Barefoot Rover – A Sensor-Infused Rover Wheel Demonstrating In-Situ Engineering and Science Extractions Using Machine Learning

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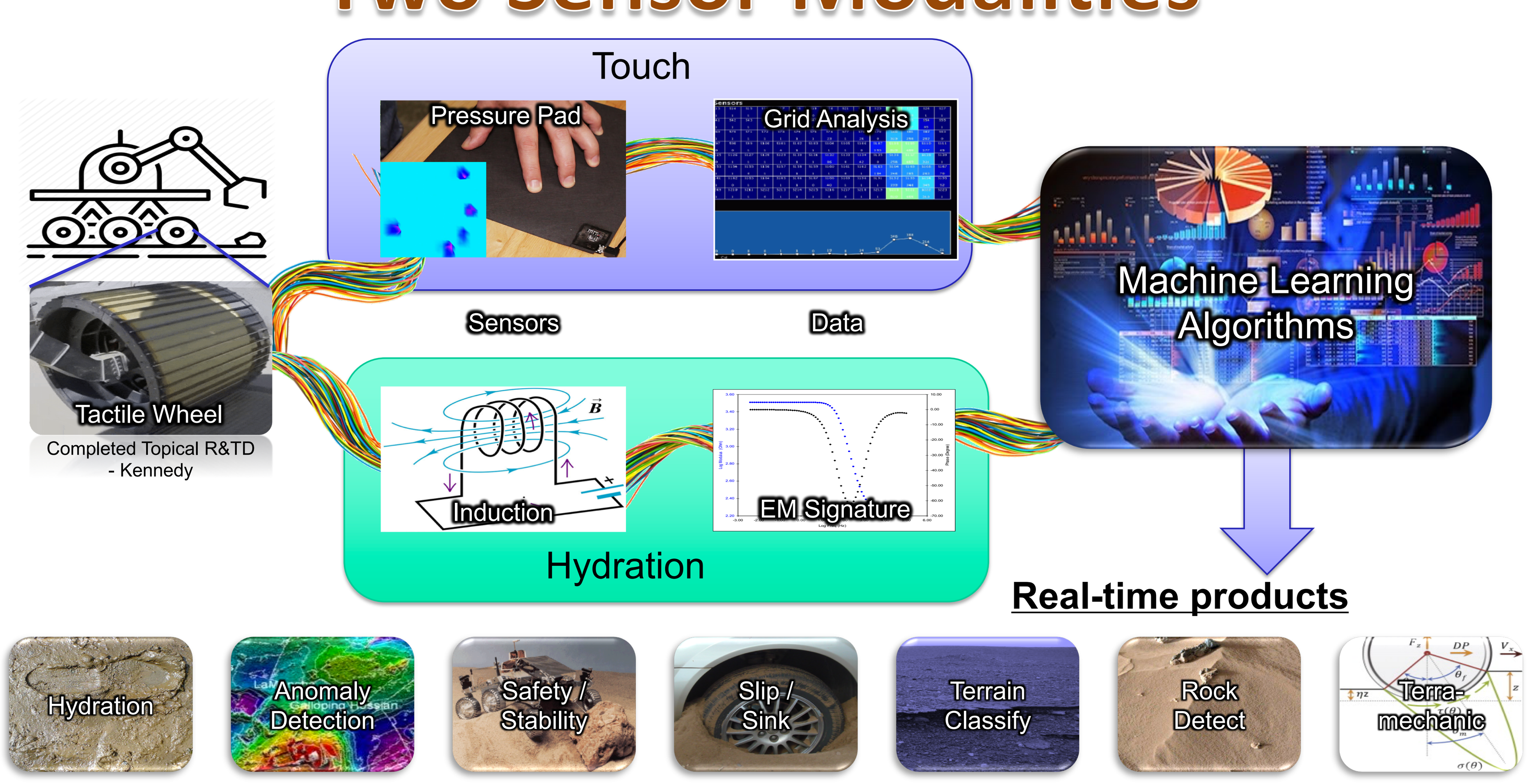
Strategic Initiative

Abstract - In this work, we demonstrate an instrumented wheel concept which utilizes a 2D pressure grid, an electrochemical impedance spectroscopy (EIS) sensor and machine learning to extract meaningful metrics from the interaction between the wheel and surface terrain. These include continuous slip/skid estimation, balance, and sharpness for engineering applications. Estimates of surface hydration, texture, terrain patterns, and regolith physical properties such as cohesion and angle of internal friction are additionally calculated for science applications. Traditional systems rely on post-processing of visual images and vehicle telemetry to estimate these metrics. Through in-situ sensing, these metrics can be calculated in near real time and made available to onboard science and engineering autonomy applications. This work aims to provide a deployable system for future planetary exploration missions to increase science and engineering capabilities through increased knowledge of the terrain.

Two Sensor Modalities



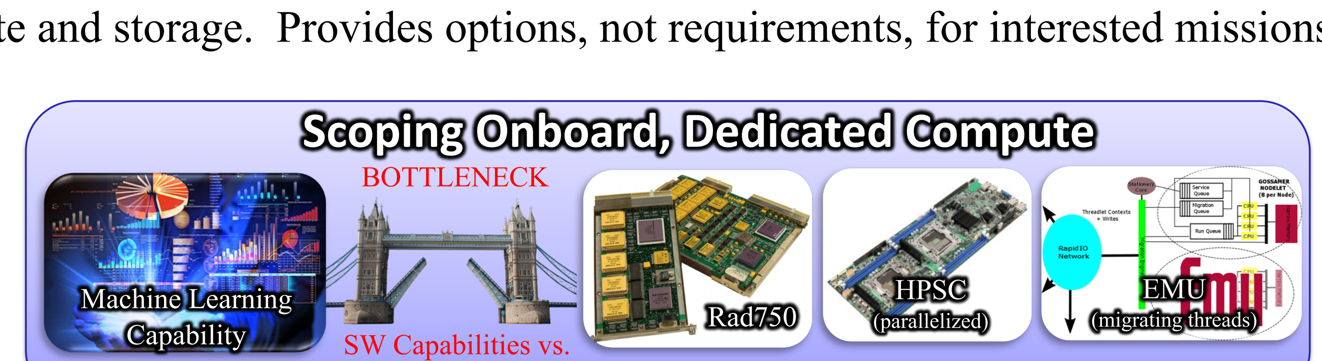
Data Science Objectives

Map real-time sensor wheel data to products useful to science, stability, and environmental awareness.

- Terrain types (3 sand coarseness, 3 water/sand mixes, 3 rock morph.)
- Slip detect (10% distance)
- Dangerous pressure/sharp detection
- Near loss-of-balance detection
- Soil hydration (to 10% weight)

Quantifying Onboard Compute Needs

- As missions move toward baselining onboard analysis capabilities, they seek system requirements for compute / storage / duty cycles.
- Quantifying system performance on RAD750 (baseline) / High Performance Spaceflight Computer (multi-core / SIMD) / EMU (Processor in Memory)
- Generating performance curves to show system capabilities as a function of available compute and storage. Provides options, not requirements, for interested missions.



Objectives

- Data collection on mobility simulant sands (M2020 Simulants / Mars Mojave)
- Introduce surface patterns, rocks, hydration, vehicle slip/sink in known locations/quantities.
- Train collection machine learning classifiers to each handle a component of the terrain model (material detection / slip estimation / rock density / hydration percentage, etc.)
- Develop near real-time system for data collection, alignment, featurization and prediction.

Methods

- Data are obtained from the pressure pad and EIS:
  - **Time series** of pressure pad contact area
  - **Images** of the pressure pad profiles matched to the gravity vector vs time
  - EIS amplitude and phase for various frequencies
- Trained models are traditional Gradient Boosted Trees with engineered image and time-series features as inputs.

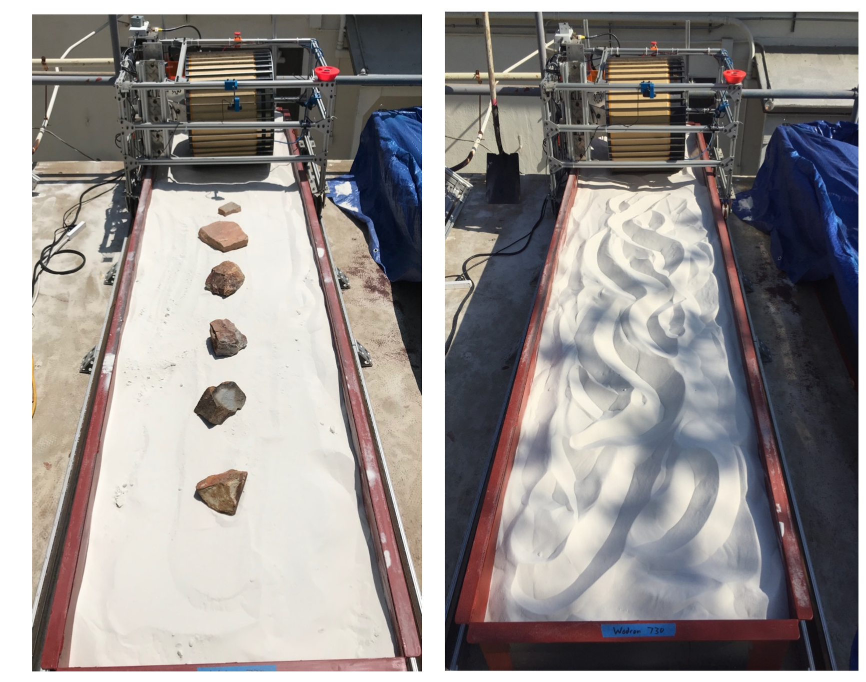
Results

- Rock detection: **92%** (accuracy)
- Slip: **~8%** (test error)
- Surface patterns: reasonably predicting pebbles, dunes and flat areas.
- Possibility of predicting buried rocks.

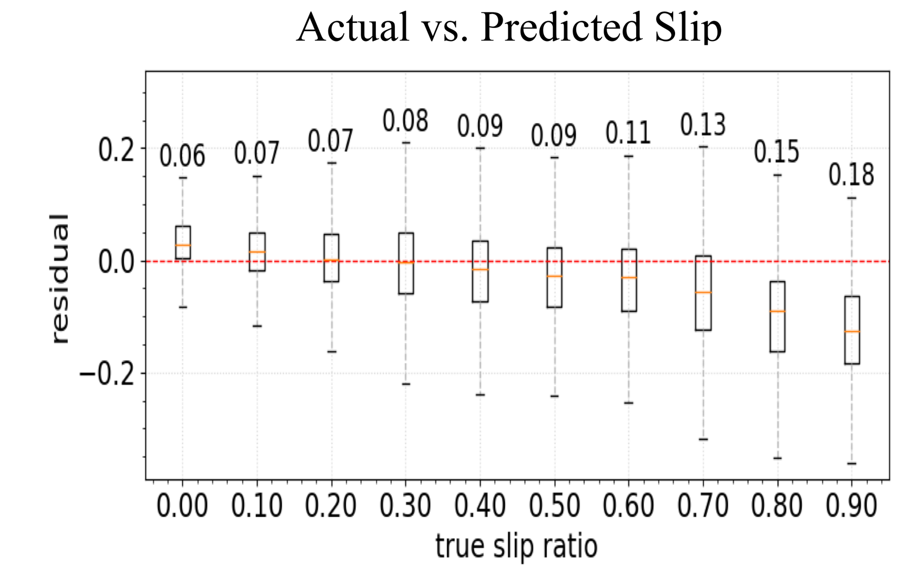
Conclusions

- Machine learning can enhance the performance of in-situ sensors.
- Autonomous instrumentation provides new capabilities for vehicle monitoring and science extractions.
- In-situ sensors provide new, and necessary, feedback loops for future onboard autonomy applications.

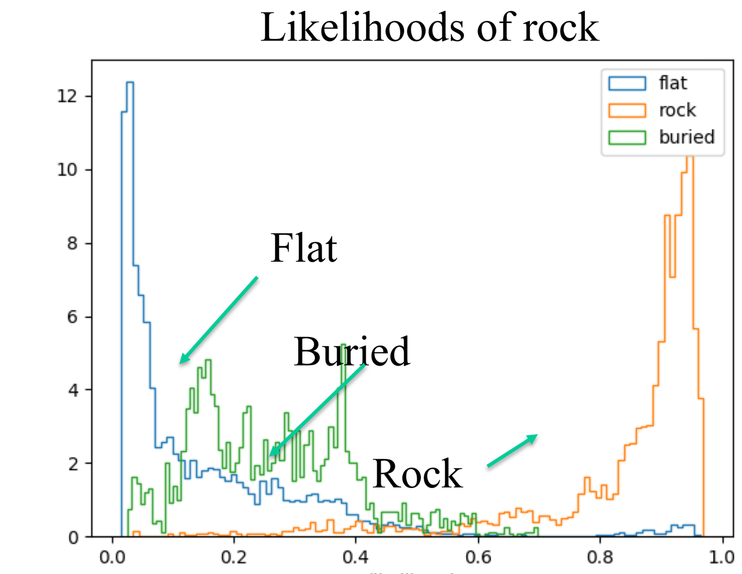
Data Collection Testbed



Actual vs. Predicted Slip



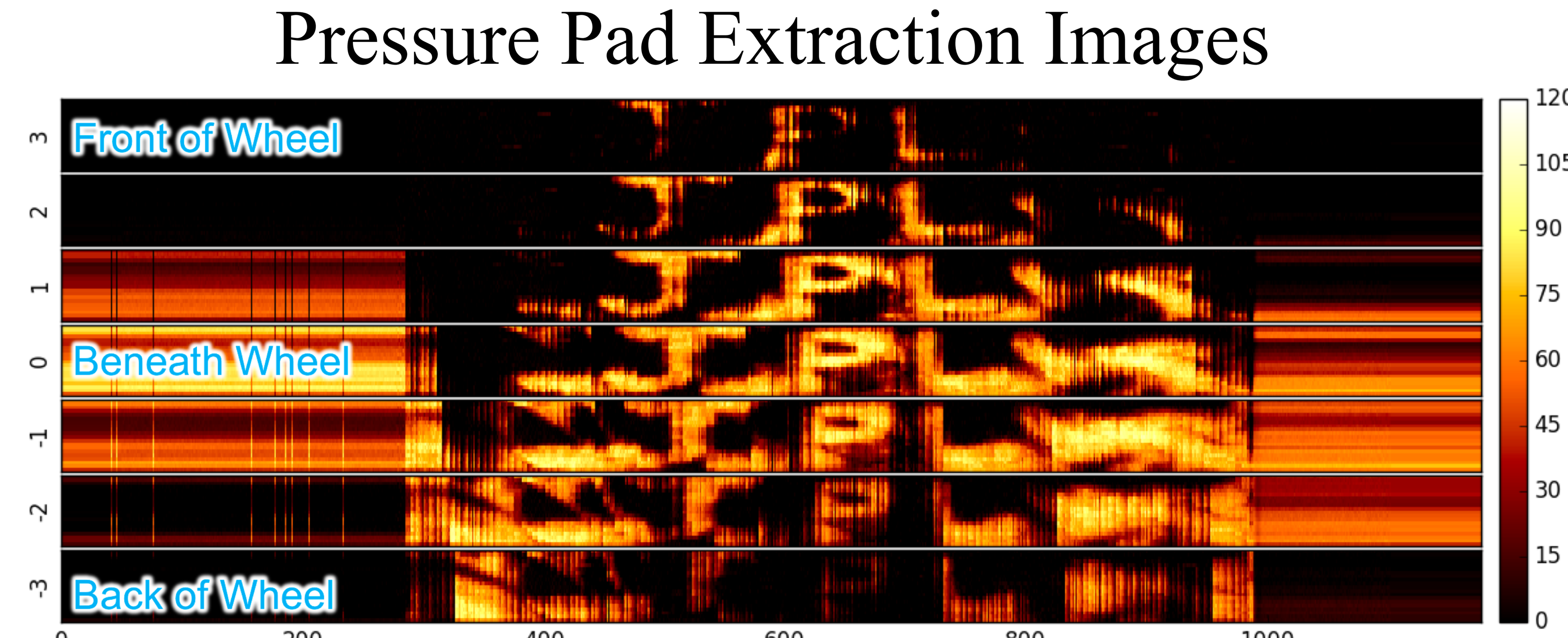
Likelihoods of rock



Infusion & Applications

- Ice road /beachfront stability assessment with autonomous scout vehicles.
- Lunar/Martian vehicle wheels, enabling drives longer than the visual viewshed.
- Inclusion of new sensors, such as neutron spectrometers, which provide complementary geochemical measurements for science/engineering.

Pressure Pad Extraction Images



Publications:

Barefoot Rover: a Sensor-Infused Rover Wheel Demonstrating In-Situ Engineering and Science Extractions using Machine Learning - ICRA 2020- International Conference on Robotics and Automation (Acceptance Pending)

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Poster No. RPC-229