SPACE EXPLORATION SYMPOSIUM (A3)
Interactive Presentations (IP)

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# DEVELOPMENT OF ROCK ANCHORS AND ROCK CLIMBING ROBOTS FOR THE ASTEROID REDIRECT MISSION AND FUTURE ROVERS

**Abstract**

Mobile rovers have dramatically increased science return by placing instruments at multiple sites. However, many of the most interesting targets are in extreme terrain where current rovers cannot go. For example, Opportunity imaged cross-bedding in exposed rock outcrops, but despite several months of effort, was unable to access these sites to perform detailed surface characterization. Remote observations of Mars have identified even more remarkable geologic regions with extreme features including large canyons, skylight entrances to lava tubes, and seasonal recurring slope linae on warm slopes. The same challenges exist on our Moon and small bodies. The recent Philae comet landing showed incredibly diverse and complex geography on a small body for which similar extreme terrain mobility solutions are needed. Unfortunately, the most interesting scientific sites are often the hardest to access.

Our team began work on a rock-climbing robot in 2011 to provide gravity-agnostic mobility for any natural terrain. The robot uses hundreds of sharp claws called microspines that adapt to a surface independently to create secure anchor points. Microspine grippers use arrays of sharp steel hooks with passive suspension structures to opportunistically grasp roughness on a surface, regardless of dust or slime (Parness 2011). Each microspine uses hooks embedded in a rigid frame with a compliant suspension system. By arraying hundreds of microspines, large loads (¿1000N) can be supported and shared between many attachment points (Parness 2009). Each spine has its own suspension structure, so it can stretch and drag relative to its neighbor to find a suitable place to grip. The hooks attach to convex and concave asperities like pits, protrusions, and even sloped faces (Asbeck 2006).

This paper presents recent demonstrations of the rock-climbing robot in lava tubes in the Mojave Desert, California and in El Malpais, New Mexico. These sites serve as planetary analogs to pit craters and skylight entrances seen on the Moon and Mars. Additional work is presented on the maturation of the rock anchors from plastic prototypes to aluminum structures that were tested with industrial robot arms in a coordinated effort between NASA's JPL, GSFC, and LaRC. Further test results are presented from a series of zero gravity experiments performed in NASA's Zero-Gravity Airplane in Houston TX. In combination, these developments and validations are paving the way for use of rock-gripping technology in NASA's Asteroid Redirect Mission, launching in 2020, and for future extreme terrain rovers.