Modeling the Attitude Determination & Control System (ADCS) on a 3U CubeSat

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Introduction

Attitude control– controlling the orientation of an object in space relative to a frame– is an important component of spacecraft. The stabilization and control of a satellite's orientation is necessary to point an antenna and relevant scientific instruments towards Earth so that accurate, interpretable data is collected for onboard experiments. Attitude control is especially critical in one of the lab's missions that utilizes surface imaging. The CubeSat must be able to determine its attitude from sensors accurately, derive the error given the measured attitude and the desired attitude, and apply torques using actuators– such as magnetorquers and reaction wheels– to minimize the error and reorient the spacecraft; collectively, this process comprise the ADCS. This research aims to model the CubeSat's ADCS through computer simulations, such as in MATLAB, and to ultimately determine necessary actuators to control the spacecraft within a calculated pointing error budget. This research will also study the complex mathematics of describing attitude and rotational dynamics to understand the subsystem.

Methods and Model Development

The rigorous mathematics and mechanics involved in creating attitude determination and control systems has made current research on the topic time-consuming to digest and difficult to penetrate. Consequently, in the time allotted for research, simpler models were opted for in this initial stage to show a working, accurate model of the CubeSat's ADCS that was capable of using environment values and a target attitude in a feedback loop, generating an output to modeled actuators and correcting the current attitude (Figure 1)

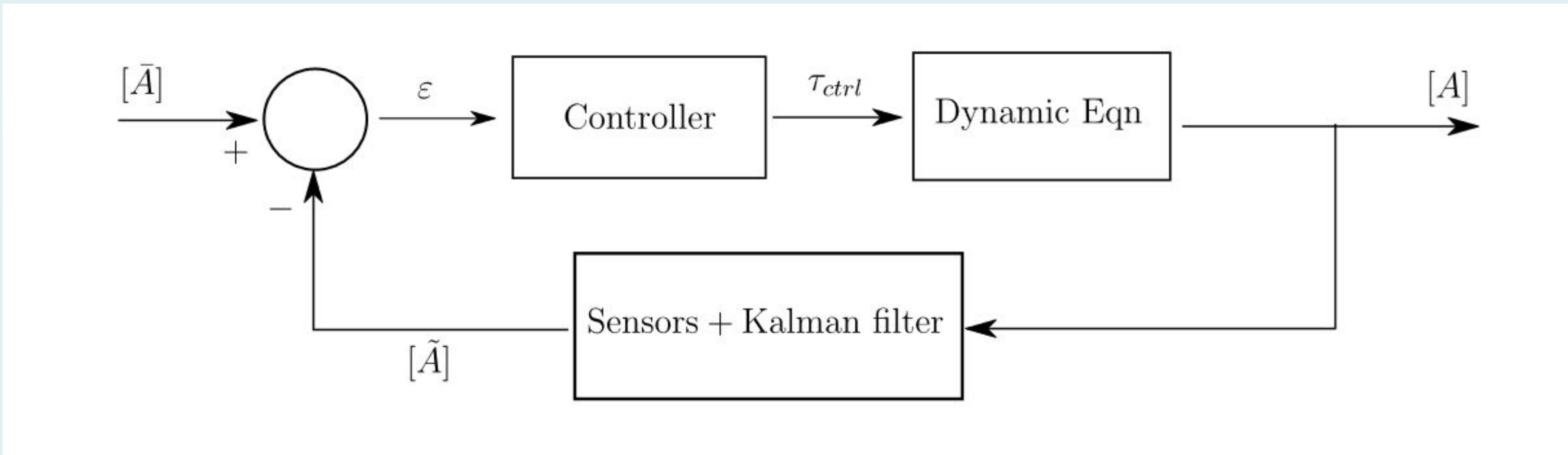

Figure 1

The required MATLAB scripts to build the feedback loop were divided and categorized into environmental, sensor, actuator, and controller models. The first step consisted of creating relevant environmental models that the satellite and the sensors would be subject to, before transitioning to the sensor models that would be onboard the satellite, and then building the actuator models.

Control Algorithm

The attitude determination and control system relies on a set of sensor readings and an extended Kalman filter (EKF) to obtain an estimation of the current satellite attitude. The Spectral Ocean Color (SPOC) satellite will have on-board magnetometers, gyroscopes, GPS and fine sun sensors, all of which contribute to attitude estimation.

All sensors are modeled as adding Gaussian noise to the relevant environment variable. All noise is characterized from system interface control documents, and is used in calibrating the EKF as well.

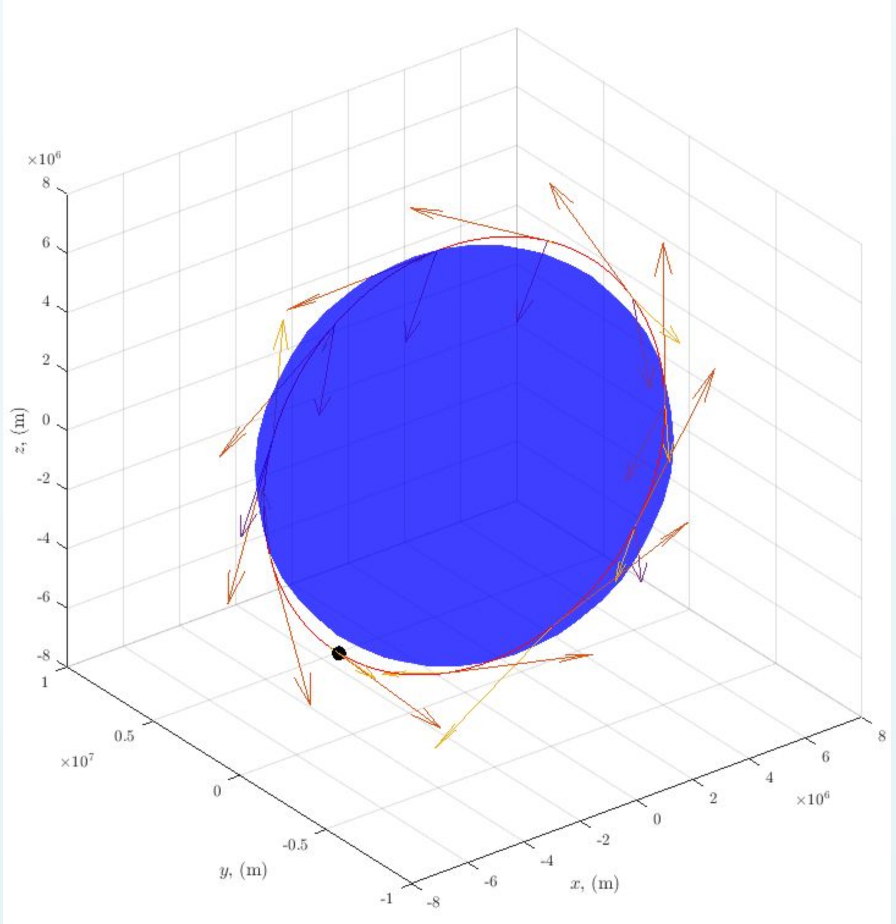

Figure 2

Attitude estimation is a prerequisite for attitude control. A desired attitude is compared to the estimate to obtain an error signal, which determines the controller response. The controller determines the amount of torque that needs to be applied to the satellite to "steer" it in the direction of the desired attitude. A standard PID control scheme is used for this model.

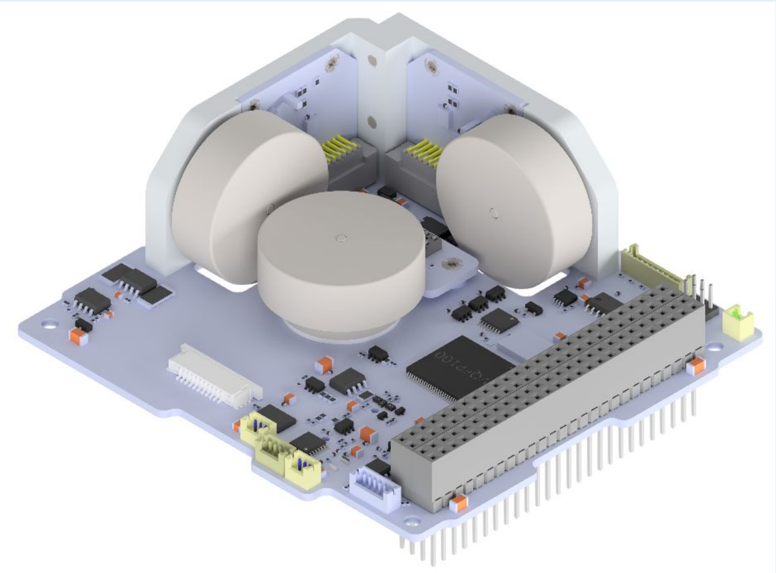

Figure 3

The control torque is one of the pieces in the satellite dynamic equation besides elements like disturbances from the environment. Figure 2 shows solar radiation pressure and aerodynamic disturbance forces. The actual control torque is limited by the saturation of the actuators. Reaction wheels (Figure 3) and magnetorquers will have limitations in the amount of torque they can supply.

The limitations of the reaction wheels are currently not accurately modeled due to lack of information from the manufacturer. Accurate sensor noise models are currently unknown, causing malfunction in the EKF.

The PID controller gains are determined by trial and error, although malfunctioning estimation algorithms are currently making the system unstable regardless of controller gains. Some modifications to sensor and estimations models will have to be made to correct for this.

Preliminary Results

The results shown in Figure 4 show some clear problems with the model as it exists currently. Firstly, the EKF does not appear to return a reliable attitude estimation. The EKF does account for the loss in attitude knowledge from the fine sun sensors (which need to have line of sight to the sun to return values), but other errors are preventing this from functioning properly.

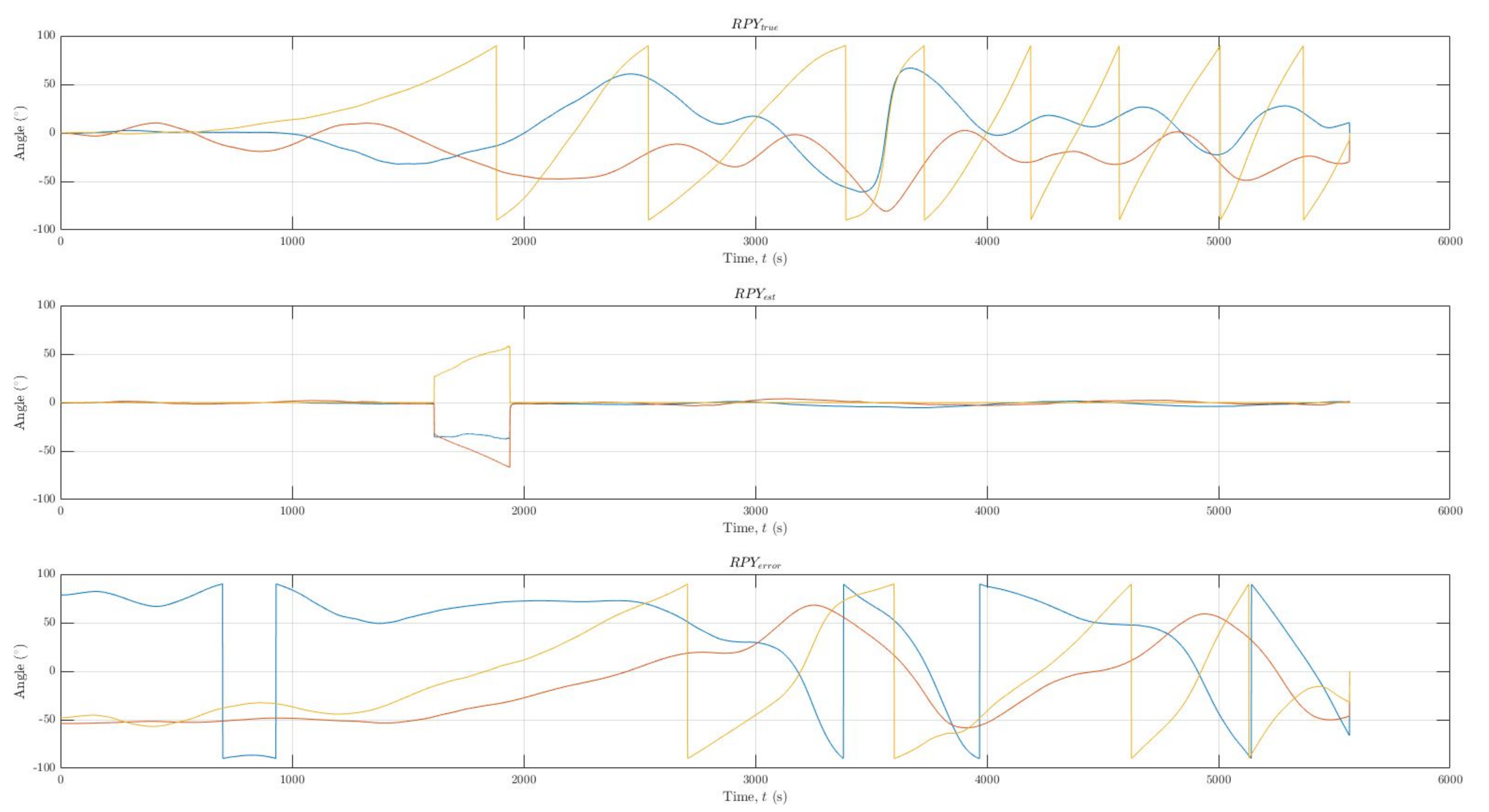

Figure 4

The malfunctioning estimator makes it hard for the controller to properly respond to changing attitude of the satellite. The attitude error graph in Figure 4 (displayed in terms of roll-pitch-yaw) shows a clear lack of stability of attitude.

In a system that is working correctly, the attitude error should reduce to zero, and the true attitude should approach the desired attitude. The attitude estimate should also closely resemble the true attitude. Currently, none of these criteria are visible from the result graphs.

Discussion and Future Work

In the future, when a proof of concept model of the ADCS is successfully functioning, analysis can take place on the controller to determine whether this model of the ADCS fulfills the pointing budget.

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