Project BRIC: A Balancing Reactive Inertial Cube

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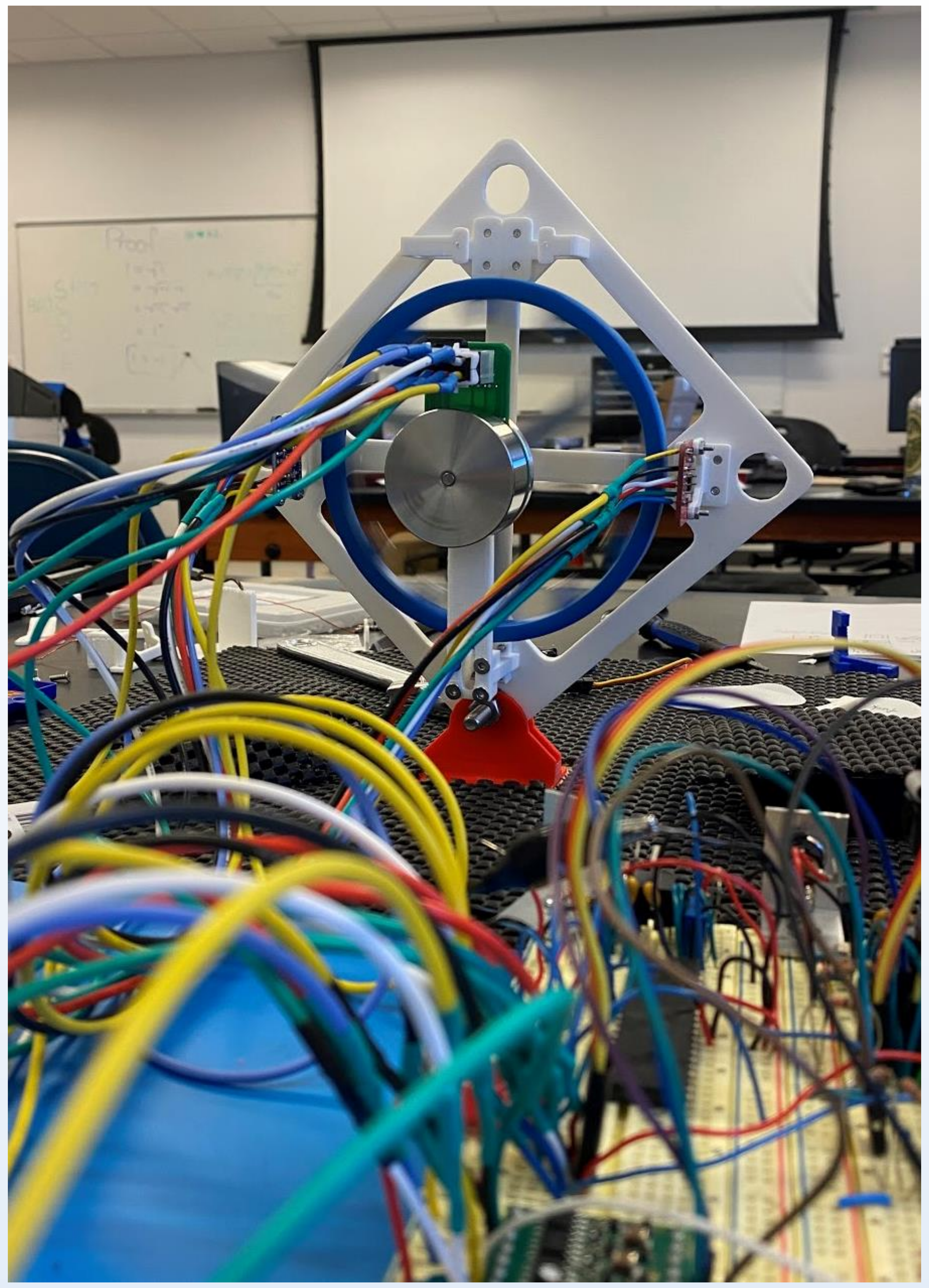
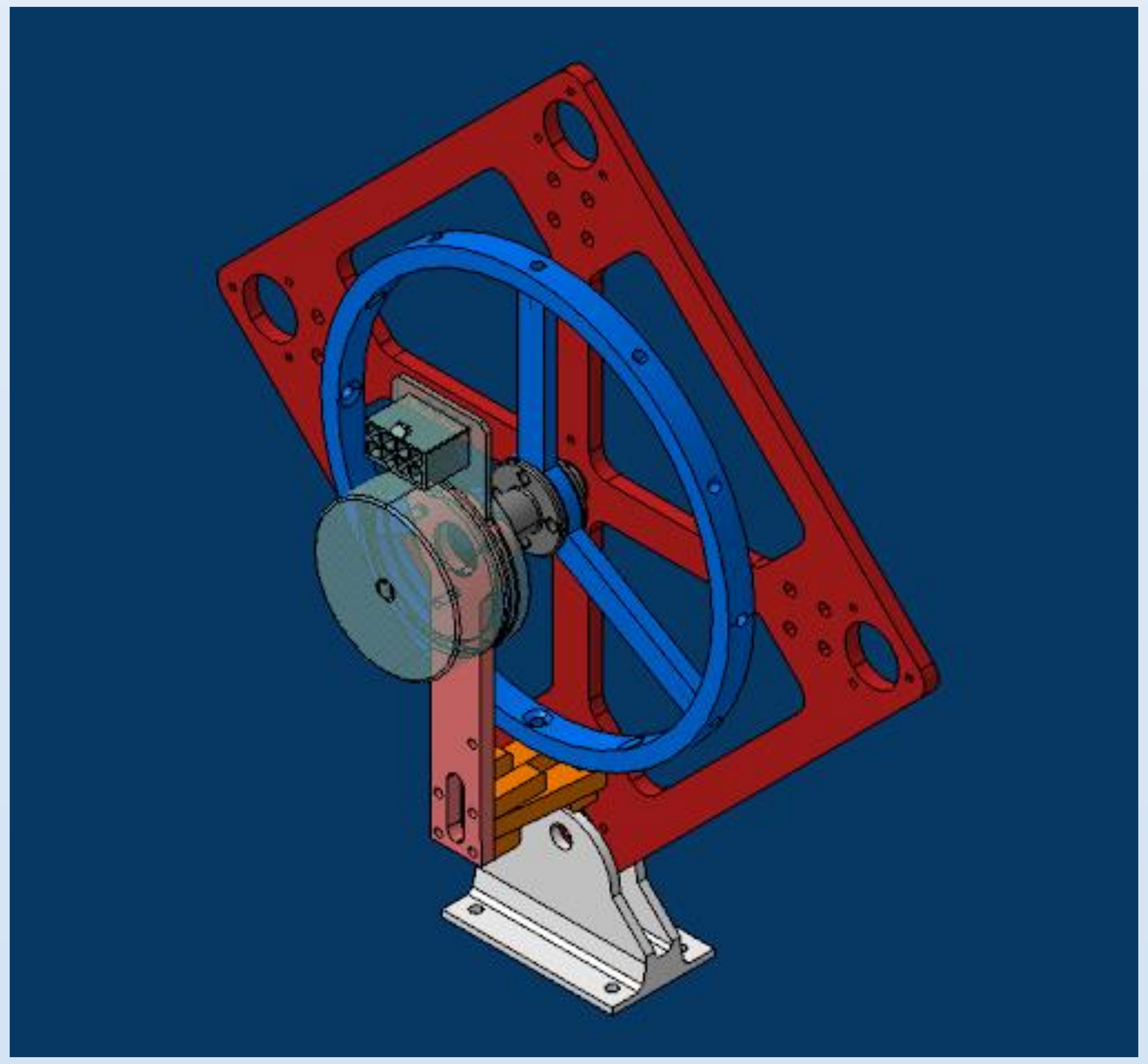
Abstract

Attitude Determination and Control Systems (ADCS) are used to detect and alter the orientation of spacecraft in orbit. Most spacecraft contain ADCS, but they are especially important for satellites whose onboard instruments require a high degree of directional precision. In satellites, reaction wheels are commonly used as the actuators of the control system. The goal of our capstone project is to apply the same technology to a ground-based system. The Balancing Reactive Inertia Cube (BRIC) is a self-contained cube that uses reaction wheels to balance on a corner. This project is inspired by the Cubli created by the Institute for Dynamic Systems and Control at ETH Zurich. Our project mostly focuses on a prototype that limits the system to a single dimension. The system can be dynamically modeled as an inverted pendulum and using a Linear Quadratic Regulator (LQR) control model we can efficiently achieve inverted balance using an 8-bit microcontroller.

Goals

The main objective for the one dimensional prototype can be broken up into two parts: the braking maneuver and the balancing. First, the reaction wheel is spun at a high speed and then the brake is applied. When the braking arm makes sudden contact with the spinning wheel, the angular momentum of the wheel is transferred to the body giving it enough energy to jump up to an equilibrium point. Once it's in an upright position it needs to be able to retain it. Project BRIC uses sensors to detect angular position and velocity information, and use an LQR controller to keep it upright.





Dynamic Modelling

A dynamic model of the system is needed both for the development of the LQR controller as well as for simulating the system's response. The system can be modelled with two equations of motion derived from classical mechanics. For BRIC, the equations of motion are the angular acceleration of the body and of the wheel.

$$\ddot{\theta}_b = \frac{mgl\sin\theta_b - C_b\dot{\theta}_b + C_w\dot{\theta}_w - k_m u}{I_b}$$

$$\ddot{\theta}_w = \frac{(I_w + I_b)(k_m u - C_w\dot{\theta}_w)}{I_w I_b} - \frac{mgl\sin\theta_b - C_b\dot{\theta}_b}{I_b}$$

The system was simulated to show its response when it experiences an impulse or essentially a small push. The impulse response shows that the system will converge back to the inverted position it began in.