Department of Electrical and Computer Engineering
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University of Windsor Space & Aeronautics Team Attitude Determination and Control Systems

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Abstract

The WinSAT team was challenged to design a 3U CubeSat capable of producing a space selfie ("Selfie Sat") for the Canadian Satellite Design Challenge (CSDC). The ADCS subdivision was responsible for the determination and control of the satellite's orbital attitude and position. This control and determination was done by developing algorithms via python and MATLAB to obtain the required parameters for the actuator and sensor inputs for the controller design. Once developed, STK provided the visual representation of the satellite moving in orbit of the earth.

Introduction

The University of Windsor Space and Aeronautics Team (WinSAT) objective is to design and construct a 3U Earth Observation Cube Satellite (CubeSat) for the Canadian Satellite Design Challenge (CSDC). This group was required to design, build, and test the following satellite subsystems:

1. **Attitude Control** – Design a control system using actuators to control the satellites orbital attitude
2. **Attitude Determination** – Collect input data from the gyroscope, magnetometer and sun sensor to output the satellite position, velocity and orientation in orbit.

Design Methodology

Reaction Wheels

The reaction wheels were designed to retain the required slew time in order to move around each axis in a 90-degree rotation.

Reaction Wheel Parameters (Python Code Generated)

- Obtain Size & Material, Required Torque & Momentum Storage

Magnetorquers

Magnetorquers were designed to maximize magnetic dipole moment and to reduce sizing of the actual metal rods/coil and air coil

Magnetorquer Wheel Parameters (Python Code Generated)

- Coil & core length/radius, Number of coil turns, Maximum dipole moment

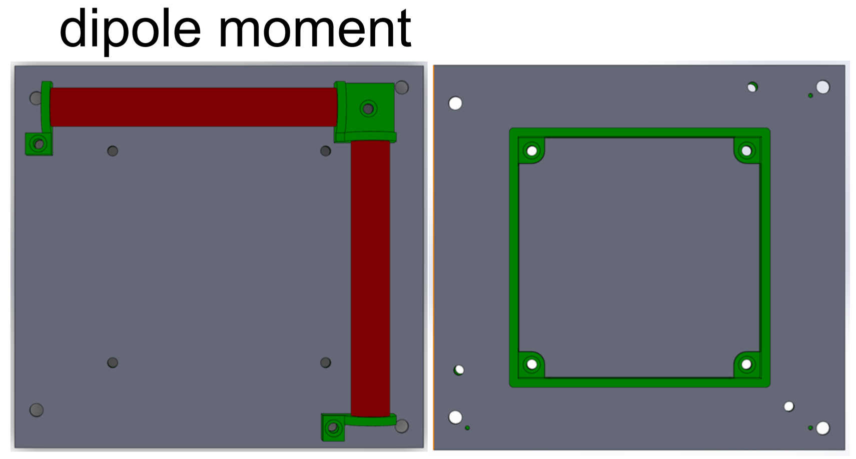

Figure 1: Top/bottom views of metal core magnetorquers and air core magnetorquer

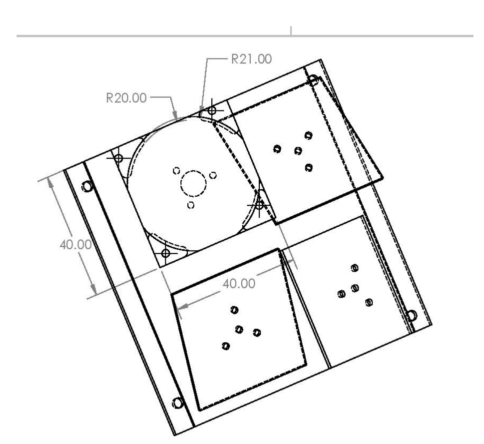

Figure 2: Preliminary work in Solid Works for the design of Reaction Wheels

Experimental Results

Sensors

Gyroscope & Magnetometer: Adafruit Precision NXP 9-DOF Breakout Board-+ FXAS21002.

Sun-sensor: Designed using planar photodiodes - SLCD-61N8 The initial voltage readings from the SLCD-61N8 is too low to be read and therefore a transimpedance amplifier has been developed in LTspice to amplify the signal to approximately 5V

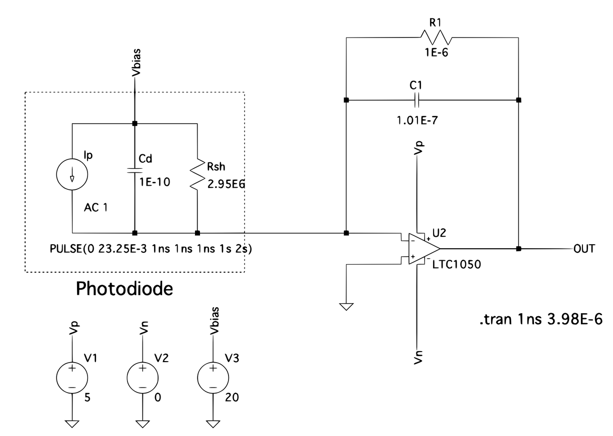

Figure 3: LTspice Model for Photodiode

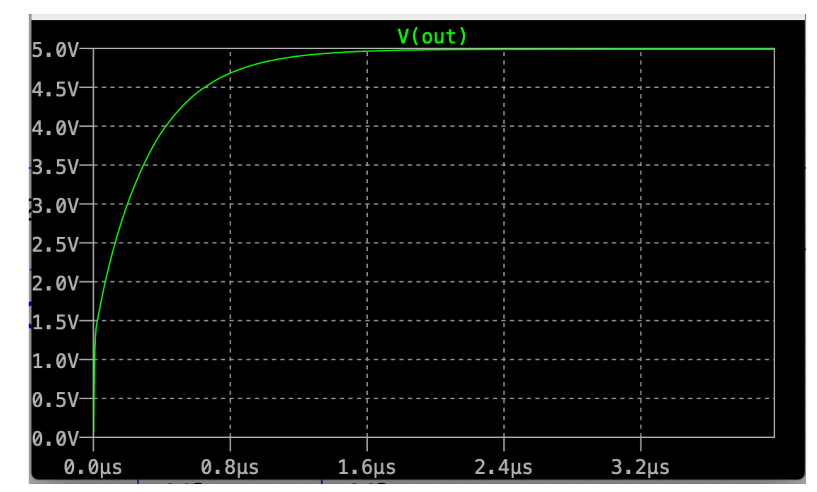

Figure 4: Simulation Result Displaying Amplification of signal to 5V

Sun vector determination: The position of the sun based on current readings of the photodiode per face in relation to the elevation (θ) and azimuth ($\emptyset$) angles was simulated in MATLAB using the following equations.

$$I_{left} = I_{max} sin\emptyset cos\theta$$
$$I_{front} = I_{max} cos\emptyset cos\theta$$
$$I_{top} = I_{max} sin\theta$$
$$V_S^B = \begin{bmatrix} sin\emptyset cos\theta \\ cos\emptyset cos\theta \\ sin\theta \end{bmatrix}$$

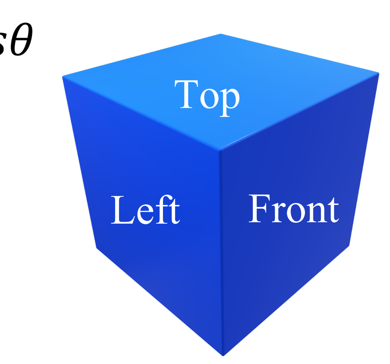

Figure 5: CubeSat Orientation

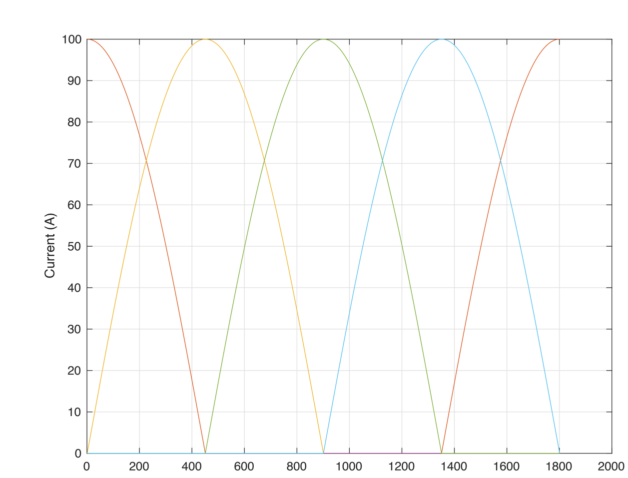

Figure 6: Change in Current per face after Elevation Angle iterations Between 0 to 2π

Controls

- A detumbling controller (B-dot) was developed to reduce the satellite's initial high angular rates to a near zero level for proper control and maneuvering.
- Nadir and Target pointing were achieved via a sliding mode controller, which allowed for the satellite to point its antenna for up/down link along with imaging.
- Attitude determination was achieved by SGP4 and TRIAD algorithms. This allowed for accurate readings of satellite orientation, position and velocity with respect to the earth centered inertial (ECI) frame.

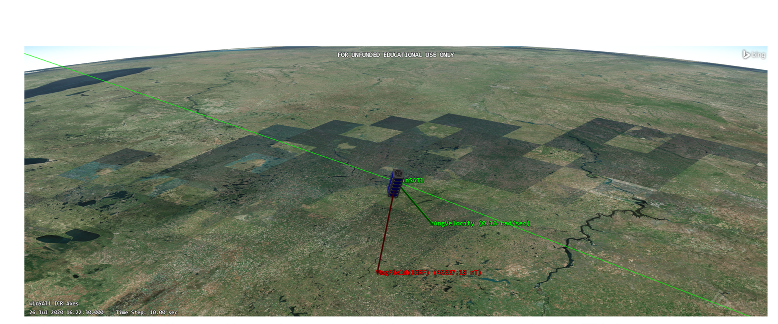

Figure 7: Visualization of 3U CubeSat in STK

Figure 8: Sun Synchronous Orbit of Satellite Visualized in STK

Deliverables

The integration of MATLAB and STK resulted in a successful output and a simulation of the detumbling stage. The angular velocity of the satellites converged to zero with time. The plots below show the results of the simulations carried out.

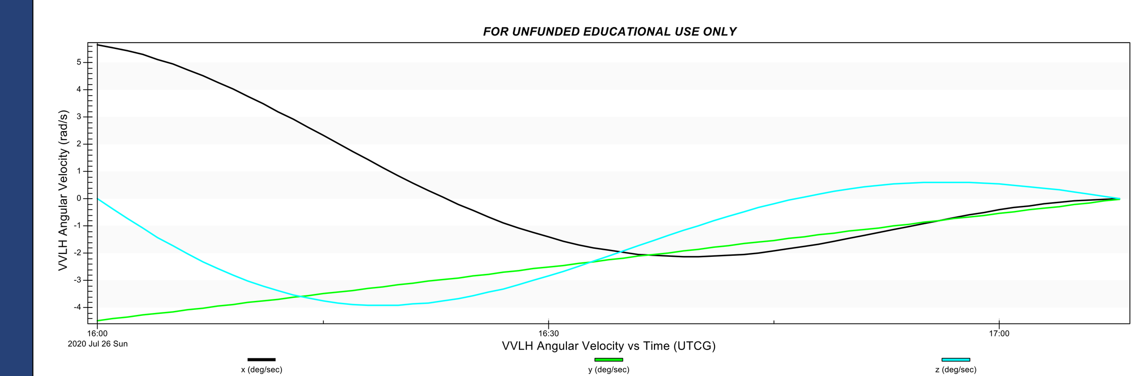

Figure 9: Detumbling algorithm converging the satellites angular velocity to near zero

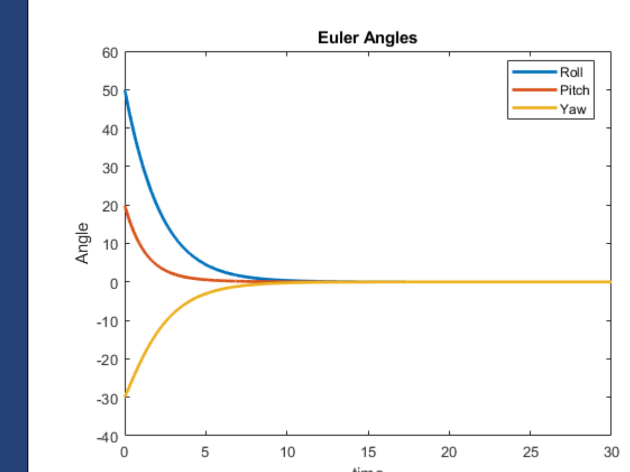

Figure10: Euler angles converging to zero and thus point to nadir

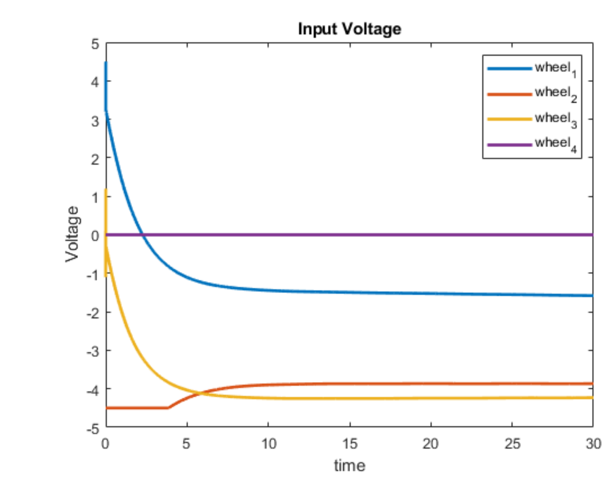

Figure 11: Voltage required for each reaction wheel to achieve and maintain nadir pointing

Conclusion and Future Work

The results of the initial calculations of the design and simulations of the satellite attitude and determination in the STK program were considered to have been acceptable. Future students who decide to take on the challenge of extending to build the 3UCubesat may continue the physical models of both actuators:

- For reaction wheels, students can select better material to reduce momentum storage which will in turn increase overall torque
- For magnetorquers, the Helmholtz cage can be constructed for physical testing.
- Students are also able to test photodiode data by performing physical analysis and integrating it with the CubeSat structure.

Students can incorporate both actuators into the control model as opposed to only reaction wheels.

Acknowledgements

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