



Introduction

Martian lava tubes offer valuable scientific opportunities but present challenging navigation requirements, with narrow entrances and irregular terrain. Legged robots with jumping capabilities can exploit Mars' reduced gravity (3.71 m/s^2) to overcome obstacles many times their size, providing access to areas unreachable by traditional rovers.

Our quadruped **Olympus** features optimized 5-bar leg mechanisms designed for powerful jumps and in-flight attitude control. Using deep reinforcement learning, we develop policies for **walking, vertical** and **forward jumping**, and **in-flight attitude reorientation**, enabling coordinated traversal of complex Martian terrain.

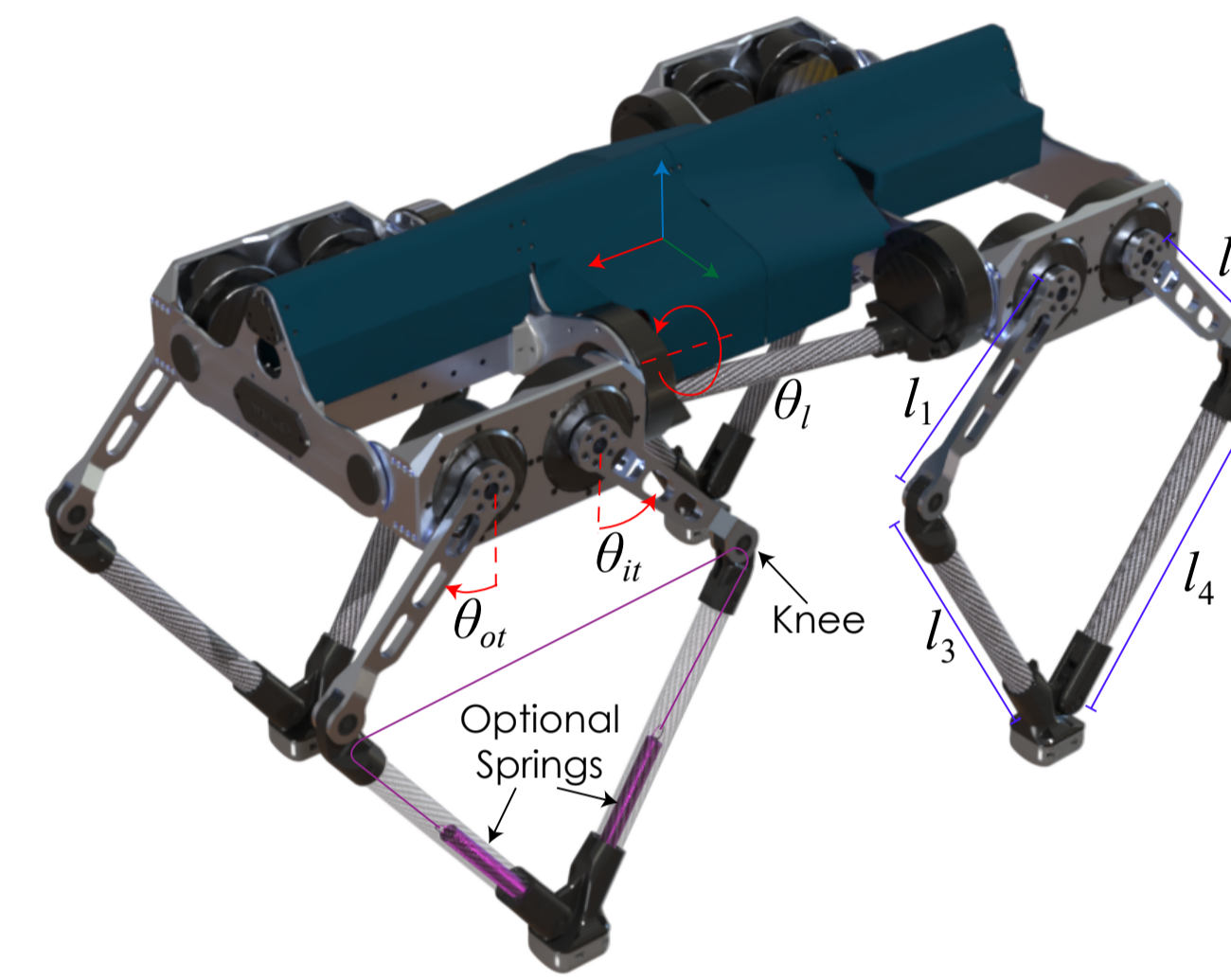


The Olympus Platform

Olympus was purpose-built for dynamic locomotion in Martian gravity. Each leg uses a 5-bar linkage with 3 degrees of freedom, providing a large workspace for in-flight reorientation alongside substantial jumping capability. Morphology was optimized in prior work to jointly maximize jump height, distance, and reorientation rates. The system also supports optional parallel knee springs (800 N/m).

Olympus specs:

Mass	14.5 kg
Body length	0.67 m
DoF per leg	3 (5-bar linkage)
Max motor torque	24.8 / 18.0 Nm
Compute	Jetson Orin NX



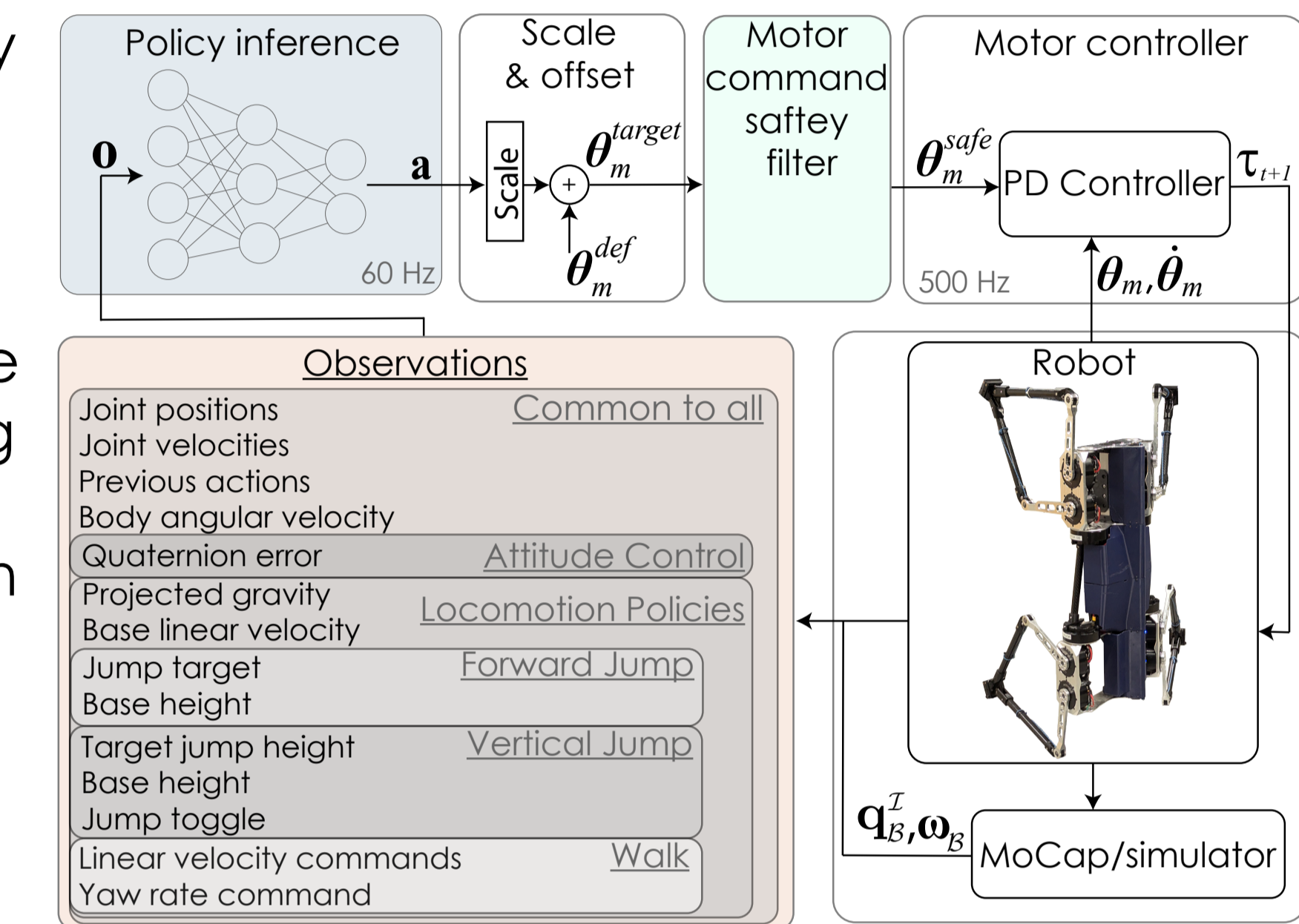
RL Policies & Training

Four task-specific DRL policies are trained in IsaacLab using PPO under simulated Martian gravity (3.71 m/s^2), with task-specific observations and rewards for each behavior.

The **Attitude Control** policy drives in-flight reorientation using quaternion error, encouraging a safe landing configuration once error falls below 5° .

The **Walking** policy tracks commanded linear velocity and yaw rate.

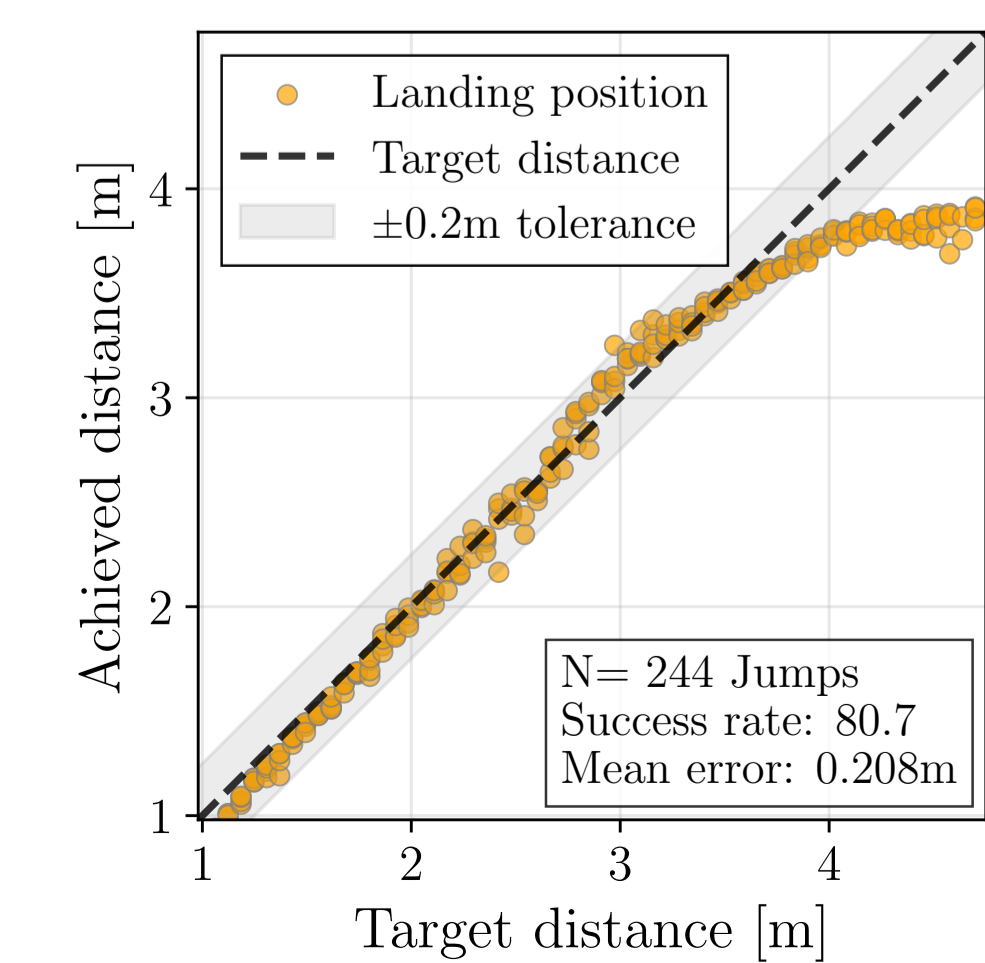
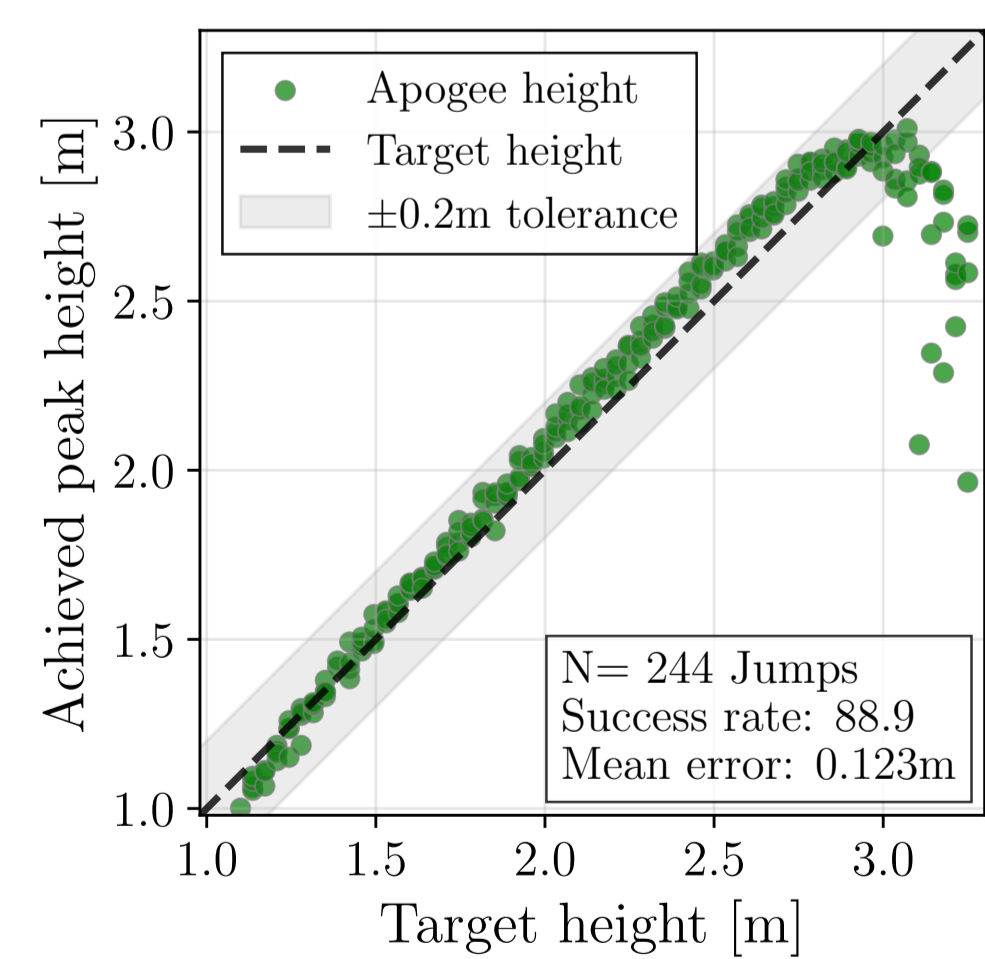
The **Vertical and Forward Jumping** policies use curriculum-based reference state initialization, spawning agents at all phases of the jump, with projectile-motion based in-flight rewards to densify the reward signal



Jumping Results

Both jumping policies were evaluated over 244 jumps with varied targets in simulated Martian gravity, with evaluation targets spanning the full training distribution and extending to the robot's physical jumping limits.

Policy	Success Rate	Mean error	Max
Vertical jump	88.9%	0.123 m	3.1 m height
Forward jump	80.7%	0.208 m	3.9 m distance

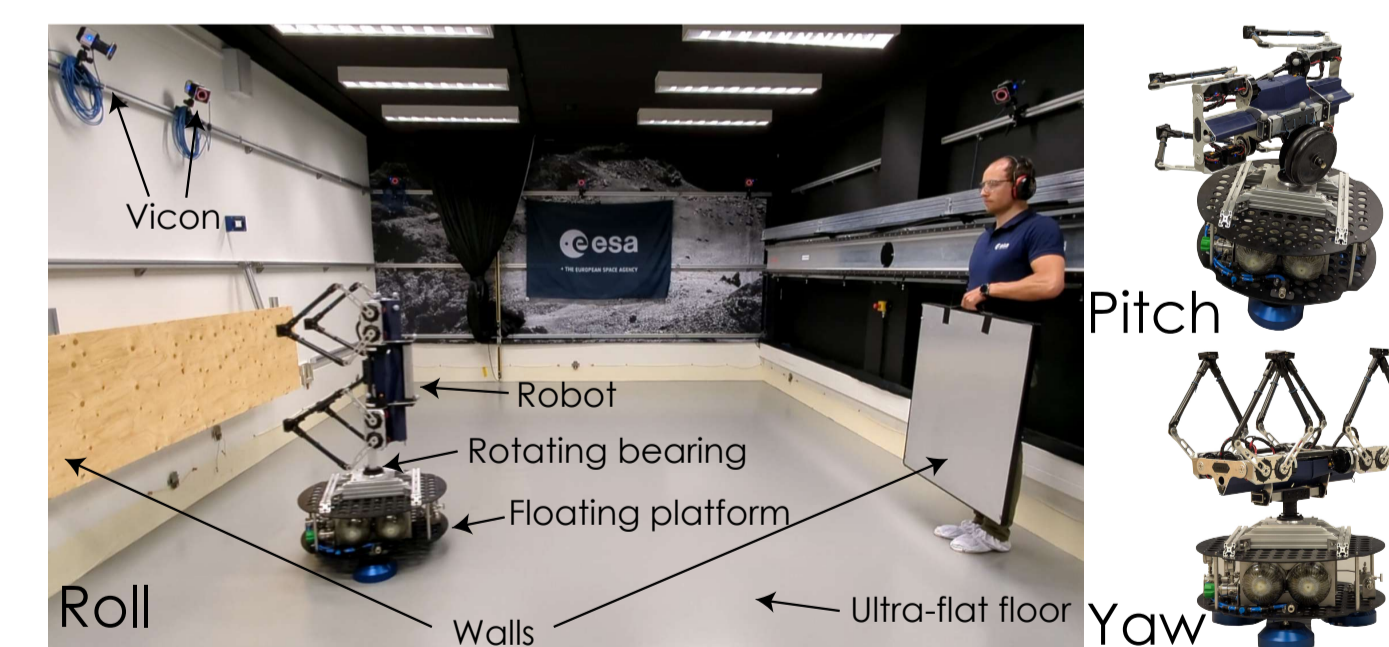


The **vertical jumping policy** tracks commanded apogee height, while the **forward jumping policy** tracks a ground-plane landing target. Failures occur primarily at out-of-distribution targets where landing stability reaches the edge of the platform's capabilities. Adding optional parallel knee springs (800 N/m) yields a further ~21% increase in both height and distance.

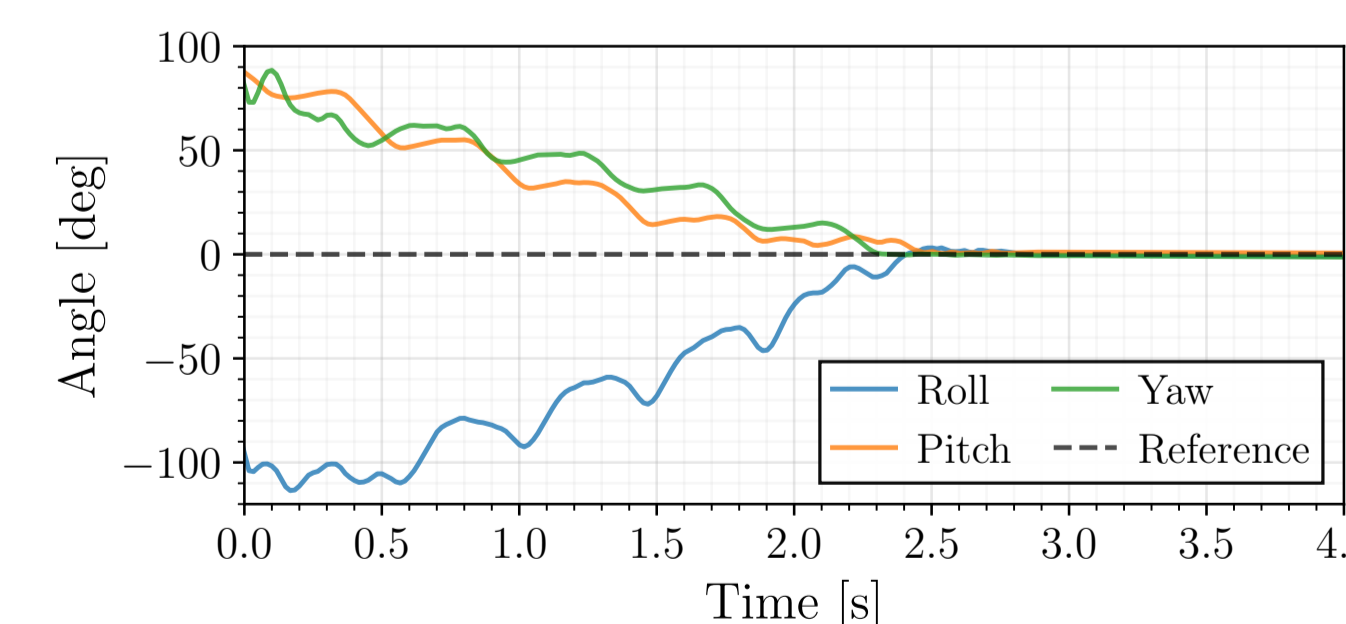
Attitude Control

The attitude control policy was validated in both simulation and hardware. A complex 3D reorientation from $[-90^\circ, 90^\circ, 90^\circ]$ to $[0^\circ, 0^\circ, 0^\circ]$ (roll, pitch, yaw) was completed in 2.45 s in simulation. Hardware validation used a floating air-bearing platform on an ultra-flat floor to simulate free-flight dynamics one axis at a time, using Vicon motion capture for state estimation.

Hardware attitude control test setup



Simulated 3D reorientation



Attitude control reorientation times

Test	Roll		Pitch		Yaw	
	Sim	Real	Sim	Real	Sim	Real
90°	0.96 s	2.6 s	1.08 s	4.2 s	1.4 s	3.9 s
180°	1.9 s	4.6 s	2.3 s	8.4 s	2.4 s	7.1 s

Planetary Exploration Pipeline

A waypoint-based hierarchical controller coordinates all four policies to traverse terrain impossible for traditional rovers. Upon reaching a jump waypoint, the robot stabilizes, the jumping policy initiates takeoff, attitude control engages once airborne, and the walking policy recovers momentum after touchdown.

The integrated system successfully traversed a complete simulated Martian mission, including rough terrain walking, a 2.1 m wide crater, a 3.5 m forward jump from a 1.1 m ledge, a 2.6 m vertical reconnaissance jump, and a challenging 1.1 m ledge clearance.

Sequential frames from simulated planetary exploration mission

