Material Testing for Robotic Omnidirectional Anchor
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Abstract - To successfully explore near-Earth Asteroids the question of mobility emerges as the key issue for any robotic mission. When small bodies have extremely low escape velocities, traditional methods, such as wheels, would send the robot hurtling off of the asteroid’s surface. To solve this problem, JPL has developed an omni-directional anchoring mechanism for use in microgravity that utilizes microspine technology. These microspines are placed in circular arrays with 16 independent carriages biasing the surface of the rock. The asperities in the surface allow the gripper to hold nearly 150N in all directions. While the gripper has been proven successful on consolidated rocks, it had yet to be tested on a variety of other surfaces that are suspected to separate the large boulders on an asteroid. Since asteroid surfaces vary widely, from friable rocks to lose ponds of regolith, the gripper was tested in a large variety of materials such as, bonded pumice, sand, gravel, and loose rocks. The forces are applied tangent, at 45 degrees, and normal to the surface of the material. The immediate results from this experiment will give insight into the gripper’s effectiveness across the wide spectrum of materials found on asteroids.

I. Introduction

A. Background

Over the past decade asteroids have increasingly become a subject of interest for future space missions. Asteroids are thought to be ideal targets for scientific exploration and experimentation. It is believed that asteroids are remnants from the beginning of the solar system that have remained untouched throughout time. This means that asteroids have some of the most primitive materials in the solar system because that they have not experienced the massive pressure and temperature transformations that planets and moons do. A sample from one of these bodies would give scientists insight into how the universe was formed.

Thus far, exploration of Near-Earth Asteroids (NEOs) has been primarily limited to observation from orbiting satellites, with the most recent being DAWN, which has photographed the two asteroids Vesta and Ceres. Landing a robotic probe would provide valuable scientific information about the composition of these astronomical bodies. This would be essential for any future manned missions or missions that plan on returning an asteroid to Earth orbit.
B. Motivation

With such a large interest in asteroids, the question of mobility arises as a key issue. The small masses of NEOs mean that the gravity forces are almost non-existent. As a result, the escape velocities on these bodies can be lower than 10 cm/s [1], which make traditional wheeled and legged mobility to dangerous. Therefore, the need arises for a system that can safely anchor a rover in microgravity. This anchoring mechanism must be able to support a load in all directions to resist the inertial forces of a moving robot.

To address these current issues, JPL has developed microspine end-effectors that can be integrated into robotic platforms. These grippers also have the potential for applications beyond the use in microgravity. For example, a robot equipped with these microspine grippers could be used to scale steep cliffs on mars that are inaccessible to wheeled rovers. It could also be used in terrestrial applications, such as, in search and rescue of hazardous situations or for the exploration of complex cave networks.

C. Microspine Grippers

Over the past two years, the omnidirectional microspine gripper has been in development at JPL. The gripper consists of 16 carriages in a circular array around a central housing. Torsion springs bias these carriages onto a rock surface. This circular arrangement allows it to hold loads in all directions. This is an improvement to previous versions of lightweight robots such as, RISE and Spinybot, which had microspine toes orientated in the same direction. This design limited their mobility and they could only support vertical loads. [2].

On the new gripper, each carriage is equipped with microspine toes. These toes are created using a manufacturing technique called Shape Deposition Manufacturing (SDM). SDM is an iterative casting technique that enables the creation of multi-material parts with embedded components. The toes have a rigid frame with embedded hooks. When the carriage is dragged across the rock surface the flexures in the toes allow each one to independently comply with the surface. The Steel hooks engage asperities in the rock and allow the gripper to handle load in all directions. The grippers have been integrated into the robotic platform LEMUR IIb and the robot has successfully climbed a vertical rock wall.

II. Objectives

While the grippers can establish a hold on consolidated rocks, it has yet to be tested on other materials. Asteroids are a collection of loose material being held together by its
own gravity forces. This material consists of a variety of materials ranging from large boulders to ponds of regolith. The anchor operates well on the consolidated rocks but it is unclear how well it can traverse the material separating large boulders. The goal is to test the gripper in materials expected on asteroids.

A. Testing Material

Thus far, not much is known about the structure and composition of asteroids. Limited reconnaissance from orbiters has shown that asteroids vary significantly from one another. While no two asteroids are alike, similarities relating to the surface qualities have appeared. Most asteroids are shown to have large rocks separated by loose soil and debris. The recent comet landing from Deep Impact reveals that the particles resemble a weak spongy material and that you could dig through with just your hands [3]. At JPL, a simulant was created using water and pumice to resemble the weak surface properties. What this material consists of is unclear since no samples have been taken. To illuminate any doubts with the gripper’s performance, a wide spectrum of materials have been selected for testing. The list of test materials consist of, bonded pumice, loose lava rocks, pea gravel, sand, Bishop Tuff, saddleback basalt, vesicular basalt, and volcanic breccia. The anchors will be tested to see whether a grip can be established on the test material.

B. Material Test bed

A material test bed was designed to accurately and objectively test the gripping strength of the test materials. To begin a test, the gripper engages the test material, then a cable attached to the gripper runs through pulleys to a winch. The winch slowly increases the force applied to the cable until the gripper slips or is released from the rock. A digital force gauge with data logger is used to measure the maximum force
and to analyze the process as the gripper engages the material. The Pulleys on the test bed can be positioned so that the force on the gripper is applied normal to, and 45 degrees to, and tangent to the material’s surface. A pivot system was designed to apply the loads where the ankle meets the housing. This system pivots on bearing allowing it to move in all directions. The extra degree of freedom minimizes torques and moments on the gripper. Testing in multiple directions will show if the anchor is omnidirectional for all surfaces.

III. Results

Testing the materials showed how well the gripper performed on materials found on an asteroid’s surface. The loose materials performed far worse than the consolidated rocks. In all three directions (normal, tangential, 45 degree angle) the loose material could barely support the weight of the gripper. The bonded pumice, lava rock, pea gravel, and sand could only handle an average load of no more than 5.15 pounds normal and only 2.2 pounds at a 45 degree angle. The bonded pumice could support an average tangential load of nearly 10 pounds while the other loose materials could only support 2 pounds. This data includes the weight from the gripper and all frictional forces. This results in a loss of accuracy and all the data will be up to 4 pounds lighter.

Of the four consolidated rocks, the vesicular basalt supported the largest force in each direction. On average, the vesicular basalt was able to support over 60 pounds of force in the tangential direction. The volcanic breccia performed the second best being able to support 36 pounds tangentially. The saddleback basalt was the worst, being able to only hold 7.2 pounds in the normal direction.

Figure 4. Gripper normal force test on Vesicular Basalt
As expected, the gripper performed very well on consolidated rock surfaces with a large number of asperities. The rocks such as the vesicular basalt, volcanic breccia, and the Bishop Tuff were all able to hold a substantial force before disengagement. Smooth rocks, such as the saddleback basalt, were unable to support the same load because it lacked the necessary asperities to establish grip. While the gripper could anchor on consolidated rocks reliably, it could only hold very small forces on loose materials. When dealing in microgravity only small forces are needed to anchor safely. This means that the small forces from the loose material could be enough to keep a robot firmly anchored on a foreign body.
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References

