The Barefoot Rover

“When you walk with naked feet, how can you ever forget the Earth?” – Carl Jung

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Jet Propulsion Laboratory, California Institute of Technology

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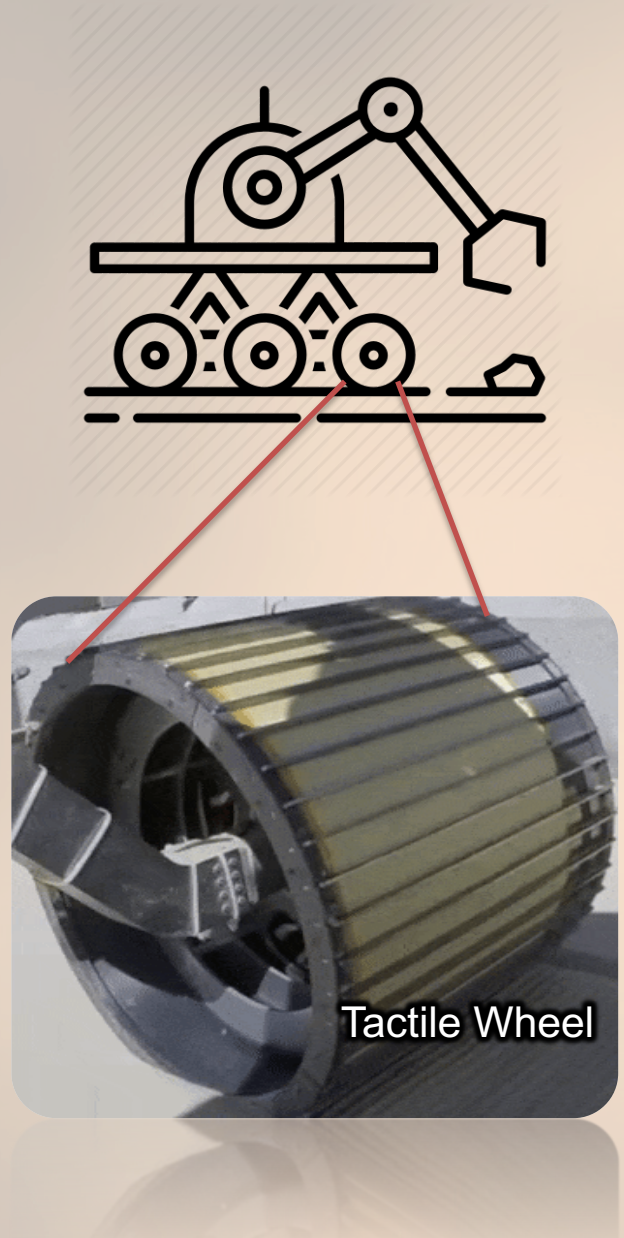
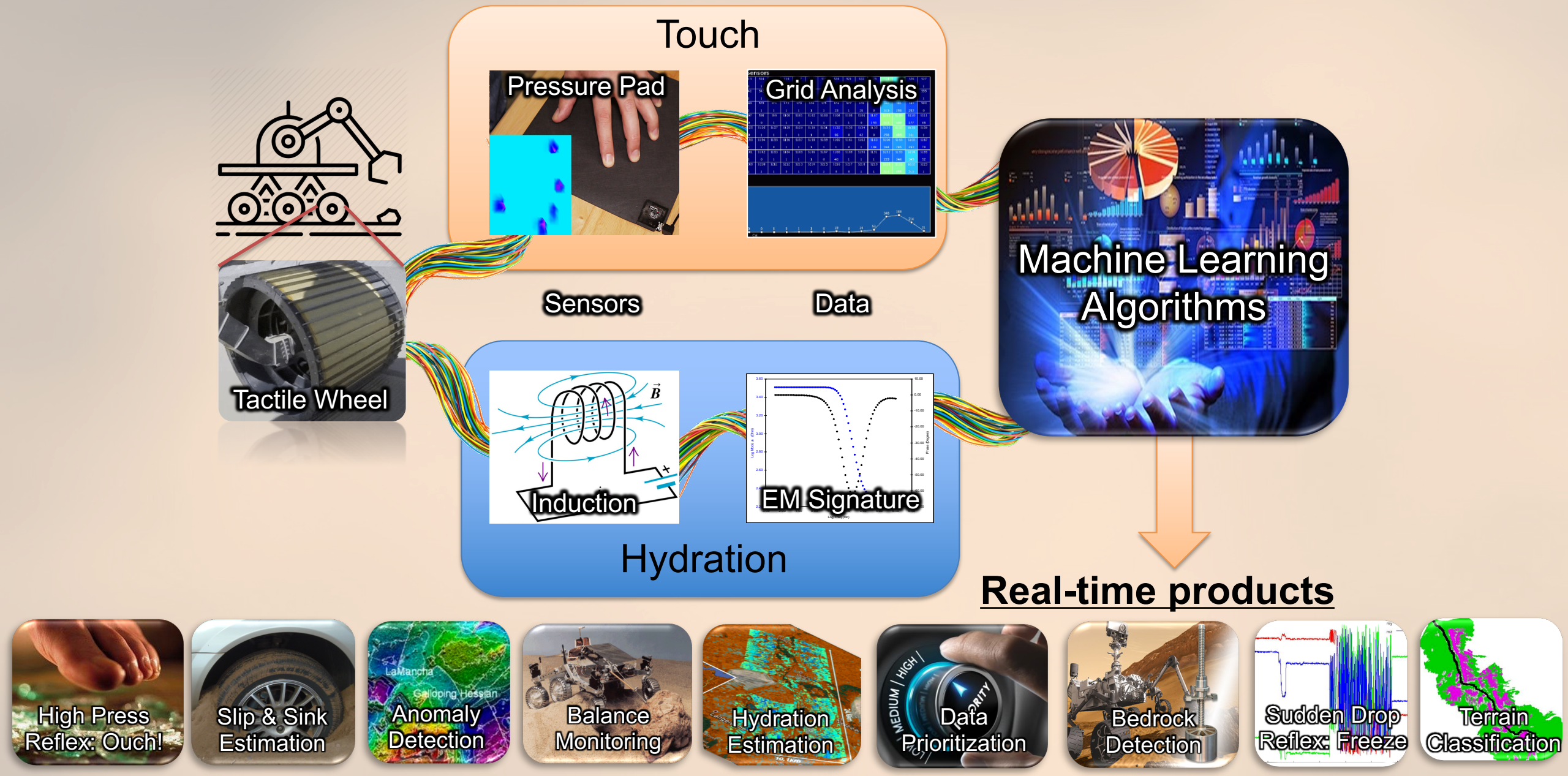
Barefoot Rover Technology



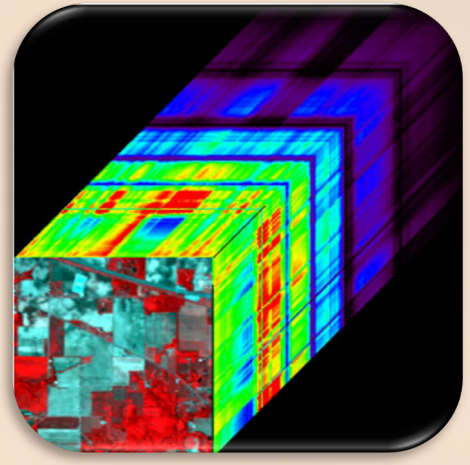
- A sensor-infused vehicle wheel which uses machine learning to predict the status of the world around it.
  - Soil hydration level prediction
  - Vehicle slip/sink state
  - Terrain composition estimation (bedrock, pebbles, sand)
  - Surface feature estimation (buried rocks, dunes, gullies)
- High level summarizations made by the wheel computer can be fed into autonomous vehicle decision making systems.
- Works in no-light conditions, a unique capability in autonomous vehicles.
- Anomaly detection, monitoring for states which haven't been observed before. Data prioritized for transmission to operators, which can either define the new state for the vehicle, or treat the prioritized data as an anomaly. Provides focus of attention.
- In-situ sensors allows the vehicle to "feel" the world around it. These insights support autonomous complex decision making in evolving environments.

Two Sensor Modalities



Software Technical Approach

Rotating sensor-wheel takes continuous pressure and hydration measurements as wheel rolls.



2D (spatial) + 1D (time) dataset = data cube

Three simultaneous approaches:

Pattern Recognition

- Computation: Moderate
- Sharpness, balance, terrain classification, rock ID
- Tech: Texturecam, tuned thresholds

Model-based Inference

- Computation: Light-Mod
- Retrieves sand grain size, hydration level, etc.
- Tech: Established literature methods

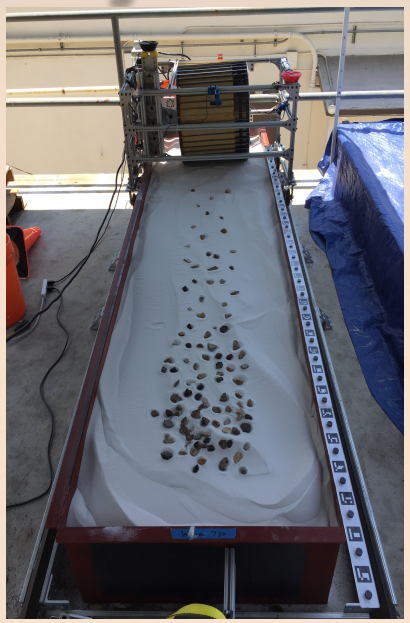
Image Time Series

- Computation: Heavy
- Slip & Skid detection, soil properties
- Tech: Adapt existing hyperspectral methods / Deep Learning CNN's

Data Collection for System Training

- Training data is collected to build machine learning models, each capable of identifying the soil / hydration / surface feature they were trained on.

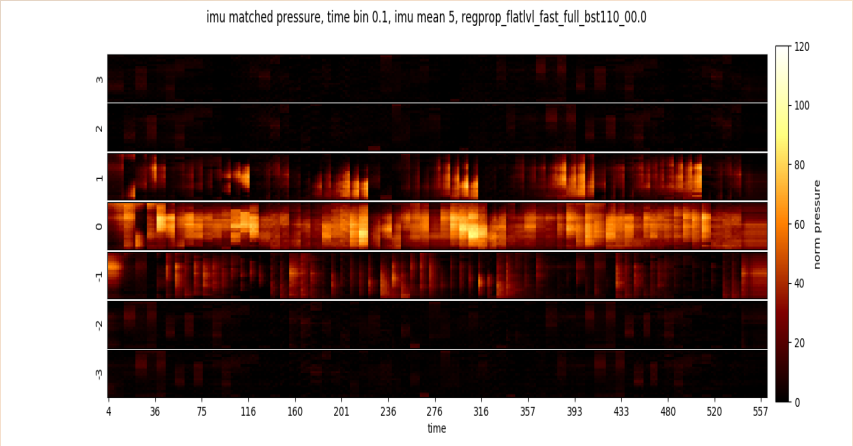
- New training models are built to enable new capabilities.



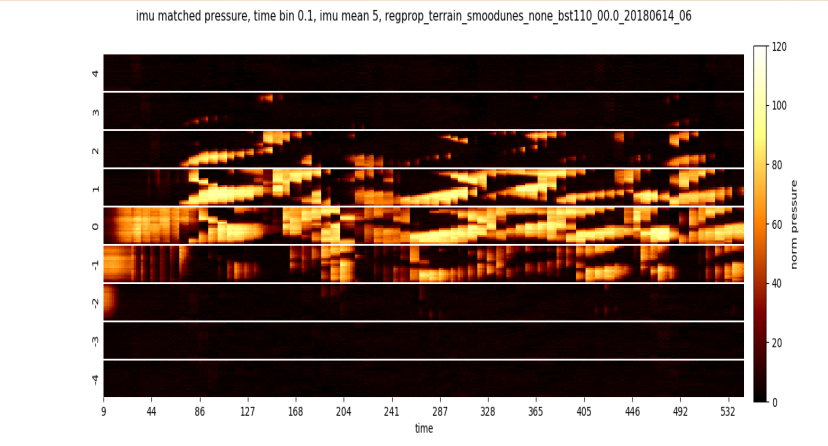
Pressure Grid Extractions

Images extracted from the pressure grid sensor data can capture a variety of terrain and engineering features.

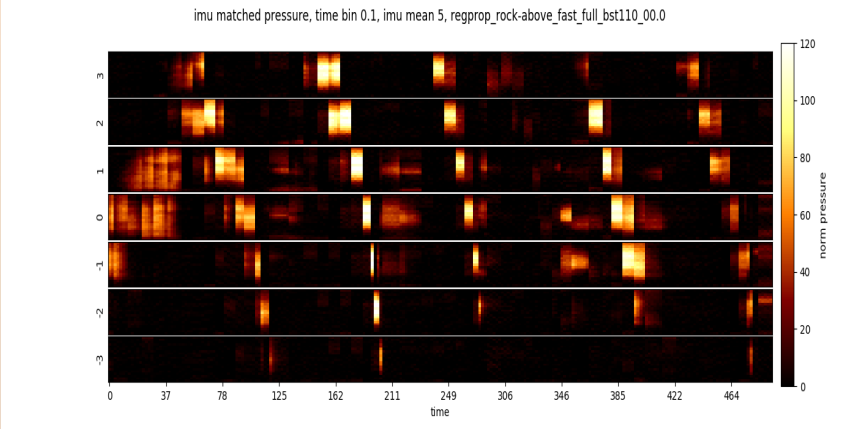
Flat Terrain



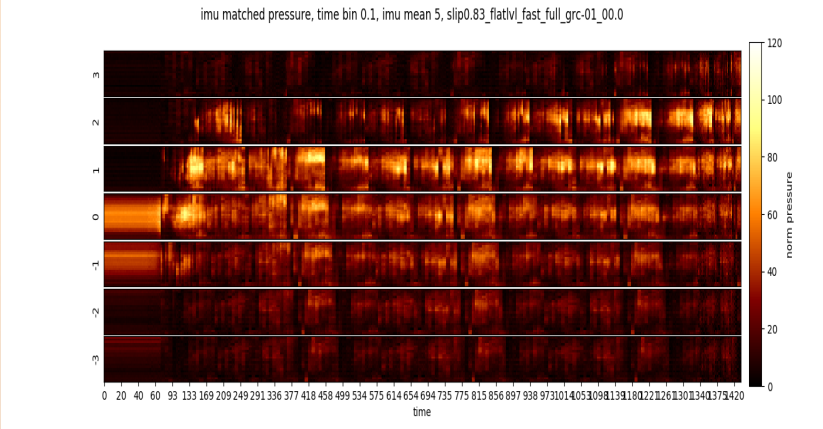
Smooth Dunes



Rocks

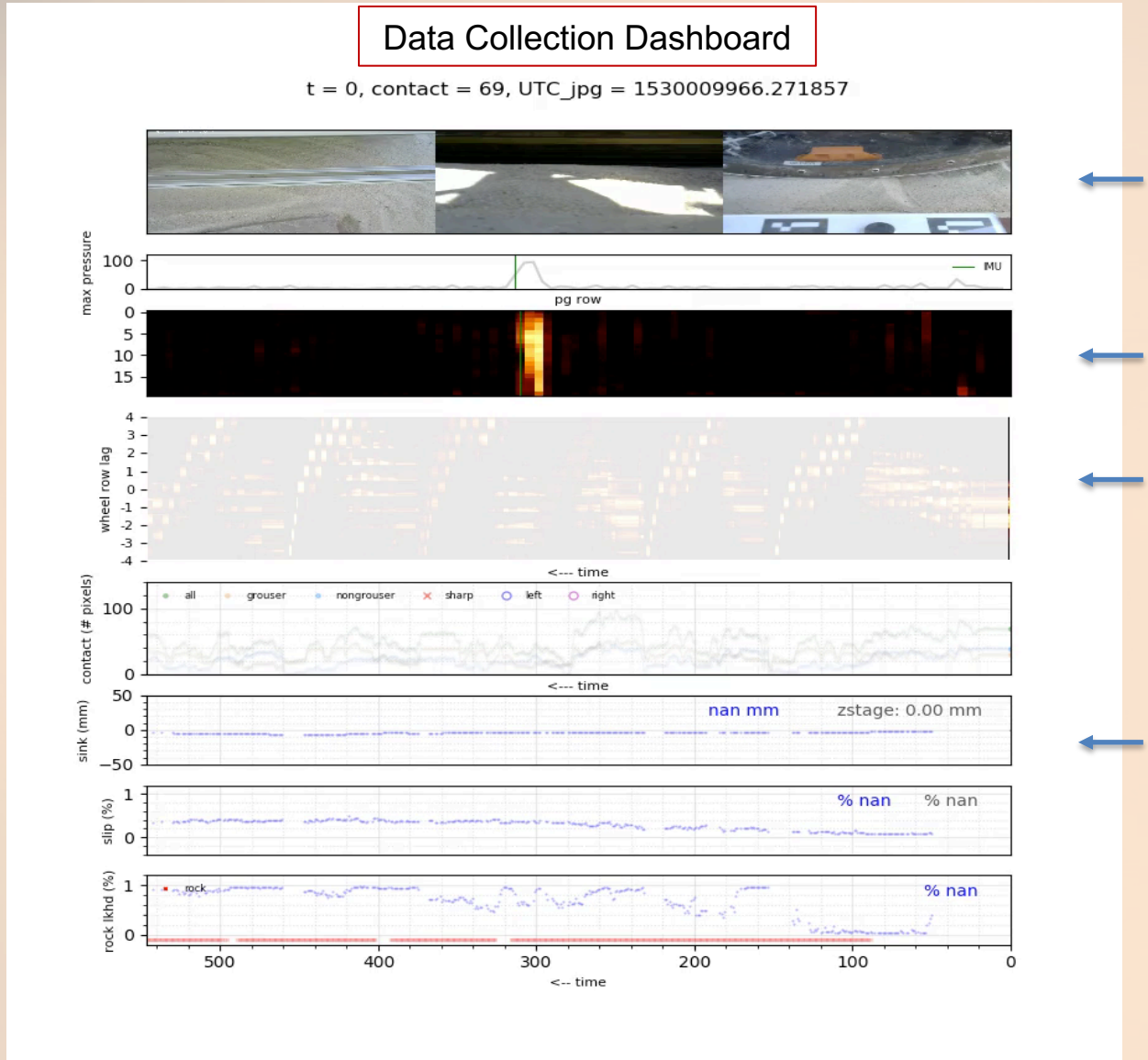


High Slip



Experimental Dashboard

Focus of attention data for operators.



Video cameras

Pressure grid imprint

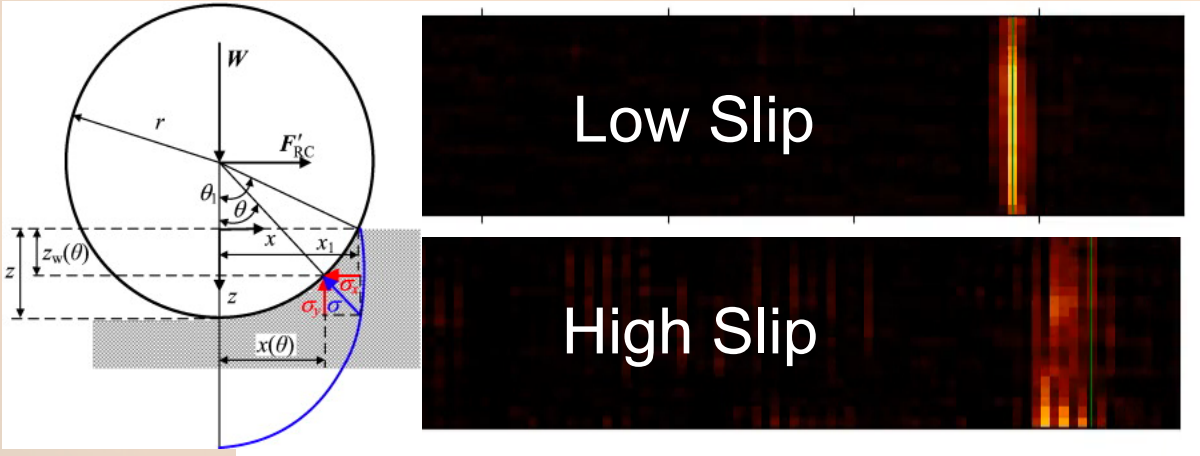
Extracted image

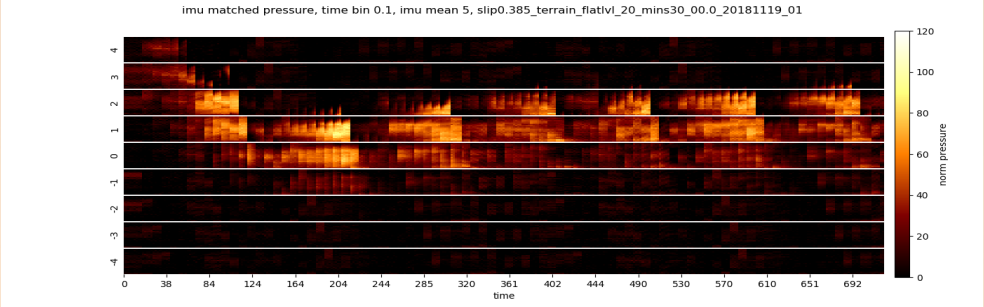
Computed and actual metrics: contact area, slip, sink, rock

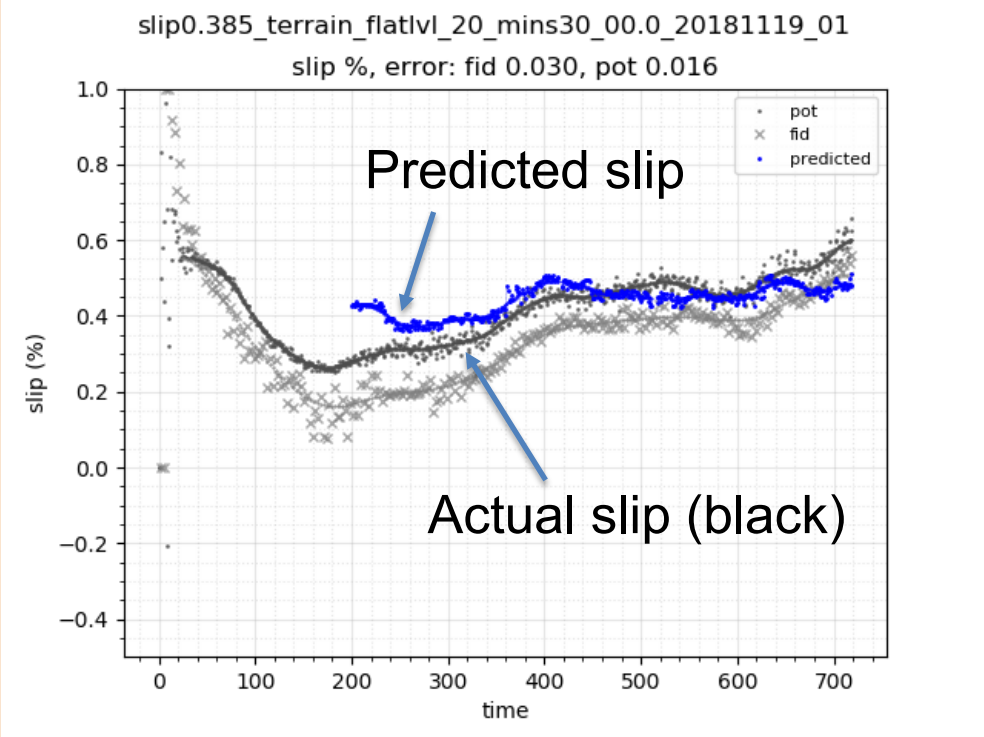
Wheel Data Determines Slip & Sink Rates

Slip predicted with ~6% accuracy. 4% improvement on visual systems and works in no-light environments.

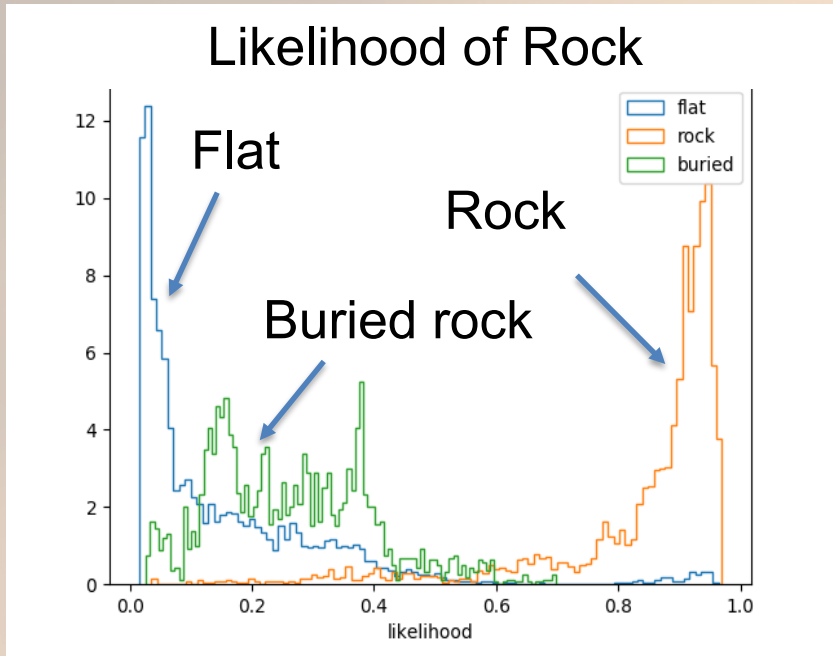
Sink estimation is a model-based extraction from the pressure grid. Informs autonomous traversability.







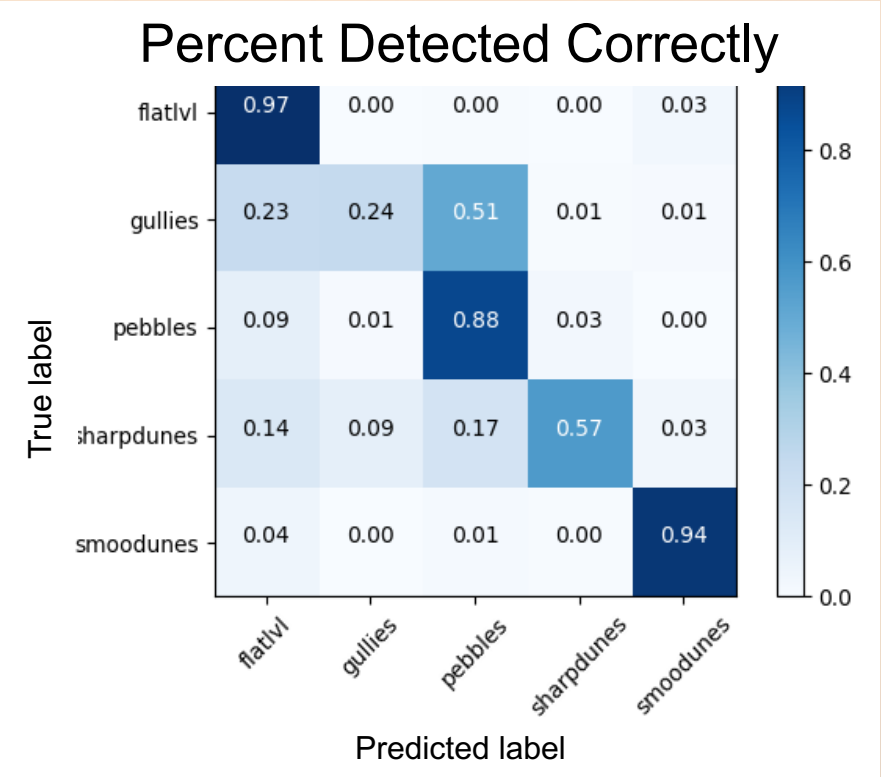
Rock / Surface Pattern Detection



Rock detections for above-ground and buried rocks.

Surface patterns and terrain classification:

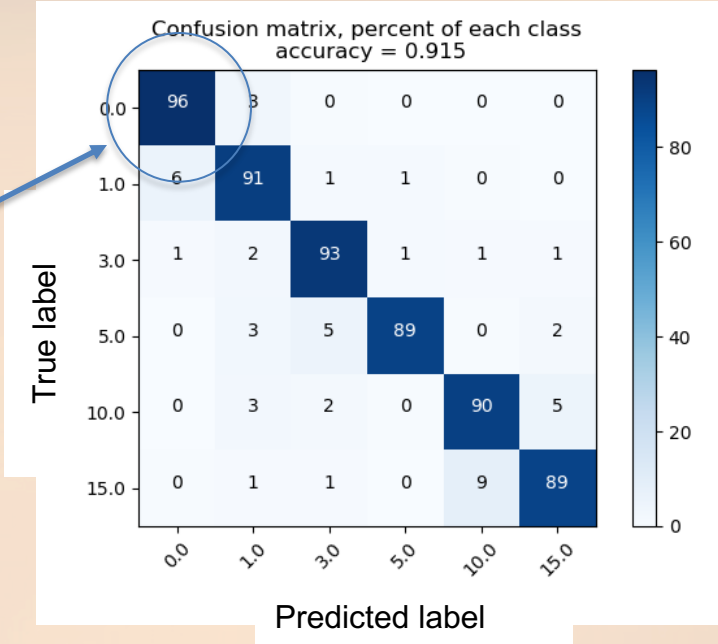
Are you driving on dunes, pebbles, gullies or something else?

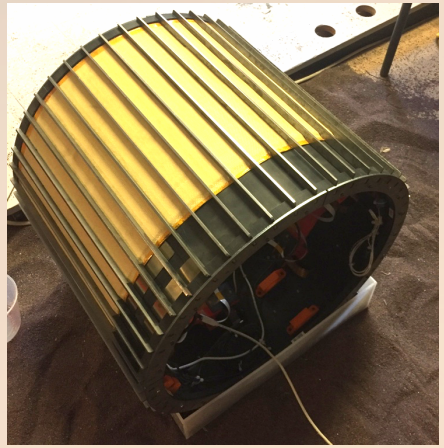


Hydration Prediction

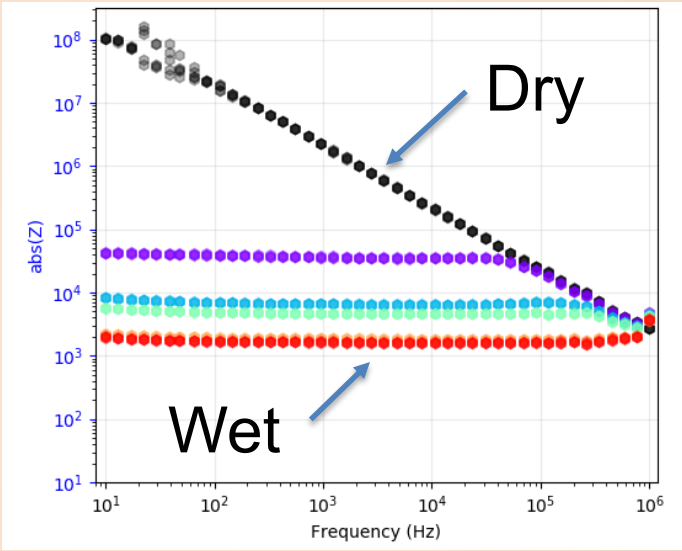
Successful hydration prediction for stationary experiments.

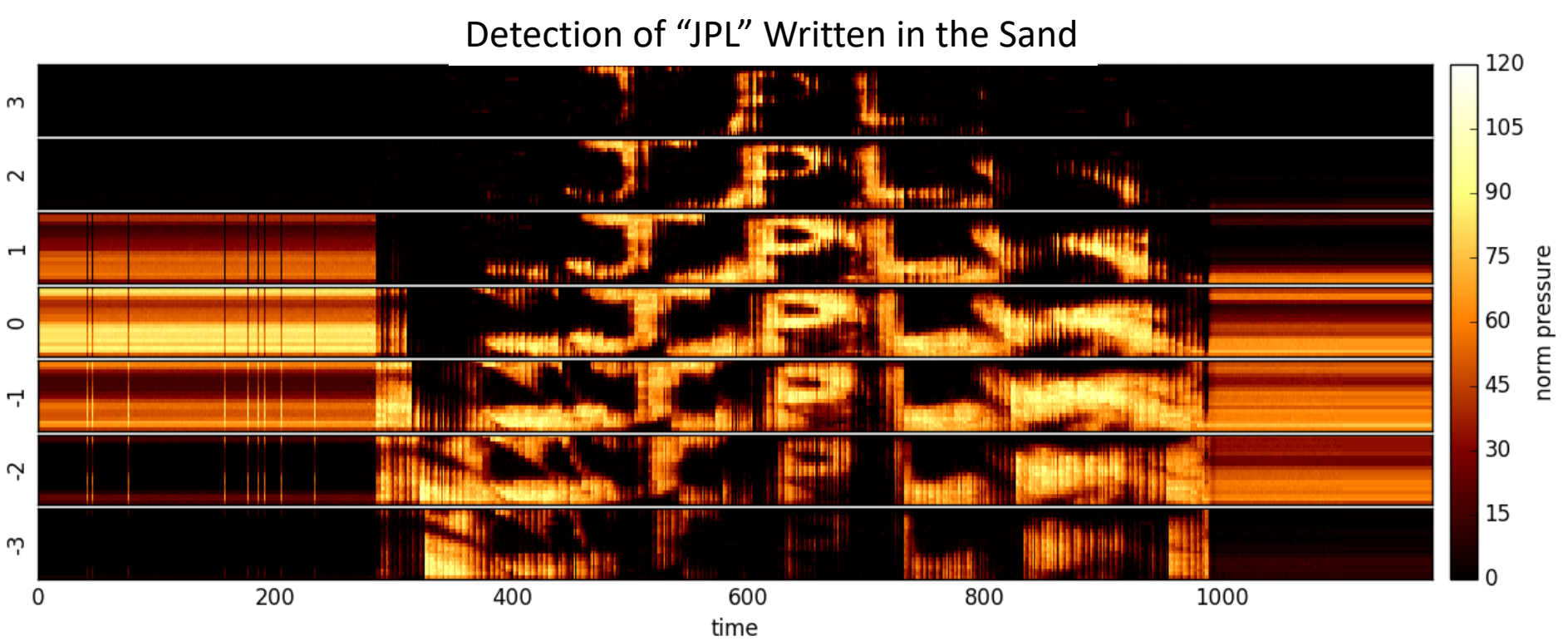
Wet vs Dry
96% correct





	Accuracy (%weight)	# sand/water ratios
Goal	10%	3
Achieved	1% (Dry vs Wet)	6
Achieved	2% - 5% (Wet)	6



Summary

- In-wheel sensors, paired with machine learning, can provide unique data extractions for autonomous vehicle applications.
- Pressure / EM Induction sensing provide insights about terrain composition and hydration in no-light environments, further enabling autonomous vehicle traversibility.
- Supplemental wheel-infused sensors enable autonomous search/mapping robots to perform tasks not suited for humans.
    - Example: Neutron spectroscopy for autonomous landmine detection.