ROCK CLIMBING ROBOT FOR EXPLORATION AND SAMPLE ACQUISITION AT LAVA TUBES, STEEP SLOPES, AND CLIFF WALLS.
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Challenge Area 3 – mid to long term

Introduction: The rock climbing robot described here utilizes a unique technology, microspines [1], that enables access to some of the most interesting locations on the Martian surface, including the observed vertical entrance lava tubes, the cliff walls of Valles Marineris, and the steep slopes where seasonal brines have been observed [2]. With the demonstrated ability to core into the surface at any gravitational orientation, including into the ceiling of a cave, this robotic approach to Mars Exploration has the flexibility to take samples no other robot could reach. A concept of this robot is shown in Figure 1.

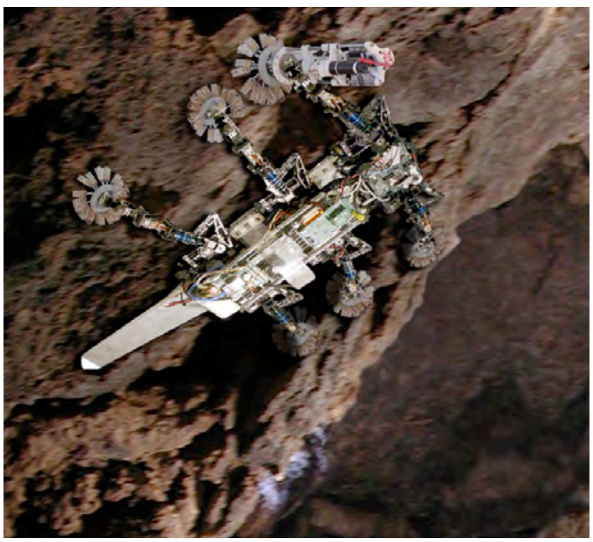

Figure 1 Conceptual rock climbing robot leveraging existing DARPA platform, RiSE.

Scientific Use – Searching for Evidence of Microbial Life in the Right Place:

The surface of Mars has become cold, dry, and is subjected to heavy doses of radiation making it an unlikely environment for current life. However, as noted in the Planetary Decadal Survey, "*Mars's subsurface appears to be more hospitable.*" The recent potential of liquid brines that may have subsurface sources makes the search for life underground even more compelling [2]. Mounting evidence of an extensive and highly biodiverse subsurface microbial biosphere on Earth existing on a variety of inorganic energy sources lends further plausibility to the idea [3].

On Mars, a rover could most easily access the subterranean realm through the lava tubes that have been observed by orbital imagers [4]. However, this is far beyond the reach of MSL-class platforms that are limited to slopes of ~25 degrees [5]. Rappelling robots offer a more attractive approach [6,7], but lack the flexibility to deal with the variety of terrain roughness at multiple spatial scales that a cave presents, and often lack critical capabilities like lateral movement and the ability to resist the forces of sampling. An emerging technology developed under DARPA funding, microspines, offers a flexible solution to NASA's Mars Exploration Program. Microspines create secure anchors on natural surfaces like rock, enabling horizontal, vertical, and even inverted mobility [8]. Further, a self-contained microspine anchor and coring drill—see Figure 2—has been demonstrated drilling holes and caching rock cores regardless of gravitational orientation [9], making a compelling case for use as an instrument on such a topologically challenging mission.

The cave environment is a window into the subsurface geology and any extant biology, and intrinsically a

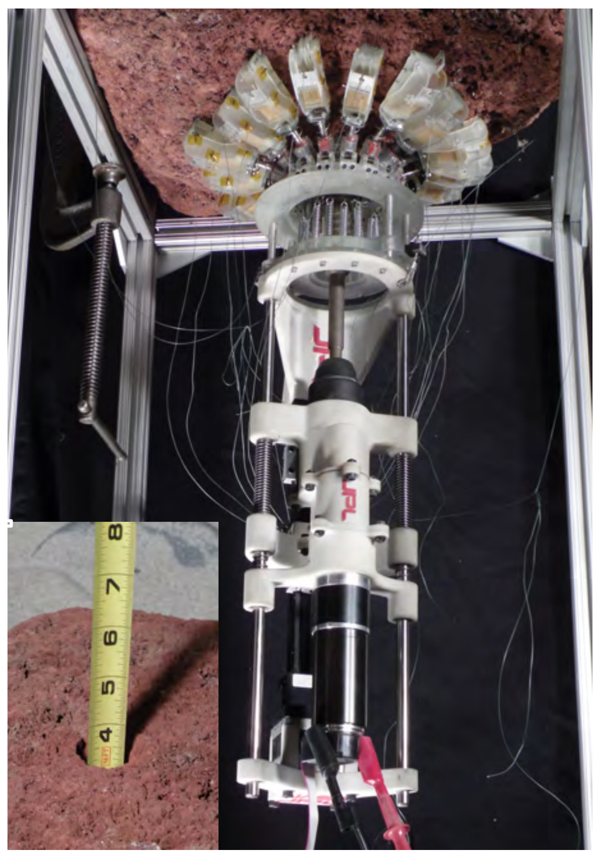

Figure 2 Demonstration of inverted rock coring on a vesicular basalt sample. 0.75 inch diameter boreholes with 0.5 inch diameter rock cores were obtained to a depth of 3 inches.

wonderful preservation environment because it protects living remains from surface processes. On Mars, caves can protect against thermal changes, wind, high intensity ultraviolet, and the extreme ionizing radiation environment. On Earth, it is no accident that some of our most exquisitely preserved paleontological remains like intact mummified thylacines, archaeological finds like extractable Neanderthal DNA, and the earliest known textiles have all been found in caves.

Human Exploration Use – Scouting and Creating Infrastructure in the Right Place:

One of the primary Strategic Knowledge Gaps identified for Mars missions is measurement of the radiation environment on the surface of the planet. One potential mitigation of the risk caused by this radiation would be to use the existing lava tubes and caves as natural shielding for human missions. A rock climbing rover with the ability to core into the rock at any orientation could set up a network of cables prior to the astronauts' arrival so that existing infrastructure would allow the assembly of such a base quickly, or even robotically before the astronauts arrived. Figure 3 shows a 4-limbed rover hanging inverted from a simulated cave ceiling.

Technical Detail: The enabling technology for this type of climbing robot is an omni-directional anchor with microspine toes that creates fast, strong attachment to a variety of natural surfaces like rock using minimal power [10]. Prototypes have been demonstrated on vesicular basalt and a'a lava rock. Each anchor can support >150 N tangent, >160 N at 45 degrees, and >180 N normal to the surface of the rock [11]. These anchors, enable the climbing and sampling from natural surfaces of any inclination with roughness at many scales (µm - m). Anchors are secured in only a few seconds so the robot can move quickly (~0.5m/min) and efficiently (>100 m on a single charge). Spaceflight designs have also been prototyped replacing all flexible polymeric components with metal extension springs, providing roughly 80% of the performance of the current terrestrial designs [11].

Figure 3 The LEMUR IIB robot hanging inverted off of a simulated cave ceiling using a microspine gripper.

References:

[1] A. Asbeck et al. (2006) "Scaling Hard Vertical Surfaces with Compliant Microspine Arrays," I. J. Robotics Research.

[2] A. McEwen et al. (2011) "Seasonal Flows on Warm Martian Slopes," Science.

[3] P. Boston et al. (2001) "Cave biosignature suites: Microbes, minerals and Mars," Astrobiology.

[4] R. Leveille and S. Datta. (2010) "Lava Tubes and Basaltic Caves as Astrobiological Targets on Earth and Mars: A Review" Planetary and Space Science.

[5] S. Squyres et al. (2004) "The Spirit Rover's Athena Science Investigation at Gusev Crater Mars," Science.

[6] I. Nesnas et al. (2007) "Axel Mobility Platform for Steep Terrain Excursions and Sampling on Planetary Surfaces." IEEE Aerospace Conference.

[7] T. Huntsberger et al. (2007) "TRESSA: Teamed Robots for Exploration and Science on Steep Areas," J of Field Robotics.

[8] A. Parness (2011) "Anchoring Foot Mechanisms for Sampling and Mobility in Microgravity," IEEE ICRA.

[9] A. Parness et al. (2012) "Microgravity Coring: A Self-Contained Anchor and Drill for Consolidated Rock," IEEE Aerospace Conference.

[10] A. Asbeck and M. Cutkosky. (2012) "Designing Compliant Spine Mechanisms for Climbing" ASME J Mech & Robotics.

[11] A. Parness et al. (2012) "Gravity-Independent Mobility and Drilling on Natural Rock Using Microspines," IEEE ICRA.

Video Demonstration of Technology: available on Wired Magazine's website, emphasizing the cross-cutting nature of the technology which also has applications to asteroids, comets, and low-gravity moons like Phobos and Deimos.

http://www.wired.com/wiredscience/2011/10/asteroid-moving/