Rate and Attitude Determination Using Solar Array Currents

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Introduction

- Cadets “Learn Space by Doing Space”
  - Real-world, hands-on experience
  - “Cradle-to-Grave” of space missions
    - Mission design
    - Payload and subsystem development
    - Assembly, integration & testing
    - Launch & on-orbit operations
    - Program management
- Support DoD space S&T objectives
  - Be a *Real* AF program
  - Do *Real* DoD science (fly SERB payloads)
- Train a cadre of space professionals
FalconSAT-3

- 8 March 2007
- Atlas V EELV/ESPA
- Orbit:
  - Altitude: 560 km
  - Inclination: 35.4 deg
- Mass: 54.3 kg (119.7 lbm)
- Size: 45.7 cm (18 in) cube
- Payloads:
  - Micro Propulsion Attitude Control System (MPACS)
  - Flat Plasma Spectrometer (FLAPS)
  - Plasma Local Anomalous Noise Environment (PLANE)
  - Shock ring vibration suppression
  - Gravity Gradient Boom
Introduction

Rate Determination
• First step to 3 axis stabilized satellite

Attitude Determination Using Solar Array Currents
• Attitude Determination Essential to Spacecraft Mission
• Small spacecraft typically use a TRIAD algorithm for attitude determination incorporating two types of sensors (magnetometers, sun/star sensors, etc.)
• Solar Arrays can be used as sun sensor
Example: BoxSat
Cube, Solar Arrays of equal size on all six sides
As BoxSat orbits the Earth, it rotates. During rotation, solar arrays change orientation relative to the Sun. Maximum current is produced when the array is perpendicular to the Sun. Peak current is the highest current produced during a given rotation.
The rotation rate over several orbits can be calculated using the frequency of the peak power.
Matlab’s Fast Fourier Transform gives the highest occurring frequency.
FalconSAT-3 Solar Array Currents 9 April 2007 1830Z

The graph shows the current values over time for different directions (+X, +Y, -X, -Y) on a FalconSAT-3 satellite. The x-axis represents time elapsed in seconds, ranging from 0 to 300, and the y-axis represents current in amps, ranging from 0 to 0.45. The data points are plotted for each direction, indicating changes in current over the specified time period.
FS3 TLM 9 April

- FalconSAT-3 Telemetry from 9 April
- ~50 data points over 5 minutes
- Very rough plot—indicates not enough data points or not enough observation time
FS3 TLM 4 April – 18 April

- FalconSAT-3 Telemetry from 6 passes during 4 April – 18 April
- ~ 200 data points
- Total Observation time ~ 33 Minutes
  - 1/3 of total orbit
- Rates Program predicts 28 minutes rotation rate.
During one revolution, each array will pass through peak power at a different time.
AO-51 TLM data from 7-8 August 2006
~3000 data points over 1 day
Gives accurate rotation rate of ~50 minutes
Shows that process works, just need more observations over time
Attitude Determination

- Three components
  - Orbit Propagation - Used to determine the Truth Sun Vector
  - Truth Sun Vector - Inertial frame vector based on orbit propagation
  - Body Sun Vector - Local body frame vector based on solar array currents
Max current indicates body sun vector is normal to array
Generally results in max current in panel facing sun and minimal current in other panels
Attitude Determination

- Peak current, or less than max current, indicates the body sun vector is incident to the array
- Using the equation below, the incidence angle sweeps out a cone on the face of the array

\[ P_{sa} = 1367 \frac{W}{m^2} \eta \cos(\theta) \]
After translating the cones to the geometric center of BoxSat, the intersection and center create a body sun vector which can be calculated as a unit vector using the below equation:

$$[x, y, z] = \left[ \frac{x_{\text{current}}}{x_{\text{current max}}}, \frac{y_{\text{current}}}{y_{\text{current max}}}, \frac{z_{\text{current}}}{z_{\text{current max}}} \right]$$
Underdetermined Condition

- If the sun is incident to only two arrays, or there are less than six arrays, the problem becomes underdetermined.
- You can use a different telemetry points, such as temperature sensors, communication gain, or magnetometers to resolve the last dimension.

\[
[x, y, z] = \left[ \frac{x_{\text{current}}}{x_{\text{current max}}}, \frac{y_{\text{current}}}{y_{\text{current max}}}, \pm \hat{z} \right]
\]
Solar Arrays can be used for attitude determination

Added sensor for no additional cost
- Substitution for malfunctioning sensor
- Extra sensor for attitude validation

Even in eclipse earthshine can be used
Questions