Attitude Determination and Control System for ESTCube-1

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Introduction

ESTCube-1, developed mainly by students in Estonia, will be the first satellite performing the electric solar wind sail (E-sail) experiment in space. E-sail is a novel space propulsion concept which uses the dynamic solar wind pressure to propel the satellite. During the ESTCube-1 mission, one 50 µm thick 10-meter long heytether will be deployed and E-sail effect will be measured.

Attitude Determination and Control System (ADCS) aims to perform one axis spin-up using only electromagnetic coils. The spin-up is required to deploy E-sail tether by centrifugal force.

Hardware

ADCS includes magnetometers, sun sensors, gyro, analog-to-digital converters, coil drivers and magnetic coils. Command and Data Handling System (CDHS) microcontrollers are used for interfacing ADCS sensors and running algorithms.

Spin-up Algorithm

Magnetic control law is

\[ m = \frac{1}{k} \text{sat} \ T \text{sat} \ m_{\text{ful}} \]

where \( k > 0 \), and \( A = W ( k + T_{\text{sat}} k_{\text{P}} + T_{\text{sat}} k_{\text{I}} ) \dot{\omega} \).

- \( u(t) = [u_x(t), u_y(t), u_z(t)] \) is the saturation function;
- \( m_{\text{ful}} = [m_{\text{ful}, x}, m_{\text{ful}, y}, m_{\text{ful}, z}] \) is the maximum dipole moment for each magnetic torquer;
- \( \mathbf{B} \) is the norm function of the magnetic field vector;
- \( W = \text{diag}(1,1,0) \) selects the coils and \( P = \text{diag}(1,1,0) \);
- \( B = [B_x, B_y, B_z]^{T} \) is the cross product matrix associated with the vector \( \mathbf{B} = [B_x, B_y, B_z]^{T} \);
- \( k_{\text{P}}, k_{\text{I}} > 0 \) are tunable gain values;
- \( \omega \) is the satellite angular velocity vector;
- \( h = \dot{h}_{\epsilon} = h_{\epsilon} \rightleftharpoons \left[ \dot{\omega}_{x}, \dot{\omega}_{y}, \dot{\omega}_{z} \right] \) is the angular momentum error;
- \( h_{\epsilon} = \omega_{\epsilon} \) is the angular momentum where \( \omega \) is the moment of inertia matrix;
- \( c_{\text{m}, \epsilon} = h_{\epsilon} \) is the angular momentum error about z-axis.

The original algorithm has been improved for ESTCube-1 mission specific requirements of aligning spin axis and satellite with the Earth’s polar axis. Desired angular velocity is now transformed from Earth-centered inertial coordinate frame to spacecraft body reference frame and the desired angular velocity in z-axis is now always positive.

Simulation Results

Attitude control algorithms for detumbling, pointing and spin-up have been developed and tested in a simulation environment to estimate and measure the controller time response, error tolerance, accuracy and stability.

Models & Simulation Environment

Orbit Propagator

The rotation of the Earth is required to determine the magnetic field and to calculate how the satellite should point in order to track targets on Earth.

Ephemeris Model

The rotation of Earth’s is required to determine the magnetic field and to calculate satellite position at a particular time.

Eclipse and Earth Albedo Models

Eclipse indication is used to disregard sun sensor measurements during an eclipse and determining Earth’s albedo gives the possibility of making more realistic sun sensor models.

Magnetic Field Model

International Geomagnetic Reference Field (IGRF) model is used for the emulation of magnetometers and calculating the control torque of the coils.

Environment Disturbances

Spacecraft orbit and attitude are disturbed by atmospheric drag and torque from solar radiation and gravity gradient.

Sensor and Actuator Models

Sensor signals are introduced with realistic noise patterns to provide input for attitude estimators during simulations.

Simulation Environment

These simulation models with attitude estimators and different attitude control algorithms are implemented in Matlab/Simulink environment.

References


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