Digging on the Moon with differentiable programming:
A pathway to advanced lunar robotic construction

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Abstract: NASA's Artemis program charts a bold new course for lunar exploration to establish a sustainable presence on the Moon. Success in this endeavor hinges on developing advanced robots capable of construction and resource utilization within the Moon's unique and challenging environment. Lunar soil, or regolith, behaves unpredictably, posing significant obstacles to traditional robotic systems. This project aims to revolutionize robotic capabilities for lunar construction, tackling the hurdles of low gravity, unpredictable soil, and the limitations of current technologies. The initiative seeks to enhance robotic learning and performance in these extraterrestrial environments by leveraging advanced differentiable simulation technologies and gradient based policy optimization.

The project aims to develop autonomous robotic systems optimized for in-situ resource utilization (ISRU). Addressing the challenges posed by the Moon's low gravity, the fluffy nature of lunar regolith at the South Pole, and the limited traction available for excavators, this research aims to create robust, efficient, and adaptive construction robots. Through the development of a differentiable digital twin and gradient-enhanced reinforcement learning (RL) algorithms, the project will enable these robots to intelligently navigate and manipulate the lunar surface's highly dynamic and unstructured terrain. The project innovatively uses video for material property inference by converting real-time lunar surface videos into 3D point clouds using Gaussian Splats, followed by employing differentiable rendering to iteratively refine these models, allowing for the accurate prediction of physical properties like Young's modulus and friction angles for lunar construction planning. This transformative approach supports the goals of the Artemis program. It lays the groundwork for future robotic exploration and construction in extreme environments, marking a significant advance in our capability to sustain human presence and activity on the Moon and beyond.