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

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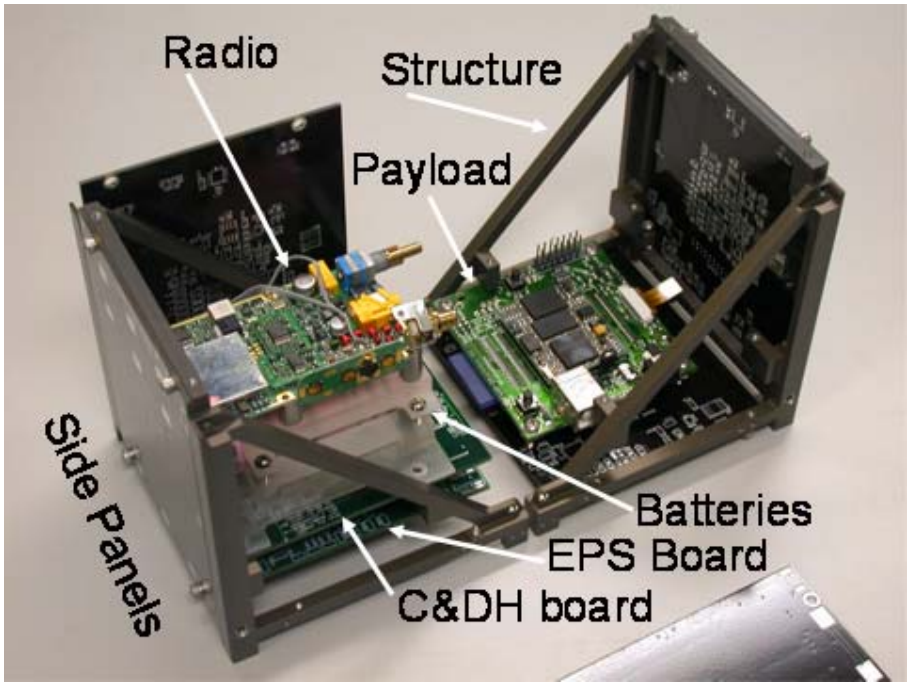
Introduction

- 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

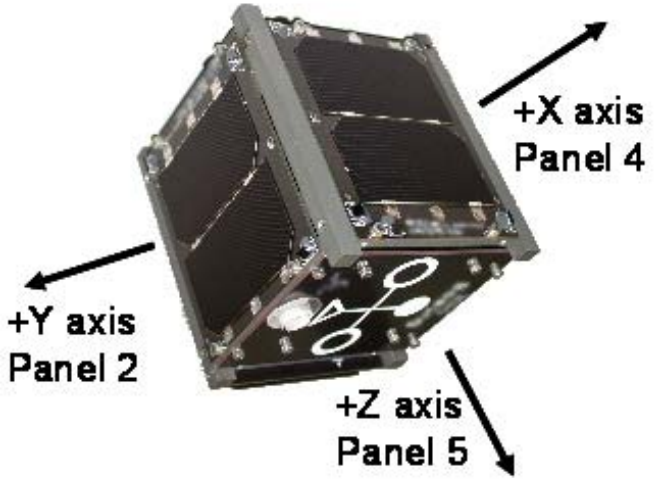


CSTB1 Attitude Determination

- 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

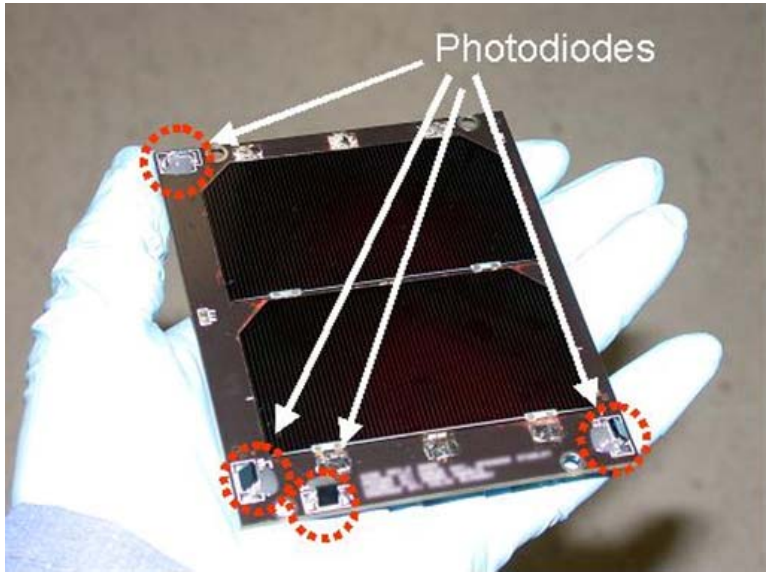
Magnetic Field Sensors Configuration



$$MagVector = \begin{bmatrix} \left(B_x^{P_0} - B_x^{P_2} - B_x^{P_3}\right)/3 \\ \left(-B_y^{P_1} - B_y^{P_3} - B_y^{P_4}\right)/3 \\ \left(B_z^{P_0} + B_z^{P_1} + B_z^{P_2} - B_z^{P_4}\right)/4 \end{bmatrix}$$

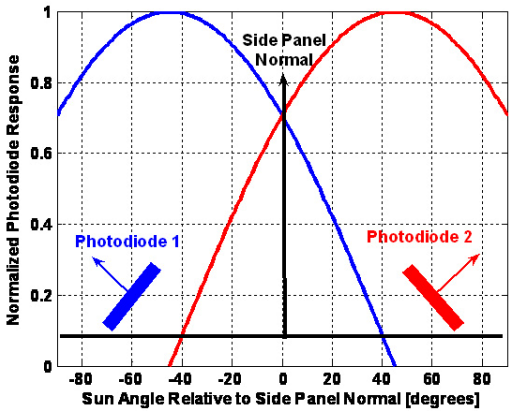
- 2-axis magnetic field sensor
  - Single magnetoresistive sensor on an IC
  - Resolution of 120 micro gauss
  - Low noise characteristics
- Sensors are integrated onto 5 of the 6 panels
  - Multiple measurements of each body axis
    - 3 X body measurements
    - 3 Y body measurements
    - 4 Z body measurements

Sun Sensor Suite Configuration



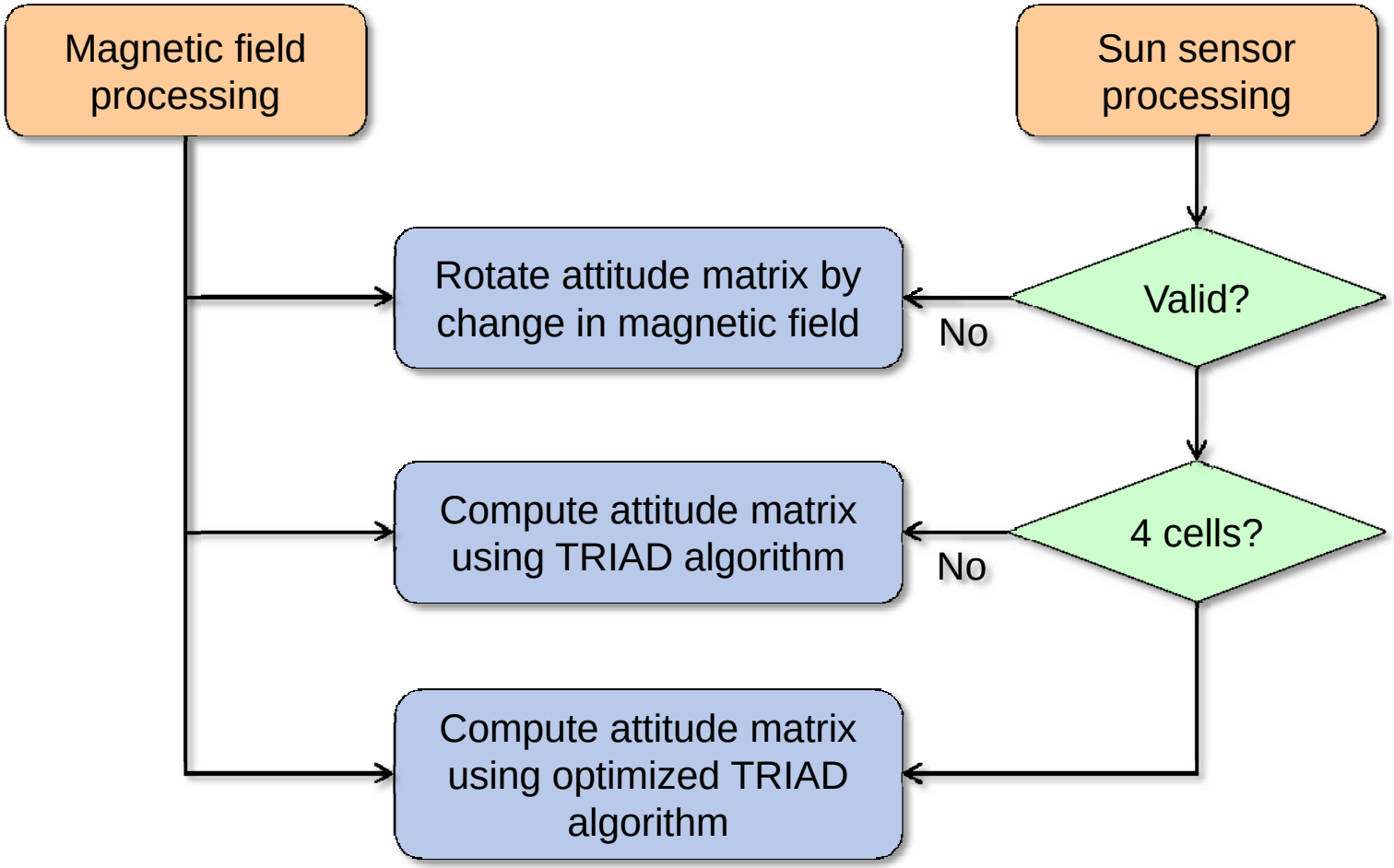
- Sun sensor suite
  - 4 photo diodes
  - 45 degree cant angle
  - 90 degrees apart
- 4 total suites providing 3 axes of coverage
- Measures sun vector relative to side panel normal

- Distributed sensor approach
  - Minimizes contiguous consumed real estate on panel
  - Works around available area around the solar cells



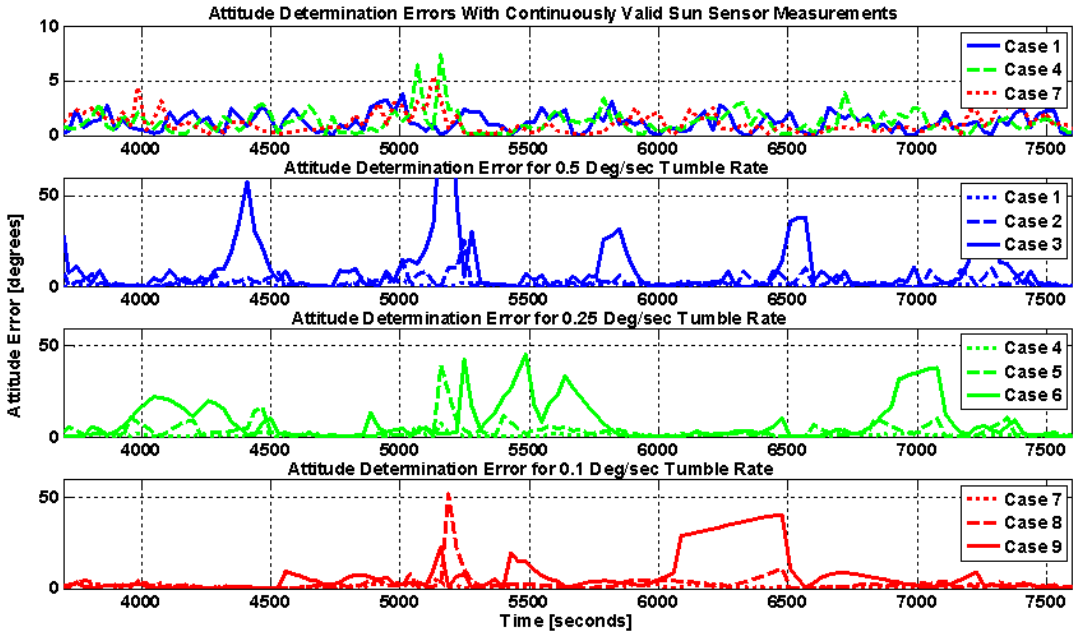
$$SunVector = \left\| \begin{pmatrix} \left(\frac{PD_2 - PD_1}{PD_2 + PD_1}\right) \\ \left(\frac{PD_3 - PD_4}{PD_3 + PD_4}\right) \\ 1.0 \end{pmatrix} \right\|$$

Attitude Determination Algorithm for Post Processing Sensor Data



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

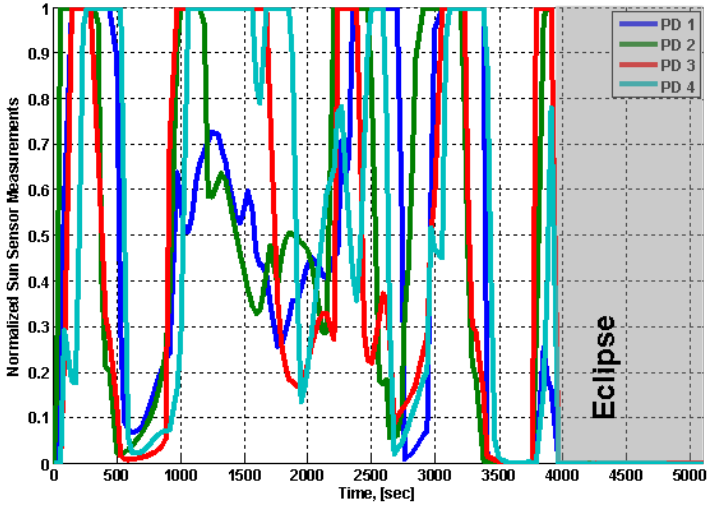


Case	Satellite Rate [deg/sec]	%Sun Sensor Unavailability
1	0.5	0
2	0.5	30
3	0.5	75
4	0.25	0
5	0.25	30
6	0.25	75
7	0.1	0
8	0.1	30
9	0.1	75

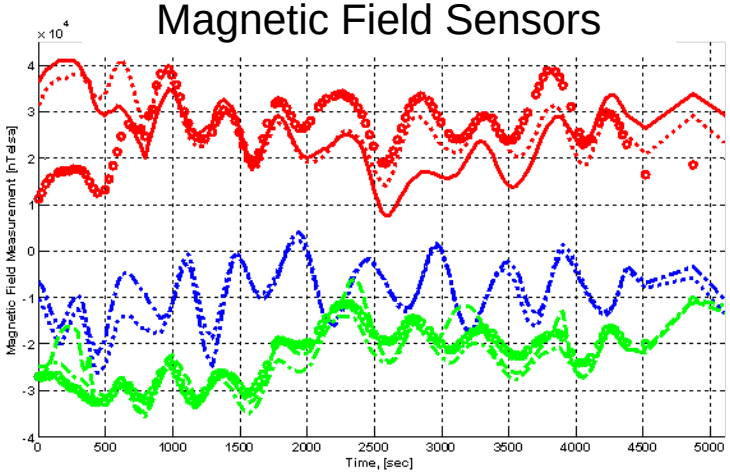
- **Performance Observations**
- Optimized TRIAD
  - Very accurate ~5 degree
- No Sun Vector
  - Attitude error would drift ~40 degrees
- Lower tumble rates resulted in better performance of attitude determination

On Orbit Sensor Data

Sun Sensor Suite on Panel 1

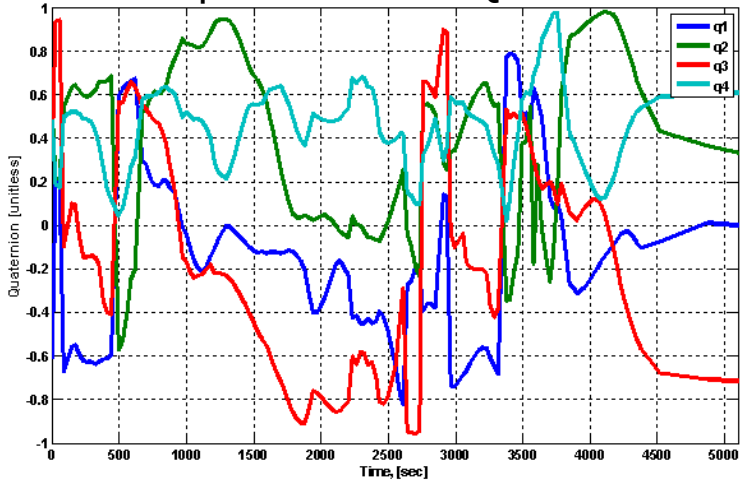


Magnetic Field Sensors



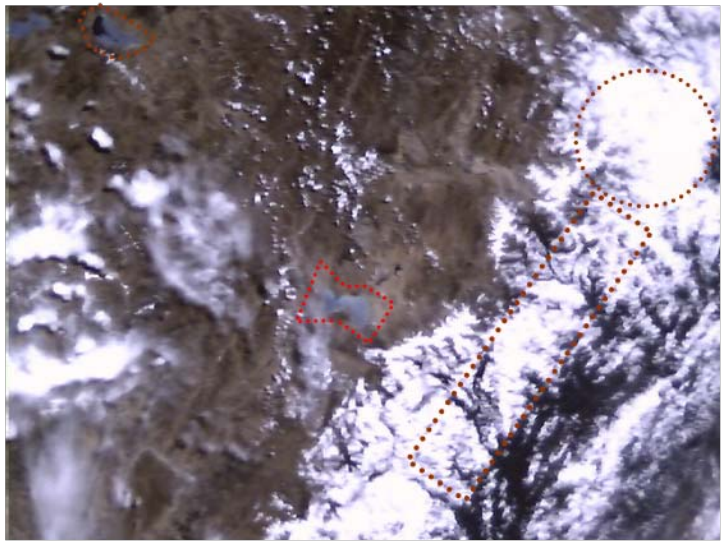
- Observations
- Sun sensors
  - Saturation in sun
  - Earth albedo
  - Eclipse clearly shows the sensors “off”
- Magnetic field sensors
  - 2 sensors failed
  - Satellite aligned with magnetic field

Computed Attitude Quaternion

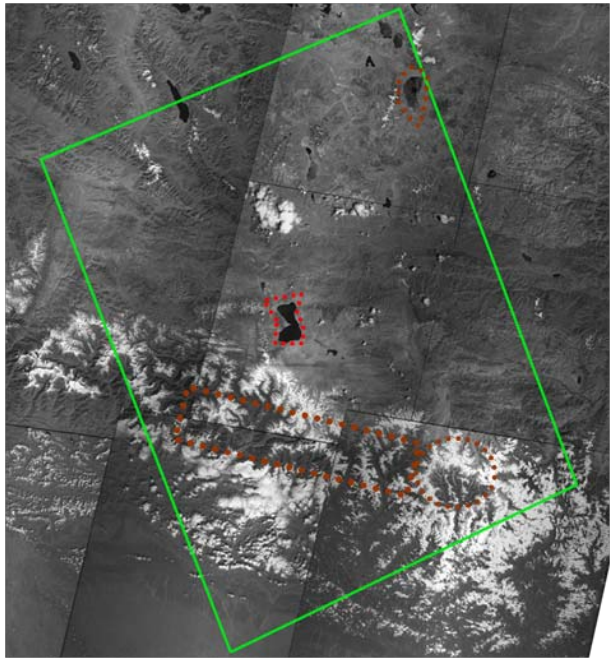


On Orbit Analysis

- 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
  - http://glovis.usgs.gov



L72140039 Image courtesy of the U.S. Geological Survey

- 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 foot print 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