ASPECT

AUTONOMOUS SITE PREPARATION: EXCAVATION, COMPACTION, AND TESTING

LSIC Excavation & Construction Meeting
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Team

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Neil Dantam – Autonomy and Planning
Jamal Rostami – Regolith Manipulation
Kevin Cannon – Simulated Lunar Surface
George Sowers – Infusion

Paul van Susante – Compaction
AJ Gemer – Mobility Platform
Justin Cyrus and Joe Kendrick
Ann Esbeck – Terrestrial Experience

NASA Glenn Research Center
Phil Abel – NASA Technical Officer
ASPECT - AUTONOMOUS SITE PREPARATION: EXCAVATION, COMPACTION, AND TESTING

Project Summary

*Develop a push-button autonomous real-time task-to-motion planning vehicle capable of preparing a lunar surface for landing pad construction. Testing and verify performance in a 10 m diameter testbed with an 83 kg vehicle which represents a 500 kg vehicle on the Moon. Tasks are to compact the surface to 90% relative density, move rocks, grade, and fill craters.*

Anticipated Outcomes

- Demonstration of site preparation in a lunar relevant test environment.
- Demonstration of sustained autonomous task and motion planning.
- Site preparation time per area.
- Infusion plan to put the ASPECT solution on a path to flight.
LuSTR Requirements

- Terrestrial rover mass to be ≤ 83kg.
  - 1g reaction forces = reaction forces of 500 kg rover on the Moon
- Demonstrate site preparation of a 10m diameter and up to 1m deep simulated lunar surface
  - LuSTR prescribes the start and end states:
    - Starting state: # of and size of craters, # and size of rocks, slope to be leveled
    - End state: over the 10 m dia. level to <1°, <1 cm RMS, 90% relative density.
Inherent challenges of site preparation on the Moon ...and solutions we are investigating

• Low lunar gravity reduces available reaction mass
  – Minimize regolith movement
  – Carefully manage cutting and traction forces
  – Move only loose, low density, regolith

• Autonomy is necessary
  – Site preparation occurs before human arrival
  – Not to use teleoperation
  – Anticipate a series of individual steps

Image Credit NASA
ASPECT LuSTR Testbed

- In Earth Mechanics Institute on campus
- Area > 100 m²
- Dust enclosure and mitigation
- Simulant: variant of CSM-LHT-1, based on Greenspar anorthosite
- Rocks: pumice for low mass simulation
Estimation and Execution Integration

- **Survey**
- **Site Prepared?**
  - **Yes**: Finish
  - **No**: Task Planning
- **Task Planning**
- **Motion Feasibility Constraints**
- **Finite Horizon Motion Plan**
- **Local Replanning**
- **Control & Estimation**

**Task Categories**
- **Move Rocks**
  - remove from site
- **Move Regolith**
  - fill craters
  - move to/from site
- **Compact**
  - craters
  - shallow surface
- **Charge**
  - Traverse to charging station
- **Smooth**
  - finishing step

**Assess site preparedness**
Visual SLAM for Rover Navigation

• Navigation challenges on moon
  – No existing navigation infrastructure
  – Regolith and lower gravity cause wheel slip

• Visual SLAM
  – Perception: Leverage distinct rocks as static lunar landmarks
    • Use color segmentation in RGB image to identify rocks
    • Use depth measurement to compute 3D position of rocks
  – State estimation: Get pose of rover and rocks concurrently using EKS (Extended Kalman Smoother)
    • Estimate and compensate for rover wheel slip using slip dynamics model
Visual SLAM for Rover Navigation

• Navigation test setup
  – Teleoperated Clearpath Husky rover with Intel RealSense L515 Lidar sensor
  – Regolith simulant chamber with rocks

• State estimation test
  – Fixed ArUco tags used as ground-truth for known trajectory
  – Successfully recovered trajectory and estimate rock landmark positions using visual SLAM

• Future work
  – Autonomous navigation using visual SLAM. Implement rock detection measurement model into estimation framework
A Task and Motion Planning Approach

**Task Planning**
- What are the high-level actions or steps?
- Approaches: search, constraint-satisfaction.

**Motion Planning**
- What are the paths to execute each task action?
- Approaches: search, sampling, optimization

[Diagram showing symbolic and geometric task and motion planning approaches with candidate task plan and incremental constraints.]
Task Planning

Planning Domain

Symbolic Planner

Task Plan
Developing a visualization to verify planning

Actual surface map will be imported into the visualizer and planner
Vehicle Chassis and Mobility Platform

Frame/Structure Subsystem
- Load bearing frame
- Electronics Box enclosure
- Outer Body Enclosure
- Light weighting using carbon fiber

Mobility Subsystem
- Drivetrains x 4
  - Motors, gearboxes, driveshafts

Payloads Mounts
- Structural mounting points at either end
Regolith Manipulation Tools

• One bucket does it all
  – Base principle: only move loose regolith
  – Multi-purpose bucket – regolith manipulation, grading, and rock removal that minimizes forces through vibration
  – Articulate the bucket to
    • Push regolith and rock – Blade vertical, forward drive
    • Lift regolith and rock – Blade low, forward drive and lift
    • Smooth – Blade low, rearward drive
    • Rip – Blade negative rotation, rearward drive

• Bucket and wheels designed together
  • Careful management of cutting/traction forces
Dozer Blade Testing

Cutting force vs. time for five sequential cuts with cut depth from 3 to 8 mm. Each cut covered a distance of 80 cm.

Results are generally in agreement with Balovnev Blade analysis.

- Mass Pushed: 15.5 kg  
  Density: 1.76 g/cc
- Mass Pushed: 12.8 kg  
  Density: 1.92 g/cc
- Mass Pushed: 7.4 kg  
  Density: 1.875 g/cc
- Mass Pushed: 6.3 kg  
  Density: 1.72 g/cc
- Mass Pushed: 6.7 kg  
  Density: 1.85 g/cc
Rock Pushing

Tests show that pushing force is < 40 N for even largest rock (30cm).

Pushing force for each of the rocks tested, with rock masses of 318 g, 2.29 kg, and 3.65 kg.

Pumice rock, approx. 0.8 g/cc density

“Small” 318 g rock

“Medium”, 2.29 kg rock

“Large”, 30 cm rock, 3.65 kg

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Wheel Testing

- Wheel test rig designed to characterize drawbar pull and slippage
- 4-bar linkage allows vertical compliance

Drawbar pull testing
- 68N/wheel w/ 20.75 kg load/wheel at 14.4% slip, 5 cm/s
- Good agreement with terramechanics model (Bekker)

With baseline wheel, a 4-wheel vehicle can pull 272 N, which exceeds maximum bucket loading
• 90% relative density naturally reached between 20-37 cm depth.

• Need to compact top 20-30 cm – estimated pressure 100 kPa
  – Based on compressibility measurements of lunar samples at 90% rel. den.
Compaction Development

Multi-pin and single pin testing

LuSTR Compactor Design

Lunar Infusion Compactor Design

Compaction development progression
Testing Single Pin in Cylinders

<table>
<thead>
<tr>
<th>Starting Compaction Relative Density</th>
<th>Achieved Compaction Lower Bound</th>
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<tbody>
<tr>
<td>49.22%</td>
<td>64.87%</td>
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<tr>
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<td>17.54%</td>
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<tr>
<td>17.49%</td>
<td>57.68%</td>
</tr>
</tbody>
</table>

- Investigating the parameter space – frequency (10’s of Hz), dwell time, sequencing, plate pressure (~15 kPa)
Infusion

- Human lander scale site preparation
- Size up to 100 m diameter landing pad
- Support and ancillary equipment
- Path to flight
Thank you!

Questions?

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