Mobile Platform Prototype for Solar Sintering Regolith Roads. Cameron Hinkle[1], Matthew Carcia[1], Trevor Maybach[1], Aidan Staszak[1], Charlie Yuroff[1], Alan Carter[2], Andrew Brewer[1], and Frances Zhu[1], [1]Department of Mechanical Engineering, Colorado School of Mines, Golden, CO, USA (cameronhinkle@mines.edu), [2]Outward Technologies, Broomfield, CO, USA (abrewer@outward.tech).

Motivation: Lunar regolith is highly abrasive and poses significant risks to astronauts and equipment, tending to stick to materials, cause severe abrasion, or wear down and puncture materials. There is a need for hardened infrastructure to support lunar habitation, such as roads and landing pads. The Sintering Of Lunar Aggregate for Roads (S.O.L.A.R) senior design project aims to provide a method of robotic in-situ lunar regolith sintering into flattened, hardened surfaces for use in lunar infrastructure.

Scope and Operational Objectives: This project aims to design, develop, and validate a rover-based prototype capable of creating durable, sintered road surfaces from lunar regolith by utilizing concentrated solar energy. This system delivers the capability for in-situ resource utilization infrastructure to mitigate the hazards posed by the abrasiveness of lunar regolith. Due to this project being a prototype to validate an end-to-end system, full flight operations were not considered.

Operational Environment and Assumptions. This prototype is designed to operate in a terrestrial laboratory or outdoor testbed environment, utilizing lunar regolith simulants CSM-LHT-1 and CSM-LMT-1 to replicate lunar highland and mare mechanical and thermal behavior. Although the prototype operates under Earth gravity and atmospheric conditions, the fundamental sintering and compaction core of this project is demonstrative of a future design for lunar conditions.

The following assumptions bound the operational scope of this prototype phase:

- The system is designed to demonstrate end-to-end performance on Earth.
- Lunar gravity effects are explicitly excluded from this prototype.
- The testing environment is assumed to be free of large obstacles, such as rocks and craters, that would impede traversal or terrain preparation.
- It is assumed that successful completion of all performance objectives in a terrestrial environment is sufficient to demonstrate feasibility for lunar deployment with targeted modifications.

System Architecture: The mobile robot platform integrates several subsystems to accomplish its technology demonstration. The S.O.L.A.R. system is mounted onto a 6U CubeRover mobile research robotics platform [1].

Arm & Sinter. The Arm and Sinter subsystem utilizes a 6-Degree-of-Freedom (6DOF) Kinova Gen2 robotic arm mounted on top of the rover chassis. The robotic arm maneuvers a custom end-effector that holds a Fresnel lens to concentrate solar flux onto a prepared section of the lunar surface.

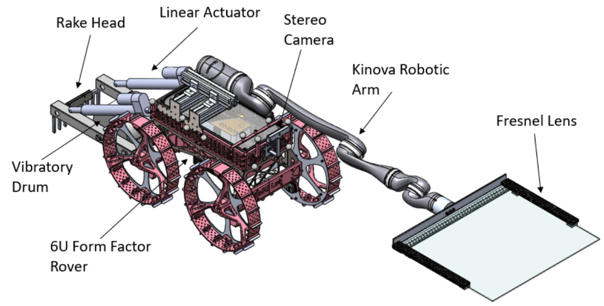

Figure 1: CAD Rendering of System Architecture. Demonstrates the Spatial Representation of the Sintering Prototype.

The control system utilizes ROS2 MoveIt Pro on Humble Hawksbill to perform behavior tree actions, along with calculating inverse kinematic solutions [2]. Discrete feedback is given after hatch patterns to refocus the sintering spot, utilizing a LiDAR ranging sensor and a 16MP camera to set focal point distance and orientation, respectively.

Excavator Blade. The Excavator subsystem utilizes a rake and roller combination to prepare the surface for sintering in a single pass. Preparing the surface consists of compacting and leveling the regolith. Compaction before sintering has been shown to increase post-sintering density, leading to a higher-quality road. Leveling is critical because the surface geometry remains fixed after sintering, and in order for the road to be sufficiently beneficial it must be easily traversable.

The rake, attached at the front end of the rover, distributes the regolith to improve material workability. The roller, following the rake, is attached to the rover via a frame and two linear actuators. The linear actuators apply additional downward compression force to the surface. In addition, they default to a partially extended position, allowing the roller to be lifted off the ground and allowing for a stowed position. A vibratory motor located inside the roller further improves regolith packing density.

Monitor Suite. The Monitor Suite consists of a comprehensive sensor package for quality verification. This includes a two-color pyrometer for melt-pool temperature readings, a stereo camera to evaluate surface roughness, a cone penetrometer for soil compactness, and a load cell for compressive testing of completed sintered segments.

Scope of Testing and System ConOps: The Concept of Operations defines the end-to-end mission profile governing the rover's autonomous execution of terrain preparation, solar sintering, and quality verification. Each phase of the process feeds directly into the next, allowing for reliable road construction from lunar regolith simulant.

The core operational requirements governing this mission are:

- **Terrain Preparation:** The system must doze and level surface regolith to compact it evenly to allow for effective sintering.
- **Sintering:** The system autonomously tracks the sun and concentrates solar flux via Fresnel lens to thermally melt regolith.
- **Quality Assessment:** Post-sintering verification of road structural integrity and surface uniformity are performed using load cells, stereo camera mapping, and pyrometer imaging.

Preliminary Testing / Results: Preliminary testing for the Arm and Sinter subsystem consisted of an initial proof-of-concept stationary prototype. This prototype was designed to allow for manual adjustments in order to evaluate the ideal lens focal length and melt spot size, as well as to identify parameters that produced the most promising sintered results. Tests demonstrated the rapid onset of sintering under favorable solar flux, verifying the system is capable of reaching the 1300°C-1500°C required for melting regolith[3]. Further control system tests were conducted to verify the control system policy, proving that the arm can provide control up to 0.05° in roll, pitch, and yaw axes.

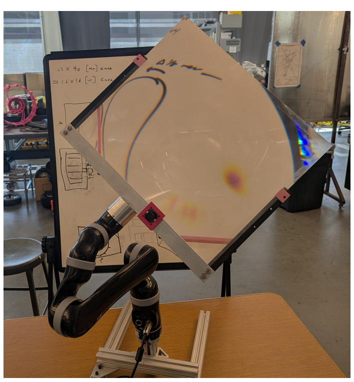

Figure 2: Final Lens Design Mounted as an End-Effector on the Kinova 6DOF Arm.

The preliminary testing for the Excavator subsystem and regolith compaction was performed using an isolated rake and a vibratory roller subassembly. Tests with and without the vibratory roller were conducted to quantify the effectiveness of vibration on regolith compaction. Preliminary results showed a 40% increase in compaction and an average increase of 7 mm of compaction depth when utilizing a vibratory motor compared to without. Additionally, Proctor soil compaction tests were performed on the regolith simulant to develop an energy-versus-density correlation that will be used to determine roller compaction during operation.

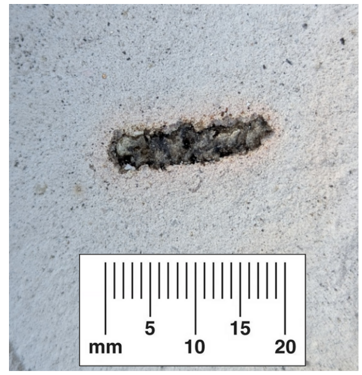

Figure 3: Sintered Glassy Regolith from Preliminary Testing.

Conclusion / Future Work: The preliminary prototype confirms the mechanical, thermal, and control feasibility of a mobile solar sintering platform. The immediate focus is full system integration onto a 6U CubeRover chassis. When full system integration is complete, further system tests will be conducted to characterize full system performance and feasibility. The team has identified several areas of future work, which include:

- Development of flight system Concept of Operations for a mobile base sintering system.
- Reflection of concentrated solar energy to improve the angle of incidence during a flight scenario.
- Define specific load values to verify via monitor suite subsystem for use during lunar missions.

Acknowledgments: The team would like to give special acknowledgment to:

- The additional senior design team members: Brian Durland, Estevan Gonzalez, Taylor Wood, Simon Igel, Neel Jasti, and Owen Jeffocat for contributing their time and ideas towards the success of this project.
- Outward Technologies for providing the senior design team with engineering mentorship and funds to prototype this project.
- Greg Proulx for providing mentorship to the team as Project Advisor.

References: [1] B. H. et al. (2025) *iSpaRo*. [2] Picknik Robotics (2024) *MoveIt Pro*. [3] Y. L. et al. (2025) *AGS*, 75, 779-789.