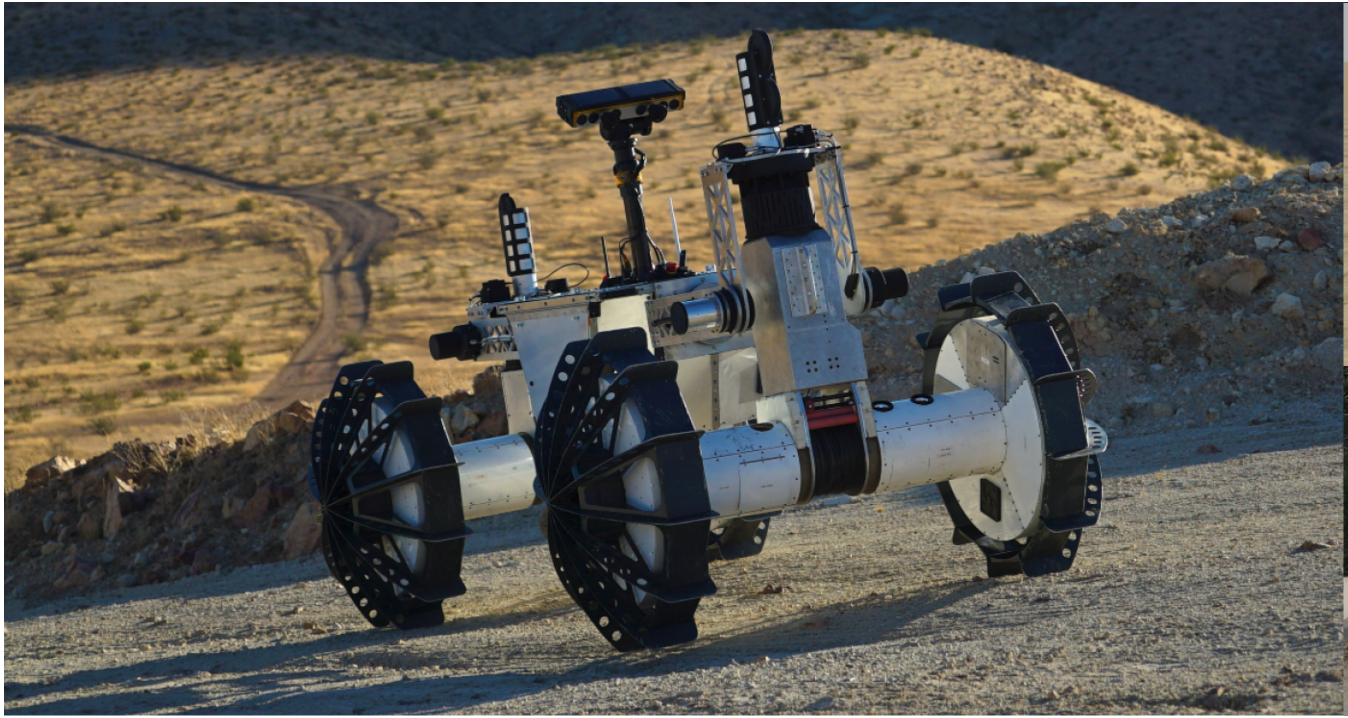
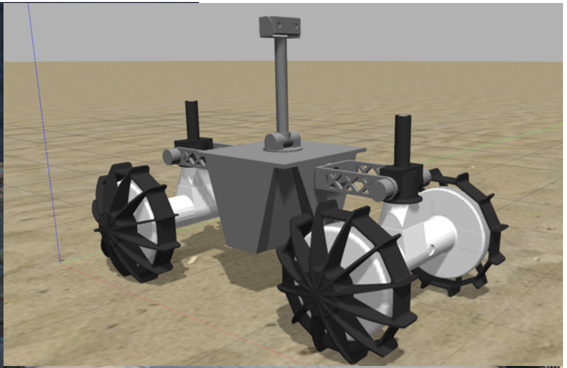




Virtual Research Presentation Conference

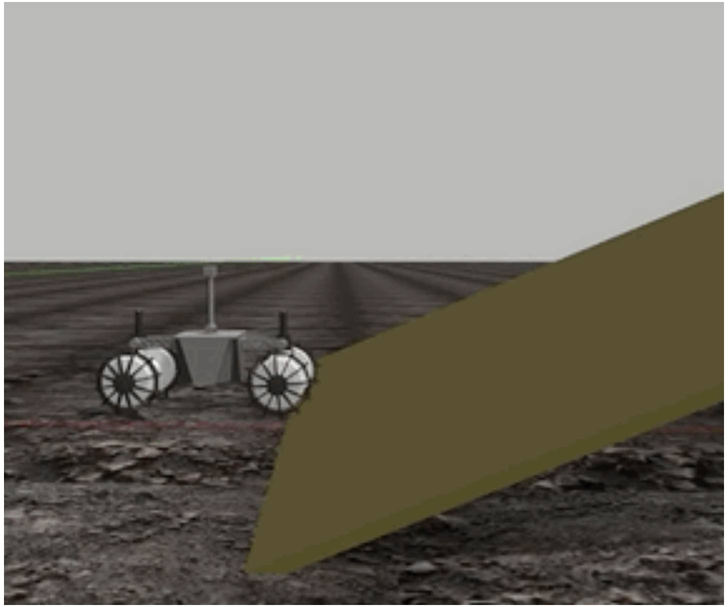
Improving Slope Stability and Traction for the DuAxel Rover through Adaptive Joint Control

Principal Investigator: Patrick McGarey (347F)
JVSRP Intern: Emanuele Aucone (Univ. of Pisa now at ETH Zurich)
Co-Is: William Reid (347F), Travis Brown (347F), Issa Nesnas (347)
Program: Spontaneous Concept

Jet Propulsion Laboratory
California Institute of Technology

Assigned Presentation # 253

Introduction



In this task we have developed and tested **control algorithms**, which **minimizes longitudinal wheel-slip** on slopes and **provides stability** over rough terrains for an articulated, mobility system comprised of twin, tethered Axel rovers joined to a central module, called **DuAxel.**

Problem Description

Emanuele Aucone
(Univ. of Pisa now at ETH Zurich)

a) The Axel/DuAxel platform has been significantly advanced under a Mars Strategic R&TD to explore extremely sloped terrain. The unique design of DuAxel offers an opportunity to advance its autonomous control to allow improved traction for upslope mobility, which is currently **limited due to its high center-of-mass**, which provides non-ideal force distribution on the wheels resulting in **excessive slip on slopes greater than 20 degrees**.

b) To address poor slope driving performance when the DuAxel is in its ‘standing’ driving configuration, we develop algorithms to control DuAxel’s pitch mechanism, normally used for ‘sitting’ and anchoring, to **change the mass distribution while driving slopes**. We also adapt wheel controllers to **stabilize DuAxel driving on rough terrain**.

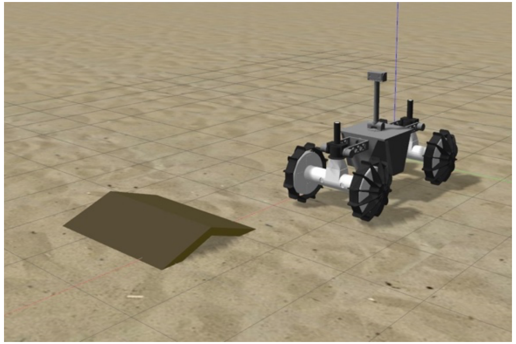
c) Enhanced mobility and control algorithms for the DuAxel system benefit near-future JPL and NASA strategic goals and mission architectures, including explorations of...

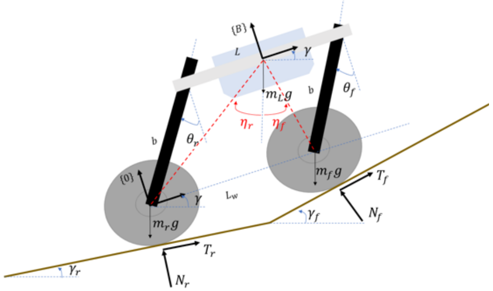
- Lunar Pits and Caves
- Martian ice deposits on slopes, caves, and RSL features

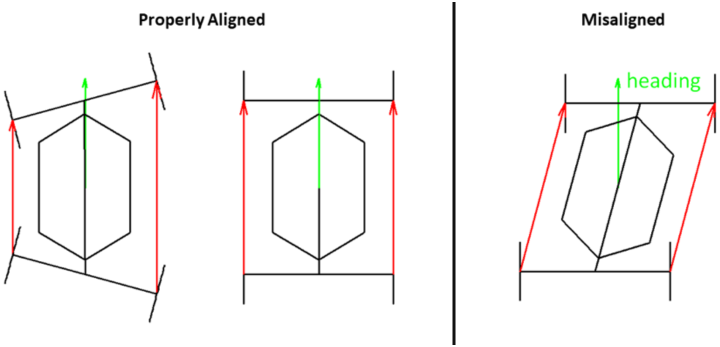
Methodology

This task focused on the following objectives

1. Development of a custom ROS package for robotic simulations using the ROS Gazebo framework
2. Optimization-based tilting control for center-of-mass adjustment to enhance DuAxel mobility over steep slopes to improve stability and minimize wheel slip
3. 3D kinematic passive-steering control with roll compensation to enhance DuAxel mobility for trajectory following along rough flat terrains in presence of obstacles





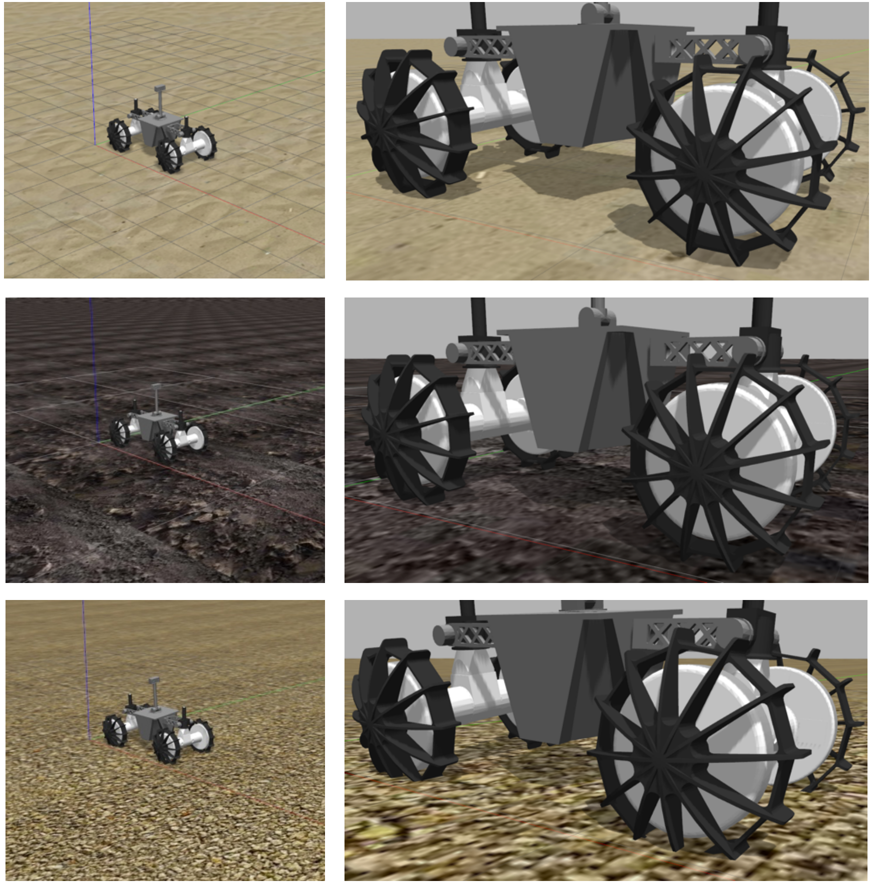


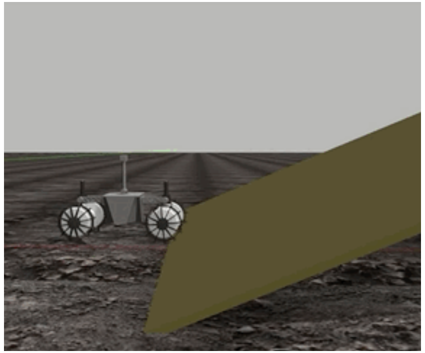
borrowed from Seegmiller and Wettergreen (2011)

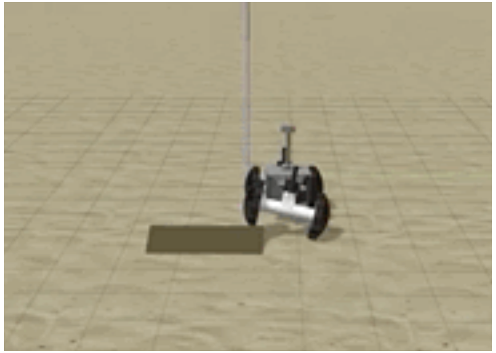
Results

Simulation Framework

- A custom ROS Gazebo simulation framework was developed and used to evaluate all algorithms in this task, later, outdoor tests confirmed these results
- Models of the rover include terrain contact on different soils, and sensors to measure wheel rotations and joint positions
- Obstacles in the environment include slopes and hazards



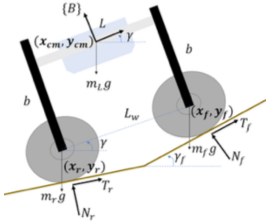


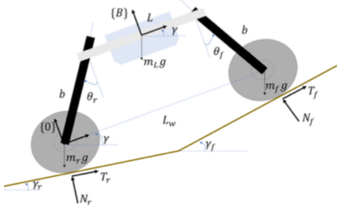


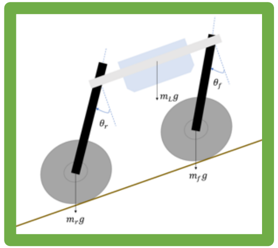
Results

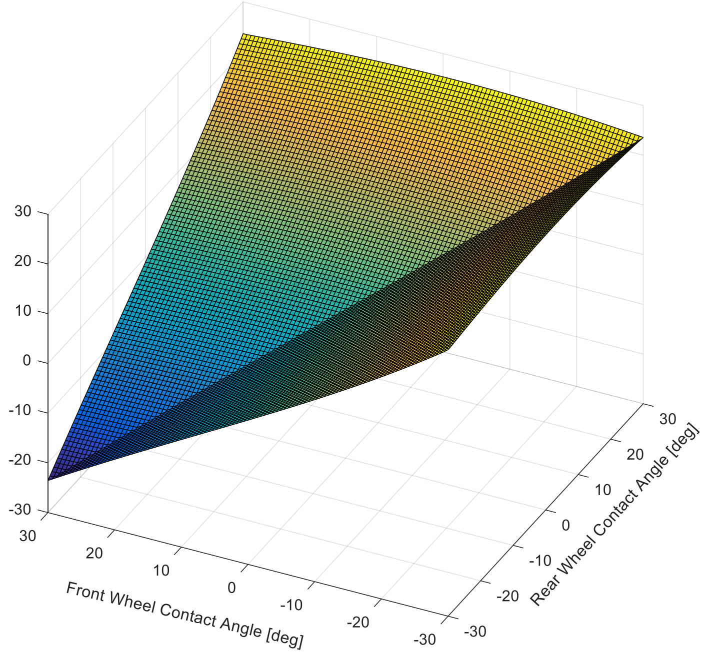
Center-of-Mass Control

- The optimization problem aims at **improving traction**, achieved if the tangential forces are applied within the limits the terrain can bear, which depends on the normal forces acting on the wheels
- We minimize the tractive to normal force ratio in order to reduce longitudinal wheel slip on slopes
- We solve for optimal pitch angles (see figure), the results suggest that 'leaning' into the hill is preferred over spreading the front and back wheels wider apart or keeping them upright









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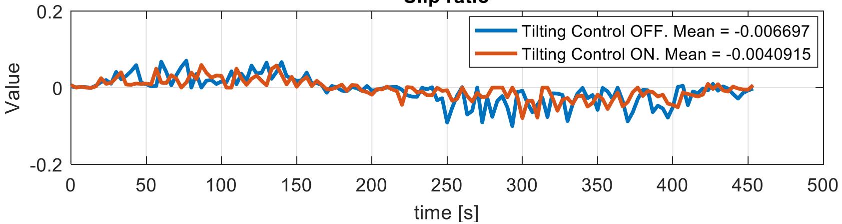
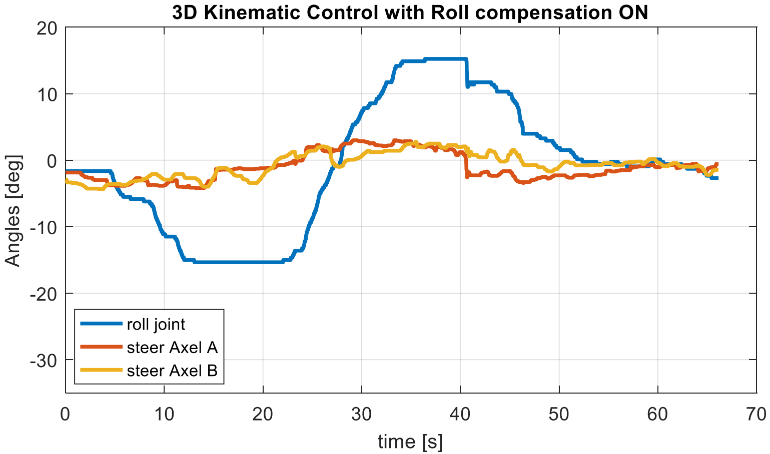
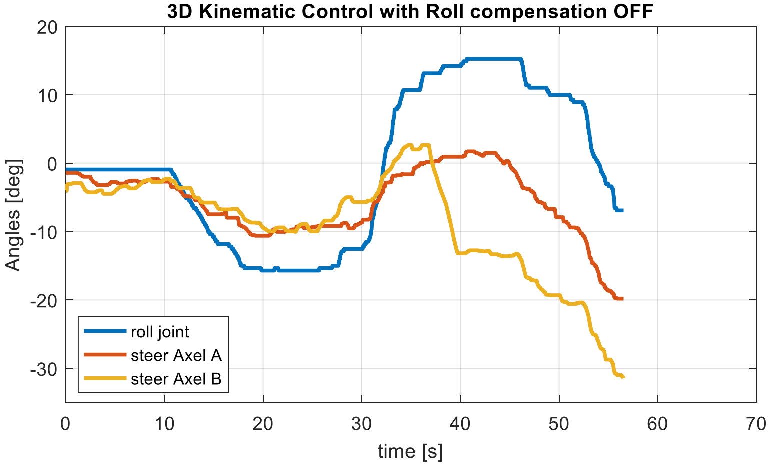


Results

Roll Compensation Control

- We developed a controller to steer individual wheels on each Axel rover, **accounting for roll motion while traversing obstacles** in order to **follow a desired heading**
- Adapted kinematic control approach for Zoe rover from CMU (Seegmiller and Wettergreen 2011)





Publications and References

Two in-progress publications were a result of this work

[1] E. Aucone, P. McGarey, “3D Kinematic Passive-steering Control With Roll Compensation For Rover Trajectory Following Over Rough Terrain” To appear in iSairis 2020.

[2] E. Aucone, P.G. Iyer, W. Reid, I. Nesnas, P. McGarey, “Optimal Tilting Control for Adaptive Rover Center-of-Mass Adjustment on Steep Terrain” To be submitted to IROS 2021.

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[1] Nesnas, Issa AD, Jaret B. Matthews, Pablo Abad-Manterola, Joel W. Burdick, Jeffrey A. Edlund, Jack C. Morrison, Robert D. Peters et al. "Axel and DuAxel rovers for the sustainable exploration of extreme terrains." *Journal of Field Robotics* 29, no. 4 (2012): 663-685.

[2] Seegmiller, Neal, and David Wettergreen. "Control of a passively steered rover using 3-D kinematics." In *2011 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 607-612. IEEE, 2011.

[3] Nakamura, Sousuke, Michele Faragalli, Noriaki Mizukami, Ichiro Nakatani, Yasuharu Kunii, and Takashi Kubota. "Wheeled robot with movable center of mass for traversing over rough terrain." In *2007 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 1228-1233. IEEE, 2007.

[4] Iagnemma, Karl, and Steven Dubowsky. "Traction control of wheeled robotic vehicles in rough terrain with application to planetary rovers." *The international Journal of robotics research* 23, no. 10-11 (2004): 1029-1040.