Modular AI for Faults: Local Watch and Efficient Response

IEEE Aerospace Conference 2025

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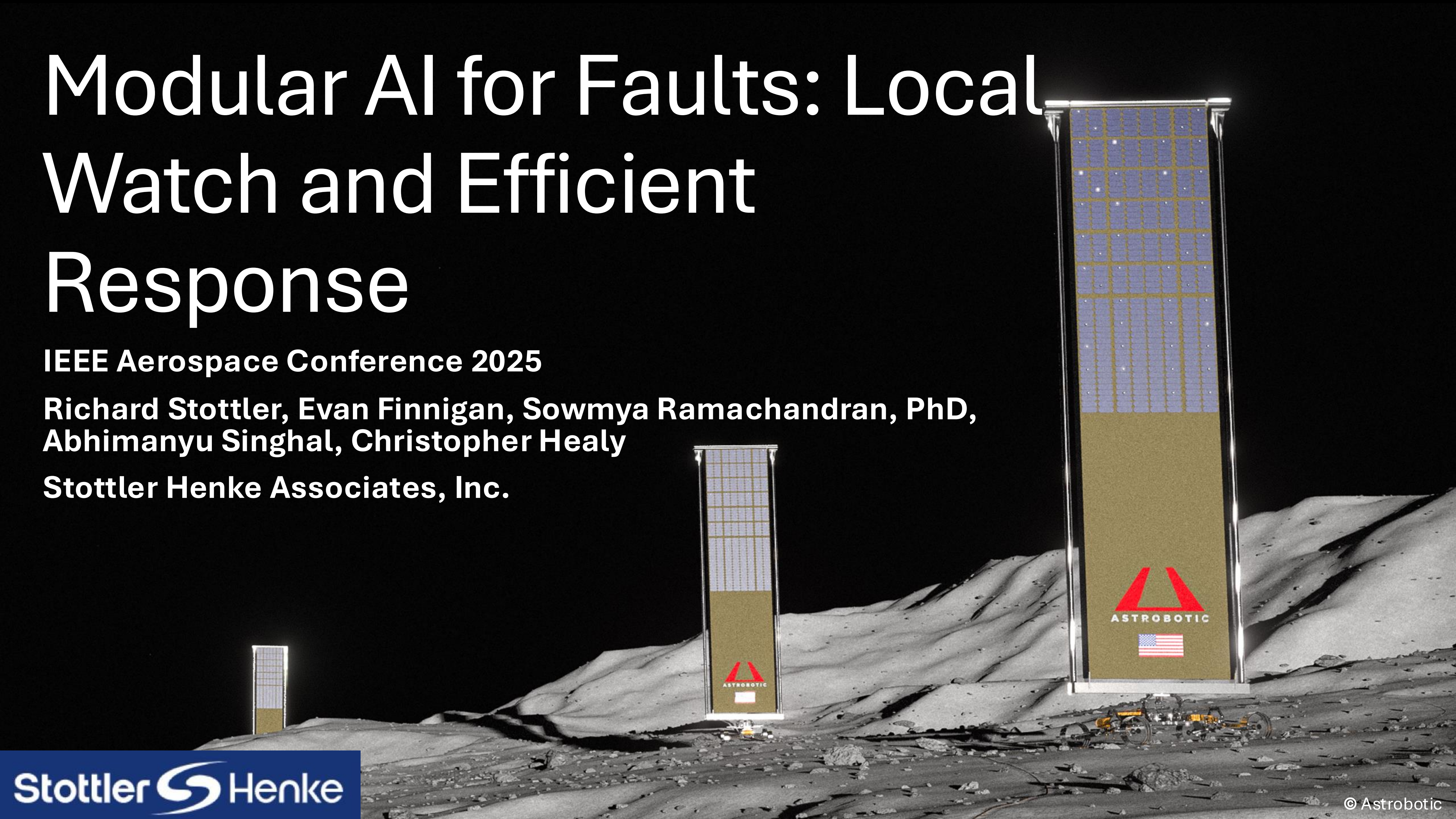

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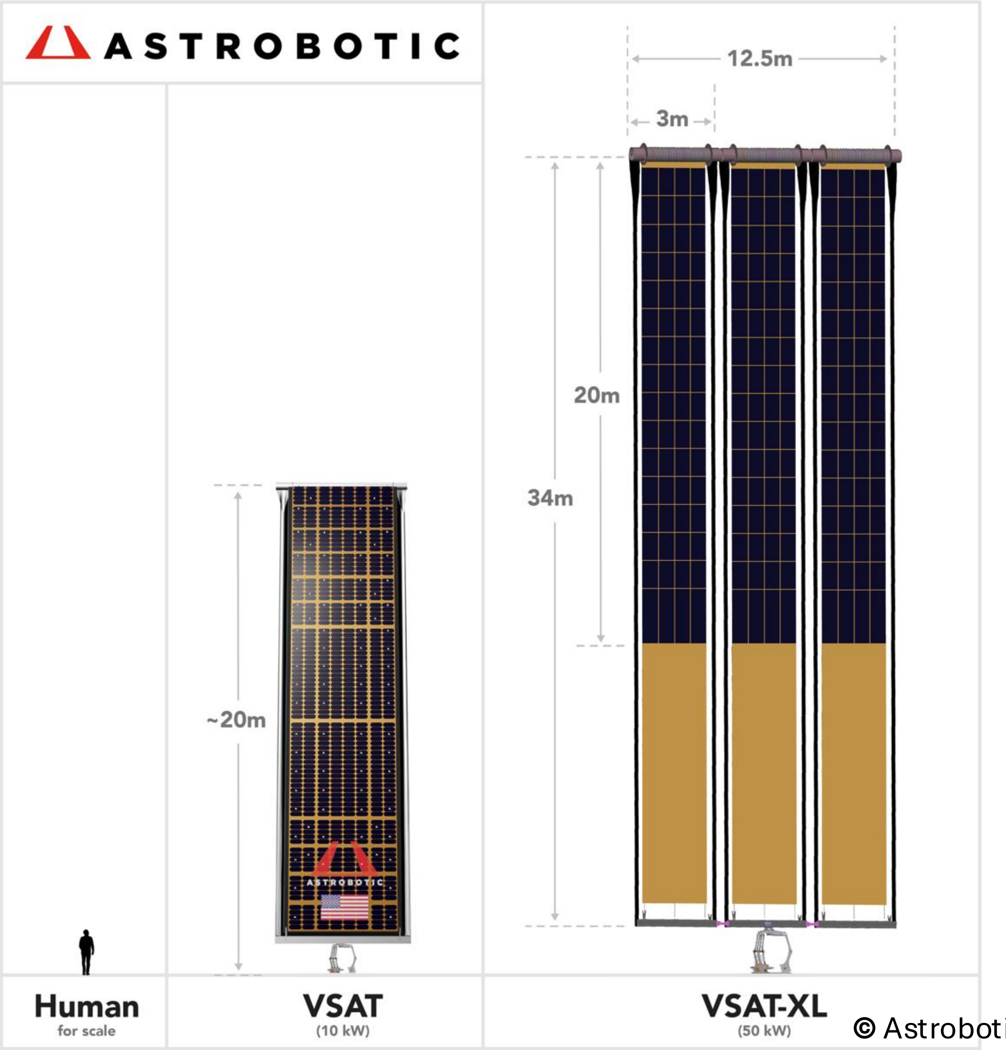
Overview

- The VOLT’s mission on the Moon
- Faults that can affect the VOLT’s mission success
- Our hybrid fault detection approach
- Fault detection example
- Applications and future work

The Lunar Power Grid for Persistent Operations on the Moon

- VOLT will power the LunaGrid which will provide power for manned and unmanned operations on the lunar surface

Overview of the Vertical Solar Array Technology for Lunar Traverse (VOLT)



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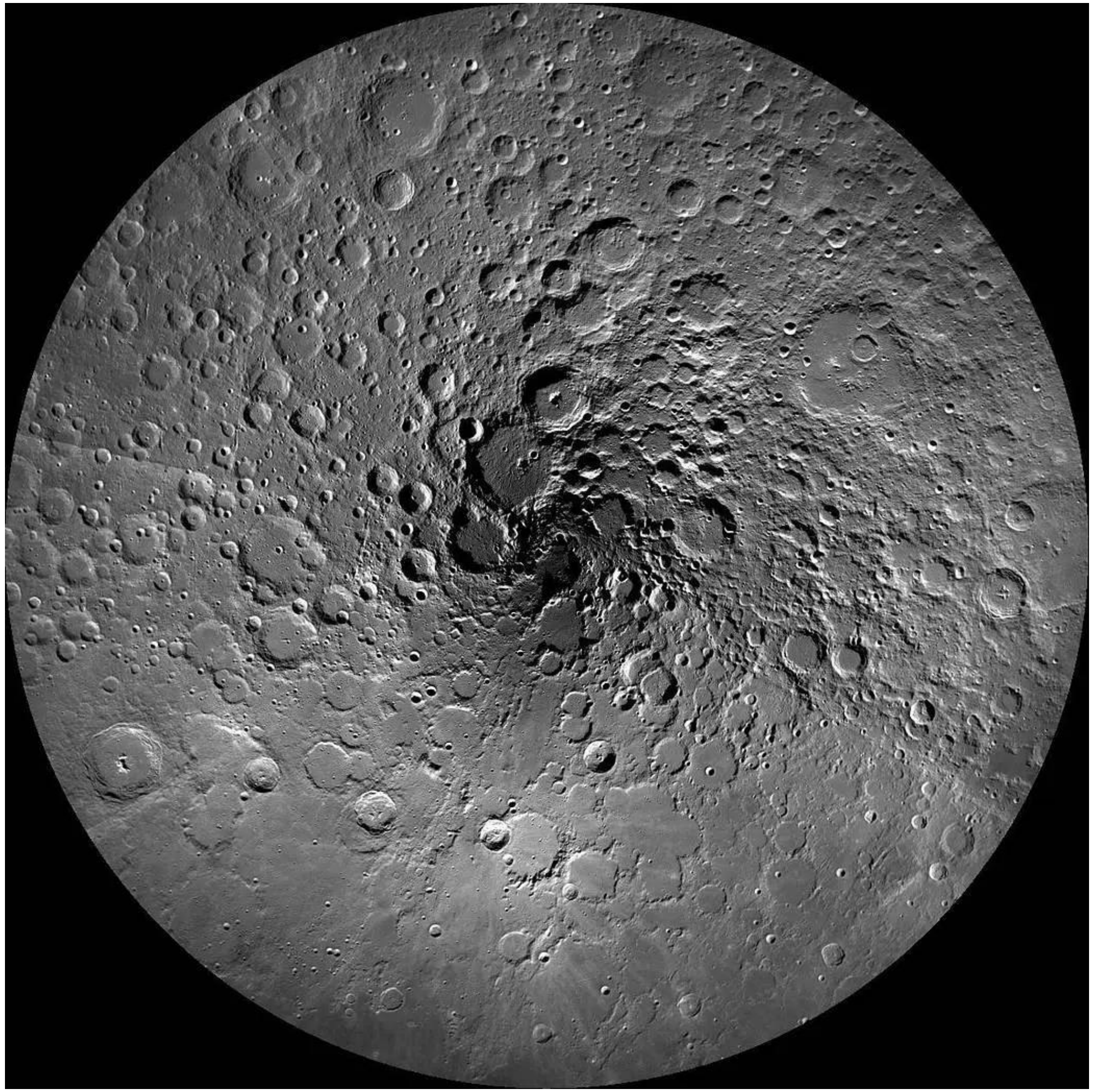
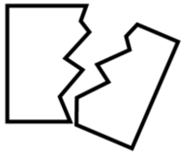
The Hazardous Environment of the Lunar South Pole

- Temperatures as low as -203° C
- Lunar dust and mega-regolith can damage rovers
- VOLT will need to navigate to a raised location to enable the ROSA to avoid lunar shadows. These raised locations typically are also inclined, increasing the risk for tipping.



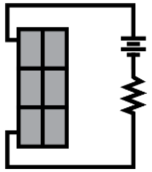
Faults That Can Affect the VOLT Mission

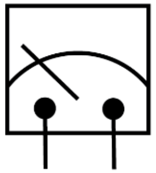
Critical faults that could cause VOLT to tip



- Soil slipping or soil collapse causes one or more rover wheels to fall, which could destabilize the VOLT
- ROSA leveling error before deployment could cause the ROSA to deploy at an unsafe angle

Secondary fault types

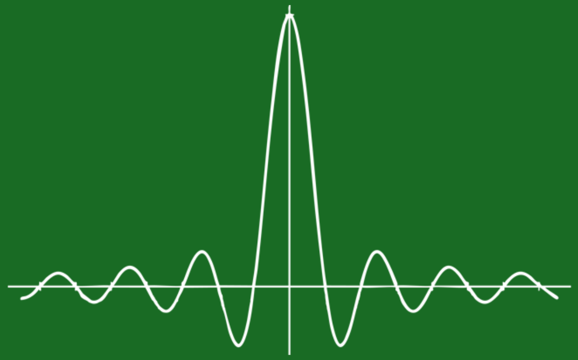




- Electrical Power System (EPS) faults can affect the solar panel modules that make up the ROSA as well as other components of the VOLT EPS
- Sensor errors could cause a false positive for a rover tipping scenario

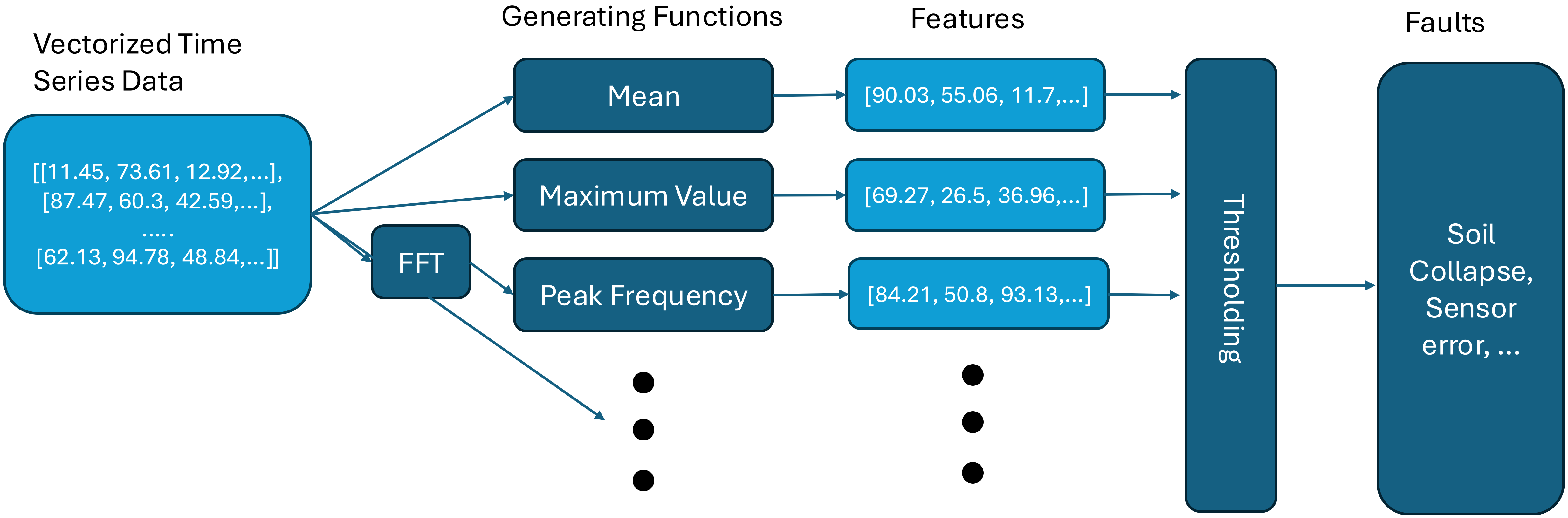
Generalized Hybrid Fault Detection and Diagnosis

Model-based reasoning encodes the schematic information of subsystems, normal behavior and known abnormal modes. During operations, MBR simulates expected behavior and detect aberrations.

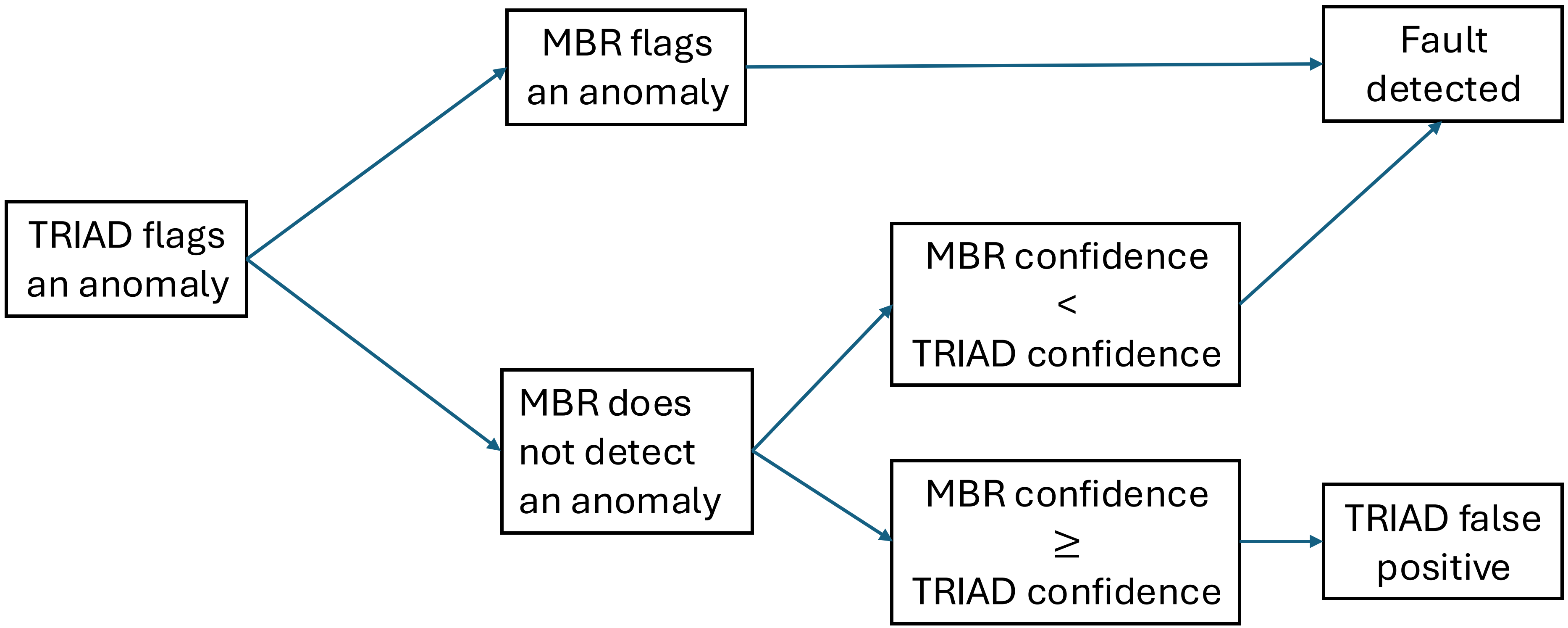


TRIAD (Thermodynamic Reasoning Intelligent Anomaly Detection) is a model-free fault detection module that creates feature encodings and then performs threshold-based detection to find off-nominal behavior.

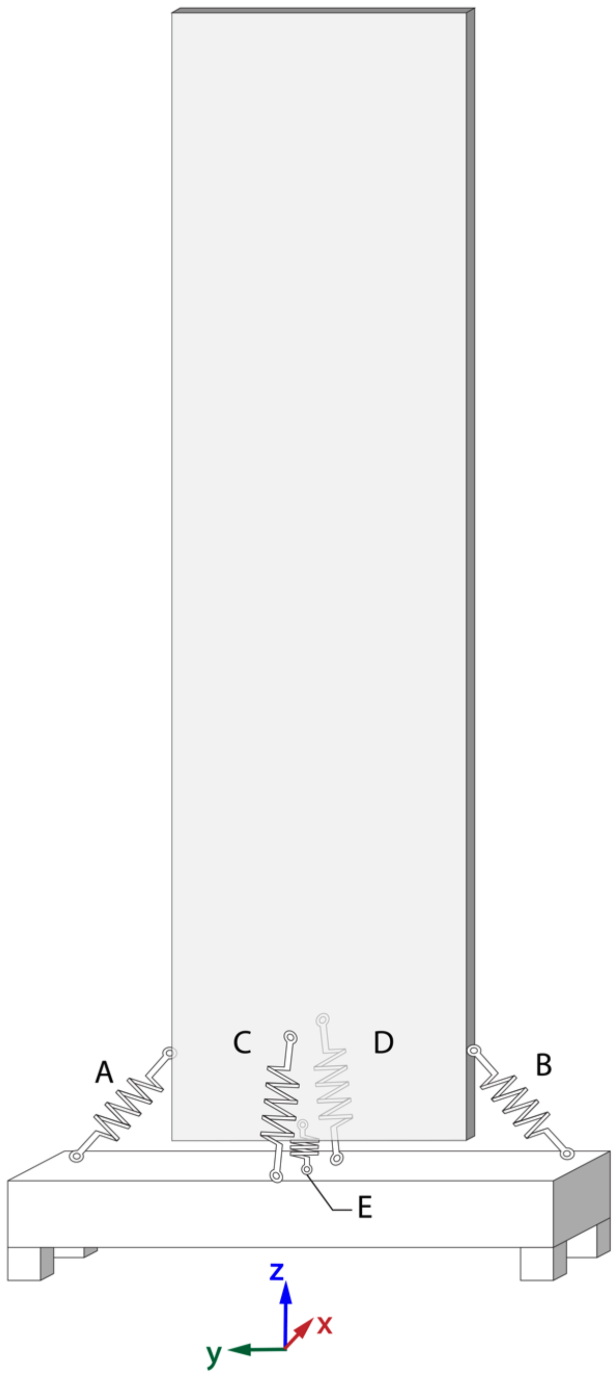
Thermodynamic Reasoning Intelligent Anomaly Detection



Handling TRIAD False Positives



Simulating the VOLT to generate synthetic data



- The ROSA is modeled as an inverted pendulum attached to sets of spring

Advantages

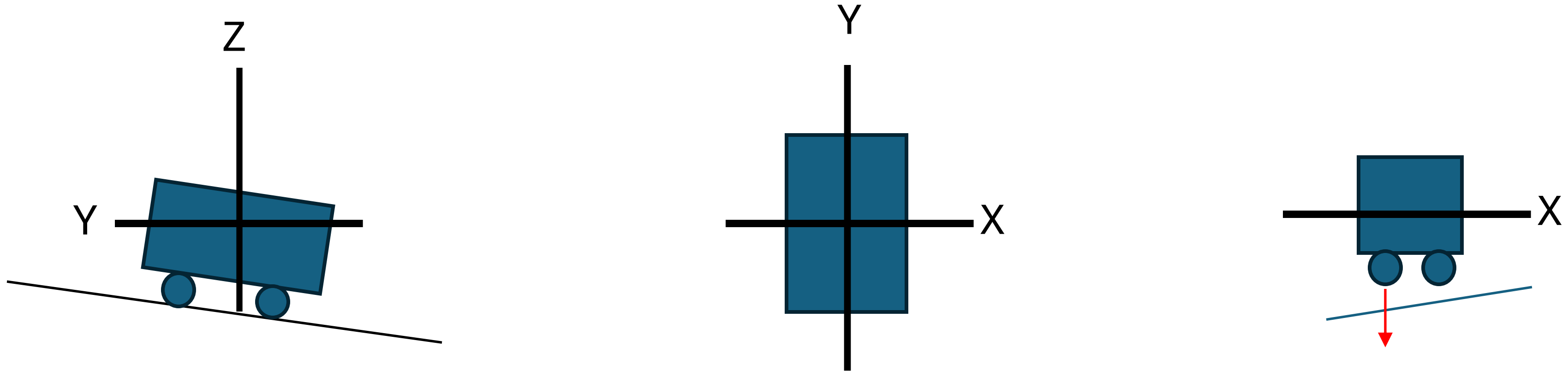
- **Hybrid** approach leverages both model-based and learning based algorithms
- MBR can **provide evidence** for diagnosis

Disadvantages

- MBR models must be **manually designed** based on rover schematics
- TRIAD can detect faults without being trained on them before, but **cannot diagnose faults that do not appear in the training data**

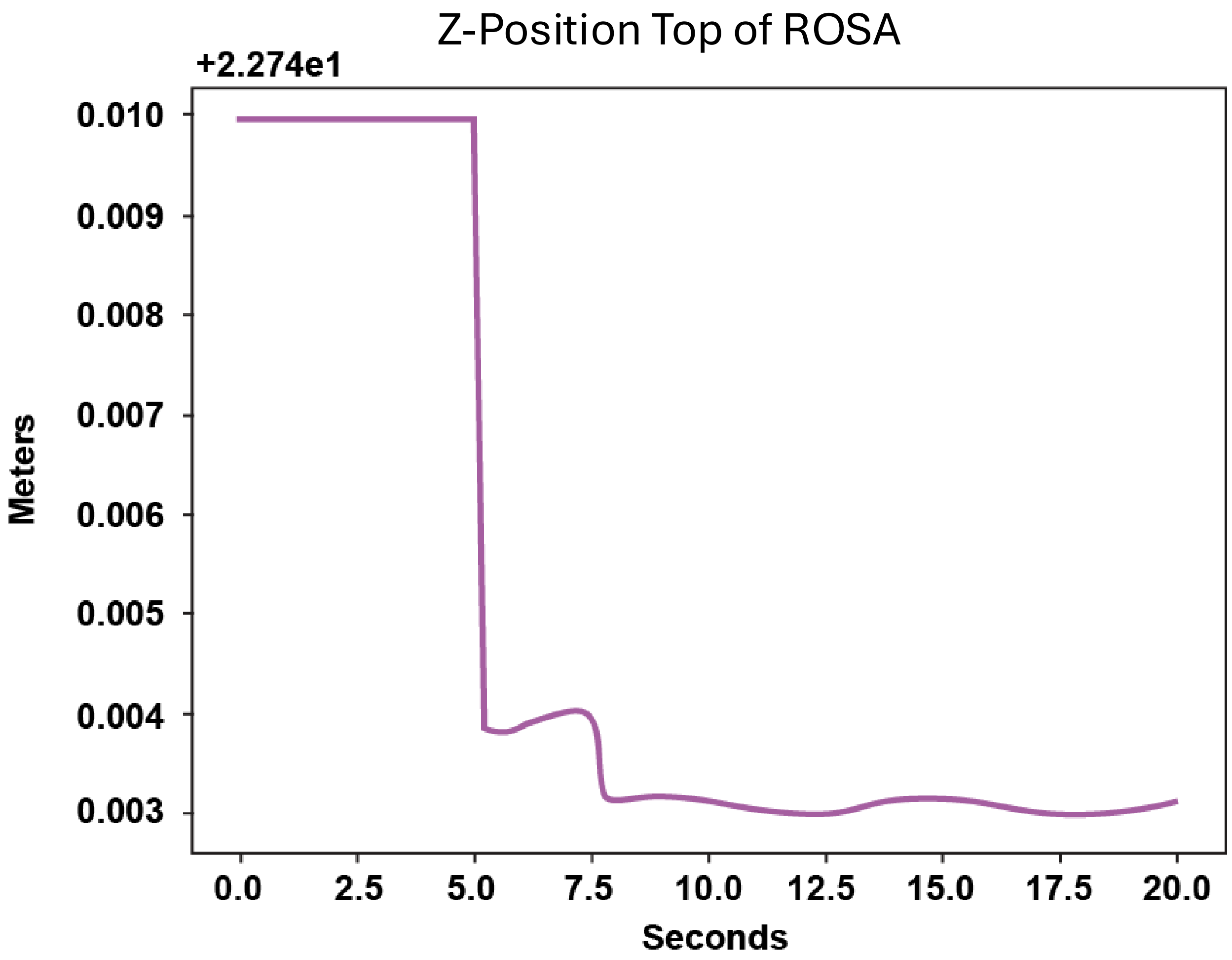
Asymmetric Soil Collapse Example

- Soil collapses under all wheels except for the front left wheel



Asymmetric Soil Collapse Example

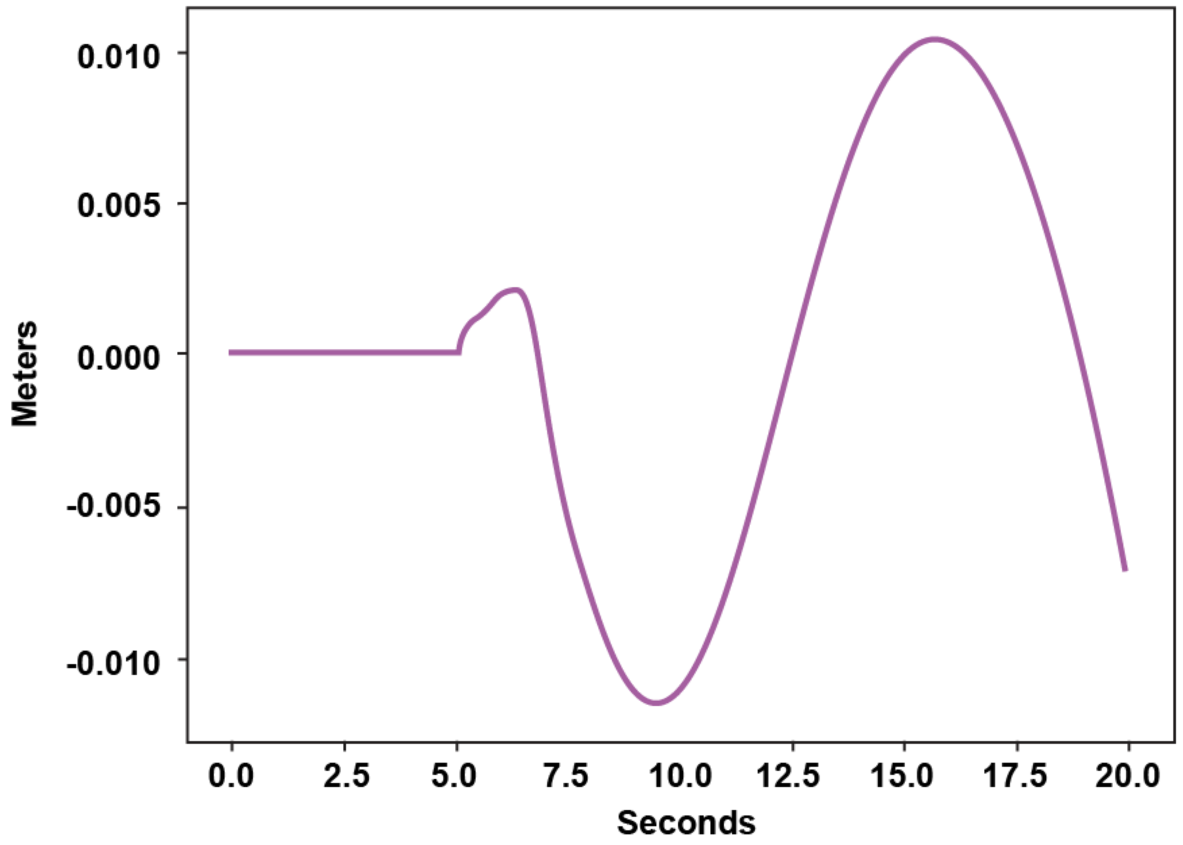
- Z-position of the ROSA drops down and then begins to oscillate



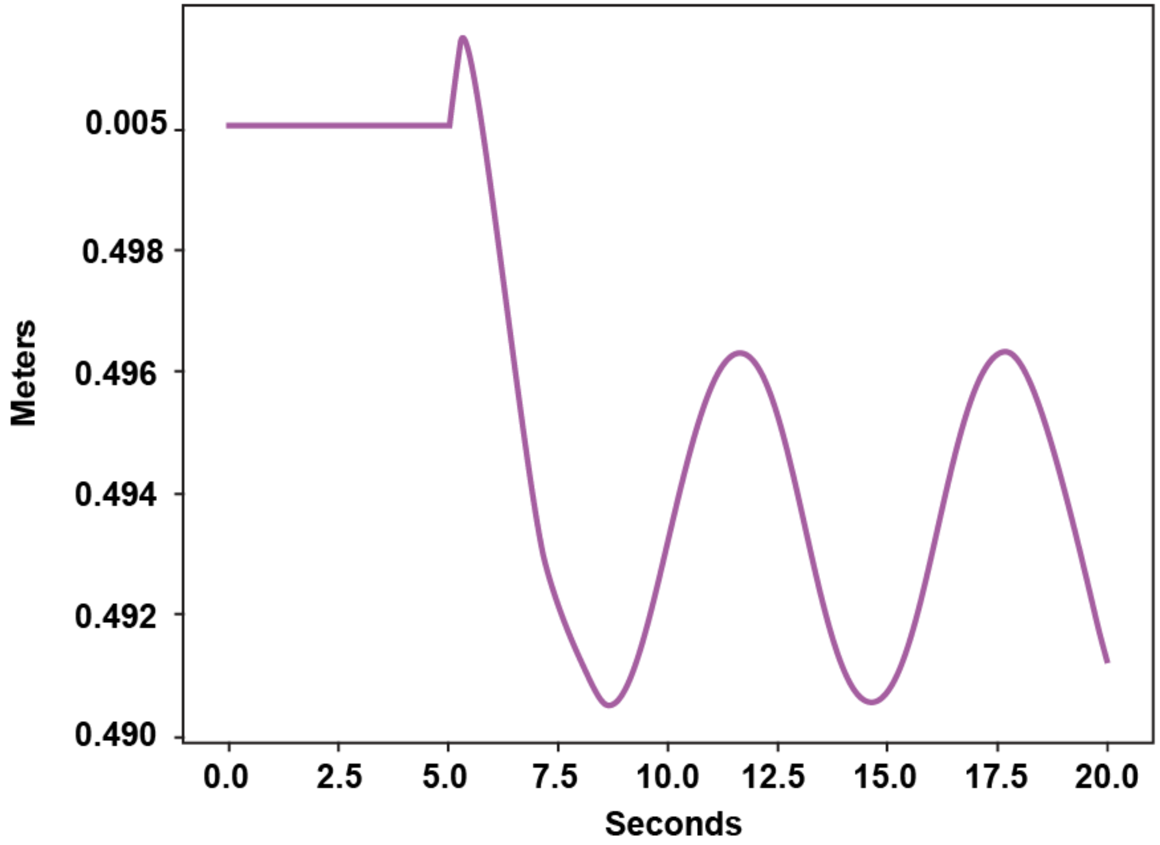
Asymmetric Soil Collapse Example

- Oscillations of the ROSA tip are more visible in the X and Y dimensions

X-Position Top of ROSA



Y-Position Top of ROSA



MBR Response to Soil Collapse Scenario

- MBR cross checks the sensors, and finds that they all read anomalous values, ruling out a sensor fault
- MBR inspects sensors for known fault patterns and finds the anomalies in the wheel sensors and gimbal accelerometers to match an asymmetric collapse
- In testing, this took 2.7 milliseconds from telemetry received to a final diagnosis.

TRIAD Response to Soil Collapse Scenario

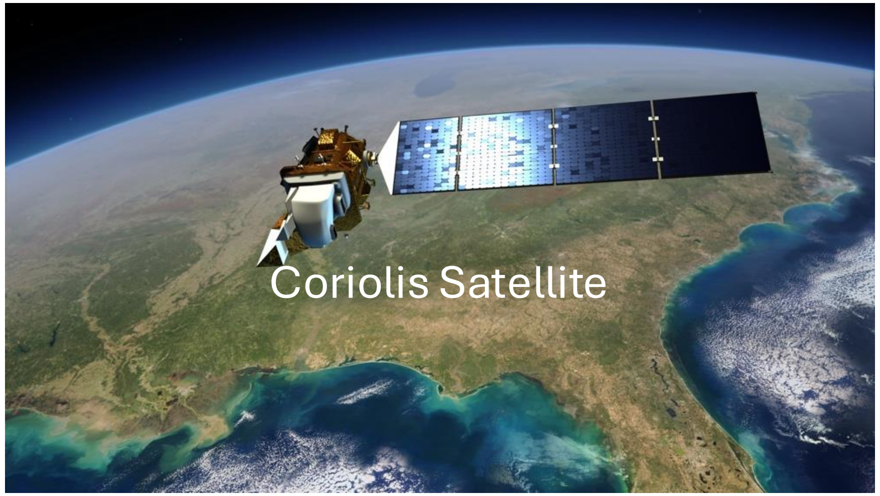
- TRIAD analyzes the frequency domain as well as summary statistics to detect an anomaly
- TRIAD detects an anomaly 0.15 seconds after the collapse, and diagnosis it after 0.3 seconds

Hybrid Fault Detection Runtimes

- These runtimes are fast enough to allow the VOLT to respond to critical faults, such as a soil collapse fault that could cause the VOLT to tip

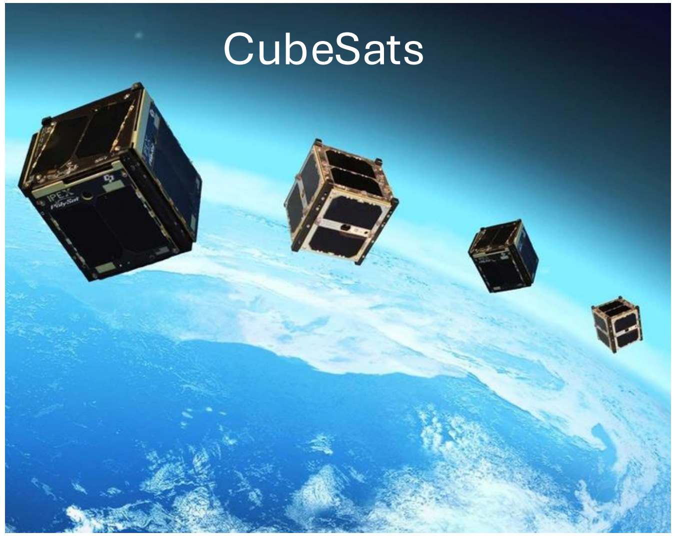
	Average Runtime
TRIAD Detection	.32 seconds
TRIAD Diagnosis	.42 seconds
MBR Detect and Diagnose	3.11 milliseconds

Applications for Hybrid Fault Detection



Moon and Mars

Satellites



Ongoing and Future Work

- Ongoing work
  - Integrating with VOLT hardware
  - Training TRIAD on data from recorded from real VOLT
- Future work
  - Implement unsupervised learning for TRIAD fault diagnosis
  - Develop an adaptive fault mitigation approach

Summary

- Hybrid fault detection system for the VOLT lunar rover
- The VOLT experiences some inherent risk because it needs to be somewhere like a ridge to avoid lunar shadows
- Our approach can detect a wide variety of soil, sensor, and mechanical faults
- Our approach can react quickly enough to avoid mission ending failures

Questions?

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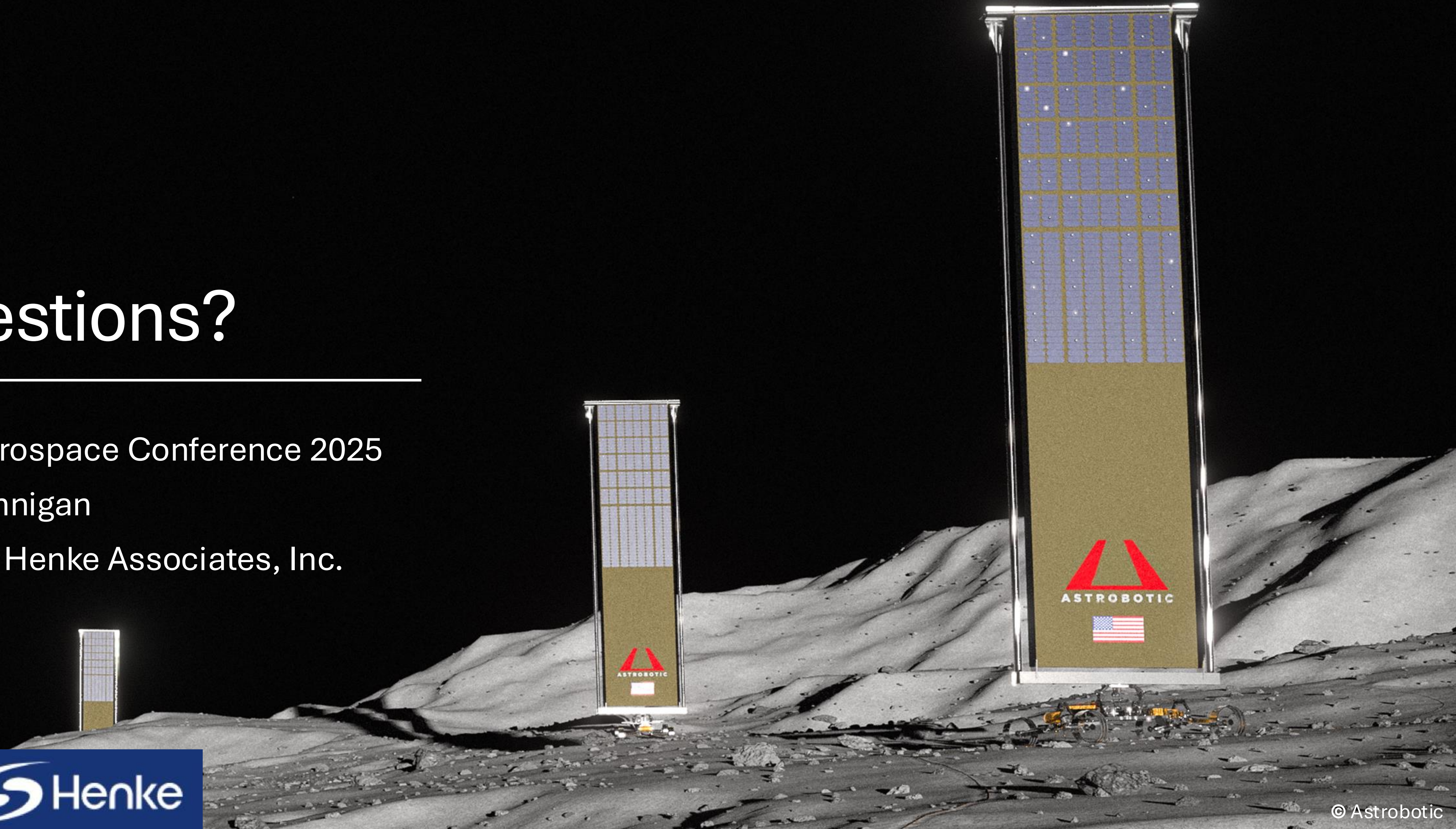

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