Small Satellite Technologies: Attitude Determination and Control

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What is Attitude Control?

• Attitude control is controlling the orientation of an object with respect to an inertial frame of reference or another entity.

• Involves using sensors and systems to adjust the angular orientation of the object due to phenomena and torque applied on the object.

• Applications:
  • Data Collection
  • Power Generation
  • Cooling
Attitude Determination

• Representation:
  • Euler Angles
  • Quaternion

\[ q = [q_1, q_2, q_3, q_4]^T \]
Attitude Determination: Relations

• Quaternion

\[ q^\circ = \frac{1}{2} \beta q \]

\[ \beta = \begin{bmatrix} 0 & \omega_z & -\omega_y & \omega_x \\ -\omega_z & 0 & \omega_y & \omega_x \\ \omega_y & -\omega_x & 0 & \omega_z \\ -\omega_x & -\omega_y & -\omega_z & 0 \end{bmatrix} \]

\[ q_1^2 + q_2^2 + q_3^2 + q_4^2 = 1 \]

• Euler Angles

\[ \omega_x = \phi^\circ - \varphi^\circ \sin \theta \]
\[ \omega_y = \theta^\circ \cos \phi + \psi^\circ \cos \theta \sin \phi \]
\[ \omega_z = \psi^\circ \cos \theta \cos \phi - \theta^\circ \sin \phi \]
Attitude Determination: Results

Initial Conditions:

\[ q = [0.12, -0.78, -0.5, 0.356] \]

\[ \omega = [0 \ 0 \ 2] \ \text{radians/sec} \]
Attitude Control

• Assumptions:
  • Inertial and Body Axes are coincident

\[
\begin{align*}
M_1 &= I_1 \dot{\omega}_1 + \omega_2 \omega_3 (I_3 - I_2) \\
M_2 &= I_2 \dot{\omega}_2 + \omega_1 \omega_3 (I_1 - I_3) \\
M_3 &= I_3 \dot{\omega}_3 + \omega_1 \omega_2 (I_2 - I_1)
\end{align*}
\]
UH Hiaka Satellite

- Moments of Inertia
- \([3.450 \ 3.314 \ 3.532] \ kg \ast m^2\)
Cylindrical

- Moments of Inertial
- $[10 \ 10 \ 18] \ kg \cdot m^2$
Attitude Control: Zero Torque Motion

Hiaka

Cylindrical

Initial Conditions:
\[ \omega = [5, 3, -2] \ \text{radians/sec} \]
Attitude Control: Non-Zero Torque

- Torque due to Mini-Thruster
- Thrust to Weight Ratio: \( \frac{1}{1000} \)
- Assumptions:
  - Mass: 95 kg
  - Thrust: 0.932 N
Attitude Control Non-Zero Torque About X-Axis

\[ \text{Thrust} \]

\[ \text{Thrust} \cdot t^2 \]

Cylindrical

Initial Conditions:

\[ \omega = [5, 3, -2] \, \text{radians/sec} \]

\[ \text{Thrust} \cdot t \]

\[ \text{Thrust} \cdot \sin(\pi t) \]
Attitude Control Non-Zero Torque About X-Axis

Hiaka

Initial Conditions:

\[ \omega = [5, 3, -2] \quad \text{radians/sec} \]