Modelling and Simulation of EIRSAT-1 Attitude Determination and Control System

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1 Introduction

This document details a study of the modelling and simulation of the Attitide Determination and Control System (ADCS) for the EIRSAT-1 cubesat. This includes the satellite attitude dynamics, orbit propagation after release from the ISS; disturbances torques, position and attitude sensor models, magnetic actuator models and attitude feedback control system. The simulation environment was developed using MATLAB/Simulink. Simulation results are presented for several different test cases. These test cases include demonstrations of different control modes, different control systems and different actuator and sensor configurations including failure of one or more devices.

2 Objectives

- Create a simulation environment for the EIRSAT-1 ADCS subsystem including:
  - Satellite attitude dynamics, modelled as a single rigid body with 6DOF
  - Orbit propagation of the satellite after release from the ISS
  - Disturbance torques including: gravity gradient, solar radiation pressure, aerodynamic, residual magnetic field

  - Orbit propagation of the satellite after

- Define the different ADCS operational modes and functional requirements for each mode

- Design feedback controllers for each mode of the ADCS:
  - first assuming ideal 3-axis actuators
  - then with two magnetorquer actuators

- Design algorithm for safely switching between control modes

- Design controllers for failure modes including:
  - failure of one magnetorquer
  - failure of attitude sensors (needs to be more clearly defined)

3 ADCS Modes and Functional Requirements

- Detumbling
- Sun/object pointing
- Nadir/zenith pointing

3.1 Detumbling

Max rate to detumble? Time taken to detumble? Power?

3.2 Sun/distant object pointing

Required pointing accuracy? Settling time from one place to another? Power?

3.3 Nadir/zenith pointing

Required pointing accuracy? Time? Power?

3.4 Switching between modes

Which switches can happen? When can they happen ? (where in orbit, in eclipse?) Time taken?

4 Mathematical Modelling

4.1 Co-ordinate systems and Reference Frames

The spacecraft moves in an inertial reference frame N with associated cartesian coordinate system $OXYZ$ where $\mathbf{n_1}$, $\mathbf{n_2}$ and $\mathbf{n_3}$ are unit vectors along the X, Y and Z axes respectively.

A second reference frame A is attached to the spacecraft rigid body with coordinate system $Cxyz$ where C is the mass centre of the rigid body and $\mathbf{a_1}$, $\mathbf{a_2}$ and $\mathbf{a_3}$ are unit vectors along the x, y and z axes respectively.

A third reference frame .... orbital frame

4.2 Satellite Dynamics

EIRSAT-1 is modelled as a single rigid body with 6-DOF (degrees of freedom). The satellite has mass m and inertia tensor I in the body fixed coordinate system

4.3 Rotational Kinematics

The attitude of the spacecraft is described by quaternions.

4.3.1 Alternative representations of attitude and conversions

The orientation of the spacecraft may also be described using a Direction Cosine Matrix.

The orientation of the spacecraft may also be described using Euler angles. Starting with the body-fixed $oxyz$ axes aligned with the $OXYZ$ axes, the body undergoes a sequence of rotations by angles θ_3, θ_2 and θ_1 about the body-fixed z (yaw), y (pitch) and x (roll) axes respectively to reach its final orientation.

The DCM (Direction Cosine Matrix) is then described by equation 1.

$$C = \tag{1}$$

4.4 Orbit Propagation

4.5 Environment

4.5.1 Magnetic Field

4.5.2 Gravitational Field

4.6 Sensor Models

4.7 Actuator Models

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6 Simulink Model Structure

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6.1.1 Spacecraft Dynamics

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Model Setup File

Simulation Setup File

7 Results