Planetary Surface Robotics:

Reaction to NASA Roadmap

TA04-Robotics, Telerobotics, and Autonomous Systems (RTA)

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NASA Technology Roadmap: Robotics, Communications, and Navigation Panel
National Academies' Keck Center
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Expertise

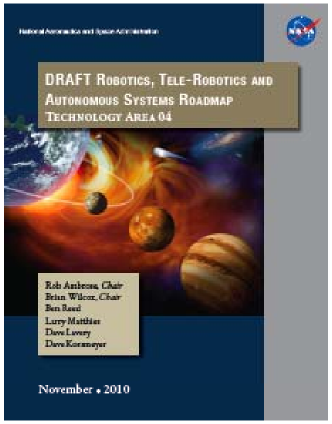
- Robot mobility, navigation & manipulation; autonomous systems & software, intelligent control & soft computing
- 24 years planetary robotics research, technology development, and flight missions; 18 years as robotics engineer at JPL
- Rover systems engineer for analogue field testing and technology demonstration
- MER Flight Systems Engineer for Autonomous Nav; Lead flight controller for Mobility/Robotic arm operations
- Space Robotics & Autonomous Control Lead at APL
- Ph.D. electrical engrg.; M.E. & B.S. mechanical engrg.
- AIAA SARTC; IEEE RAS TC on SR; VP IEEE SMC Society

Comments on Roadmap TA-04

Past NASA Robotics-related studies, roadmaps, & visions

Technological advances have been slow

The menu of needs has changed little



The TA-04 RTA roadmap is similar…

Advanced autonomous mobility	**Autonomy and operations**	**ISRU and outpost tasks**
• steep slope mobility • autonomous mobility in dark/ shadowed environments • Subsurface access mobility and mechanisms • reconfigurability • in-space mobility	• robotic autonomy software • autonomous control • "human equivalent" robotic operations • human-robot and autonomous systems V&V • advanced operations software • remote robotic system supervision and teleoperation • human-system interaction	• site/resource characterization • regolith excavation • regolith manipulation and transportation • landing site preparation • resource/cargo predeployment

Robotic systems	**Robotic capabilities**
• robotic assistants • construction robots • environment/site survey rovers • cooperative robotic networks • autonomous monitoring and repair robots	• precise instrument placement and manipulation • end-effectors w/dust tolerant mechanisms • sample gathering, handling, and analysis • remote sensing for robotic surface systems • automated rendezvous and docking

Omissions / Improvements

- No glaring omissions for surface mobility or manipulation, but…
- Technologies offering functional longevity for longer-duration missions seem lacking

- Adding ***low-risk learning/adaptation*** would address this

Top Technical Challenges

- Reasonably well covered in general terms for planetary surface robotics
  - Agree with human-like vehicle piloting, extreme terrain access, highly dexterous manipulation, fusion of manipulation sensing, non-cooperative object handling, and immersive telepresence where teleoperation is involved
- Would add ***subsurface access*** and ***controlled mobility on small bodies***

Uncovered Technology Gaps

Perception algorithms/techniques

- Perception broadly impacts surface robotics involving a hardware-software duality. Capability increases in both lead to highest payoffs.
- The roadmap seems to place an unbalanced emphasis on algorithms & software techniques -- the heart of perception -- with most emphasis on sensor hardware

- An explicit subtopic addressing the ***sensor data processing and automated reasoning*** associated with perception should be included.

Uncovered Technology Gaps

Proprioception

- Mentioned twice in the roadmap prose but never elaborated on
- Advances are needed for robustly stable performance on challenging terrain and for manipulation (e.g., what makes Boston Dynamics' BigDog so fascinating, in part, is proprioception and associated control).
- Advances will lead to more capable rovers beyond MER and MSL, and is essential for autonomous mobility dominated by gravitational forces (on slopes, cliff faces, in low-g, etc)

Uncovered Technology Gaps

Low-Risk Learning/Adaptation

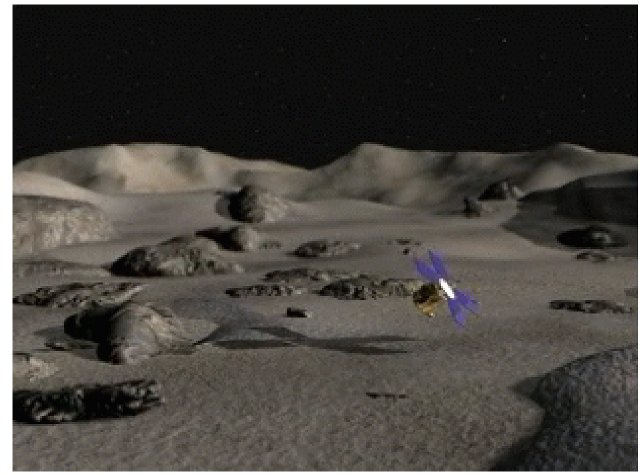
- To maximize functional capability in the face of degrading subsystems (e.g., mobility w/faulty wheel(s) or leg(s))
- Learning by demonstration for certain complex manipulation / sampling tasks
  - A means to embed human-like intelligence without performing burdensome detailed computation based on complex yet inadequate models)
  - A means to improve performance over time

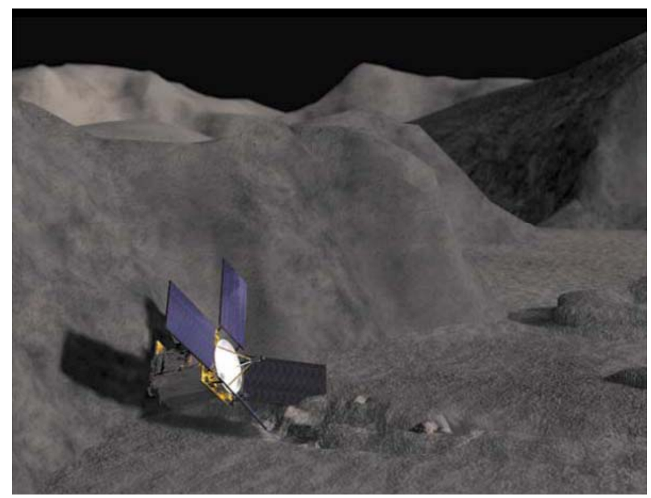
"Game Changing" technologies

- Candidates include technologies for which
  - there is little foundation in the research literature, or
  - an integral piece is yet to be invented, or is replaced by a solution offering a quantum leap in some metric
- We do not know the potential of these technologies until some progress begins to offer a glimpse at how it may transform how we do missions

"Game Changing" technology

- ***Controlled attachment to and mobility on small/low-gravity bodies***
- We do not know how yet but it could define how we explore NEA surfaces -- a purported class of destinations for future precursor and human missions
- Responsive to NASA Space Tech. Grand Challenge of *All Access Mobility* with relevance to terrain access in higher gravity wells





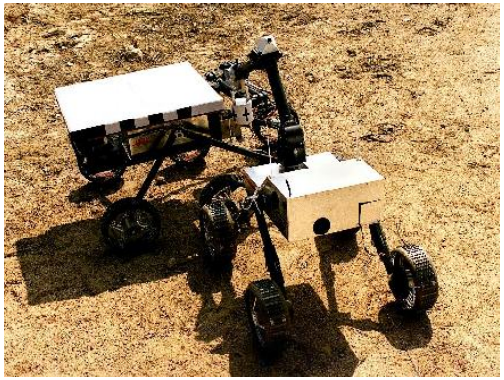
Artist's concept of NEAR Shoemaker on surface of Eros

"Game Changing" technology

- ***Controlled attachment to and mobility on small/low-gravity bodies***
- Requires driving convergence of technologies from different robotics application domains
  - Various mobility concepts for asteroids
  - Climbing robots for military recon. and search & rescue
  - Hybrid mobility & manipulation systems
- Would allow local mobility in persistent contact with the surface in high priority regions of interest

Technologies at a Tipping Point

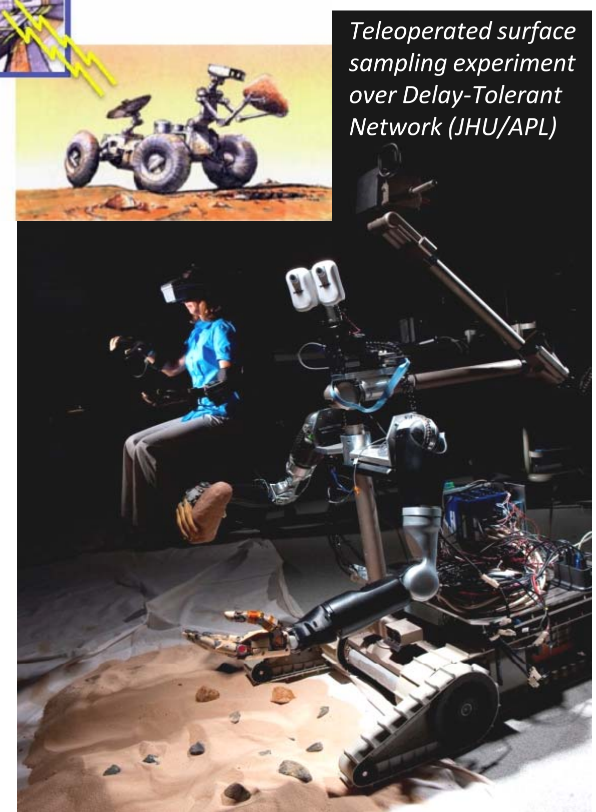
- Considering ***MSR**** ***sample caching rover*** as a pull technology, the required mobility and manipulation is near a tipping point
- Similarly for a later ***fetch rover*** for cached-sample retrieval
- Prototype systems demonstrated in the field by JPL as recently as a decade ago (mid-TRLs)



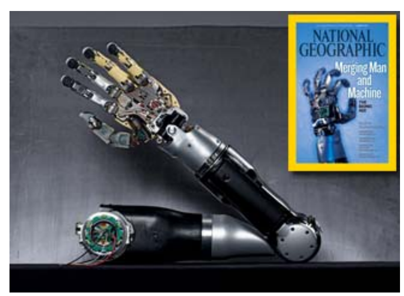
***** *Mars Sample Return*

Technologies at a Tipping Point

- ***Multi-arm, dexterous telerobotics*** w/immersive telepresence, haptics, etc over time-delay or delay tolerant networks
- Related modular technology akin to Robonaut-2 with potential for use of cognitive interfaces and the like



Teleoperated surface sampling experiment over Delay-Tolerant Network (JHU/APL)



High-priority Technology Areas

for planetary surface robotics

- Tipping point technologies (for MSR and dexterous telerobotics)
- Access to small body surfaces
- Access to planet subsurfaces
- For long-duration missions, low-risk learning/adaptation

Alignment with NASA

- Most high-priority technology areas align w/NASA expertise, capabilities, facilities, & role (learning systems are possible exceptions)
- The larger robotics community can be leveraged for better alignment through transfer and acclimation of relevant robotics technologies useful for space missions
- Despite disparity between technology capabilities for Earth- and space-based robotics, much of the former may apply with skilled tailoring for space mission use
- There is a large and growing open-source, or otherwise collective, development community advancing the field, and space is not benefiting.

Competitive-placement

- The technology development proposed by the roadmap is competitively-placed considering that the specialized domain knowledge and skill needed for space RTA forges a small community of performers
- Again, leveraging the larger RTA community is highly recommended and fosters richer competitive teaming to more quickly advance TRLs

Time Horizon for Insertion

- Technologies mentioned could be matured and readied within the range of 5 to 15 years.
- Most uncertainty on game changing technology

Robotics for planetary and small body surface access

Payoff

- instrument delivery to multiple, disparate surface locations
- large area coverage and access to extreme/hard-to-access terrain
- Physical sample acquisition, caching, return
- with low-risk learning/adaptation, maximum capability or functionality as systems degrade over the course of long duration missions

Risk

- Low-Med.; robotics for space are largely proven and will improve with each mission, paring risk down/bounding risk in new areas

Technological barriers

- Few with exception of unknowns in new technology areas yet to be explored

Chance of success

- Med.-High; substantial RTA technology foundations exist and could advance with consistent funding

Q&A

B A C K U P

Least-covered planetary surface robotics technology areas

…considering work at nearly 30 organizations

- Small-body surface access / mobility
- Subsurface access
- Self-repair & maintenance/repair in general
- Sampling and sample handling/caching
- Tele-surgery
- Adaptation / learning
- Cognition
- Cybernetic & symbolic human-robot interaction
- Networked robotic systems
- …

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