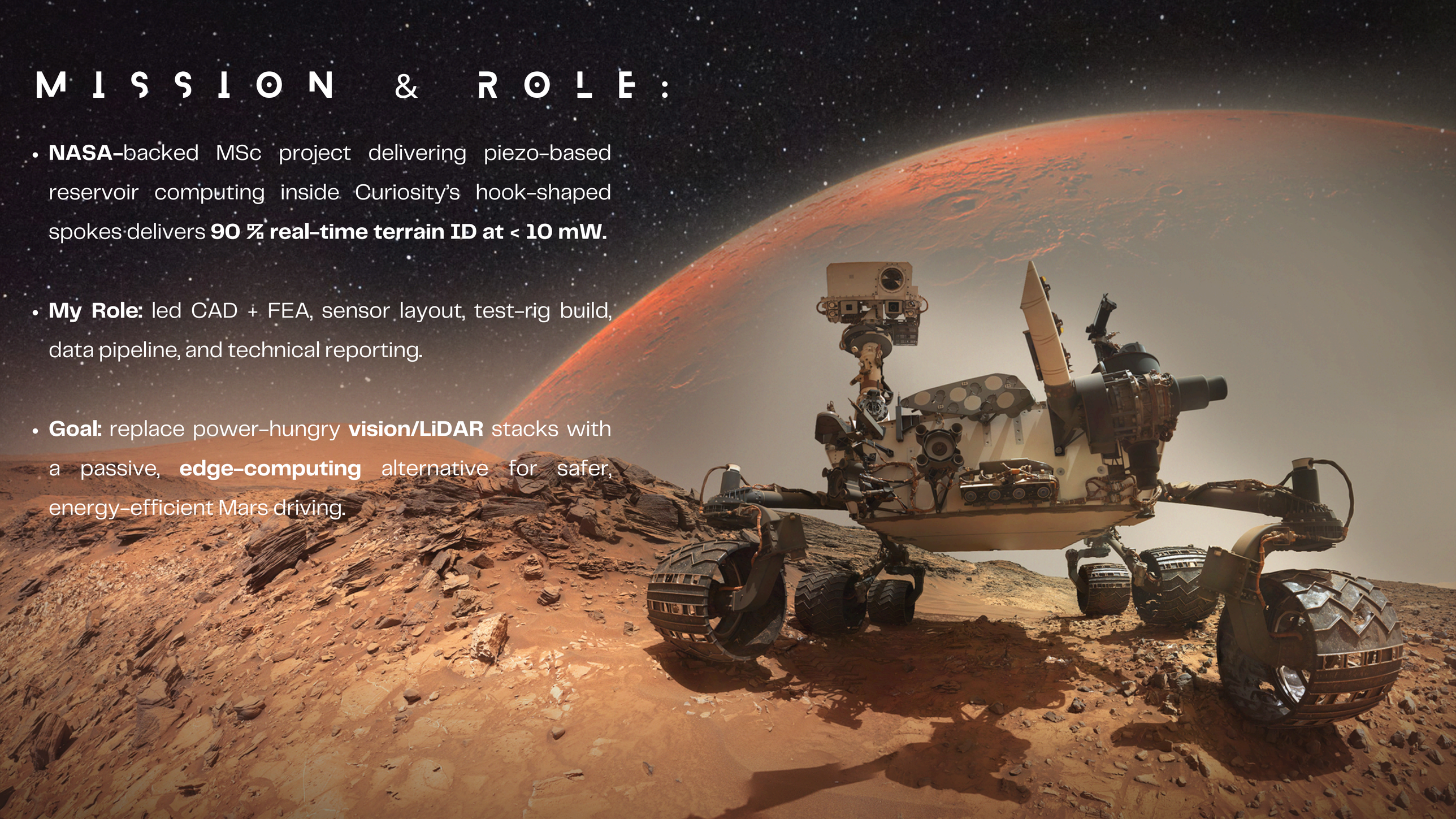

REDSENSE

MISSION & ROLE:

- **NASA**-backed MSc project delivering piezo-based reservoir computing inside Curiosity's hook-shaped spokes delivers **90 % real-time terrain ID at < 10 mW.**

- **My Role:** led CAD + FEA, sensor layout, test-rig build, data pipeline, and technical reporting.

- **Goal:** replace power-hungry **vision/LiDAR** stacks with a passive, **edge-computing** alternative for safer, energy-efficient Mars driving.



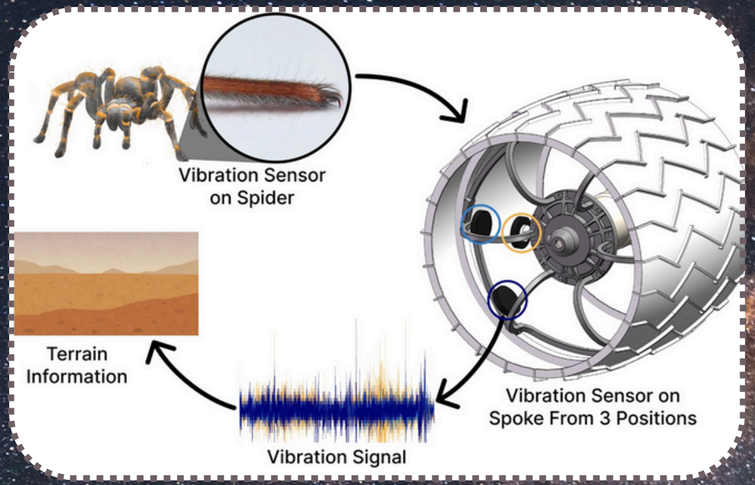
PROBLEM → INNOVATION:

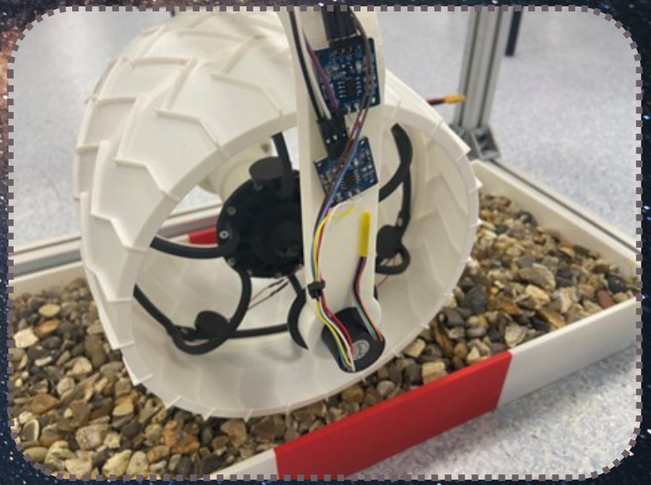
- **Cameras/LiDAR** demand heavy compute; **IMUs/audio** add noise & hardware weight.

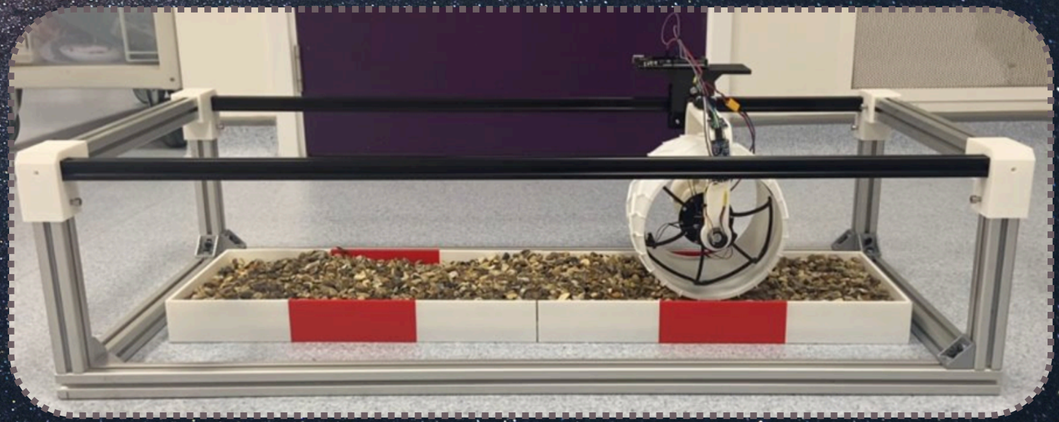
- Hook-shaped spoke acts as a **mechanical reservoir**, naturally amplifying terrain-specific vibrations.

- FEA revealed resonance peaks at **90 Hz & 200–300 Hz;** three stress hotspots capture **low-, mid-, high-band** signatures.

- Embedding **piezo sensors** here turns each wheel into a **self-powered tactile probe**.

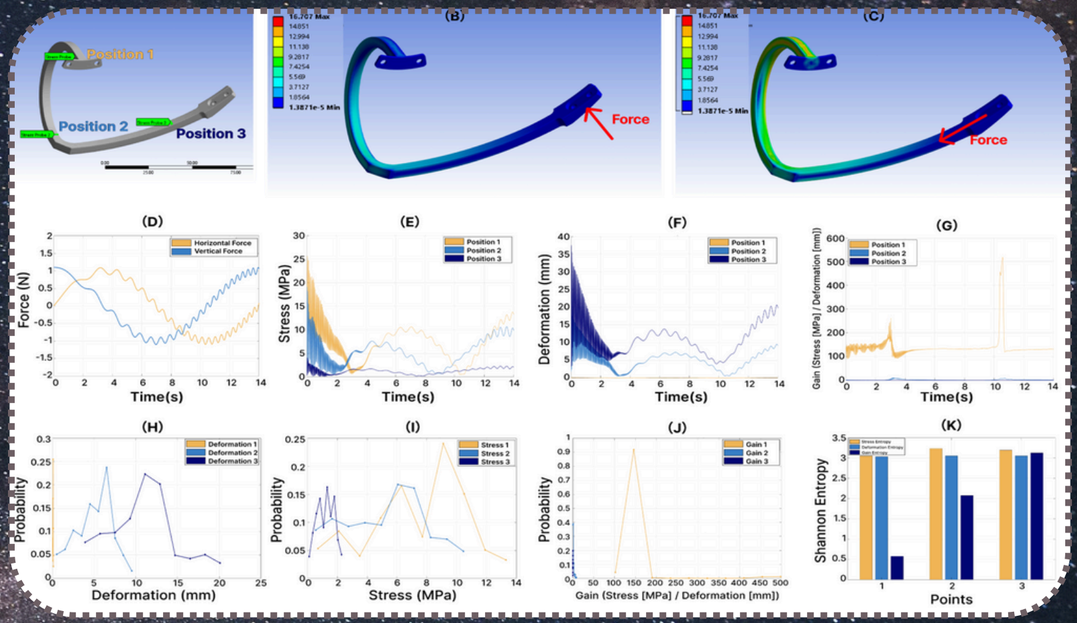


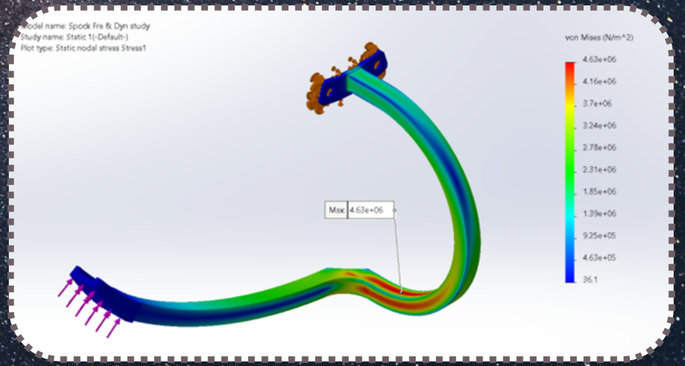


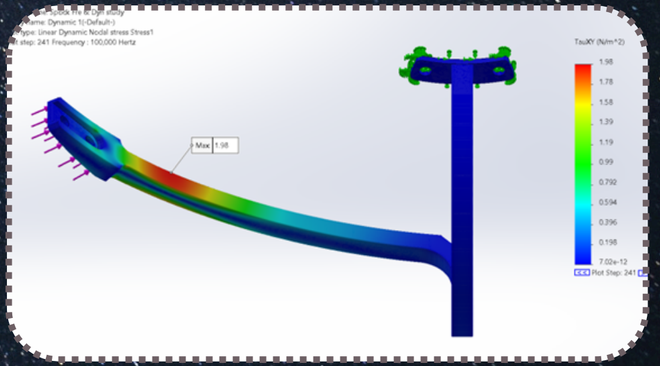


ENGINEERING & TEST PLATFORM:

- **1 : 4 3-D-printed** rover wheel (PLA shell, resin spokes) driven at **67 mm s^{-1}** on a six-terrain rail bed.
- **Harmonic FEA** with **73 k nodes** showed $Gain_1$ ≈ **600 MPa mm^{-1}** at Position 1, guiding sensor bonding.
- **20 mm piezo sensors** + < 5 mW charge amp; total system draw < 10 mW.
- Rig logged **9 500 samples/terrain** at 720 Hz; FFT traces match FEA-predicted frequency bands





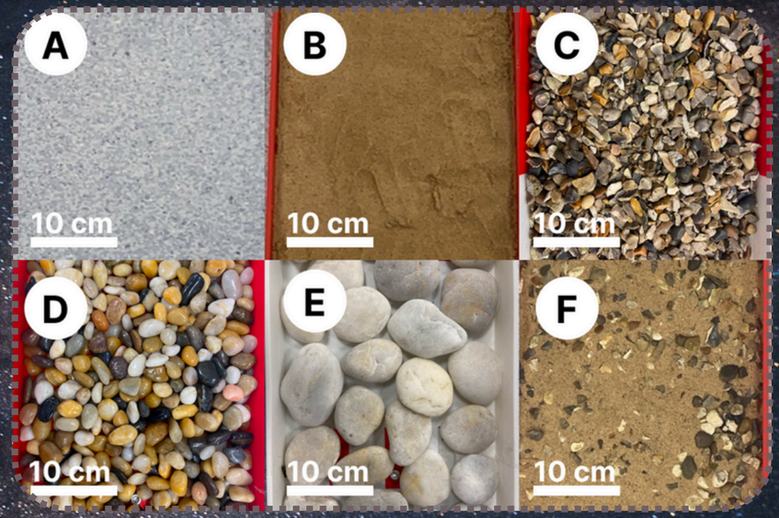


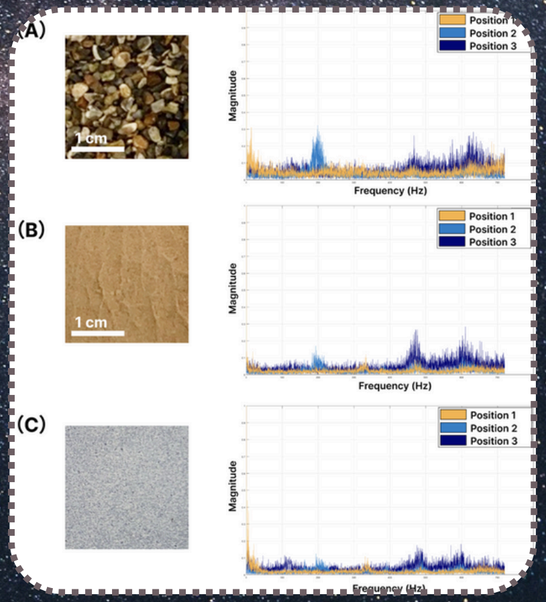
FEATURE PIPELINE & ML:

- **Position-tuned feature set:** 1–50 Hz RMS & σ (compliance), 200 Hz autocorr & smoothness (periodicity), 400–800 Hz σ & kurtosis (micro-roughness).

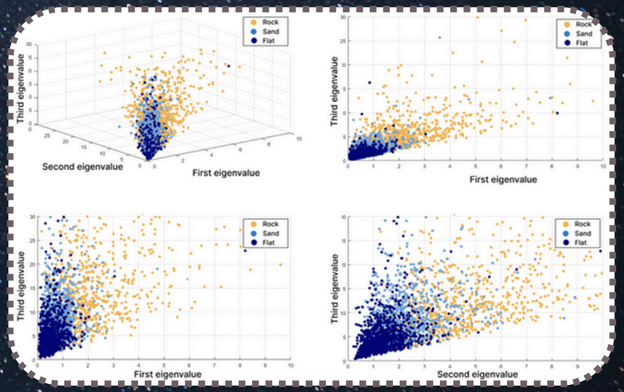
- SVM classifier hits **90 % accuracy** in a **1.5 s** window (2 000 rows, 1 440 Hz).

- **Unknown terrain filter:** combine Euclidean + Mahalanobis distances to rank similarity and estimate roughness in real time.





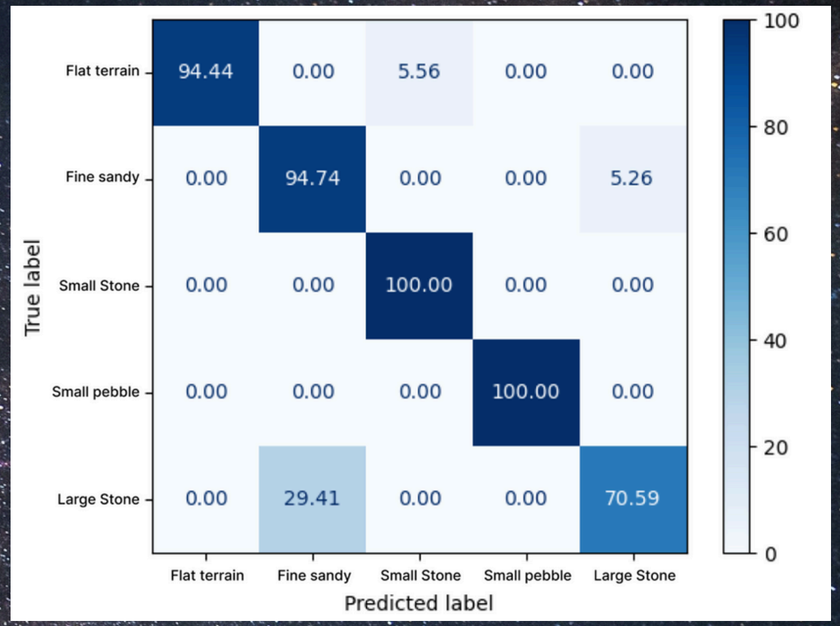
Three terrain surfaces along with the FFT spectrum of the raw viberation signal, used to evaluate the performance of the pieszo sensors. (a) Small Rock. (b) Sand. (c) Flat Surface



Eigenvalues of the piezo sensor outputs for three sampled terrain surfaces in Eigen space for terrain classification.

RESULTS & IMPACT:

- **Clear separation** of flat, sand, pebble, and stone classes; most reach **100 % precision**, slip-induced overlap only between large stones & sand.
- **< 50 ms latency** from vibration to classification; fully passive sensing keeps rover power budget intact.
- Distance-metric fusion **tags mixed/unknown terrains** on the fly, supporting a**daptive speed & path planning.**
- Framework scales to other **rovers or UGVs**, lowering compute load while boosting autonomous safety.



Confusion matrix of reservoir computing prediction success rate averaged over 120 randomly trials (2000 data sets), with robot speed of 67 mm/s and the sampling frequency of the whisker at 1440 Hz with the final accuracy is 90%.