Roverside Assistance: Rescuing Rovers on Remote Planets

MRSD Team I: The Moon Wreckers

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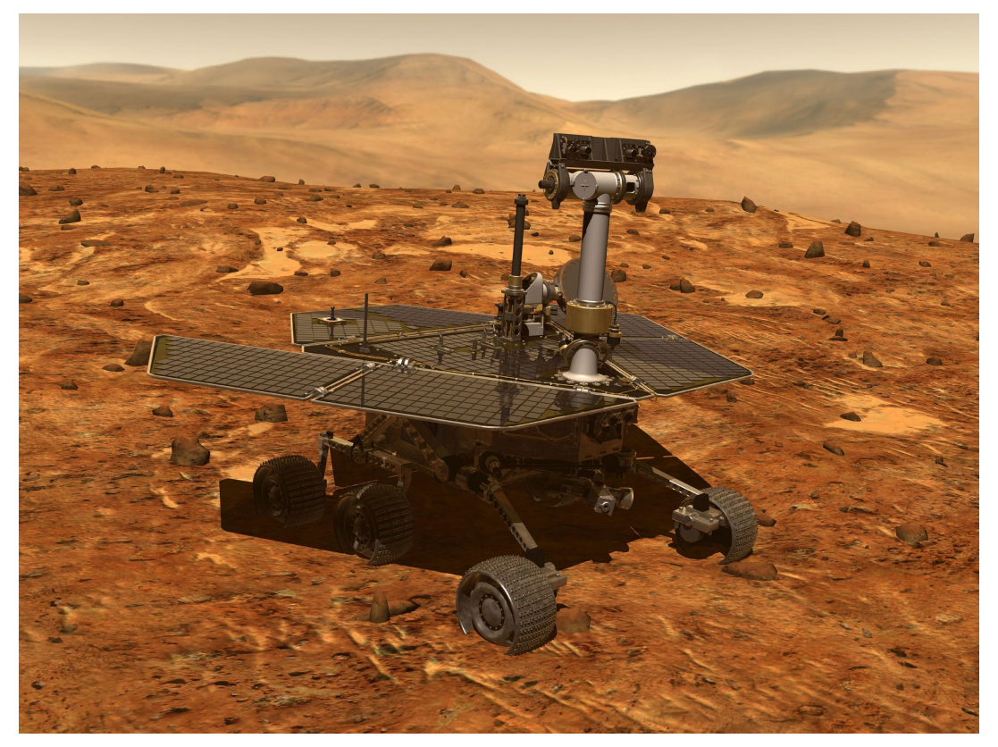
MOTIVATION

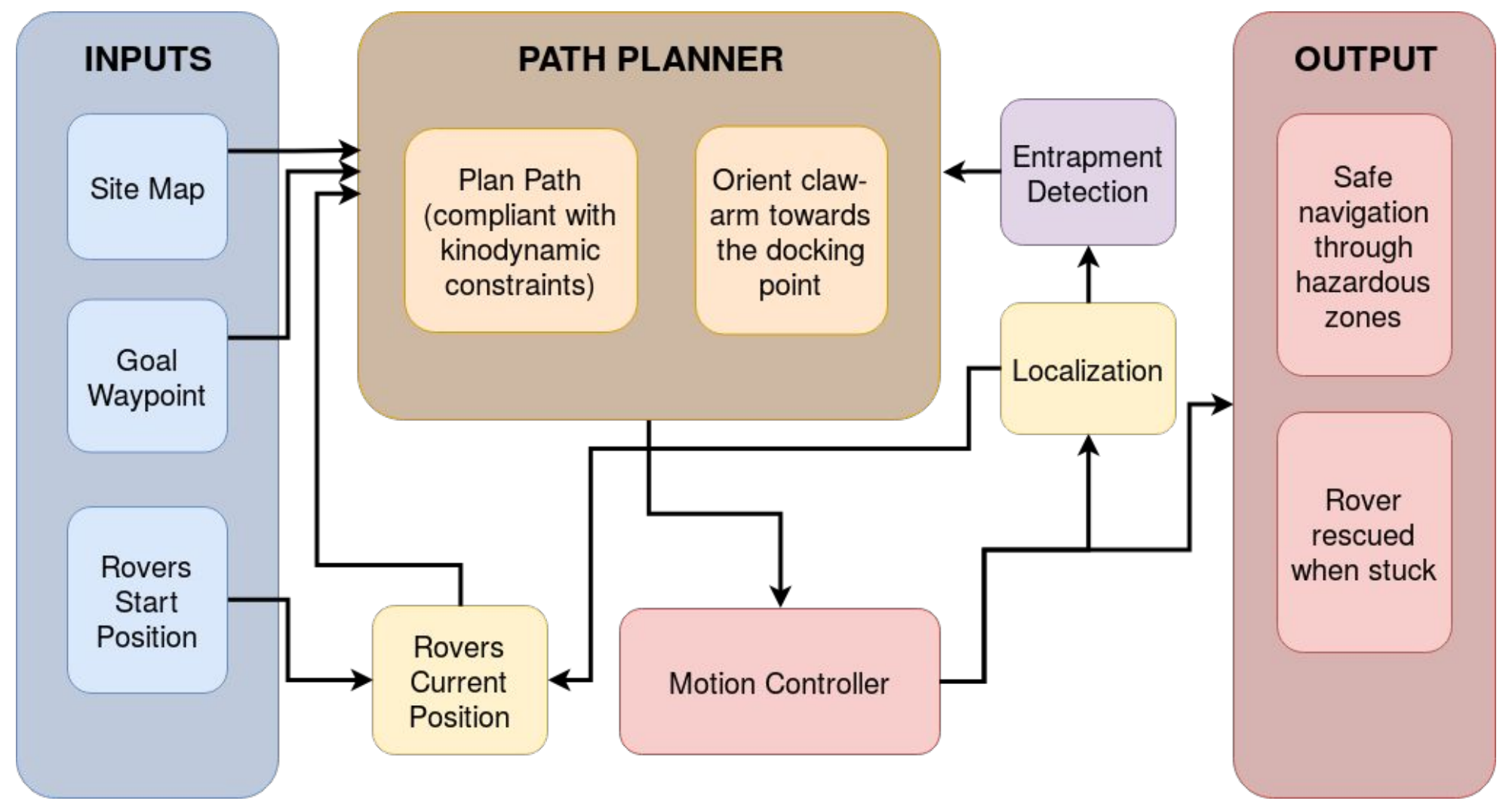
Most autonomous ground vehicle systems that exist today are designed around a single rover. While this is simpler and cheaper to field, solitary robots are limited in the areas they can explore due to the unacceptable risk of a robot getting trapped in a difficult to navigate terrain. Extraterrestrial rovers are also constantly at risk of entrapment for a host of other reasons. A real life example of this is the Mars Spirit rover, which became permanently stuck after driving over a thin crust of normal looking dirt on top of very soft sand.



PROJECT DESCRIPTION

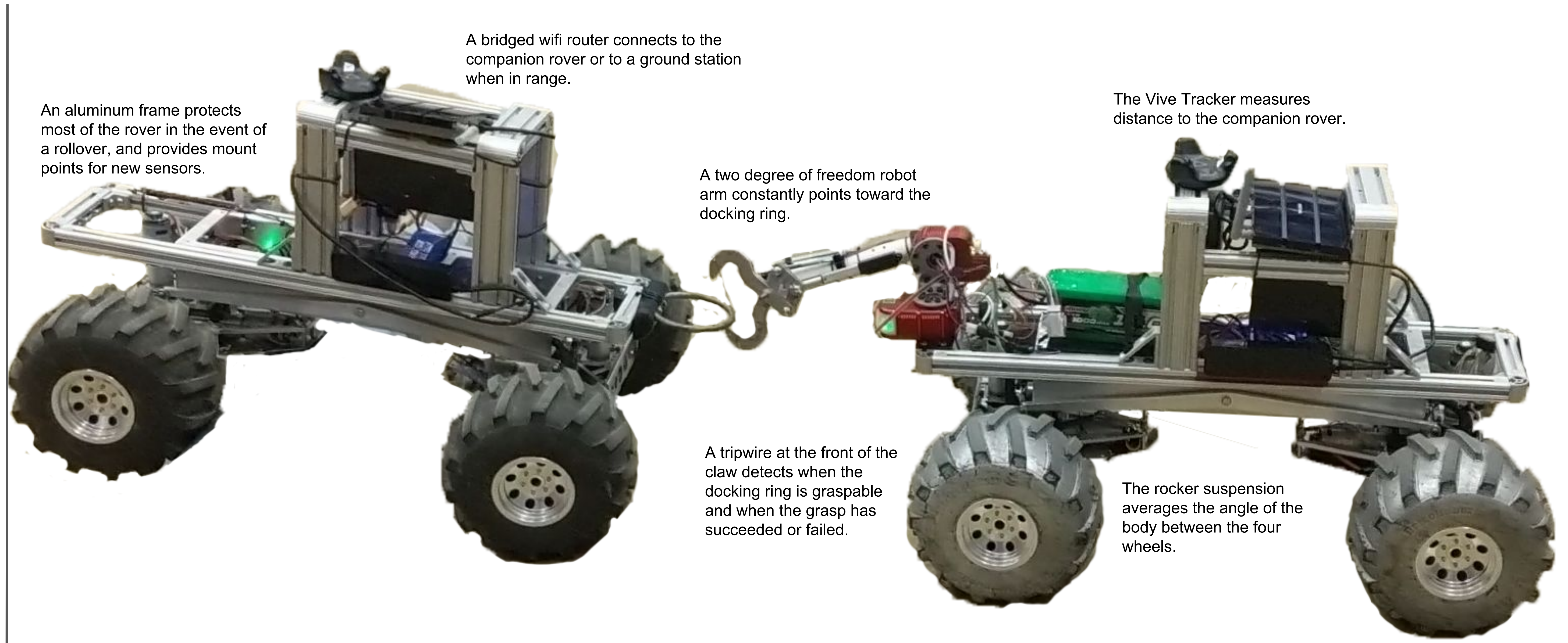
This project demonstrates the capability of a two rover system to recover from high centering entrapment events. Because the target systems experience significant time delays that render direct human control infeasible, this system demonstrates autonomous recovery behavior.

SYSTEM ARCHITECTURE



CONCLUSIONS

- Simple control strategies free rovers from many orientations in rough terrain.
- Highly robust hardware is required.
- Accurate relative localization is required for docking.
- Coordination between robots is essential - one robot generally can't generate enough force to free another robot of similar mass.



A bridged wifi router connects to the companion rover or to a ground station when in range.

An aluminum frame protects most of the rover in the event of a rollover, and provides mount points for new sensors.

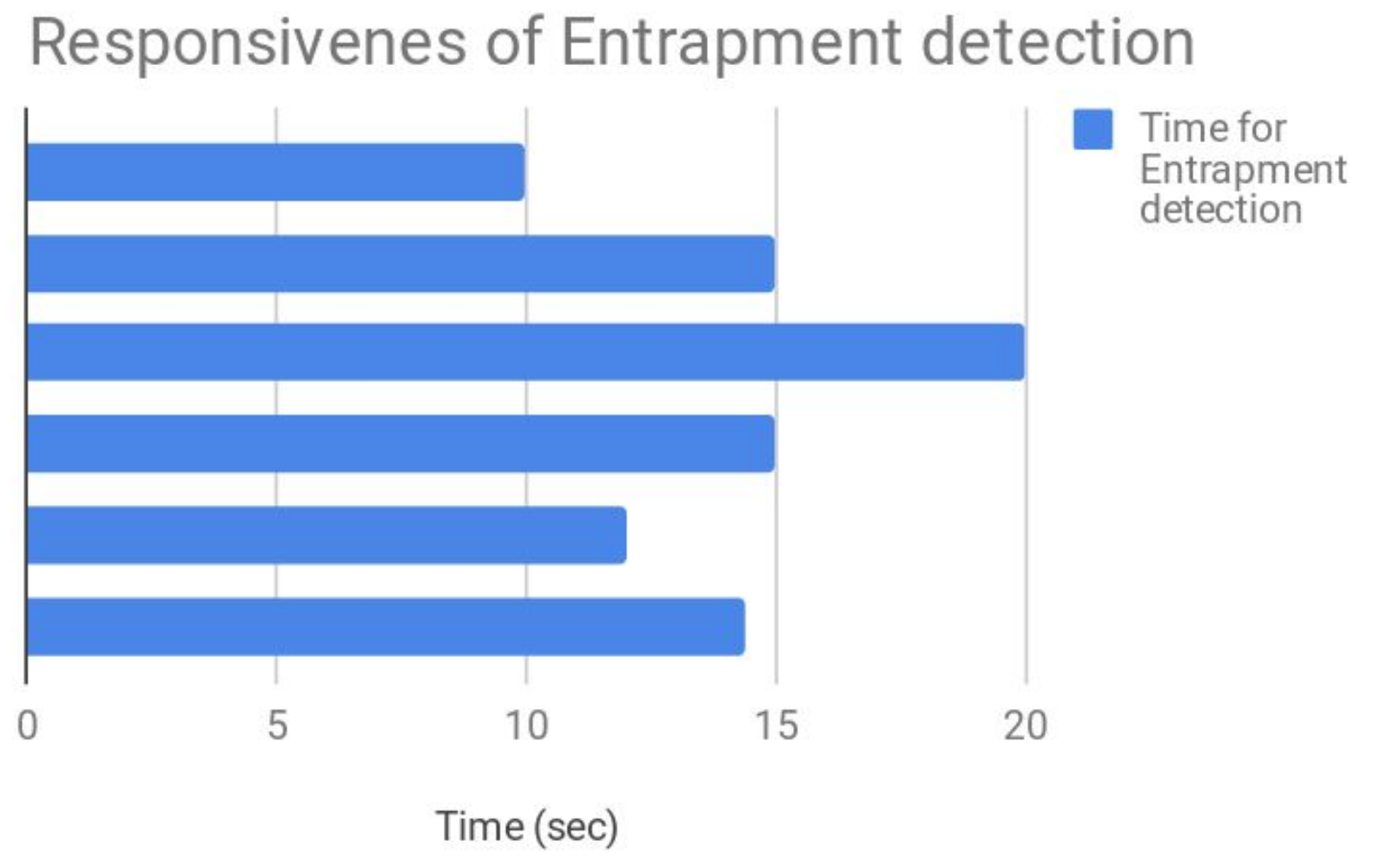
The Vive Tracker measures distance to the companion rover.

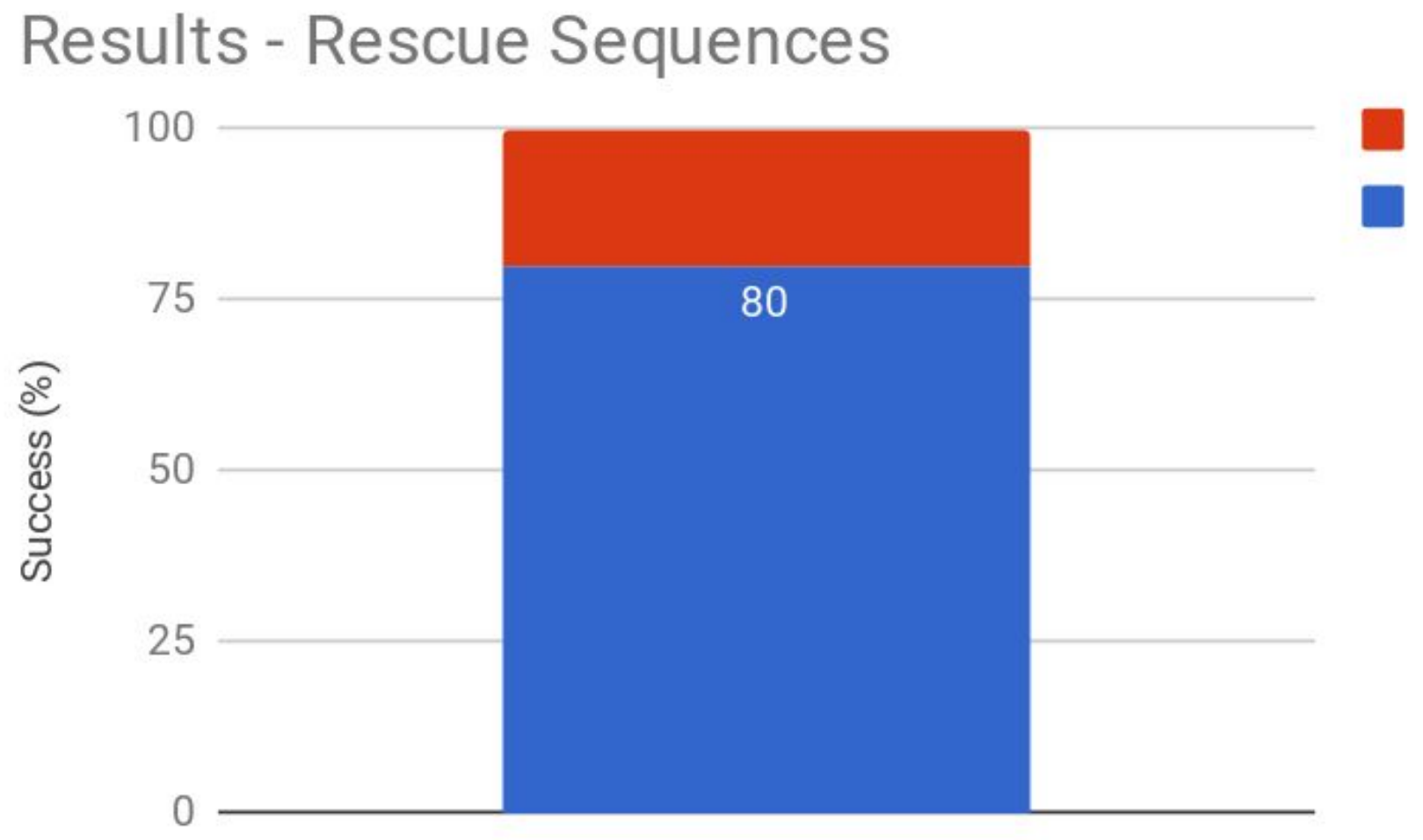
A two degree of freedom robot arm constantly points toward the docking ring.

A tripwire at the front of the claw detects when the docking ring is graspable and when the grasp has succeeded or failed.

The rocker suspension averages the angle of the body between the four wheels.

RESULTS





Entrapment Detection

Measuring the probability of entrapment by incorporating divergence (between wheel odometry and reference odometry) and rover movement status using Bayesian process.

Benefits to have the probabilistic approach:

- Both status and confidence level become accessible;
- The detector is then more robust to noise.

Entrapment Criteria: $\|\dot{\mathbf{x}}_g\| < 0 + \epsilon_0 \textit{ and } \left\| \frac{\partial \mathbf{FK}(\mathbf{q})}{\partial \mathbf{q}} \dot{\mathbf{q}} - \dot{\mathbf{x}}_g \right\| > \epsilon_{ag}$

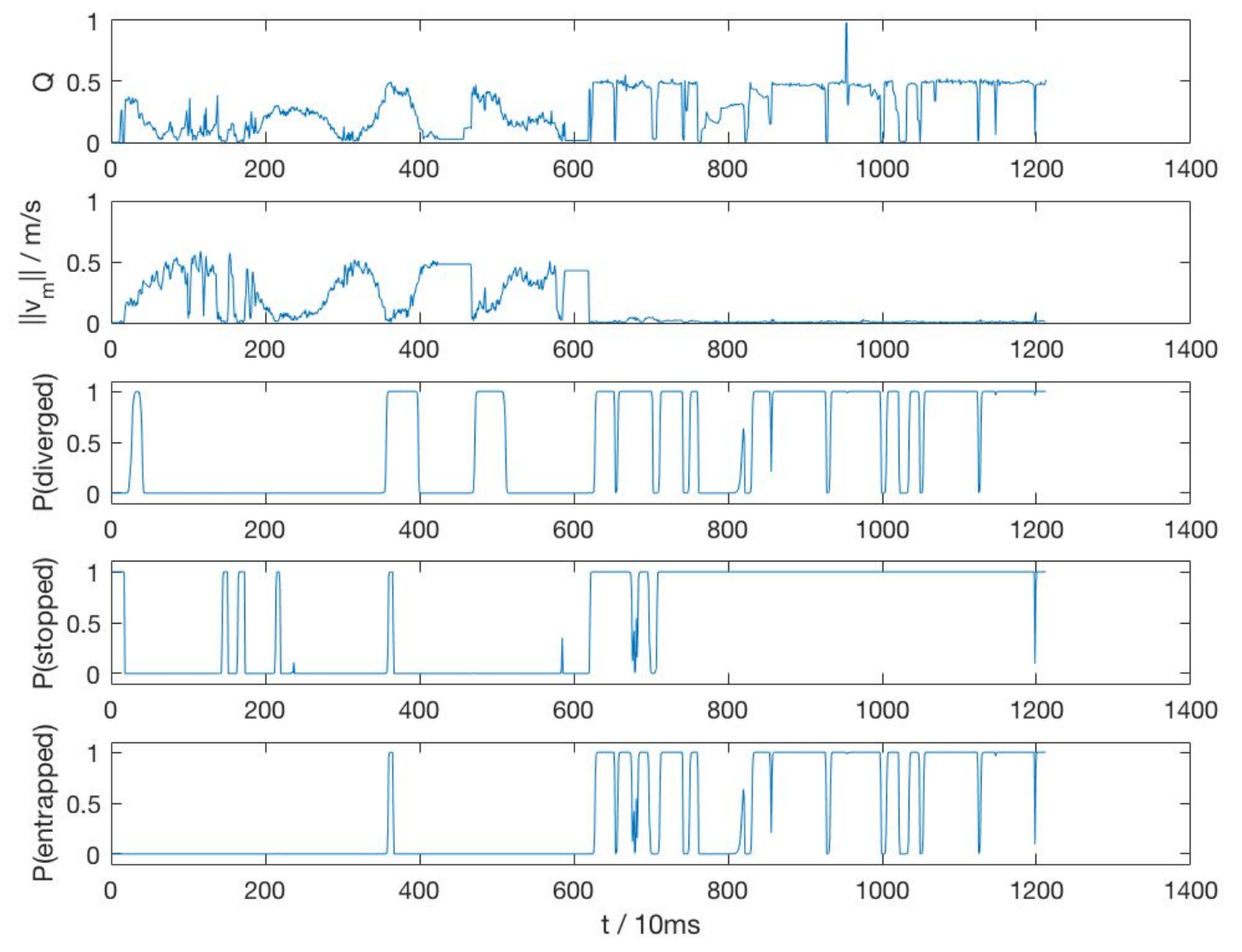
Divergence Status: $\mathbf{Pr}(D|Q) = \frac{\mathbf{Pr}(Q|D)\mathbf{Pr}(D)}{\sum_d \mathbf{Pr}(Q|D=d)\mathbf{Pr}(D=d)}$

$$Q = \sqrt{\begin{bmatrix} e_v & e_\omega \end{bmatrix} R \begin{bmatrix} e_v \\ e_\omega \end{bmatrix}}$$

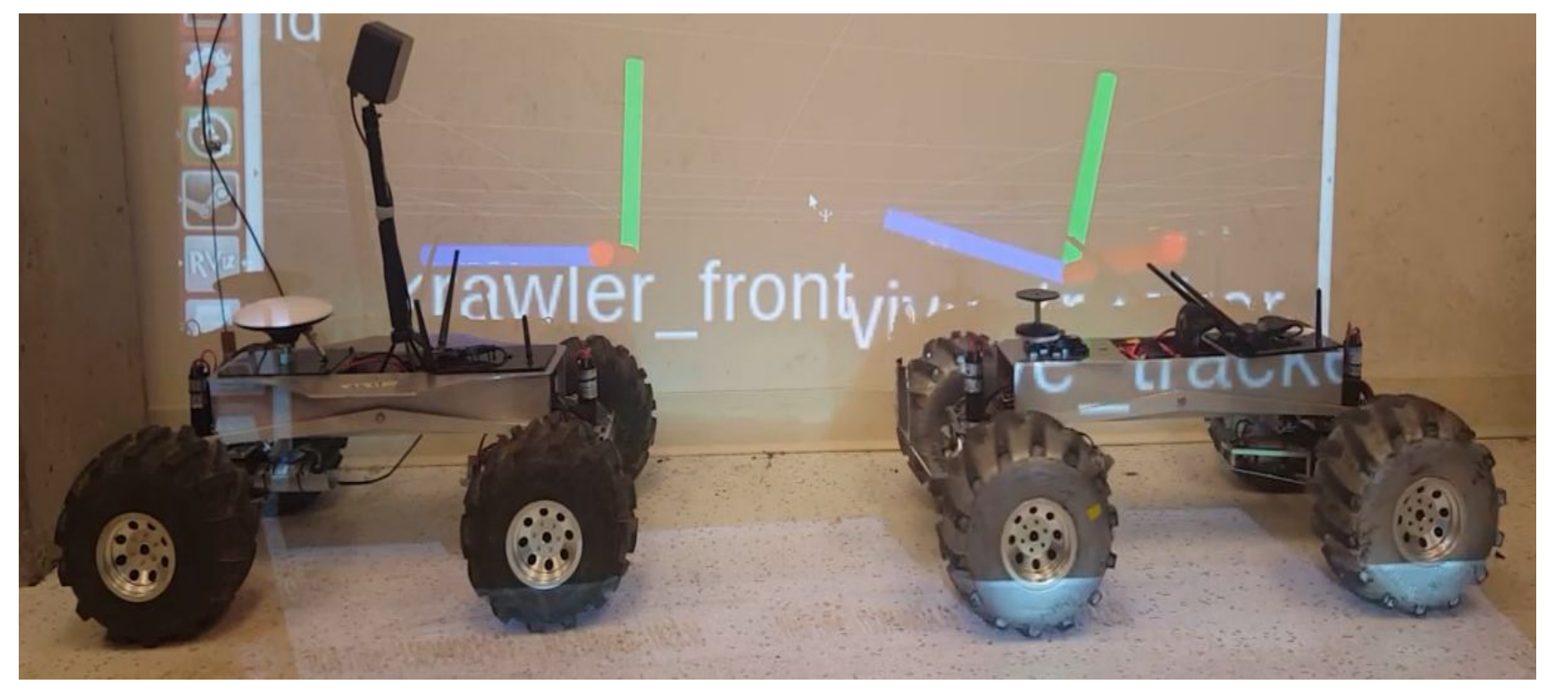
Movement Status: $\mathbf{Pr}(M|\|\mathbf{v}_m\|) = \frac{\mathbf{Pr}(\|\mathbf{v}_m\||M)\mathbf{Pr}(M)}{\sum_m \mathbf{Pr}(\|\mathbf{v}_m\||M=m)\mathbf{Pr}(M=m)}$

Entrapment Status:

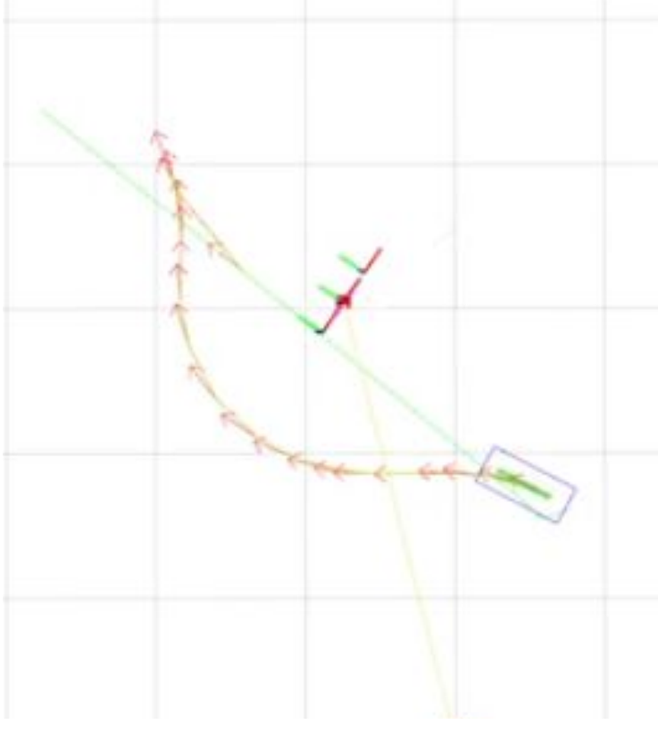
$$\begin{aligned} &\mathbf{Pr}(S = \textit{entrapped}|Q, \|\mathbf{v}_m\|) \\ =&\mathbf{Pr}(D = \textit{diverged}, M = \textit{stopped}|Q, \|\mathbf{v}_m\|) \\ =&\mathbf{Pr}(D = \textit{diverged}|Q)\mathbf{Pr}(M = \textit{stopped}|\|\mathbf{v}_m\|) \end{aligned}$$



Robot Localization & Navigation



Docking requires accurate relative position measurement between the two rovers. This measurement is taken by the HTC Vive Tracker. This provides positional accuracy within 5mm and rotational accuracy within 10°, and a range of 6m, all sufficient for reliable docking.



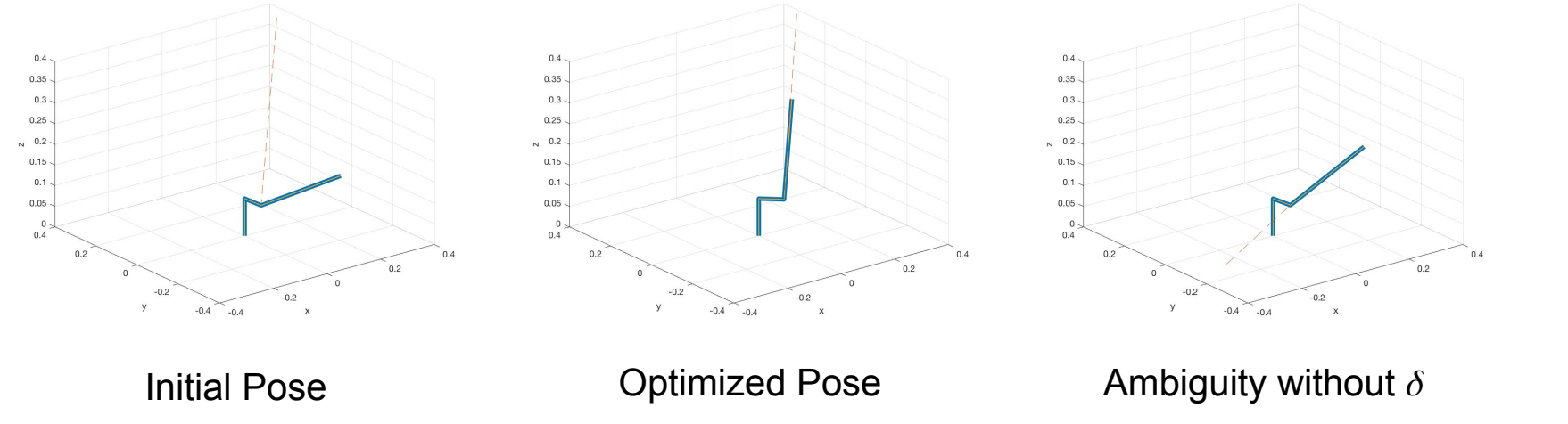
Towing another rover necessitates planning/ re-planning a path to a desired position and orientation while respecting kinodynamic constraints of the rover. Time-Elastic-Band (TEB) planner generates locally optimal trajectories online while avoiding obstacles, minimizing execution time and being compliant with desired velocities and accelerations.

Docking with Claw Manipulator

With the claw manipulator always pointing its end effector (the claw) towards the companion rover's ring, the docking mechanisms of the rescue rover and the entrapped rover shall passively dock, when the rescue rover approaches the entrapped rover.

Objective Function: $L = \frac{1}{2}\delta(\mathbf{v}_e^\mathsf{T}\mathbf{v}_r)\|\mathbf{v}_e \times \mathbf{v}_r\|^2 \quad \begin{cases} \mathbf{v}_e = \mathbf{x}_e - \mathbf{x}_1 \\ \mathbf{v}_r = \mathbf{x}_r - \mathbf{x}_1 \end{cases}$

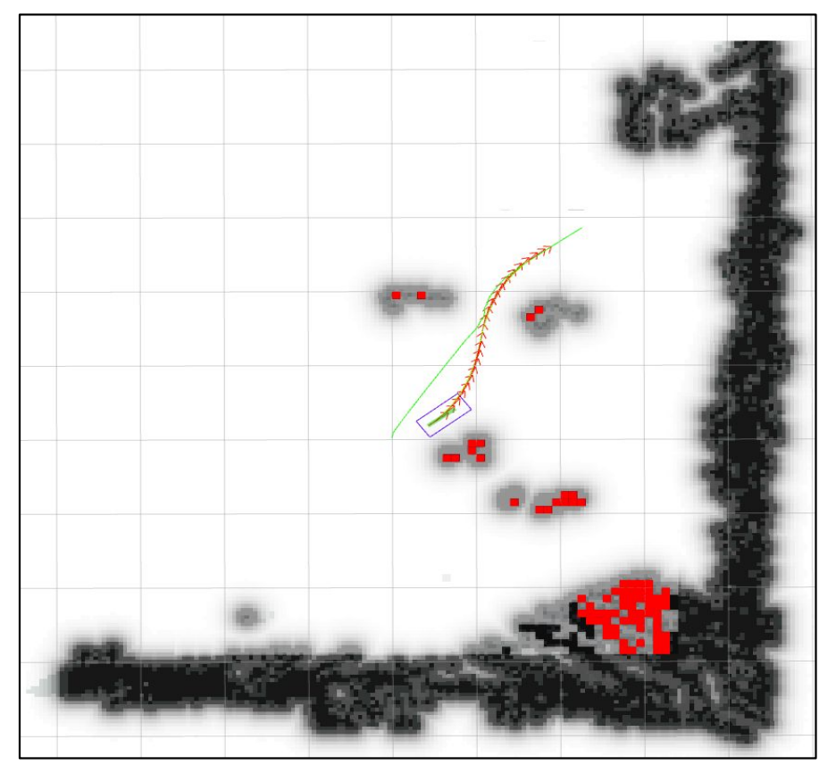
Physical Gradient: $\frac{\partial L}{\partial \mathbf{q}} = \frac{\partial \mathbf{u}}{\partial \mathbf{q}} \frac{\partial L}{\partial \mathbf{u}}$



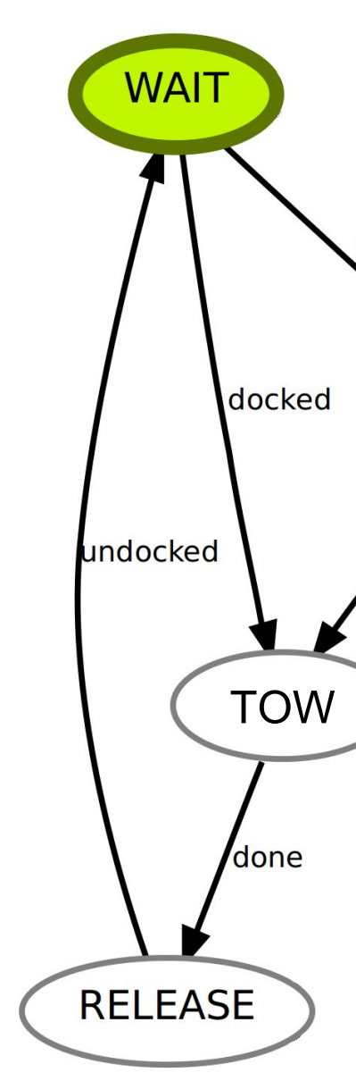
Initial Pose — Optimized Pose — Ambiguity without δ

Dynamic Mapping

To detect environmental obstacles the rovers build a point cloud of their environments using the Intel Realsense D435 depth camera. From the point cloud surface normals are estimated and used to detect high slope features in the terrain. These features are then labeled as obstacles In the map and avoided by the path planner.



State Machine



The rovers use state machine library SMACH to control the high level actions of the robot.

The state machine allows for the disruption or failure of any part of the towing process. The rovers will replan and reattempt the rescue operation until the entrapped rover is freed.

Karthik, Dave, Dan, Abdul, and Matt

References
Qiu, Dicong. "Naive Bayes Entrapment Detection for Planetary Rovers." arXiv preprint arXiv:1801.10571 (2018).
Qiu, Dicong and Paga, Karthik. "Planning for Autonomous Rover Docking." arXiv preprint arXiv:(submission) (2018).