CubeSat Attitude Control Simulator

Justin Bachmann

Purdue University – School of Aeronautics and Astronautics

Summer 2025

1. Abstract

This project simulates a 3-axis CubeSat's attitude control system using quaternion-based rotational dynamics, reaction wheel torque actuation, and a proportional-derivative (PD) controller. The system incorporates actuator saturation, external disturbances, and an Extended Kalman Filter (EKF) for attitude estimation. MATLAB was used to develop and visualize the spacecraft's dynamic response, including real-time 3D animations and GIF exports. The simulator models realistic spacecraft control scenarios for autonomous spacecraft design and GNC validation.

2. Objectives

- Model 3D attitude dynamics using quaternions to avoid singularities
- Implement PD control via reaction wheel torque with saturation
- Simulate external disturbances acting on the spacecraft
- Integrate an Extended Kalman Filer for attitude estimation
- Visualize real-time 3D orientation and export to animated GIF

3. System Modeling

- State Vector: Quaternion orientation, angular velocity, and wheel speeds
- Dynamics: Euler's equation for rotation and quaternion kinematics
- Actuators: Three orthogonal reaction wheels with torque limits
- Tools: MATLAB ODE45 for integration, quat2dcm for visualization

4. Control Design

A PD controller computes desired torque based on quaternion error and angular velocity:

$$\vec{u} = -J_w^{-1}(K_p \cdot \overrightarrow{q_{err}} + K_d \cdot \vec{\omega})$$

with torque saturation imposed.

5. Estimation with EKF

The EKF predicts and updates the quaternion state based on noisy measurements, simulating fused sensor data from IMUs:

- **Prediction:** Based on quaternion dynamics
- **Update:** Using direct quaternion observations with Gaussian noise

6. Results

- Attitude converges to desired orientation within ~40s
- All quaternion components stabilize with minimal overshoot
- Control torque remains within actuator limits
- EKF tracks true state with low error
- 3D GIF visualizes rotational convergence

7. Conclusion

This simulator demonstrates robust CubeSat attitude control under realistic constraints. Future work could incorporate flexible body dynamics, real sensor models, and optimal control laws such as LQR or MPC.