# Demonstrations of Gravity-Independent Mobility and Drilling on Natural Rock Using Microspines

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***Abstract*—The video presents microspine-based anchors being developed for gripping rocks on the surfaces of comets and asteroids, or for use on cliff faces and lava tubes on Mars. Two types of anchor prototypes are shown on supporting forces in all directions away from the rock; >160 N tangent, >150 N at 45°, and >180 N normal to the surface of the rock. A compliant robotic ankle with two active degrees of freedom interfaces these anchors to the Lemur IIB robot for future climbing trials. Finally, a rotary percussive drill is shown coring into rock regardless of gravitational orientation. As a harder-than-zero-g proof of concept, inverted drilling was performed creating 20mm diameter boreholes 83 mm deep in vesicular basalt samples while retaining 12 mm diameter rock cores in 3-6 pieces.**

## I. VIDEO SUMMARY

Mineralogical analysis will be a primary objective of future missions to the surfaces of asteroids and comets or to the surface of Mars. For this analysis, subsurface cores are favored over surface rock and regolith because the rock has been protected from weathering [1] and can provide additional information from stratigraphy and grain boundaries. Drilling a core sample on a body with no gravity, however, is a significant challenge. On Mars, drilling into a vertical wall or into the ceiling of a lava tube presents similar obstacles. A method to react the forces of drilling locally is required. Microspine anchors are one such potential method.

JPL's omnidirectional anchors use a radial arrangement of microspines, which are sharp hooks attached to independent flexible suspensions [2]. Previous designs of microspines with 1 hook [3], [4] were adapted to include 3 hooks per spine to increase the chance of catching on an asperity on the surface of the rock. The anchor uses a centrally tensioning degree of freedom to load the microspines in opposition to one another. A torsion spring biases 16 carriages of 12 microspines each into the rock face regardless of gravitational orientation so that the toes will establish a grip, even in an inverted configuration. The radial configuration creates a secure anchor that can resist forces in any direction away from the surface. In a hierarchical approach, the carriages conform to cm-scale roughness while the microspines conform to mm-scale roughness and below.

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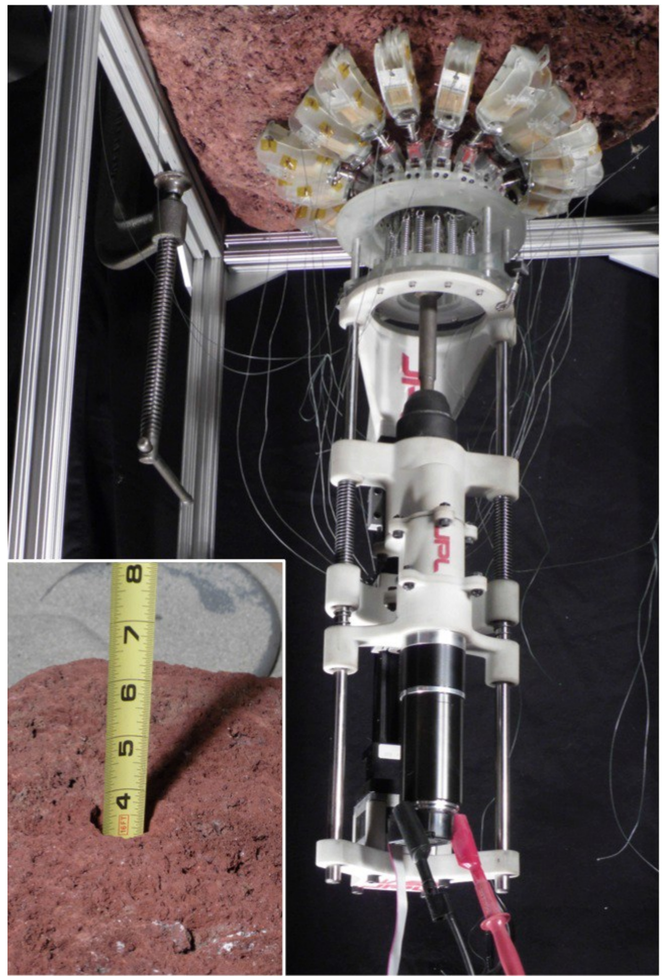

Fig. 1. The forces of drilling are reacted by the microspine anchor. Excerpted from the video here, inverted coring is shown, a harder than zero-g proof of concept.

In addition to a microspine-based anchor, a more flight-like anchor was also fabricated using the principals of microspines (opportunistic gripping of the surface and distributed load sharing between large arrays of contact points) but replaced the elastomeric flexures that cannot survive in cold temperatures with steel extension springs. The video shows each anchor supporting >130 N tangent, >150 N at 45°, and >140 N normal to the surface of the rock. This is strong enough to support the weight of the LEMUR IIB robot with only one anchor in Earth's gravity. Both anchors were successfully engaged and detached more than 100 times, and were tested to failure of the grasp nondestructively. The

Fig. 2. A custom coring bit creates a 20 mm diameter borehole and retains a 12 mm diameter rock core.

microspine anchor was built with an interface that would allow it to be operated manually, or by the robotic ankle.

The drill-anchor system, shown in Figure 1, is successfully demonstrated in the video coring on vesicular basalt in an inverted configuration, a harder-than-zero-g proof of concept. A 20 mm diameter borehole 83 mm deep can be seen in Figure 2 from one such inverted test. Including hole-start and core removal, the drilling sequence takes 3-10 minutes when drilling in very hard, lava rocks like vesicular basalt and a'a. A 12 mm diameter rock core is retained with stratigraphy in 3-6 pieces in each case. The Mars 2018 technology development team has created a sample caching system that can encapsulate and containerize many rock cores [5]. Such a system could be modified for use with this drill on future asteroid or comet missions. To date, all drilling and gripping experiments have been performed on hard consolidated rocks. Future testing will characterize the performance on softer or friable rocks. The properties of rocks on the surfaces of asteroids and comets is not widely known and likely varies widely.

Future work is focused on fabricating four ankle-anchor systems and performing climbing trials with the LEMUR IIB robot. A legged robot like LEMUR IIB could be used to explore asteroids and comets where there is very little gravity, and to access vertical cliff walls and the ceilings of lava tubes on Mars, where high value scientific samples reside. The anchor and drill are also relevant to manned missions to Near Earth Objects, as proposed by president Barack Obama [7]. Astronauts will encounter similar mobility challenges on the surfaces of these microgravity objects, and a precursor robot or an anchoring tool could provide additional capabilities to a manned mission in go-ahead and real time scenarios.

## II. Acknowledgments

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Fig. 3. The LEMUR IIB robot [6] hanging by a single microspine anchor on a vertical vesicular basalt wall (total weight of 130 N). A robotic ankle allows the robot to engage and disengage the gripper.

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