Armen Samurkashian

Fall 2017 Alpha CubeSat Report

Professor Mason Peck

Introduction

Alpha is a 1U CubeSat with the objective of demonstrating the successful deployment of a light sail for applications such as the Breakthrough Starshot mission. This document will cover work completed in the September 2017-December 2017 timeframe, focusing on attitude control.

Simulink Model

Translational Kinematics

The simulation for the spacecraft's attitude control system is a Simulink file titles "Starshotsimv3.6.slx". All initial conditions are set by the matlab file "Starshotsim_initv2.m". Both of these files reside in the project's Google drive folder. The kinematics are set up using assumptions from the Restricted 2-body problem, with the Earth represented as a point mass and the spacecraft's translational kinematics only subject to the Earth's gravitational field. The spacecraft's position is described by the vector $\vec{r}$ and is represented in the ECI coordinate system where:

$$^{xyz}\vec{\boldsymbol{r}} = \begin{bmatrix} \boldsymbol{r_x} \\ \boldsymbol{r_y} \\ \boldsymbol{r_z} \end{bmatrix}$$

Position is computed by the numerical double integration of Newton's equation for gravitational acceleration. Acceleration for each component of $\vec{r}$ is obtained by projecting the acceleration vector onto the component's respective axis such that:

$$\ddot{\boldsymbol{r}}_{\boldsymbol{i}} = \frac{\boldsymbol{\mu_{earth}}}{|\vec{\boldsymbol{r}}|^3}(\vec{\boldsymbol{r}} \cdot \hat{\boldsymbol{\imath}})$$

Where i is a dummy variable for the three components of the chosen components for the coordinate system components x, y, z.

Rotational Kinematics

The spacecraft rotational dynamics are computed using the following governing equation.

$$\vec{\boldsymbol{\tau}} = \boldsymbol{I}\dot{\vec{\boldsymbol{\omega}}} + \vec{\boldsymbol{\omega}} \times (\boldsymbol{I}\vec{\boldsymbol{\omega}})$$

Rearranging the equation, we compute angular acceleration $\dot{\vec{\omega}}$.

$$\dot{\vec{\boldsymbol{\omega}}} = \boldsymbol{I}^{-1}(\vec{\boldsymbol{\tau}} - \vec{\boldsymbol{\omega}} \times (\boldsymbol{I}\vec{\boldsymbol{\omega}}))$$

Integrating the equation numerically to solve for $\vec{\boldsymbol{\omega}}$, we convert the angular rate vector into the quaternion form $\dot{\vec{\boldsymbol{q}}}$ which we can then integrate to obtain spacecraft orientation expressed by the vector $\vec{\boldsymbol{q}}$.

Magnetic Field Model

Since the CubeSat's only method of attitude control is the use of magnetic torquers, the spacecraft's Simulink simulation contains a model of earth's magnetic field. Version 3.6 of the Simulink simulation uses the Earth magnetic dipole model. As the control system is tuned, this will be replaced by a more realistic, Matlab-based model that represents the local variations in Earth's magnetic field. The magnetic field takes the following form in a radial and tangential component.

$$B_r = -2B_0\left(\frac{R_{Earth}}{r}\right)^3 \cos(\theta)$$

$$B_r = -B_0\left(\frac{R_{Earth}}{r}\right)^3 \sin(\theta)$$

The two components are rotated into and expressed in terms of the ECI coordinate system.

Control System

The mission concept of operations call for establishing a spin about the Earth's magnetic North-South axis. This is challenging considering that a magnetorquer cannot produce a torque about the axis with which it is aligned. The spacecraft will have to establish its spin before aligning itself with the North-South axis and then orient itself about that axis after the spin has been established. Currently, the spacecraft's control laws neglect this and a pseudo-torque is applied that ignores the spacecraft orientation relative to the Earth's magnetic field. The device is referred to amongst team members as a "magic torquer". This setup is only to verify the control laws and rotational dynamics model of the spacecraft. At the time of writing of this document, a representative magnetorquer model is being implemented in the simulation.

The torque command is a result of the feedback loop of the spacecraft's angular orientation with respect to earth's North-South axis, given by the vector $\vec{B}_{cmd}$ expressed in spacecraft body coordinates and the spacecraft's z axis. Angular rates are controlled by the difference between the angular velocity vector $\vec{\omega}$ and the desired vector $\vec{\omega}_{cmd}$. Specifically,

$$\vec{T} = K_p\left((\hat{B}_{cmd} - \hat{z}) + \frac{d}{dt}(\hat{B}_{cmd} - \hat{z})\right) + K_d(\vec{\omega}_{cmd} - \vec{\omega})$$

Next Steps

The next step is to introduce the physical limitations of the magnetorquer into the rotational kinematics and replacing the "magic torquer". After the new control system's functionality is verified, a more refined magnetorquer simulation, specifically modeled after our mission specific magnetorquers will be incorporated into the overall Simulink model. Afterwards, our focus will shift to systems integration and testing, both on a hardware and software model.