FIELD EXPERIMENTS IN NONPREHENSILE TERRAIN MANIPULATION WITH PLANETARY EXPLORATION ROVERS. C. A. Pavlov[1] and A. M. Johnson[1], [1] Carnegie Mellon University Department of Mechanical Engineering (5000 Forbes Ave, Pittsburgh PA 15213, {cpavlov, amj1}@cmu.edu)

Abstract: Robotic space exploration missions are highly constrained in mass, volume, and complexity; gaining additional functionality from existing onboard actuators is therefore of great interest. Here, we consider the technique of using existing actuators as manipulators for the purpose of modifying the robot's environment. Nonprehensile terrain manipulation takes advantage of incidental robot-environment interactions such as that of a wheel with the terrain and leverages them to perform manipulations. For example, the wheels of planetary exploration rovers can be used to modify terrain through careful choice of wheel speed and angle. Previous work modeling the shape of terrain left behind a rover wheel while has been validated in a controlled laboratory setting [1]. The developed closed-form model takes a wheel's sinkage, speed, angle, and the soil angle of repose, and outputs the shape of the terrain deformed by the wheel. Here, we show this model's predictive ability in field experiments conducted in the Atacama Desert, as well as present several interesting demonstrations of NPTM's potential.

Tests were conducted on NASA Ames Research Center's KREX-2 rover outfitted with lugged rubber tires (Figure 1) in unprepared soil in Chile's Atacama Desert, which is commonly used as a Mars analog. The soil was soft and relatively noncohesive, with a fragile crust layer less than 1 cm thick. Several tests were conducted: hole digging/soil pile construction, trenching, and mission scenario demonstrations. For the digging and trenching experiments, the terrain was mapped before and after manipulation with a FARO LIDAR scanner (Figure 2). For trenching experiments, the rover was tracked with a Leica Total Station to record position and velocity, and this data was correlated with the FARO scans.

Seven holes/soil piles were constructed by moving a single wheel with the rover stationary. Maximum slope angle measurements were used to estimate soil angle of repose, which was used to predict trench geometry. This measurement was done with a handheld inclinometer but can also be extracted from LIDAR scans. 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-degree angles relative to rover direction of travel. Using the measured angle of repose and sinkage measured from LIDAR data, the model developed in [1] was able to qualitatively predict the shape of the terrain after trenching, as shown in Figure 3. Significant soil motion was observed, with the rover digging trenches up to 1/3 of the wheel diameter. Additionally, robot-teaming mission scenarios were performed, with the KREX-2 rover clearing obstacles for a miniature legged robot, MiniRHex. These experiments were the first demonstration of nonprehensile terrain manipulation in a real-world environment.

Figure 1. KREX-2 rover in the Atacama Desert with a trench dug by a wheel at 60°.

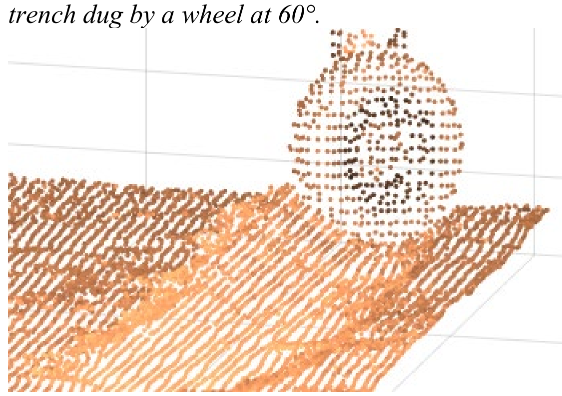

Figure 2. LIDAR scan of a trench dug at 60°.

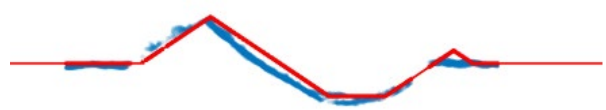

Figure 3. Model prediction of trench shape (red) compared to measured shape (blue).

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References:

[1] Pavlov, C., & Johnson, A. M. (2019). Soil displacement terramechanics for wheel-based trenching with a planetary rover. ICRA 2019.