Design and Use of the Cold Operable Lunar Deployable Arm End Effector for Geotechnical Investigations.

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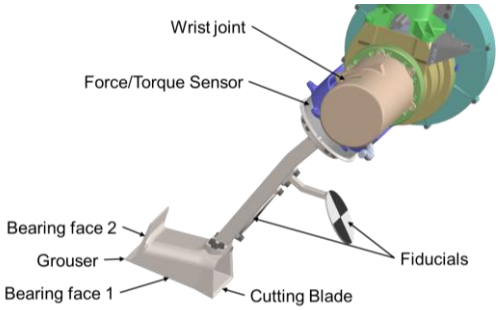

Figure 1. COLDArm end effector

Introduction: The Cold Operable Lunar Deployable Arm (COLDArm) is a Lunar technology demonstrator project that consists of a 4 Degree-of-Freedom (DOF) robotic arm developed in partnership with Motiv Space Systems and a geotechnical end effector designed by JPL [1]. The primary technology demonstration goals of the project are to use the arm and end effector to perform basic excavation and geotechnical surface interactions in the lunar regolith to characterize its properties at a previously untested, far-side, high-latitude location and to validate the operation of the novel actuators and motion control electronics at cryogenic temperatures. The data from the geotechnical interactions can be used to inform models of regolith terramechanics (important for landers, rovers, and human explorers), and processability (important for in-situ resource utilization purposes) in support of future missions. The project is funded by the Lunar Surface Innovation Imitative (LSII) and is currently targeting a 2024 mission aboard a Commercial Lunar Payload Services (CLPS) lander.

End Effector: The end effector, shown in Figure 1, consists of a six-axis force torque (F/T) sensor and scoop mounted at the end of the robotic arm. The robotic arm can control the translation and pitch degrees of freedom of the end effector. The F/T sensor is mounted immediately distal to the wrist joint of the arm and can resolve the combined forces and moments applied to the end effector. The scoop is designed to perform both excavation and geotechnical tests. It incorporates a cutting blade and bucket for excavation, a large flat face for pressure-sinkage (bearing plate) tests, and a small flat face (approximately half the area of the larger face) with a grouser like feature extending out from it for both pressure-sinkage and shear tests. Lastly the end effector includes two fiducials that may be tracked by a stereo camera aboard the lander to measure its position accurately to support the geotechnical tests.

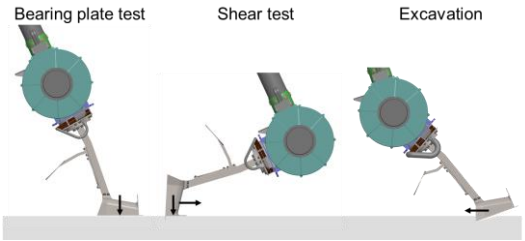

Figure 2. Geotechnical tests using the end effector

Geotechnical investigations: We have identified a number of operations that can be performed by the robotic arm and end effector to collect data that may be used to estimate various geotechnical properties of the regolith as shown in Figure 2. First, we propose to perform a pressure-sinkage test by pressing bearing face 1 of the end effector into the regolith with the robotic arm while measuring the applied force with the F/T sensor and displacement with the camera and fiducials. The pressure-singkage test may be repeated with bearing face 2 to act as a second length-scale dependent measurement or to increase the applied ground pressure within the force producing capabilities of the arm. Next, we propose to perform a shear measurement by applying a quasi-constant vertical pressure followed by commanding lateral shearing motions with bearing face 2 and the grouser. Loads and displacements are measured continuously during the tests. The force displacement data collected during these tests in the lunar regolith may be correlated to standard geotechnical properties through laboratory testing.

Since the end effector will also be able to perform limited excavation, we anticipate that it may be able to perform other opportunistic geotechnical investigations including measuring the forces required during excavation, monitoring how the excavation forces change with depth, observing the angle of repose of a pile of excavated material, and performing slope failure tests next to an excavation trench and observing the failure of the side of the hole.

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References: [1] McCormick et al. (2020) LEAG