Boeing’s CubeSat TestBed 1 Attitude Determination Design and On-Orbit Experience [SSC09-X-6]

Christian Rayburn

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Introduction

- CSTB1 Overview
- CSTB1 Attitude Determination System Description
- Simulation Analysis Results
- On Orbit Data and Analysis
- Summary
CSTB1 Overview

- **MISSION**: Accelerate the maturity of CubeSat related components and general infrastructure & operations for this class of spacecraft.

- **MISSION PAYLOAD**: Ultra-low power CMOS imager and low power high performance microprocessor

- **Bus Features**
  - Leverages commercial-off-the-shelf components
  - Highly integrated
  - Ultra-low power

- **Multi-Functional Elements**
  - **Side Panels**
    - Solar cell power generation
    - Structure
    - Sun sensor suites
    - 2-axis magnetic field sensors
CSTB1 Attitude Determination

- Goals for the attitude determination algorithms are to provide coarse attitude knowledge to support imager testing
- Evaluate the usage of COTS components as simple low cost sensors
- The attitude determination sensors are integrated onto the multifunctional side panels
  - Five 2-axis magnetic field sensors
  - Four sun sensor suites
- Sensor information is contained in the satellite telemetry snap shot and is downloaded to the ground for post processing to determine attitude
- Implement simple sensor data processing and attitude determination via the TRIAD method

Simple sensors providing multiple axes of information to provide a reliable coarse attitude solution
Magnetic Field Sensors Configuration

- 2-axis magnetic field sensor
  - Single magnetoresistive sensor on an IC
  - Resolution of 120 micro gauss
  - Low noise characteristics

- Sensors are integrated onto 5 of the 6 panels
  - Multiple measurements of each body axis
    - 3 X body measurements
    - 3 Y body measurements
    - 4 Z body measurements

\[
\text{MagVector} = \begin{bmatrix}
\frac{(B_{x}^{P1} - B_{x}^{P2} - B_{x}^{P3})}{3} \\
\frac{(-B_{y}^{P1} - B_{y}^{P3} - B_{y}^{P4})}{3} \\
\frac{(B_{z}^{P0} + B_{z}^{P1} + B_{z}^{P2} - B_{z}^{P4})}{4}
\end{bmatrix}
\]
Sun Sensor Suite Configuration

- Sun sensor suite
  - 4 photo diodes
  - 45 degree cant angle
  - 90 degrees apart
- 4 total suites providing 3 axes of coverage
- Measures sun vector relative to side panel normal

- Distributed sensor approach
  - Minimizes contiguous consumed real estate on panel
  - Works around available area around the solar cells
Attitude Determination Algorithm for Post Processing Sensor Data

Magnetic field processing

Rotate attitude matrix by change in magnetic field

Compute attitude matrix using TRIAD algorithm

Compute attitude matrix using optimized TRIAD algorithm

Sun sensor processing

Valid?

4 cells?

No

No

Valid?

No
Simulation Analysis

- A simple rigid body simulation is used to evaluate the attitude determination performance
  - Sensor models
  - Satellite and orbital dynamics modeled
  - Magnetic and sun environments
- 9 cases evaluated with different tumble rates and sensor availabilities

Performance Observations

- Optimized TRIAD
  - Very accurate ~5 degree
- No Sun Vector
  - Attitude error would drift ~40 degrees
- Lower tumble rates resulted in better performance of attitude determination
On Orbit Sensor Data

- Observations
  - Sun sensors
    - Saturation in sun
    - Earth albedo
    - Eclipse clearly shows the sensors “off”
  - Magnetic field sensors
    - 2 sensors failed
    - Satellite aligned with magnetic field
On Orbit Analysis

- The CSTB1 camera was used to take an image during the time period of the presented sensor data.
- The computed attitude was used to determine the location of the image.

- Given:
  - Attitude of CSTB1
  - Sub-satellite point at time of image
- Yields: (33.4N, 81.8E)
- Search for comparison image

- Actual location (29N, 86E)
- Computed pointing error between coordinates
  - 2.2 degrees
Closing Comments

- Design Simplicity was Key Goal
  - Low cost by using COTS components
  - Integrated as multifunctional elements to work within volume, area, mass and power constraints of a CubeSat
  - Sensor data is a small footprint in the state of health telemetry
  - Ground processing provided coarse knowledge of satellite pointing

- Lessons Learned
  - CSTB1 aligned naturally with the magnetic field which aided in predicting when the payload would be facing the earth
  - Leave lots of margin in the sensor analog to digital converter, the sun is brighter than you think
  - Fly with multiple simple sensors
    • COTS parts have a higher probability of failure and redundancy is cheap

- Status
  - CSTB1 was been sending telemetry for 27+ months now!
  - Other than the two initially failed magnetic field sensors, the remaining sensors are functioning properly
  - Over 1,000,000 data points & 50 images have been collected to date