LUNAR REGOLITH: SMALL SCALE ROBOTIC SITE PREPARATION AND GEOTECHNICAL EXPERIMENTS WITH SCOOPS

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Introduction: NASA's Moon-To-Mars Planetary Autonomous Construction Technology (MMPACT) project seeks to research, develop, and demonstrate lunar surface construction capabilities. Quantification of lunar regolith's geotechnical properties allows for effective prediction of forces and displacement during excavation and construction and is critical to facilitating regolith sintering capabilities all of which benefit lunar infrastructure plans. Knowledge of shear strength, Mohr-Coulomb cohesion, angle of internal friction, bearing strength, bulk density, etc. is needed. The use of ground-based testing of various lunar simulants with relevant hardware (e.g., robotic arm tools) enables validation of technology choices, tool paths, and lunar surface construction activities. In addition, the use of Taguchi methods [1] will minimize the number of needed experiments to explore critical input parameters.

Investigations:
The following set of experiments in lunar regolith simulant are proposed for finding the desired geotechnical parameters using various mounted plates, sensors, and scoops on the end of a Universal Robotics (UR)-10 robotic arm. Each is to be completed with three density scenarios per simulant: at bulk density, at an average density between the min and max, and at the max density:

- Site Preparation for Regolith Microwave Sintering

Action: A 2' by 2' pad will be built up with four 1" layers by excavating adjacent material, sorting it, and depositing it on the pad site. A topography scan will be completed after each layer is deposited to measure volume, after which fine grading, compacting, and sintering will occur.
Inputs: VS (Scoop Volume), nS (Number of Scoops)
Outputs: VL (Layer Volume), ρL (Layer Density)

- Pressure-Sinkage Test

Action: Slowly press down normal to regolith surface with bearing plate until desired or max allowable force (or max allowable displacement) is reached.
Inputs: P (Applied Pressure), b (Plate Width)
Outputs: z (Vertical Displacement)

- Shearing Test

Action: Slowly press down normal to regolith surface with bearing plate with grouser until desired load is reached, then translate horizontally by a set distance.
Inputs: A (Shearing Plate Area), σ n (Applied Normal Load)
Outputs: τs (Shear Stress at Failure)

- Excavation Test

Action: Approach regolith surface with scoop at desired rake angle, then vertically translate scoop cutting edge down into the regolith to the desired depth. Translate the scoop horizontally as needed (dependent on scoop depth & rake angle) then rotate up to collect sample.
Inputs: β (Rake Angle), DT (Trench Depth), LT (Trench Length)
Outputs: LS (Surface Excavation Length), Ft (Tip Force), Tt (Tip Torque)

- Angle of Repose Test (Figure 7.)

Action: Excavate desired volume of regolith then translate scoop diagonally over above a flat surface. Slowly angle the scoop to dump contents onto the surface at a relatively constant rate, creating a pile.
Inputs: V (Sample Volume), nS (Number of Scoops), dd (Drop Distance)
Outputs: rp (Pile Radius), hp (Pile Height)

The design of these experiments in a mission context will be discussed as it relates to a planned lunar Commercial Lunar Payload Services (CLPS) lander technology demonstration for sintering a small 2' x 2' area on the actual lunar surface to prove feasibility of horizontal construction with consolidation of the regolith granular materials by microwave sintering.

References

[1] Taguchi G. (1987) Methods to Optimize Quality & Minimize Costs.
[2] Long-Fox et al. (2022), 18th Biennial ASCE Earth & Space Conference, (In Review)
[3] He et al. (2013), Journal of Aerospace Engineering, 26(3)
[4] Suescun-Florez et al. (2015), Journal of Aerospace Engineering, 28(5)

[5] Bernstein R.S. (1913), Der Motorwagen, 16, pp. 199-206.
[6] Reece A.R. (1965), Proceedings of the Institution of Mech. Eng., 180(1), pp. 45-66.
[7] Bekker M.G. (1969) Michigan Publishing, 1st ed., University of Michigan
[8] Hettiaratchi, D.R.P., & Reece, A.R. (1974) Geotechnique, 24(3), pp. 289-310.
[9] Luengo et al. (1998) IEEE/RSJ International Conf. on Intelligent Robotic Systems