ATTITUDE CONTROL STRATEGY FOR HAUSAT-2 WITH PITCH BIAS MOMENTUM SYSTEM

Space System Research Lab.

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Introduction of Space System Research Lab. (SSRL)
Introduction of SSRL

Space System Research Laboratory (SSRL) was established in 2000

First nano- / pico- satellite systems are being developed by graduate students in Korea

Funded by government (MOST), research institutes, and industries

Staffed by full-time graduate students and advisor group

Significant contribution to space education

- Provision of space education program
- Academic research opportunities
- Challenging space system development

Research Area

- Low-cost space missions
- Pico, nano, and micro-satellite technology research and development
- Student training (design, assembly, integration, test, LEOP and operation)
Current SSRL Program

HAUSAT Series (Hankuk Aviation University SATellite)
- Ultra-Small Satellite Series which are developed by SSRL, Korea
- “Faster, Cheaper, Better”
- Educational Tool
- Means for Space Verification

HAUSAT-1 (CubeSat)
- 1 kg, Pico Satellite
- International CubeSat Program
- Mission
  - Space-borne GPS Receiver Verification
  - Home-made Sun Sensor Verification
  - Solar Panel Deployment Mechanism

HAUSAT-2
- 25 kg, Nano Satellite
- National Research Lab.(NRL) Program
- Mission
  - Animal Tracking
  - Measurement of Plasma in LEO
  - Measurement of TID during Mission Life in LEO
  - Star Tracker Verification
  - Space-borne GPS Receiver

LEO
- 800 km
- 700 km
- 600 km
- 500 km

Ground
- 0
HAUSAT-1 Project (1/2)

HAUSAT-1 pico-satellite system development

Purpose

- Development, launch, and operation of pico-satellite (CubeSat)
- Space qualification of space components
- Develop core satellite system technology
- Establish satellite system development infrastructure
- Cultivate professionals in field of satellite systems
- Accomplish national-first purely student managed program
  - Exposing students to multi-disciplinary engineering spanning from satellite bus to payload
- Experience full scope of satellite development

Similar in composition to medium/large satellites

- Structure, power, on-board computer, thermal, attitude control, comm subsystems

Excellent Educational Tool
HAUSAT-1 Project (2/2)

<table>
<thead>
<tr>
<th>ITEM</th>
<th>SPECIFICATION</th>
<th>REMARK</th>
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<tbody>
<tr>
<td>Altitude</td>
<td>511 Km</td>
<td></td>
</tr>
<tr>
<td>Inclination</td>
<td>about 98 deg</td>
<td>Sun-synchronous</td>
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<tr>
<td>Mass</td>
<td>&lt; 1kg</td>
<td>Payload Included</td>
</tr>
<tr>
<td>Volume</td>
<td>10 × 10 × 10 cm³, Cubic</td>
<td>Payload Included</td>
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<tr>
<td>Power</td>
<td>&gt; 1.3 W</td>
<td>@EOL</td>
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<td>Attitude Control Accuracy</td>
<td>&lt; 5 deg</td>
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<tr>
<td>Payload</td>
<td>Space-borne GPS Receiver, Solar Panel Deployment</td>
<td></td>
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<td></td>
<td>Mechanism, Sun Sensor</td>
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<tr>
<td>Up/Downlink</td>
<td>1200 bps</td>
<td>FSK</td>
</tr>
<tr>
<td>Data Storage Capacity</td>
<td>16Mbits for SOH 32Mbits for GPSR</td>
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<tr>
<td>Mission Life</td>
<td>1 yr</td>
<td></td>
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<td>Development Model</td>
<td>EM, QM, FM-1, FM-2</td>
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<td>Launch</td>
<td>July. 26, 2006</td>
<td>Dnepr</td>
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HAUSAT-1 Program Success Criteria

H-1 Project Success Class D
HAUSAT-1 Launch Failed

- Dnepr launch vehicle malfunctioned during launch
  - 1st stage rocket engine shutdown (July 26, 2006)
  - All payload lost
- HAUSAT-1 could not accomplish mission, but main GOAL has been ACHIEVED
  - Develop core satellite system technology
  - Establish satellite system development infrastructure
  - Cultivate professionals in field of satellite systems
  - Accomplish national-first purely student managed program

Success from University Perspective
## HAUSAT-2 Project – Overview

### HAUSAT-2

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<th>Item</th>
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<td>Altitude</td>
<td>650 ~ 800 km</td>
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<td>Inclination</td>
<td>98 deg (Sun-synchronous)</td>
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<td>Mass</td>
<td>&lt; 25 kg</td>
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<td>Size</td>
<td>32 cm × 32 cm × 40 cm</td>
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<td>Generation Power</td>
<td>&gt; 20 W</td>
<td>Average @EOL</td>
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<tr>
<td>Accuracy</td>
<td>Pitch : ±1 deg</td>
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<tr>
<td></td>
<td>Roll, Yaw: ±3 deg</td>
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<td>Mission Payloads</td>
<td>Animal Tracking System</td>
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<tr>
<td></td>
<td>Electric Plasma Probe</td>
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<td></td>
<td>TID Meter</td>
<td>-</td>
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<td>Technical Payloads</td>
<td>Star Tracker</td>
<td>-</td>
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<td></td>
<td>GPS Receiver</td>
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<tr>
<td>Downlink</td>
<td>9600 bps</td>
<td>FSK</td>
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<td>Uplink</td>
<td>2400 bps</td>
<td>FSK</td>
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<tr>
<td>Design Mission Life</td>
<td>2 yrs</td>
<td>Operational Mission Life: 1 year</td>
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HAUSAT-2 Project – System Definition

Electric Plasma Probe

HAUSAT-2

Animal Tracking System

Launch

Animal Tracking Terminal

User

HAUSAT Ground Station

ssrl@hau.ac.kr
ykchang@hau.ac.kr
Animal Tracking System (ATS)

- Terminal attached to animal transmit signal
- Less than 5% of host animal
  - GPS included terminal: bigger animal
  - GPS excluded terminal: birds

Case 1: GPS Data Acquisition
Case 2: Tracking using Doppler Effect
### < ADCS Specification >

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<td>Mass</td>
<td>&lt; 4.2 kg</td>
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<td>Average Power Consumption</td>
<td>&lt; 6 W</td>
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<td>Attitude Control</td>
<td>Pitch Momentum Control</td>
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<tr>
<td>Pointing Direction</td>
<td>Earth Pointing</td>
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<tr>
<td>Pointing Accuracy</td>
<td>&lt; ± 1 deg (Pitch)</td>
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<td></td>
<td>&lt; ± 3 deg (Roll &amp; Yaw)</td>
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### < Sensors & Torquers Performance >

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<th>Performance</th>
<th>No.</th>
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<td>CSS</td>
<td>48g</td>
<td>0.1W</td>
<td>±0.115deg</td>
<td>1EA</td>
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<tr>
<td>FSS</td>
<td>87.5g</td>
<td>0.1W</td>
<td>±0.35deg</td>
<td>4EA</td>
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<td>MAG</td>
<td>40g</td>
<td>0.2W</td>
<td>±30nT</td>
<td>2EA</td>
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<tr>
<td>ST</td>
<td>1.2kg</td>
<td>6.5W</td>
<td>10arcsec</td>
<td>1EA</td>
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<tr>
<td>MTQ</td>
<td>225g (1EA)</td>
<td>1W (1EA)</td>
<td>2Am²</td>
<td>3EA</td>
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<tr>
<td>MW</td>
<td>1.5kg</td>
<td>1W</td>
<td>0~4Nms</td>
<td>1EA</td>
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### < ADCS Configuration >

- **Magnetic Torquer (MTQ)**
- **Coarse Sun Sensor (CSS)**
- **Fine Sun Sensor (FSS)**
- **Star Tracker (ST)**
- **Magnetometer (MAG)**
- **Star Tracker Electronic Unit (STEU)**
- **Momentum Wheel (MW)**
Pitch Bias Momentum System
Assumptions

Earth magnetic field model
- 10th Order IGRF (International Geomagnetic Reference Field) 2005 Earth’s magnetic field model

Orbit parameters
- Sun-synchronous orbit of 650km altitude

HAUSAT-2’s moment of inertia
- $I = \text{diag}(0.3078, 0.2865, 0.2747) \text{kg m}^2$
- Momentum wheel
  - Angular momentum : 0.09Nms
  - Nominal wheel speed : 2500 rpm
- Magnetic Torquer
  - Maximum magnetic dipole moment : 2Am$^2$
Detumbling Control

Detumbling controller must stabilize satellite’s initial rapid angular rate

Assumption for simulated detumbling process
- Worst initial tip-off rate of satellite separating from launch vehicle is 0.1 rad/sec (1 rpm) in each axis
- Simulation carried out until values fell below 0.003 rad/s for all axes
B-dot Controller

- B-dot controller generally used to control initial angular rate (detumbling)
  - Only earth’s magnetic field measurements are needed

Magnetic dipole moment in each axis

\[ \mathbf{M} = -K \mathbf{\dot{B}}, \quad (K > 0) \]

- \( K \) : Control gain constant
- \( \mathbf{\dot{B}} \) : Differentiated earth’s magnetic field vector \( \mathbf{B} \) in each axis

\[ \mathbf{\dot{B}} = \frac{\mathbf{B}(t) - \mathbf{B}(t-T)}{T} \]

- \( T \) : sampling time
B-dot Controller

Performance of B-dot controller

- Trend in angular rate change according to gain $K$
- Optimum gain $K$ was chosen considering detumbling time and actuator power consumption from simulation results

Angular Rate and Power Consumption Trends According to Control Gain $K$
B-dot Controller

Performance of B-dot controller

- B-dot controller performance according to initial angular rate has been verified using chosen gain, $K = 5 \times 10^5$
- Simulation was performed for varying initial angular rate from $\pm 0.1\ \text{rad/s}$ to $\pm 0.07\ \text{rad/s}$ for each axis
- Detumbling time: approximately 70 minutes

B-dot Controller Performance According to Initial Angular Rate Change
A New Detumbling Control Method

Disadvantage of B-dot controller

- Low torque level of magnetic torquers
- Takes relatively long time to control angular rate

For missions requiring fast on-orbit checkout and initial operation time, B-dot controller may not be suitable

We propose a new detumbling method that uses both magnetic torquers and momentum wheel
A New Detumbling Control Method

The control torque generated by MTQ

\[ T_M = M \times B = -K \dot{B} \times B \]

➤ Pitch axis control torque has to come from momentum wheel
➤ Wheel controller can be designed as follows by taking second column of matrix

\[ T_W = T_{M2} = K_W \cdot (B_3 \dot{B}_1 - B_1 \dot{B}_3) \]

Controller described by above equation is modified such that executable constant torque is generated

\[ T_W = K_W \cdot \text{sgn}(B_3 \dot{B}_1 - B_1 \dot{B}_3) \]

\[ \text{sgn}(A) = \begin{cases} +1 & : A \geq 0 \\ -1 & : A < 0 \end{cases} \]

➤ This modified controller is termed “momentum wheel detumbling controller”.
MW Detumbling Controller

Performance of MW detumbling controller

- Angular rate change trend according to $K_W$
- Optimum control gain $K_W$ chosen through simulation
  - Taking into account wheel conditions, detumbling time, and actuator power consumption.

Angular Rate, Momentum Wheel RPM and Power Consumption Trends According to Control Gain $K_W$
MW Detumbling Controller

Performance of MW detumbling controller

Control gain of $K_W = 5 \times 10^{-5}$ chosen for momentum wheel detumbling controller

All initial angular rates stabilize within 20 minutes

Performance of Momentum Wheel Detumbling Controller According to Initial Angular Rate Change
Momentum Wheel Start-up

Wheel start-up can be tricky
- Rest → nominal rpm can cause attitude instability
- Must maintain stability during wheel start-up

Common factor in previously studied wheel initial start-up methods: require satellite to be spin-stabilized before start-up of momentum wheel

For detumbling to be done using new proposed method, spin-stabilization cannot be achieved
- Propose new wheel start-up method
Conventional Wheel Start-up Method

**MW start-up procedure**

- **Step 1:** Detumbling control using B-dot controller
- **Step 2:** Pitch spin-stabilization (Y-Thomson Spin) to arbitrary angular rate
  
  \[
  M_1 = K_s (\omega_2 - \omega_{2-target}) \text{sgn}(B_3)
  \]
  
  \[
  M_2 = -KB_2, \quad (M_3 = 0)
  \]

- **Step 3:** Momentum wheel speed-up at constant angular acceleration (open-loop)
  
  - Momentum wheel speed is increased at constant rate of 0.01 Nms (In the case of HAUSAT-2) in open-loop fashion

- **Step 4:** 3-axes attitude stabilization
  
  - For 3-axes stabilization, magnetic torquers use B-dot controller and momentum wheel uses PD controller
Conventional wheel start-up method

Simulation Results

- Able to achieve 3-axes stabilization in about 250 minutes

(a) Attitude

(b) Angular Rate, Wheel RPM and Magnetic Dipole Moment
A New Method for Wheel Start-up

For new proposed detumbling method, spin-stabilization cannot be achieved

MW Start-up Procedure

Step 1: Detumbling control using momentum wheel and B-dot controller

Step 2: Wheel speed-up using momentum dump controller

\[ M_1 = -K_{WS} \cdot B_3 \cdot (h_W - h_{W-Target}) \]
\[ M_3 = K_{WS} \cdot B_1 \cdot (h_W - h_{W-Target}) \]
\[ M_2 = -KB_2 \]

\[ h_{W-Target} \]: Control target wheel angular momentum

Step 3: 3-axes attitude stabilization
A New Method for Wheel Start-up

Simulation Results

Total simulated time for overall stabilization is about 150 minutes

(a) Attitude

(b) Angular Rate, Wheel RPM and Magnetic Dipole Moment
Conclusions

Newly proposed detumbling control method
  ➤ Able to control angular rate within 20 minutes
  ➤ Considerable time reduction compared to conventional methods

New method for stable momentum wheel start-up
  ➤ Overall results show faster control time compared to general methods
  ➤ Nominal wheel start-up and 3-axes stabilization while maintaining stability

Can be effectively applied to micro/nanosatellites

Much time saved
  ➤ May not matter to some, but very important to quick-response type missions
    ➤ E.g. military application that needs quick response and minimal on-orbit checkout time