

## 1. Motivation

Rough terrain couples mechanics and control the moment the ground stops being flat. Wheels slip on loose soil (Moreland et al., 2011). Legs don't, they can step, grip, and reshape how force meets the ground.

Two extremes already exist:

- ✓ **RHex** (Saranli et al., 2001): one actuator per leg, rugged, but fixed clock and teleoperated.
- ✓ **Modern quadrupeds** (Lee 2020; Miki 2022): autonomous, but 12+ actuators and learned policies.

### How much control complexity is actually needed for autonomous terrain adaptation?

**Identity**, Team Euler's six-legged rover for the 2026 COSGC Challenge, answers that question on a Raspberry Pi 3B+ and one actuator per leg, adapting to seven terrain classes by varying only **impact window, duty cycle, global speed, and gait selection**. Chassis, gains, and safety thresholds stay fixed.

## 2. Hypotheses

**H1** Traversal success rate > 90% across all tested terrain categories.

**H2** Mean actuator load remains below stall threshold with ≥ 10% margin on all surfaces.

### H3 CENTRAL HYPOTHESIS

Seven terrain classes can be traversed while holding chassis geometry, controller gains, and safety thresholds fixed, varying only impact window, duty cycle, gait selection, and speed setpoint.

## 3. Test Protocol

**32-trial pilot validation** across seven terrain classes under a fixed binary pass/fail rule.

### Trial Definition

- ✓ 3-meter marked course segment
- ✓ Fully autonomous traversal (no human intervention)
- **Pass:** complete without stall shutdown, intervention, or loss of >1 leg contact

Controlled Variables (held fixed)	Varied by Terrain
<ul style="list-style-type: none"> <li>Chassis geometry   Leg geometry</li> <li>Controller gains</li> <li>Safety thresholds (sensor thresholds and safety governors)</li> </ul>	<ul style="list-style-type: none"> <li>Impact window</li> <li>Duty cycle</li> <li>Global speed setpoint</li> <li>Gait selection (walking pattern)</li> </ul>

**Field conditions:** 10:00 - 14:00 | 8 - 15 °C | Dry substrate  
30s Cooling between runs | Single-observer scoring

### Seven Terrain Classes Tested



## Identity at Great Sand Dunes National Park

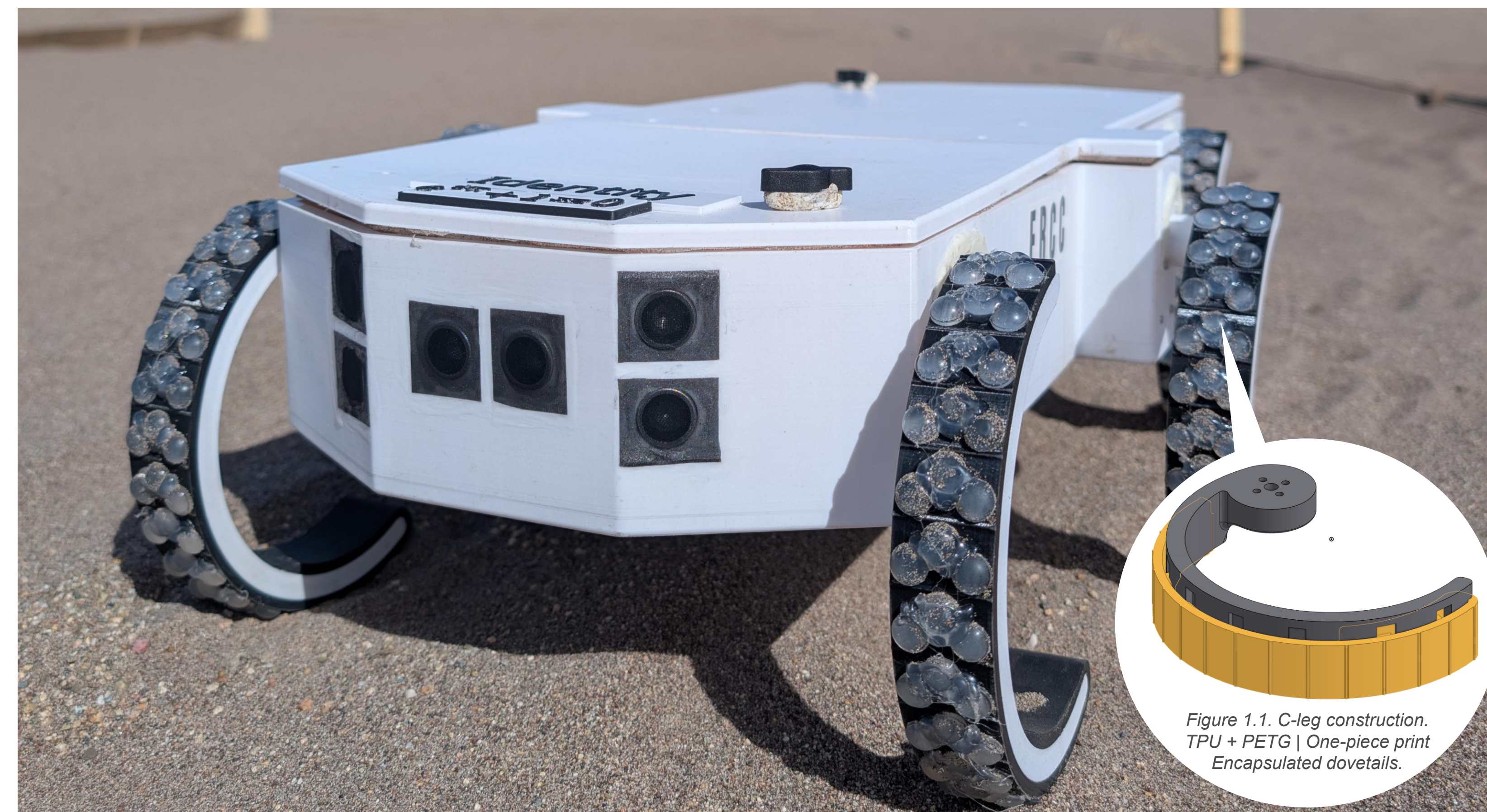


Figure 1. Identity (rear view) at Great Sand Dunes National Park. Chassis: 511×280×74 mm, 2.8 kg, six C-shaped legs (125 mm radius).

## System block diagram

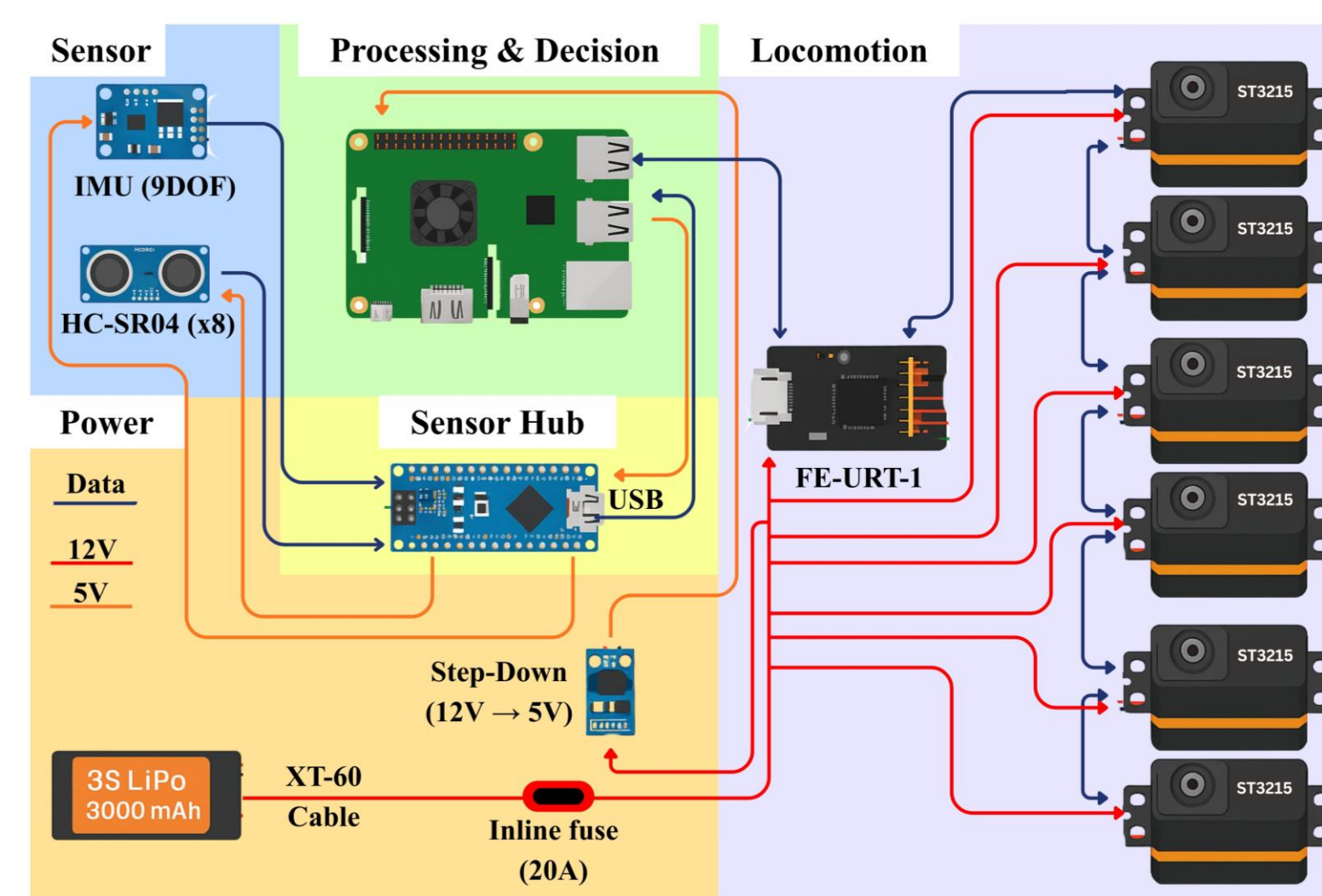


Figure 2. Built for under \$500. 8 ultrasonics + 1 IMU fused into a 20-column CSV; the Arduino handles sensor timing, the Pi classifies terrain and commands the gait.

## Brain/Heart dual-process architecture

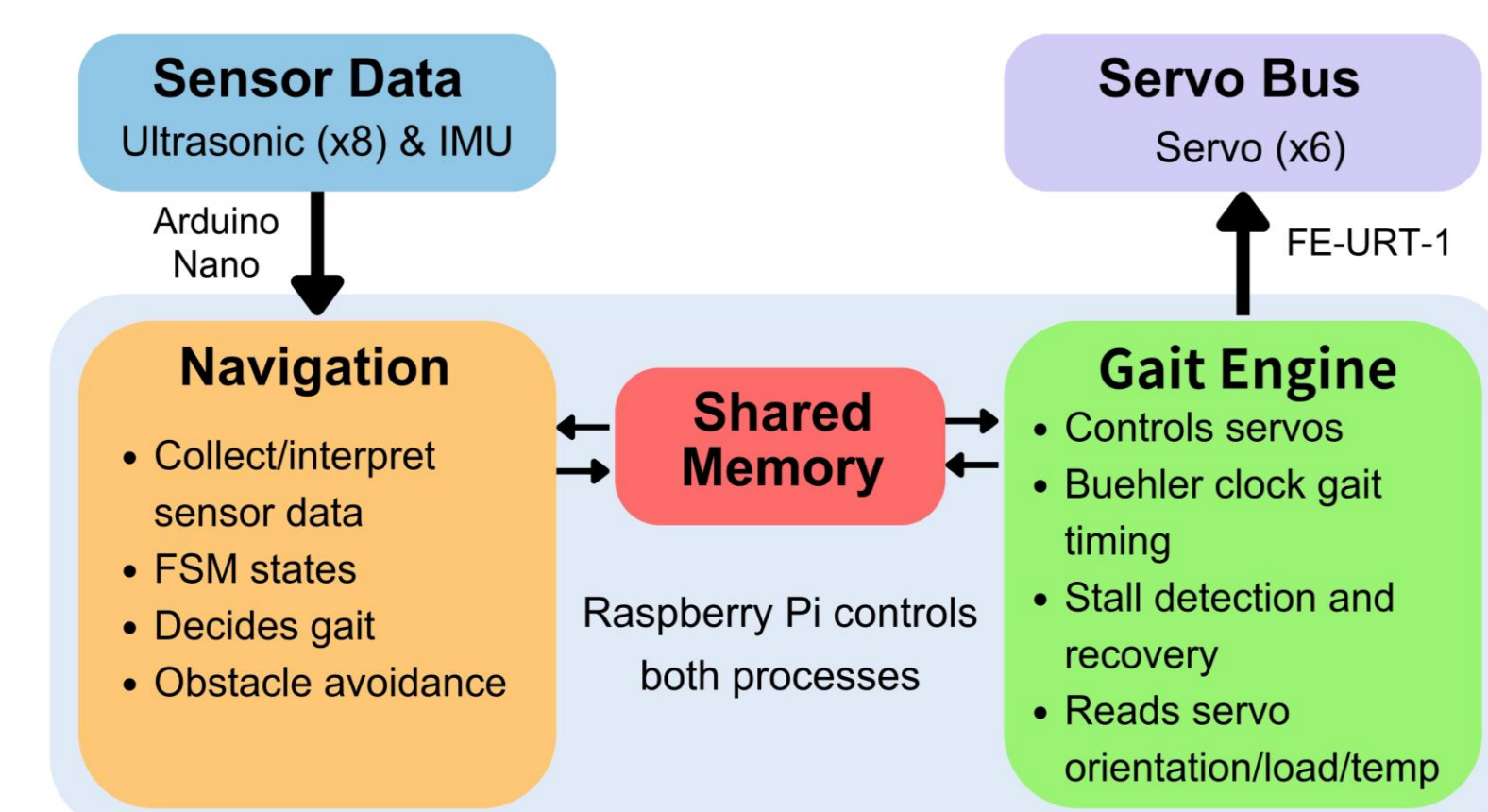


Figure 3. Navigation (Brain, ~10 Hz) handles sensor interpretation and FSM decisions; the Gait Engine (Heart, 30 Hz) maintains the servo loop, isolating timing-critical control from navigation.

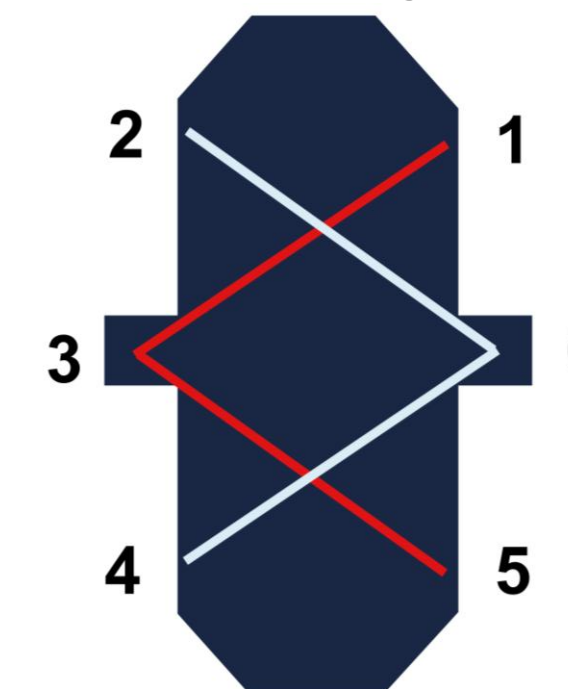
## Gait patterns: Wave | Quadruped | Tripod

Trigger Condition (sensor)	Speed Multiplier	Gait
Default (no trigger active)	1.0	Tripod
Hard flat sprint (pitch < 15°, roll < 15°, load < 280°, no stalls)	1.0	Tripod
Moderate slope (pitch or roll > 15°)	1.0	Quadruped
Steep climb (pitch > +25°)	1.0	Wave
Steep descent (pitch < -25°)	0.85	Wave
Moderate load (350 < load ≤ 600)	1.0	Quadruped
Heavy load (load > 600)	0.85	Wave

Table 1. Terrain Overlay Parameters.



Figure 4. Tripod phase groups (top view).



## 4. Results

**96.9%**

pass rate (31/32 pilot trials)

**42%**

min load margin to stall

Mean servo loads stayed below the 800-unit stall threshold on all surfaces. Load increased monotonically from tile (120) to 20° incline (465).

**Single failure:** Abrupt gravel-to-hardpack transition at 22°, terrain heterogeneity within one stride, not terrain severity, was the limiting factor.

## 5. Servo load across terrain types

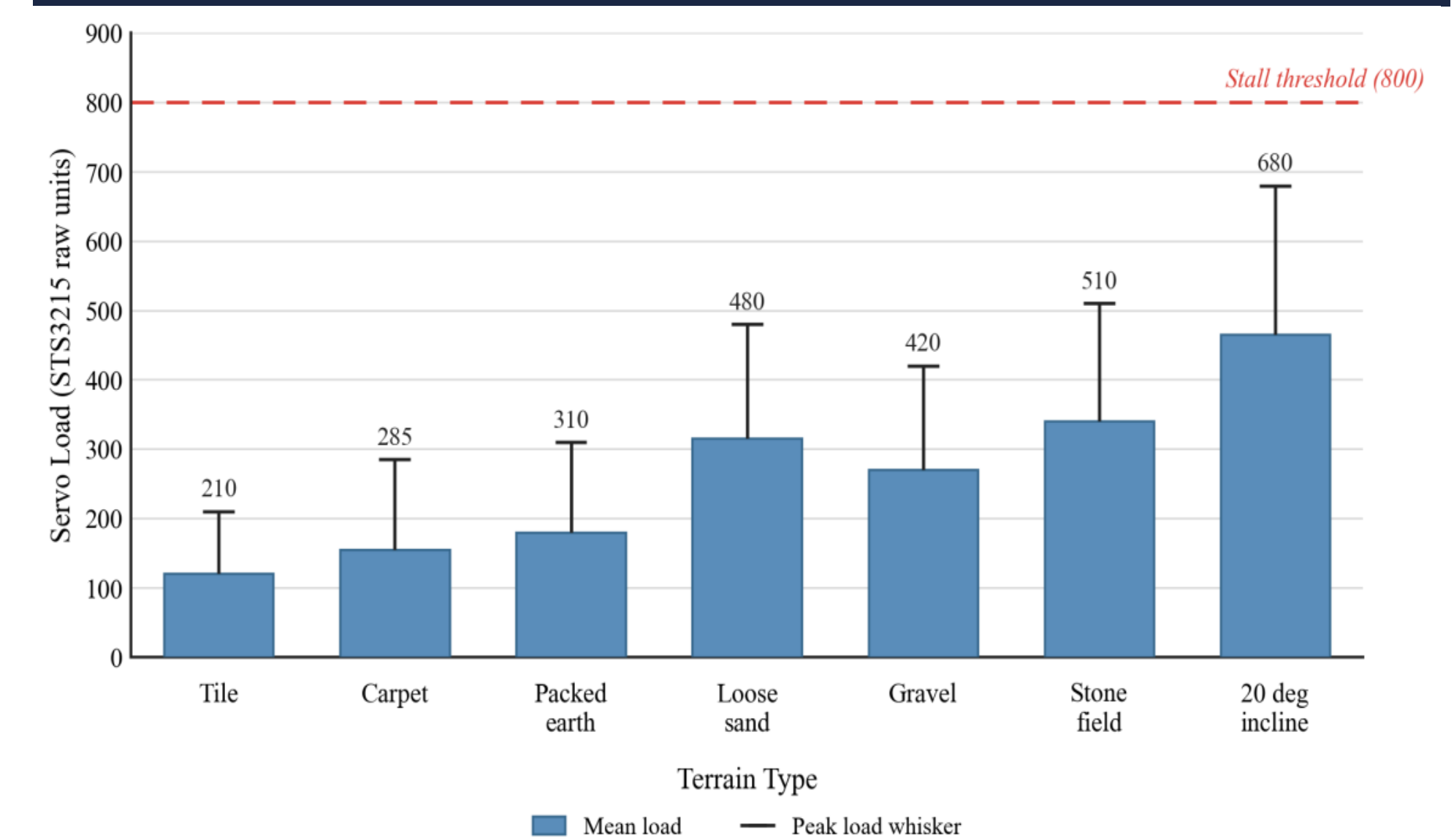


Figure 5. Mean servo load (bars) and peak load (whiskers) in STS3215 raw units. Dashed line = 800-unit stall threshold.

## 6. Hypothesis evaluation

**H1: Partially supported:** 96.9% observed, but 95% Confidence Interval (CI) [83.8%, 99.9%] includes <90%.

**H2: Supported:** Max mean 465/800 (42% margin). Peak 680 still 15% below stall.

**H3: Supported:** 3.9× load range across 7 surfaces with fixed core settings.

✓ **Pilot scope:** 32 trials show feasibility; 105+ needed to confirm 90% at conventional power.

✓ **Key finding:** The practical limit was not terrain difficulty, but terrain changes within a single stride.

## 7. Conclusion

Identity demonstrates that a CPG-driven, single-actuator hexapod can achieve useful terrain adaptation, **96.9% traversal across 7 terrain classes**, using a **small parameter set rather than per-joint trajectories**, on commodity hardware.

**Compliant C-shaped legs absorbed terrain variation passively**, reinforcing the RHex principle that when leg geometry handles ground interaction, active control can be simplified rather than expanded.

The clearest design boundary was not terrain severity alone, but rapid terrain change within one stride, pointing to within-stride transition detection as the priority for future work.

Within the tested range, the simpler architecture was enough, a **bounded sufficiency claim, not a general one**.

## 8. References & Acknowledgements



All cited works available via QR

**Identity**  
 $e^{i\pi} + 1 = 0$