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# LOW-COST REACTION WHEEL FOR CUBESAT ATTITUDE CONTROL SYSTEM


CONTROL SYSTEMS AND INSTRUMENTATION ENGINEER PROGRAM

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## Introduction

CubeSats are standardized nanosatellites (10 × 10 × 10 cm per "1 U" unit) that have transformed access to space by enabling low-cost, rapid-development missions across scientific, commercial, and educational domains. As the space economy grows, there is increasing demand for these small platforms to achieve both affordability and precision—yet precise attitude control remains a core challenge. This project presents a compact reaction-wheel system tested on an Earth-based rig to demonstrate repeatable, high-accuracy pointing, with the goal of making professional-grade CubeSat stabilization accessible to researchers and educators.

## Project Overview

A 15 cm × 15 cm × 15 cm 3D-printed cube serves as our Earth-based test rig, emulating a 1 U CubeSat's single-axis attitude control. An Arduino Nano runs a cascade-PID loop that drives a reaction wheel powered by a 30 A ESC and brushless DC motor, using real-time yaw measurements from a BNO055 IMU. Set-point commands are issued via a PS2 controller over an HC-06 Bluetooth link. This compact prototype enables a pointing accuracy and dynamic response under repeatable lab conditions.

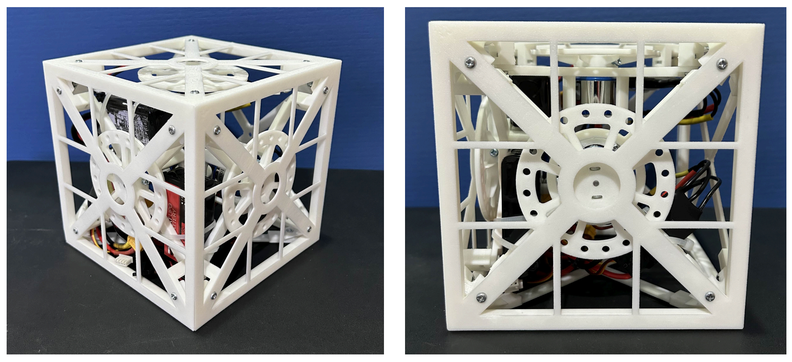


**Figure 1 CubeSat**

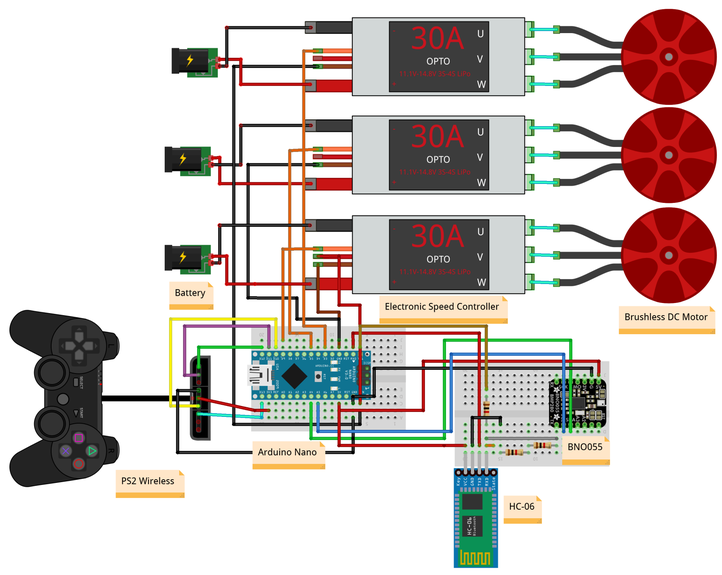



**Figure 2 Circuit diagram of the CubeSat**

## Method

The attitude-control loop is Start/Stop by a PS2 gamepad and its 2.4 GHz receiver wired into the Arduino Nano: × starts the cascade-PID attitude control, while ○ stops it. The Nano stores the desired yaw set-point in firmware; once started, it reads yaw and angular-rate data from the BNO055 IMU, computes position and rate errors, and outputs a PWM command to a 30 A ESC driving the BLDC reaction wheel. Pressing ○ to stop the process. Meanwhile, an HC-06 Bluetooth module streams IMU and control-status data to a user device for logging and analysis.

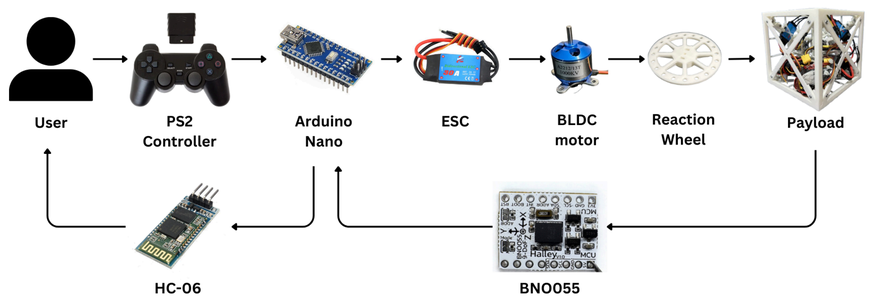



**Figure 4 System Overview**

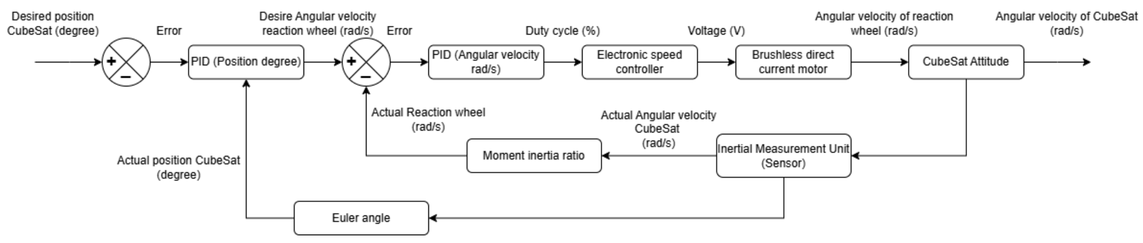



**Figure 5 Cascade PID Control-System Block Diagram**

## Result

The graph below shows the yaw response of the reaction-wheel controller under a ±180° step. The spin-up time is approximately 12 s, and the settling time within a ±2° band is about 30 s. Peak overshoot stays below 5°, and the steady-state error is under 1°. Motor command (PWM) remains at 1500 µs with excursions up to ±30 µs, illustrating the fine control afforded by the dual-PID cascade.

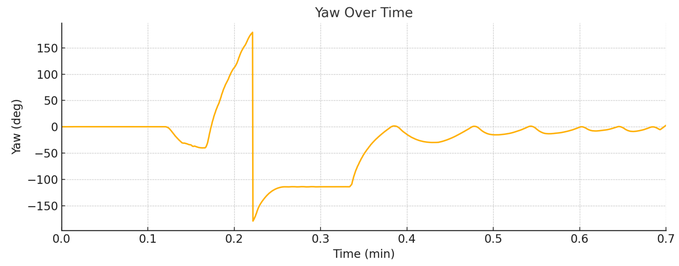



**Figure 5 Attitude Control Result**

| Metric | Value |
|---|---|
| Spin-up time | 12 s |
| Settling time (±2° band) | 30 s |
| Peak overshoot | < 5 ° |
| Steady-state error | < 1 ° |
| PWM deviation | ± 30 µs |

**Table 1 Performance Summary**

## Conclusion

Our project demonstrates that a reaction-wheel assembly built for under ฿2,000 using an Arduino Nano, BNO055 IMU, 30 A ESC, and off-the-shelf BLDC motor delivers professional-grade single-axis attitude control. In response to a ±180° step, the system spins up in 12 s, settles within a ±2° band in 30 s, and maintains steady-state error under 1°, with PWM deviations confined to ±30 µs. This simple cascade-PID implementation shows that ±1° pointing accuracy is attainable affordably and with minimal hardware complexity, paving the way for accessible CubeSat development by academic and small-scale teams.

| Component | Cost (THB) |
|---|---|
| Arduino Nano | 115 |
| BNO055 IMU (Halley sensor) | 690 |
| 30 A Hobby ESC | 232 |
| AA2212 BLDC Motor | 250 |
| Acrylic reaction wheels | 180 |
| 3S Li-Po 11.1 V 1 500 mAh | 415 |
| Misc. wiring & connectors | 100 |
| Total (Core) | 1,982 |

**Table 2 Budget Breakdown for Low Cost Reaction Wheel**

## Future Directions

**1. Full 3-Axis Stabilization:**
Extend the single-axis cascade-PID to a three-reaction wheel mount on each axis for roll, pitch, and yaw control.

**2. Multi-Axis Step Testing:**
Execute individual and combined step responses such as roll, pitch, yaw, roll+pitch, etc, to quantify cross-axis coupling and decoupling performance.

**3. Air-Bearing Evaluation:**
Mount the three-axis rig on an air-bearing platform to characterize behavior in near-frictionless conditions and refine PID gains.

## Reference


[1] NASA, "What are SmallSats and CubeSats?," NASA, Feb. 26 2015; rev. Aug. 6 2017. [Online]. Available: https://www.nasa.gov/what-are-smallsats-and-cubesats/

[2] A. Shawki, H. Hendy, and M. Ashry, "Developing CubeSat Attitude Control: A Simulation of Reaction Wheels with Genetically Optimized Control System," in Proc. Int. Telecom. Conf. (ITC-Egypt), Military Technical College, Cairo, Egypt, Jul. 22 2024, pp. 99–104.