obliquity?
- What is the composition of the water ice?
  - What are the water qualities (activity, Eh, pH, ion composition, etc)? Do they support habitability?
  - Does the water presence host life (extant to recently dead over 10,000 yrs)?
- Monitoring of weather conditions
  - How do environmental conditions affect the physical state of the water ice recovered from the subsurface

→ Map accessible water for future ISRU mission over 100 km (TBR) radius

→ meteorology data might support future missions (esp. Human Exploration)

Payload for a Baseline DRM (1 of 2)

Fleet of rovers with:

- Ice and hydrated mineral measurement such as Near IR?
- Subsurface sounding measurements such as ground penetrating radar
- Ice solute composition measurements such as Phoenix ISE
- Drill and sample acquisition capability
- Weather station on all spacecraft
- Imagers for surface feature detections and navigation
- communicate with other surface S/C and orbiters
- Fleet shall have wide area wireless network capabilities with delayed tolerant networking (DTN) (scalable)

Payload for a Baseline DRM (2 of 2)

Mothership with:

- biosignature detection capability
- sample receipt capability
- powerful science data processor
- Robust communications capabilities between Earth and Mars and among the rovers and with orbital assets

Potential Trades

- include helicopters for terrain and geology mapping, additional weather measurements?

Scalability, Extendability and Extensability

- Infrastructure **scalability** (spatial), mission **extendability** (time), and **extensability** to other missions (integration and growth)
  - **Payload elements fit a standard form factor** (unit size, power, interface, etc)
    - Future servicing/upgrading by robots
    - Supports broader range of contributed instruments from diverse teams
  - Computing and networking environment **expandable to N nodes** and **expandable data storage environment**

Assumptions

- Orbiter assets are in operation with “cloud” based computational resources, and high band with comms with Earth – a fully connected network of all assets
- Tactical planning (activity sets that may occur over 1 or many sols) is autonomous. Long term planning will still involves humans in the loop.

Key messages

- While steps in the mission architecture could be done without autonomy today, autonomy introduces such **high efficiency that it transforms the exploration paradigm and orders of magnitude in science return.**
- Most of the specific autonomy capabilities do not yet exist today and need to be developed.
- This DRM architecture will enable extensibility

Notes to NASA

- Need funding for machine learning of calibration materials for specific instrument types. Teach the machine to recognize complex data and interpret it. Train on Earth, send to Mars to put into operation.
- Need to start developing this now… very small, low powered, peer-to-peer interface standards for multiple agents. (could be used for the Moon too)
- We need funding for development of autonomy (software based) with hardware design considerations

Individual Agent Task Planning

ITEM	Question	Response
A	Describe a specific Design Reference Mission objective or mission requirement to be addressed with autonomy.	
B	Describe an autonomous capability that could be used to accomplish (A).	Individual agent planning. Science event detection and response. For example, rover detects a white streak in it's wheel tracks and explores it. This deals with knows of interests as well as outliers.
C	List the core autonomy technologies needed by (B). Refer to the Autonomous Systems Taxonomy table on the last slide for a list of technologies.	*Sensing and perception (1.1), Mission Planning and Scheduling (2.1), Activity and Resource planning (2.2), Goal and Task negotiation (3.3), Adaptive Science Strategy (2.1, 2.2, 2.4)*
D	List any other supporting technologies needed by (B), including assets from potential commercial partners.	Surface imaging computing into Digital Terrain and Geology Map (DTGM) High performance computing power In-situ sub-surface structure remote sensing at rover scale for integration with DTGM for 3-D model Onboard spectral analysis to mineralogical content Onboard interest operator to analyze, prioritize and decide next activity especially for transient events
E	List any related/relevant R&D projects for (C) and (D). Include references (e.g. citation, URL, name of PI, name of org or private sector company performing the research).	*Develop I&T approach for each element of autonomy including independent safety management at a "do no harm" level.*
F	Is (B) enabling or enhancing for (A)? Can this capability only be enabled with autonomous technology? Explain.	
G	Provide a rough estimate of the development costs for (B), and describe how (B) will increase (or decrease) overall mission cost (development or ops). Cost can be $, schedule, staffing, etc.	
H	Describe how (B) will increase (or decrease) mission risk (development or ops). Risk can be performance, schedule, etc.	
I	Optionally list any comments, key points, questions, etc. not covered in the sections above.	

Collaborative Multi-agent Task Planning

ITEM	Question	Response
A	Describe a specific Design Reference Mission objective or mission requirement to be addressed with autonomy.	
B	Describe an autonomous capability that could be used to accomplish (A).	Collaborative multi-agent planning: peer to peer organization and coordination among all mission assets (rovers, mothership and orbiter). For example, integrated development of DTGM and to identify next area of interest and efficiently deploy assets to explore.
C	List the core autonomy technologies needed by (B). Refer to the Autonomous Systems Taxonomy table for technologies.	*Task Allocation (3.3), Joint Knowledge and Understanding (3.1), State Estimation and monitoring (1.2), Adaptive Science Strategy (2.1, 2.2, 2.4), Operational Trust (3.4)*
D	List any other supporting technologies needed by (B), including assets from potential commercial partners.	*Delay Tolerant Networking (DTN)* *Mesh Networking* *Peer to peer interface standards for multiple interacting agents* *High performance, remote computing*
E	List any related/relevant R&D projects for (C) and (D). Include references (e.g. citation, URL, name of PI, name of org or private sector company performing the research).	*Develop I&T approach for each element of autonomy including independent safety management at a "do no harm" level.*
F	Is (B) enabling or enhancing for (A)? Can this capability only be enabled with autonomous technology? Explain.	
G	Provide a rough estimate of the development costs for (B), and describe how (B) will increase (or decrease) overall mission cost (development or ops). Cost can be $, schedule, staffing, etc.	
H	Describe how (B) will increase (or decrease) mission risk (development or ops). Risk can be performance, schedule, etc.	
I	Optionally list any comments, key points, questions, etc. not covered in the sections above.	

Sample Acquisition and Delivery

ITEM	Question	Response
A	Describe a specific Design Reference Mission objective or mission requirement to be addressed with autonomy.	
B	Describe an autonomous capability that could be used to accomplish (A).	*Sample Acquisition and Delivery: Post target selection activities including approach to the target, smart safe drilling, a safety checker, sample collection and delivery to mothership.*
C	List the core autonomy technologies needed by (B). Refer to the Autonomous Systems Taxonomy table for technologies.	*All situation and self awareness (1.x), all of reasoning and acting (2.x)*
D	List any other supporting technologies needed by (B), including assets from potential commercial partners.	*Light weight drill capable of 5m (TBR)* *Sample collection capability* *Handoff of potentially wet sample to mothership* *Sample mass or volume verification*
E	List any related/relevant R&D projects for (C) and (D). Include references (e.g. citation, URL, name of PI, name of org or private sector company performing the research).	*Develop I&T approach for each element of autonomy including independent safety management at a "do no harm" level.*
F	Is (B) enabling or enhancing for (A)? Can this capability <u>only</u> be enabled with autonomous technology? Explain.	
G	Provide a rough estimate of the development costs for (B), and describe how (B) will increase (or decrease) overall mission cost (development or ops). Cost can be $, schedule, staffing, etc.	
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Navigation

ITEM	Question	Response
A	Describe a specific Design Reference Mission objective or mission requirement to be addressed with autonomy.	
B	Describe an autonomous capability that could be used to accomplish (A).	*Navigate safely to the region of interest, validating and improving maps along the way. Use uncertainty aware navigation to optimize speed.*
C	List the core autonomy technologies needed by (B). Refer to the Autonomous Systems Taxonomy table for technologies.	*2.3, 2.4, 2.7, 1.3, 1.2, 1.1*
D	List any other supporting technologies needed by (B), including assets from potential commercial partners.	*Stereo images* *Software for autonomy*
E	List any related/relevant R&D projects for (C) and (D). Include references (e.g. citation, URL, name of PI, name of org or private sector company performing the research).	*Develop I&T approach for each element of autonomy including independent safety management at a "do no harm" level.*
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DRM Autonomy Summary

(Single-row summary for each DRM objective or requirement.. duplicate this slide if you need more rows)

DRM Scenario	Autonomy Requirements/Goal	Key Question & Knowledge Gaps	Technology Innovations and Partnerships	Current SOA, Projects and Products
Coordinated Mulit-agent task planning	<List of all the autonomy capabilities needed to address this DRM requirement>	<Key questions and technical unknowns in developing these autonomy capabilities>	<Key areas of required technology innovation, approach to achieve solutions, including commercial partnerships >	<Current state of the art of technology which constitutes a basis for development, including commercial systems>
Individual agent task planning. Science event detection and response.	<List of all the autonomy capabilities nee address this DF requirement>	<Key questions and	<Key areas of required ion, e commercial partnerships >	<Current state of the art of technology which constitutes a basis for development, including commercial systems>
Sample acquisition and delivery				
Navigation	<List of all the autonomy capabilities needed to address this DRM requirement>	<Key questions and technical unknowns in developing these autonomy capabilities>	<Key areas of required technology innovation, approach to achieve solutions, including commercial partnerships >	<Current state of the art of technology which constitutes a basis for development, including commercial systems>

Work in progress

Candidate DRM White Papers

Propose one or more white papers that should be published in order to define and promote the key autonomy innovations identified by this working group.

- Mars Autonomy Workshop DRM
- <White paper title #2>
    - White paper abstract>

…

- <White paper title #n>
    - White paper abstract>

Autonomous Systems Taxonomy
Summary Table – for your reference

1.0 **Situation and Self Awareness**	2.0 **Reasoning and Acting**	3.0 **Collaboration and Interaction**	4.0 **Engineering and Integrity**
1.1 Sensing and Perception	2.1 Mission Planning and Scheduling	3.1 Joint Knowledge and Understanding	4.1 Verification and Validation
1.2 State Estimation and Monitoring	2.2 Activity and Resource Planning and Scheduling	3.2 Behavior and Intent Prediction	4.2 Test and Evaluation
1.3 Knowledge and Model Building	2.3 Motion Planning	3.3 Goal and Task Negotiation	4.3 Operational Assurance
1.4 Hazard Assessment	2.4 Execution and Control	3.4 Operational Trust Building	4.4 Modeling and Simulation
1.5 Event and Trend Identification	2.5 Fault Diagnosis and Prognosis		4.5 Architecture and Design
1.6 Anomaly Detection	2.6 Fault Response		
	2.7 Learning and Adapting		

For complete document, click here: https://go.usa.gov/xPTZa

Fong, Terrence W. et al, "Autonomous Systems Taxonomy", *NASA Technical Report, Autonomous Systems CLT Meeting*, NASA Ames Research Center. 5 May, 2018.