Field Experiments in Nonprehensile Terrain Manipulation with Planetary Exploration Rovers

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Motivation

The wheels of planetary exploration rovers can be used to modify terrain through careful choice of wheel speed and angle, in what we call Nonprehensile Terrain Manipulation (NPTM). This has been done in an ad-hoc manner by Mars rovers [1]. Previous work predicting the shape of terrain left behind a rover wheel while has been validated in a controlled laboratory setting [2].

Methods

Tests were conducted on NASA Ames Research Center's KREX-2 rover outfitted with lugged rubber tires in unprepared soil in Chile's Atacama Desert. The soil was soft and relatively noncohesive, with a fragile crust layer less than 1 cm thick.

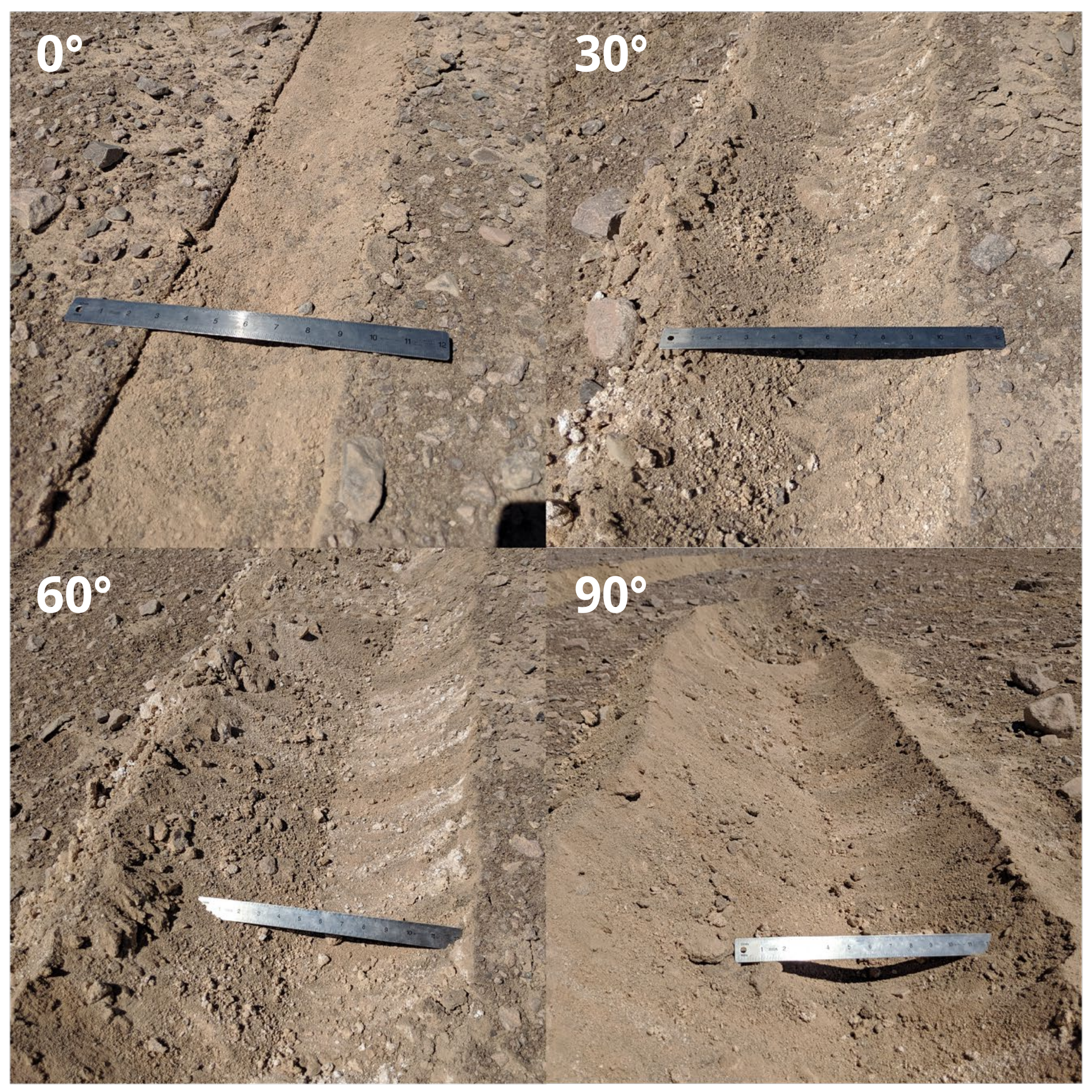
Terrain was mapped with a FARO LIDAR scanner (below, left), and the rover was tracked with a Leica Total Station to record position and velocity. Seven holes/soil piles were constructed by moving a single wheel with the rover stationary (below, right). Maximum slope angle measurements taken with a handheld inclinometer were used to estimate soil angle of repose as in [1].

Trenching Experiments

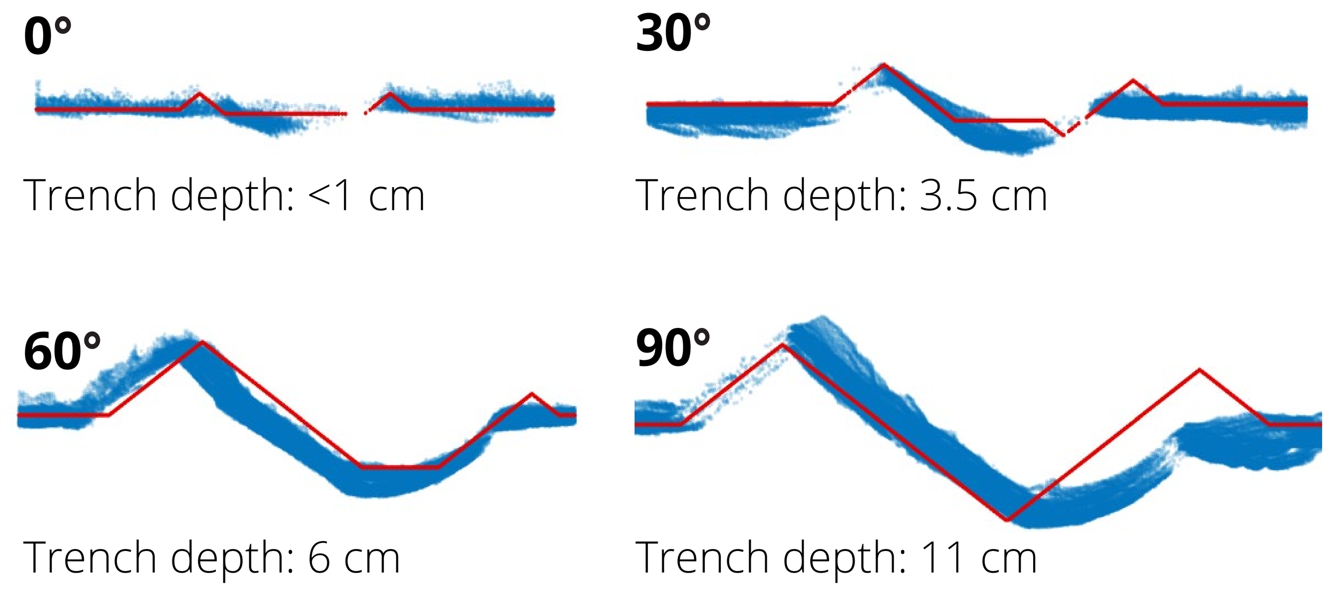
Hand-tuned trenching primitives were run with the rover driving at 20 cm/s, with the rear right wheel spinning at 50 cm/s and at 0°, 30°, 60°, and 90° angles relative to rover direction of travel.

In the photo above, white material in the trench shows the subsurface presence of halites in the soil.

Trench width and depth varied greatly with wheel angle, as shown below. Trenches ranged from 18 cm wide with the trenching wheel at 0° to 55 cm with the wheel at 90°. Significant soil motion was observed, with the rover digging trenches up to 1/3 of the wheel diameter.



Model Analysis



Predicted trench shapes (above, red) showed very good qualitative agreement with those measured in the Atacama (above, blue). Scans were manually centered, and wheel sinkage was manually extracted from LIDAR data, though it can also be predicted to some degree with terramechanics models. As previous tests in [2] were on prepared, uniform substrate, this was the first demonstration in a real-world environment.

Additional Demostrations

Multipass trenching was performed (above), with the trenching wheel driven at a slip angle of 30° and slip ratio of 0.6 for all passes. **There was some increase in trench width from the first (left) to second (center) pass, but little change from second to third (left).**

A robot-teaming scenario was conducted with KREX-2 and the MiniRHex [3] platform (above). MiniRHex attempted to ascend a body-scale step in the terrain (left), but was unable to and flipped over (center left). **KREX-2 used its wheel to dig a ramp into the terrain (center right), which MiniRHex was able to ascend (right).**

For video, see: https://youtu.be/jlq6pzfWUE8

References. [1] Sullivan, R., et al., (2011). Cohesions, friction angles, and other physical properties of Martian regolith from Mars Exploration Rover wheel trenches and wheel scuffs. Journal of Geophysical Research E: Planets. [2] Pavlov, C., & Johnson, A. M. (2019). Soil displacement terramechanics for wheel-based trenching with a planetary rover. ICRA 2019. [3] Barragan, M., et al. (2018) "MiniRHex: A Small, Open-source, Fully Programmable Walking Hexapod. In RSS 2018 Workshop on " Design and Control of Small Legged Robots".

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