Modeling Robot/Terrain Interaction

Robomechanics Lab Research Highlights

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Robomechanics Lab
https://robomechanics.net/

Motivation

In my lab we want to make robots that can go anywhere in the world.




Soil Flow Model

How can we predict the shape of a trench left behind when a wheel drives through it?

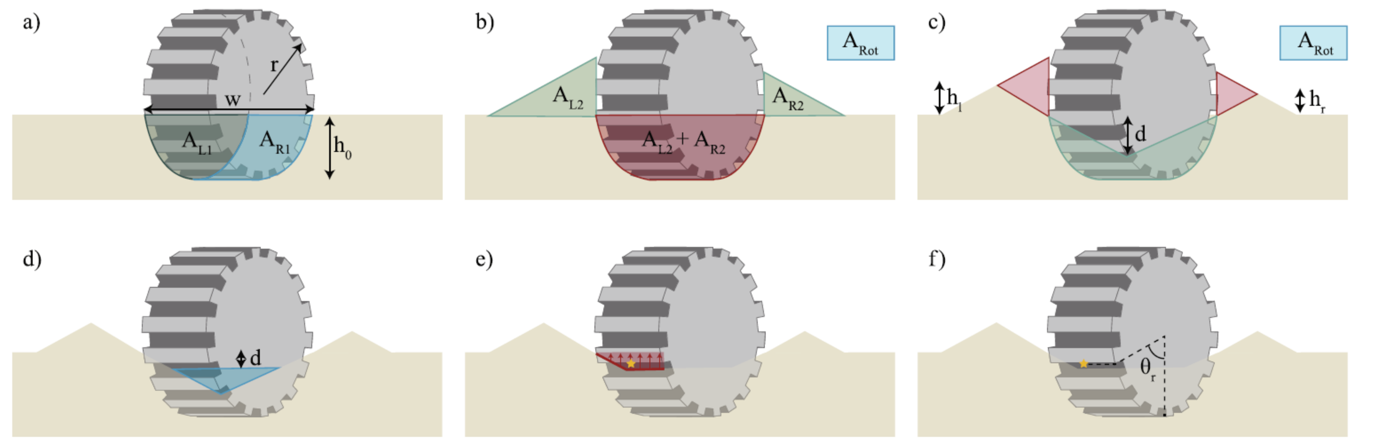
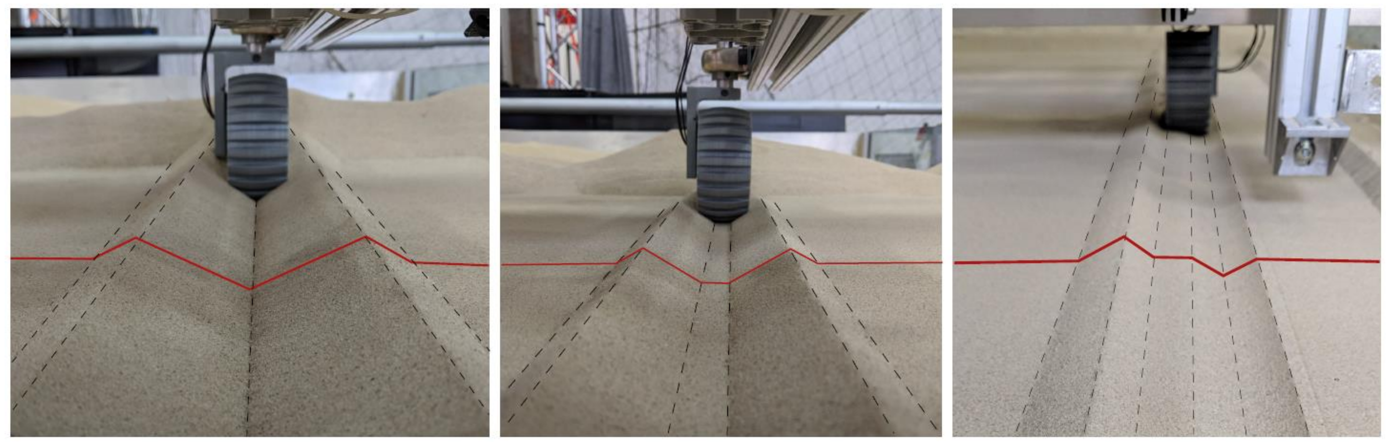


Fig. 2. Illustration of the soil flow model used to determine exit angle θ_r. (a) The projected area of the wheel is used to separate the terrain into soil contacting the wheel face, A_{L1}, and wheel rim, A_{R1}. (b) The soil caught in the grousers, A_{rot} is separated out, and the remaining soil is piled to the sides of the wheel. (c) The soil is allowed to flow behind the wheel. (d) The soil caught in the grousers is deposited onto the soil profile. (e) The region of the rear rim contacting the soil profile is identified, and the average depth along that portion is identified. (f) The average depth along the contact region is converted to exit angle θ_r. Figure adapted from Pavlov and Johnson (2019).

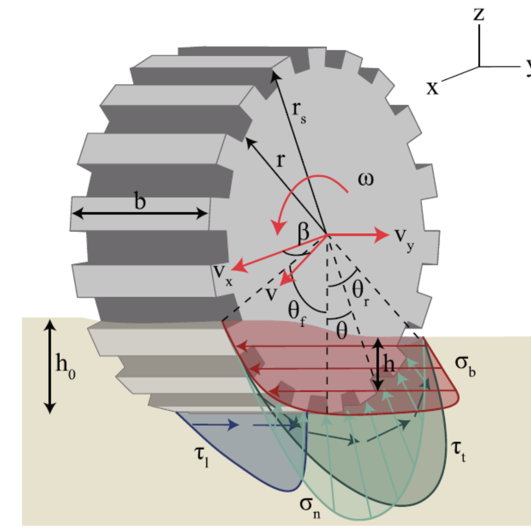
We take a first principles approach based on wheel geometry and angle of repose to predict the shape.

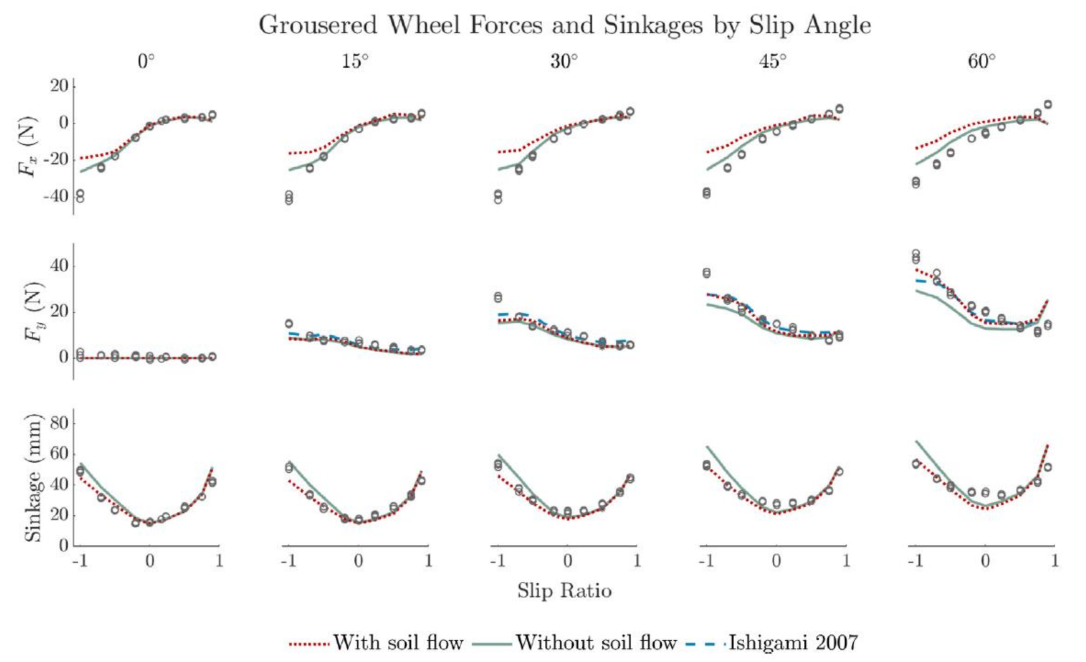


Catherine Pavlov and Aaron M. Johnson. "Soil Displacement Terramechanics for Wheel-Based Trenching with a Planetary Rover." In *IEEE Intl. Conference on Robotics and Automation*, pages 4760–4766, May 2019.

Terramechanics Model

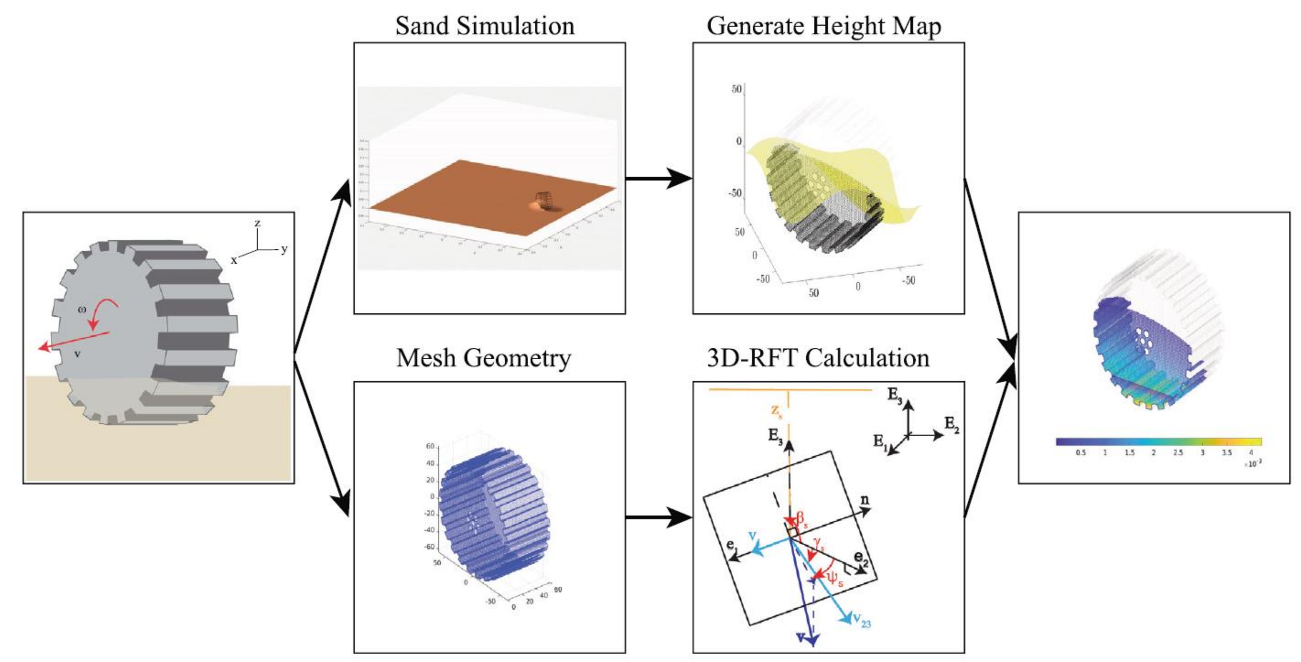
How can we predict the forces on a wheel when driving in off-nominal conditions?
Here we extend classical terramechanics to handle high slip angle and slip ratio driving, incorporating the soil flow mode.



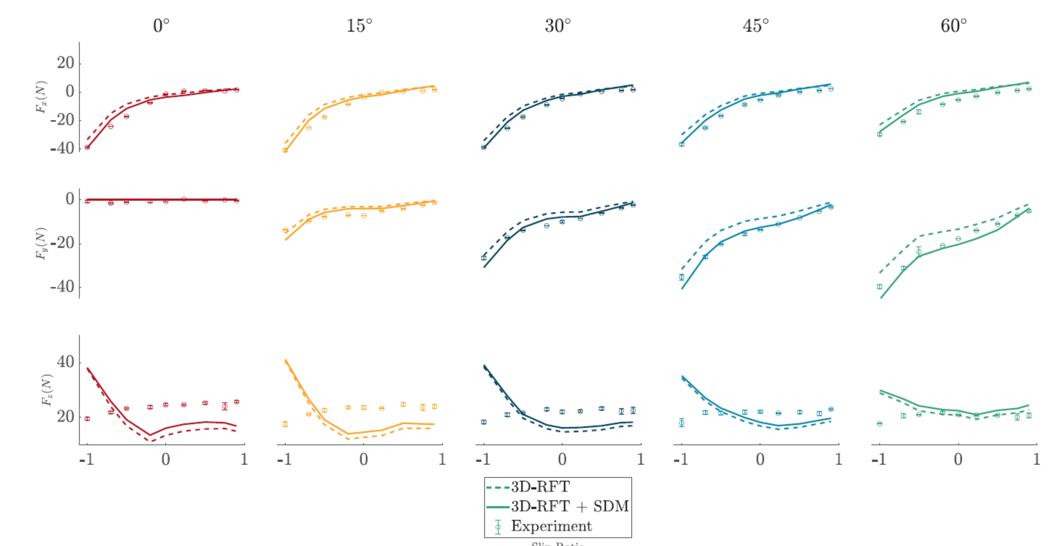


Catherine Pavlov and Aaron M. Johnson. "A terramechanics model for high slip angle and skid with prediction of wheel-soil interaction geometry." *Journal of Terramechanics*, 111: 9–19. 2024.

RFT Model



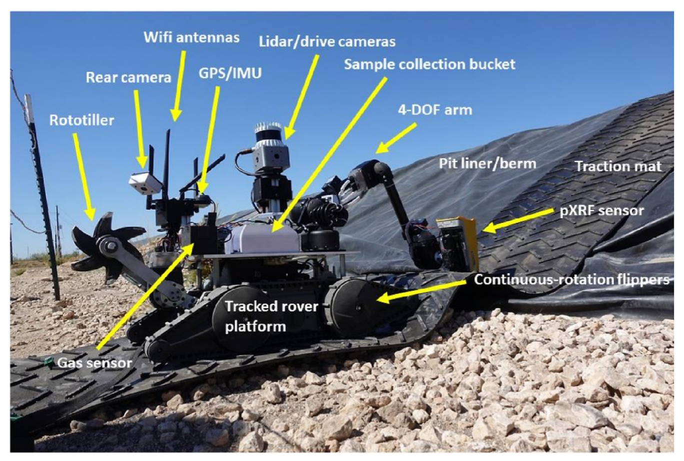
Alternatively, if the soil is not initially flat or the wheel geometry is not known, resistive force theory (RFT) provides a more flexible alternative. Here, we combine 3D RFT with a sand deformation map that predicts both forces on the wheel and resulting terrain shape.



Qishun Yu, Catherine Pavlov, Wooshik Kim, and Aaron M. Johnson. "Modeling Wheeled Locomotion in Granular Media using 3D-RFT and Sand Deformation." *Journal of Terramechanics*, 115: 100987. October 2024.

Application: Environmental Monitoring

One application we focus on is environmental monitoring. Can we send a robot out to autonomously explore, dig in the dirt, search for contamination, or other environmental monitoring task?




Joe Norby, et al. "Path to Autonomous Soil Sampling and Analysis by Ground-Based Robots." *Journal of Environmental Management*, 360, 2024.

This work was sponsored in part by:

Application: Planetary exploration

Planetary exploration rovers need better models to plan safe paths, overcome actuator failure, and even perform basic terrain modifications.



Catherine Pavlov and Aaron M. Johnson. "Terramechanics-Based Joint Failure Compensation and Soil Manipulation." *In prep.*
Catherine Pavlov. "Off-Nominal Rover Driving: Terrain Manipulation and Degraded Mobility Compensation." *Ph.D. Thesis*, Mechanical Engineering Department, Carnegie Mellon University, Pittsburgh, PA, February 2023.