Modelling, breadboarding and experiments for planetary environment representative interaction investigation

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Modeling and **laboratory breadboarding** are key drivers for TRL enhancement in planetary exploration. This work (Task 1.4.2) articulates on parallel research lines supporting **in-situ science**, including: high-fidelity numerical modeling of **interaction with non-cohesive soils**; validated **synthetic image generation** for autonomous landing GNC; breadboarding of **anchoring** solutions; and miniaturized **soil sampling** mechanisms.

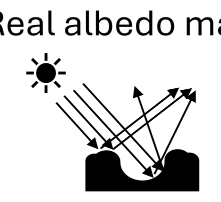
Physically-Based Synthetic Data Generation for Planetary Landing[2]

MOTIVATION AND OBJECTIVES

To address the scarcity of high-resolution datasets required for **training Vision-Based Navigation** algorithms, a **rendering pipeline** based on Blender and its Cycles engine is developed. The tool overcomes the **resolution limits** of orbital Digital Elevation Models (DEMs) through a **multi-stage enhancement** process and reproduces the lunar environment with **high physical accuracy**.

METHODS

Custom Hapke BRDF model & Real albedo maps



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DEM enhancement:
- Diamond-Square (DS) **upsampling**
- **Fractal noise** modelling (SRA)
- **Artifacts** (craters and boulders) addition

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Open-source rendering pipeline in Blender + Cycles (**python API**)

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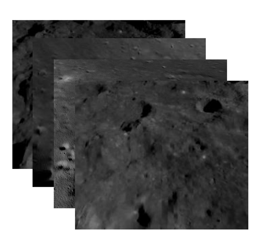
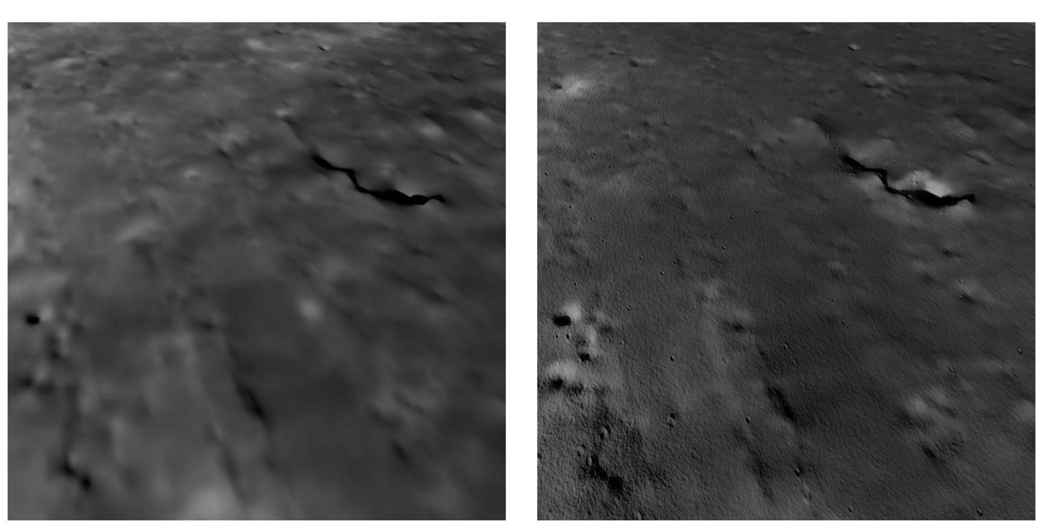
Versatile, reproducible, realistic planetary surface renderer



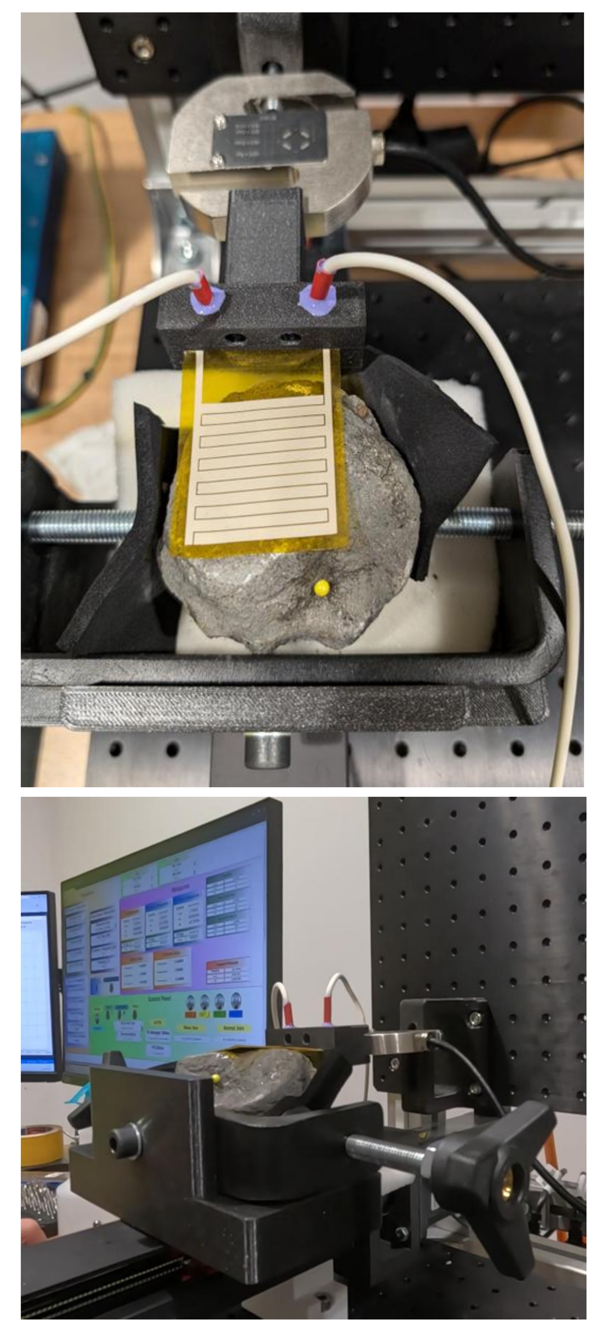
RESULTS



Original (left) vs enhanced (right) DEM rendering at 2 km from the surface.

- ❑ **Upsampling from** original **120 m/px** resolution **to 1.9 m/px**
- ❑ Camera: pinhole, 1024x1024 px, 60° FOV
- ❑ Enhancement **removes smoothness**, **blur** and **artifacts**
- ❑ Higher **morphological fidelity**
- ❑ **Fine-scale** surface **roughness** and features

Electro-Adhesive Anchoring: Experimental Testing on Regolith Simulant[3]



Top and side view of Adaptronics' experimental setup.

MOTIVATION AND OBJECTIVES

- **Electro-adhesion** represents an innovative anchoring strategy for the robotic exploration of asteroids and comets.
- This work *experimentally* evaluates the **effectiveness** of the electro-adhesive technology developed by Adaptronics onto a **regolith simulant rock.**

METHODS

Adaptronics' experimental setup (*see pictures*) allows to measure the **maximum shear force** acting on the electro-adhesive pad, a key performance index of electro-adhesion.

1. The electro-adhesive pad is placed onto a *flat area* of the regolith simulant rock and attached to a **load cell**.
2. The rock is clamped and *gradually moves away* from the pad thanks to a **mechanical linear axis**.
3. The load cell measures the shear force acting on the pad **until slippage**.

KEY FINDINGS

- Adaptronics' electro-adhesive pads **are effective** on regolith simulant.
- **Surface roughness** significantly **penalizes** the achievable attractive force.

CONCLUSION

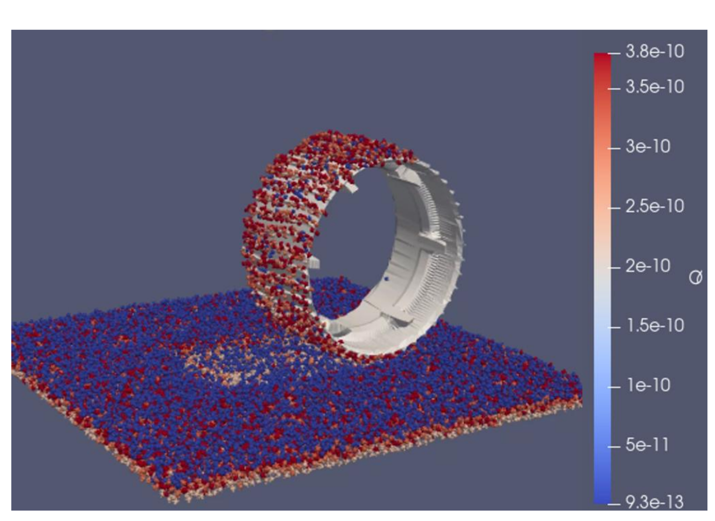
Electro-adhesion can be a **promising anchoring strategy** for small bodies; however, **to achieve high performance, an optimized and compliant device is required**, capable of conforming to rough and uncertain surfaces, such as regolith rocks.

From Environment Modelling to System Breadboarding[1]

MOTIVATION AND OBJECTIVES

Planetary environment modelling enables the simulation of how **external objects interact with the surface and with regolith** under representative conditions.
Multi-physics DEM based approaches allow the investigation of regolith interaction behavior by accounting for mechanical, thermal and electrostatic effects.

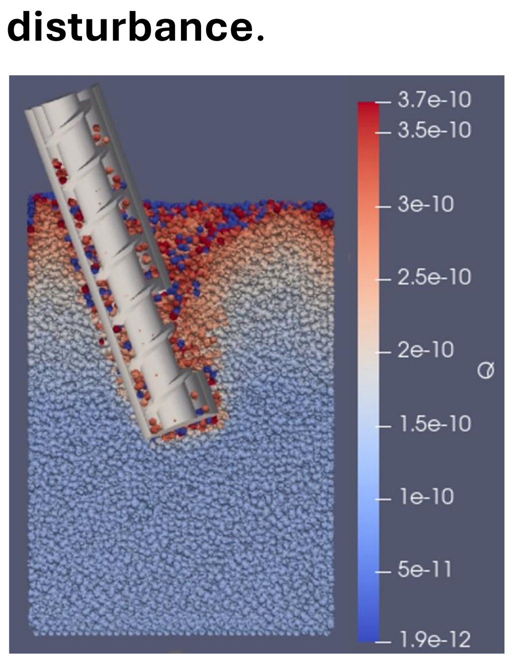
Environment–system interaction simulations are used to:
- ❑ Support **mission and system design**
- ❑ Anticipate surface interaction effects
- ❑ Define representative and reliable **breadboard configurations**



APPLICATION: Miniaturized drilling and sampling system

A conveyor-based drilling and sampling system has been developed for **small lander platforms** operating on non-cohesive, regolith-like materials.

- ❑ The system enables controlled regolith intake and transport while **minimizing reaction forces and surface disturbance**.
- ❑ The design was supported by numerical interaction analyses and validated through **breadboard implementation and experimental testing** in a high-fidelity planetary loose soil simulator.

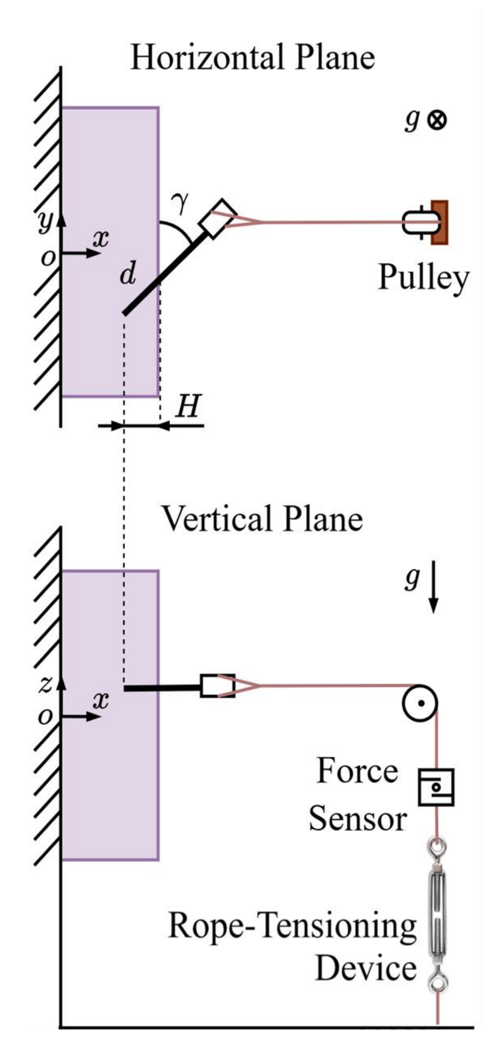


- ❑ Tests were performed to assess the influence of conveyor geometry and operational parameters.

Experimental Investigation of Anchoring Performance on Asteroid Analogs[4]

MOTIVATION AND OBJECTIVES

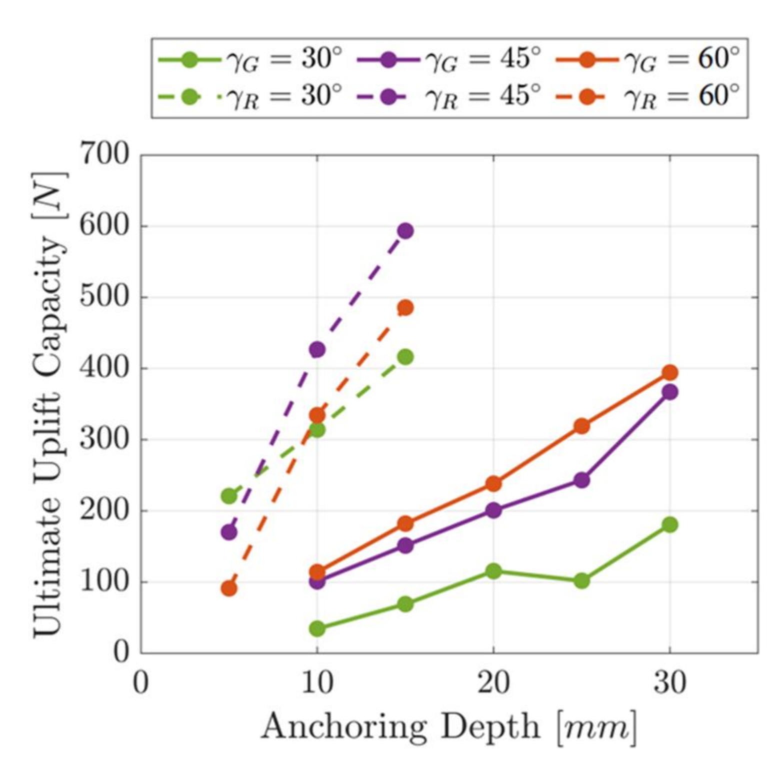
- Experimental characterization of the **ultimate uplift capacity (UUC)**,
- UUC = **maximum pullout force** sustainable by an ultrasonic/sonic driller/corer (USDC)
- Tests performed on **representative asteroid analogue materials**.



METHODS

Most asteroids fall into the Carbonaceous (C-type) and the Silicaceous (S-type) categories.

- **Material selection** (mechanical similarity):
  - **Gypsum**: representative of C-type asteroids
  - **Basaltic Stone** from Mount Etna: representative of S-type asteroids
- **Experimental Setup**:
  1. **Holes** are **drilled** in the material at **different depths** *d* **and angles**
  2. The **drill bit** (2,75 mm in diameter) is **inserted in** a **hole**, where it serves as the anchoring rod
  3. A **pullout** force perpendicular to the surface is **applied to** the **extract** the rod
  4. **UUC**: maximum force measured before failure



KEY FINDINGS

- UUC for **Gypsum** ranges from 35 N at a depth of 10 mm to 400 N at 30 mm, while for the **volcanic stone** it ranges from 100 N at 5 mm to 600 N at 15 mm.
- **Volcanic stone** provides **a larger UUC** thanks to its superior mechanical parameters, however, it is **harder to penetrate** this material.
- An **increasing trend** In UUC **with the anchoring depth** is observed for all anchoring angles.

QUESTIONS?
Scan for more information or to contact the authors directly