Toward Density-Aware Granular Loco-Manipulation for Obstacle-Aided Mobility on Steep Slopes

Parnia Shokri, Feifei Qian

Ming Hsieh Department of Electrical and Computer Engineering, University of Southern California

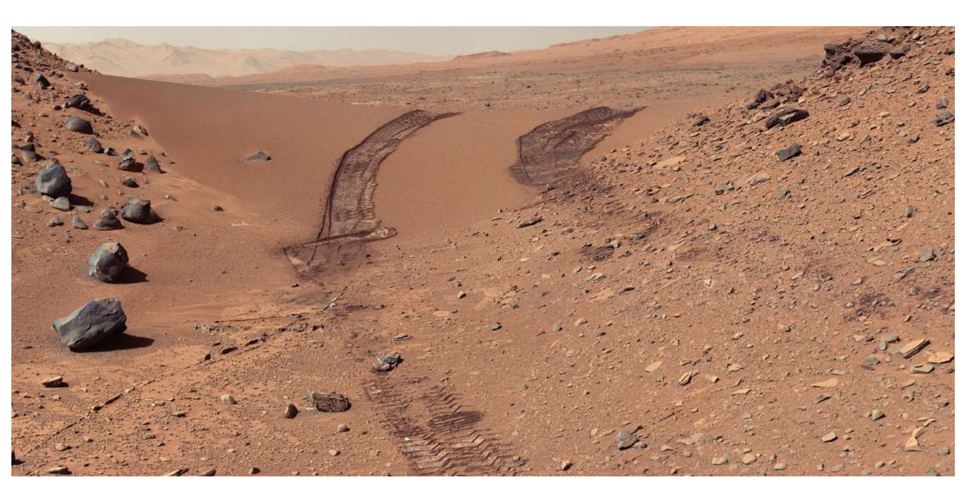
Summary

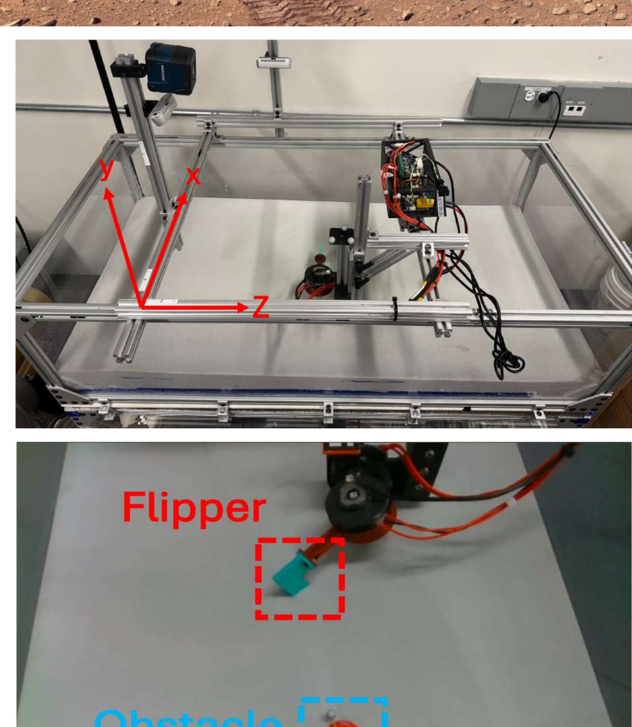
Robots on steep granular slopes may improve mobility by reshaping sand and repositioning obstacles, rather than only avoiding unstable terrain. Here, we test whether obstacle density changes how same-geometry objects respond to repeated robotic disturbance. Using a 2-DOF flipper on an inclined sandy slope, we find that light obstacles rise and move farther downslope, while dense obstacles sink and stabilize. These results motivate density-aware prediction and planning for granular loco-manipulation.

Granular Terrain as a Manipulable Environment

Robots on steep granular slopes face slip, sinkage, and loss of support. By reshaping sand and repositioning obstacles, they may create safer paths or useful supports.

However, obstacle response to external perturbation depends on their physical properties. Even with the same geometry, density can affect if an object rises, sinks, moves downslope, or stabilizes.

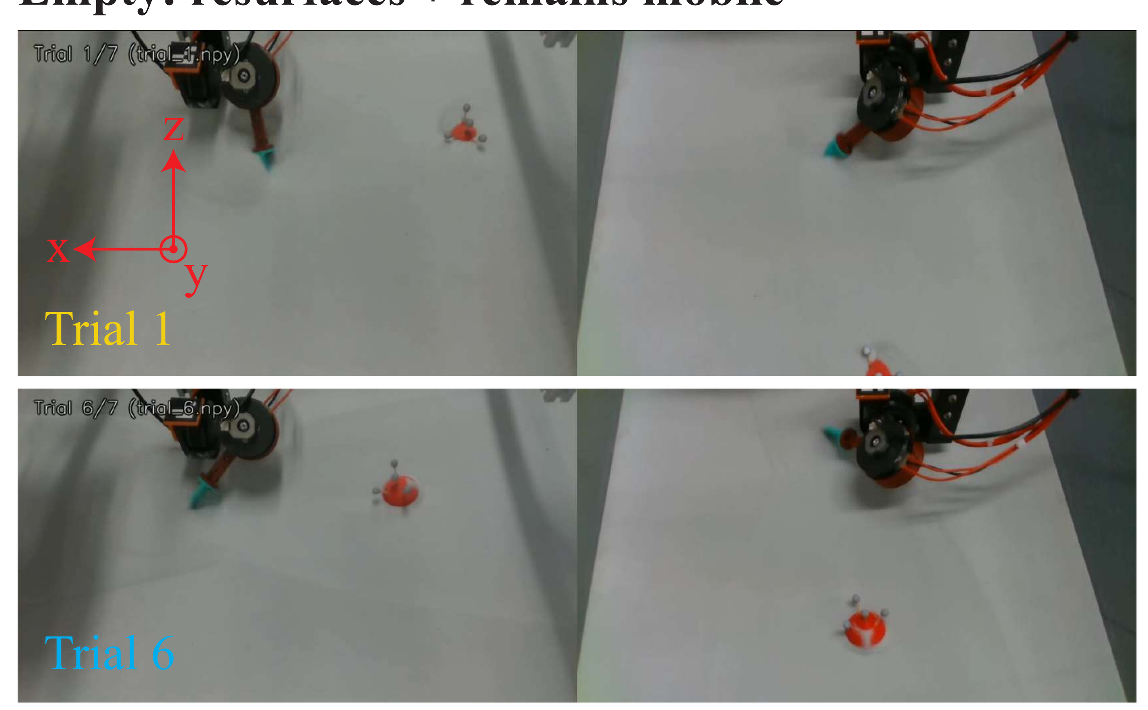


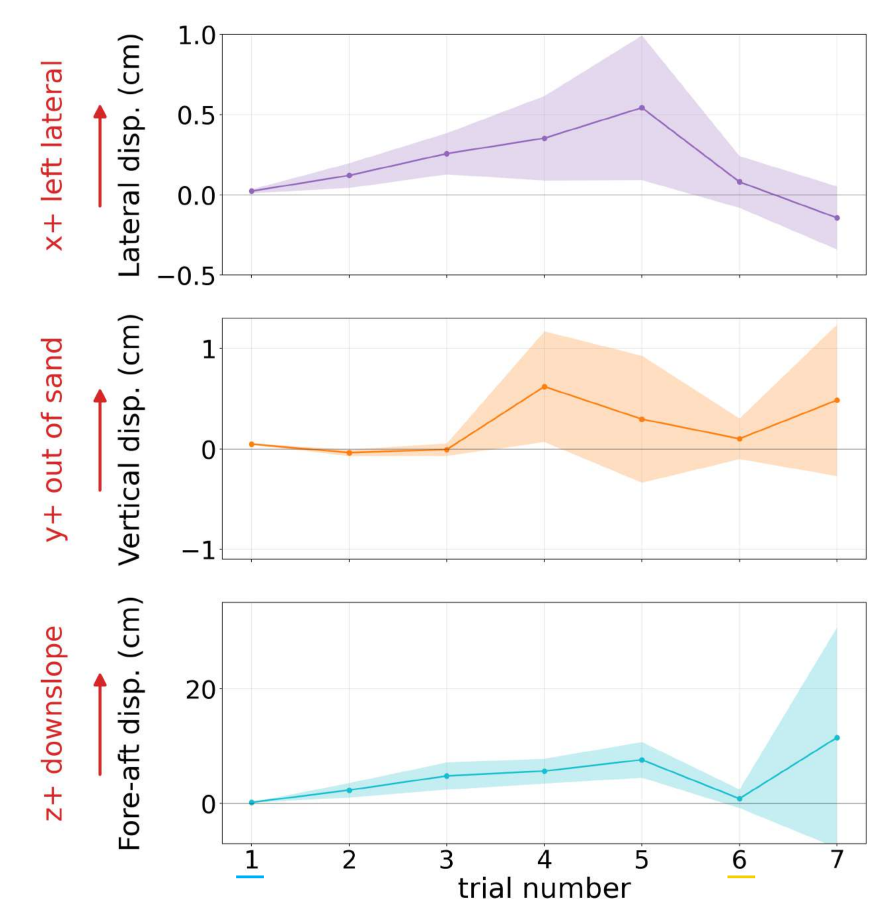


From field motivation to controlled experiment: steep granular slopes motivate a lab setup where a robotic leg repositions obstacles through strategic sand avalanche

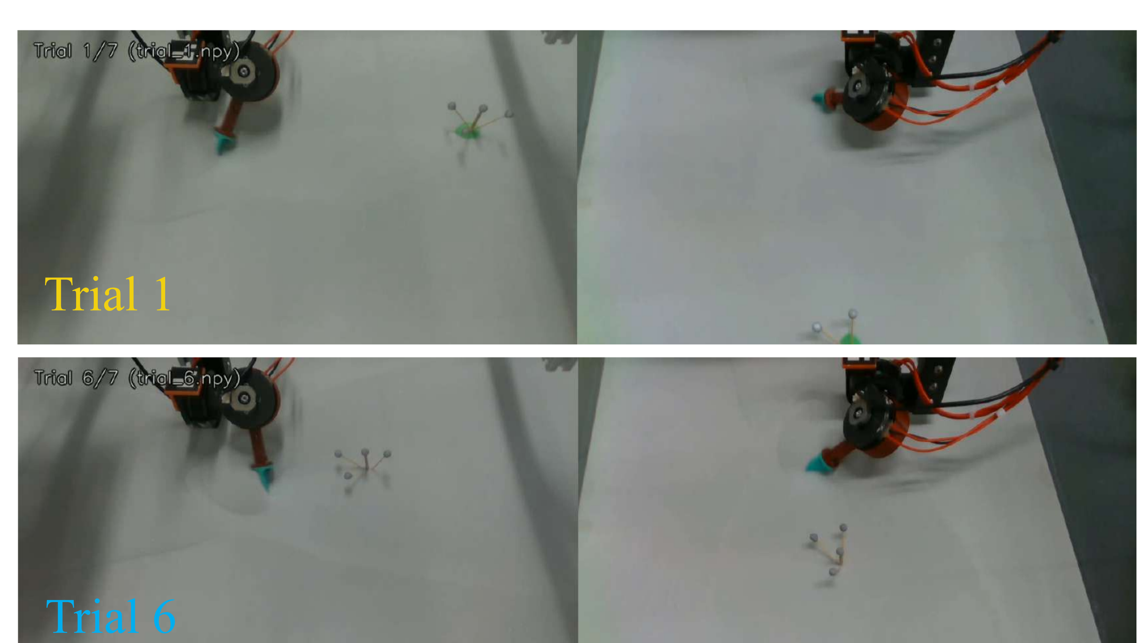
Density Controls Rising, Sinking, and Downslope Transport

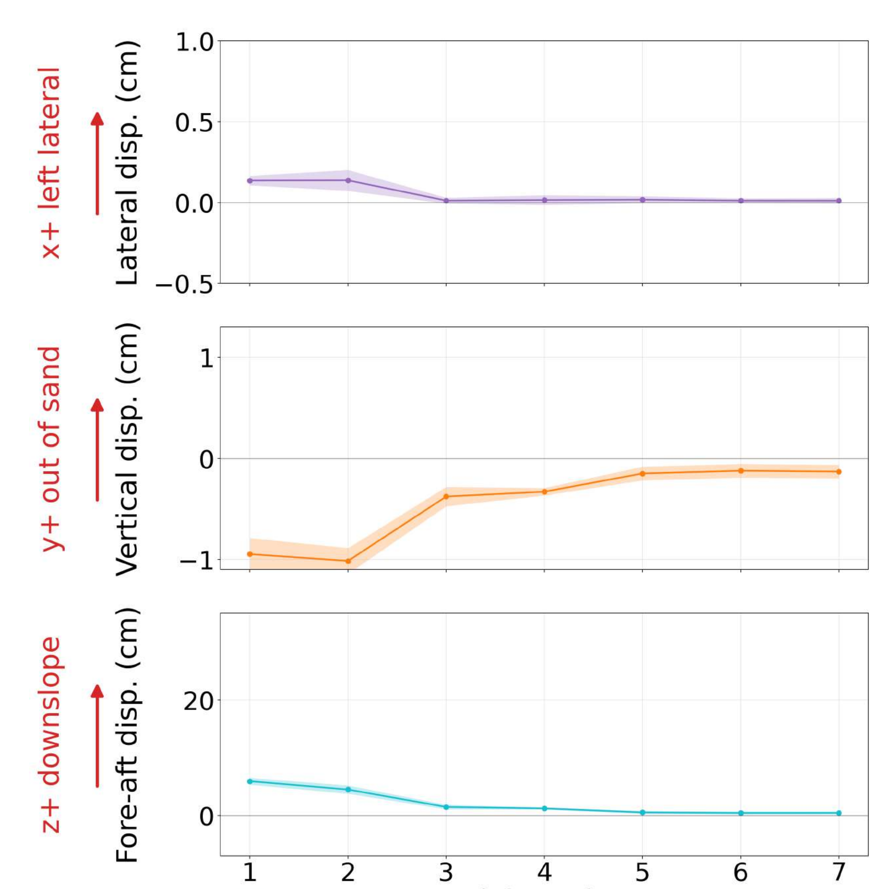
Empty: resurfaces + remains mobile





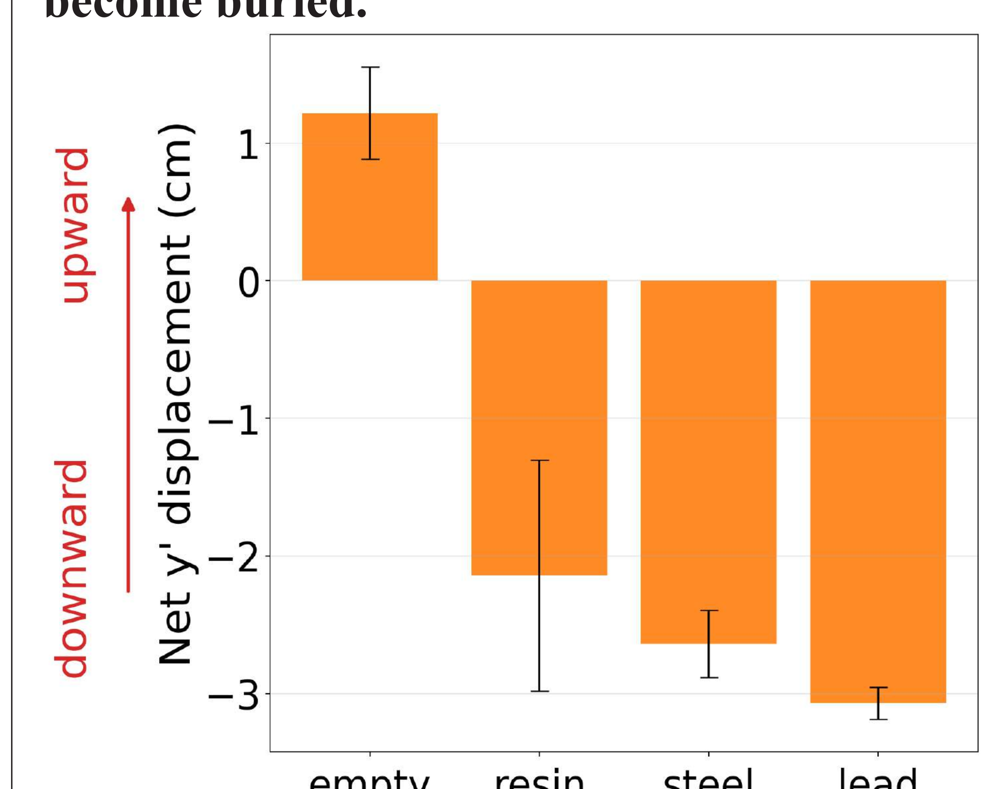
Lead-filled: sinks + stabilizes



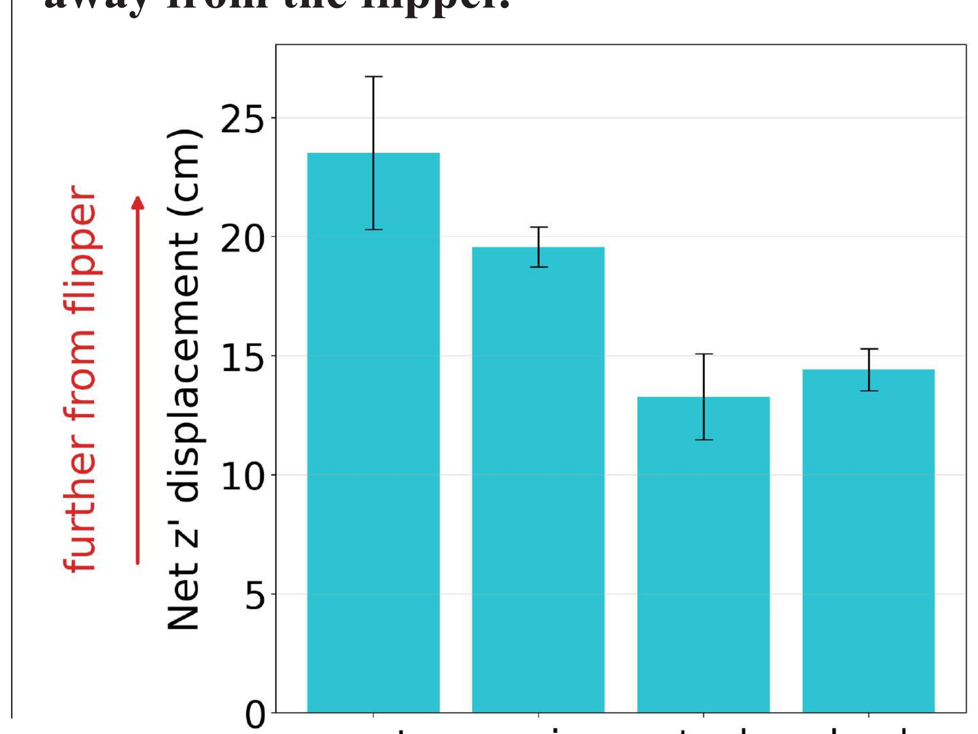


Qualitative and trial-wise comparison of empty and lead-filled obstacles. The empty obstacle rises and moves farther downslope across trials, while the lead-filled obstacle sinks into the sand and shows limited later motion.

Light obstacles resurface; denser obstacles become buried.



Lighter obstacles travel farther downslope / away from the flipper.



Toward Density-Aware Prediction and Planning

Observed motion history
$o_{0:t}, a_{0:t}, \phi$

↓

Infer latent density
$\hat{\rho}_t = g(o_{0:t}, a_{0:t}, \phi)$

↓

Predict future motion
$o_{t+1} = f(o_t, a_t, \phi, \hat{\rho})$

↓

Planning decision

Dense/stable: potential support
Light/mobile: displace away from path

Acknowledgements This project is funded by NASA Planetary Science and Technology Through Analog Research (PSTAR) program, Grant 80NSSC22K1313, the NASA Lunar Surface Technology Research (LuSTR) program, Award # 80NSSC24K0127, and the NASA Mars Exploration Program (MEP) program.

RoboLAND
Robot Locomotion And Navigation Dynamics

USC Viterbi
School of Engineering
Ming Hsieh Department of Electrical and Computer Engineering