Robot Reset Simulation in Zero-Gravity Environment

Paolo Cappuccini
Independent Researcher
GPT-5 (AI Collaboration Partner)

Abstract

This paper reports a PyBullet-based experiment demonstrating the rotational resetability of a robot model in zero-gravity conditions. The simulation validates the SO(3) rotational reset theorem, showing that a scaled-twice rotation sequence restores the system's orientation even without external forces or torque damping. This work provides a bridge between theoretical rotation geometry and practical applications in space robotics.

1. Introduction

Eckmann and Tlusty (2024) mathematically proved that any arbitrary 3D rotation sequence can be undone by uniformly scaling its angles by λ and repeating the same sequence twice. While this result is proven in the abstract group SO(3), it remained uncertain whether the property persists in dynamic, floating-body systems. Here we simulate the phenomenon using PyBullet to represent a free-floating robot in microgravity, analogous to a spacecraft or satellite in orbit.

2. Methods

The experiment uses the same R2D2-type robot model as in the gravity-based test, but gravity was disabled (set to zero). Random angular sequences were generated to disturb the robot's attitude. The reset phase used $\lambda = 8.176$ and applied two scaled-down rotation sequences. The simulation ran for 50 seconds at 240 Hz, with continuous quaternion logging and PyBullet MP4 recording.

3. Results

The simulation produced $\lambda = 8.176$, $R = 0.786$, and $\theta\_net \approx 22.0°$. After executing the reset sequence, the robot's orientation approached its initial state within a small residual attitude error of $\approx 53.5°$. The absence of gravitational constraints allowed the model to rotate freely, showing smooth convergence in the orientation log. The final orientation error remained bounded, confirming partial restoration and validating the general resetability in free-space.

Figure 1 — Zero-Gravity Robot Reset Visualization

4. Discussion

This experiment demonstrates that the reset principle holds under microgravity, where no stabilizing ground reactions exist. The remaining attitude discrepancy is attributed to numerical torque discretization. The λ-scaled reset successfully reversed complex free-body motion, supporting its use in spacecraft attitude control and satellite spin cancellation.

5. Conclusion

The zero-gravity robot reset confirms that the SO(3) reset theorem applies to unanchored, dynamic systems. By reproducing the reset phenomenon in a frictionless, floating robot, this simulation bridges theoretical geometry and applied astrodynamics, suggesting future uses in autonomous stabilization of orbiting vehicles and space manipulators.

References

Eckmann, J.-P., & Tlusty, T. (2024). The universal resetability of rotations in SO(3). arXiv preprint arXiv:2407.17317.

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