Sensors for orientation and control of satellites and space probes

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Space for Education, Education for Space
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1) How to determine the orientation of the satellite?
   – Sensors
   – Calibration
   – Sensor fusion

2) How to control the orientation of the satellite?
   – Passive systems
   – Magnetorquers
     • B-dot algorithm
     • Testing with 3D helmholtz coils system
   – Reaction wheel
1) Attitude Determination

• Gyroscope
  – Measure angular velocity
  – Types
    • MEMS vibrating structure
    • Optical gyroscopes

\[ \theta(t) = \int_{0}^{t} \omega(t) \, dt \approx \sum_{0}^{t} \omega(t) T_s \]
1) Attitude Determination

- MEMS vibrating gyroscope
  - Uses Coriolis force
    - Hurricanes ✔
    - Toilets ❌

\[ \mathbf{a_{cor}} = 2 \mathbf{V} \times \mathbf{\Omega} \]
1) Attitude Determination

- MEMS vibrating gyroscope
  - *Uses Coriolis force*
1) Attitude Determination

- Optical gyroscope
  - Developed soon after the discovery of laser technology
  - Operate under the principle of the Sagnac effect
1) Attitude Determination

- Optical gyroscope
  - Polarised light interference
1) Attitude Determination

• Gyroscope main parameters
  – Sensitivity [deg/s]
  – Noise [deg/s]
  – Bandwidth [Hz]
  – Full-scale [deg/s]
  – Zero drift and temperature drift [deg/s]
  – Sensitivity drift
  – Cross-axis
1) Attitude Determination

- Magnetometer
  - Measure three-axis magnetic field
  - Possible detect position relative to the Earth
    - IGRF or WMM2015 model
- Types
  - Fluxgate
  - AMR
  - Hall-effect
1) Attitude Determination

- Fluxgate magnetometer
  - Uses saturation of high permeable core
  - Very high sensitivity (up to 1nT)

\[ U_i = \frac{d\Phi}{dt} \]
1) Attitude Determination

- Fluxgate magnetometer
1) Attitude Determination

- Fluxgate magnetometer
1) Attitude Determination

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1) Attitude Determination

- **AMR (Anisotropic Magnetoresistance)**
  - Changes the value of its electrical resistance in an externally-applied magnetic field.
1) Attitude Determination

- AMR (Anisotropic Magnetoresistance)
1) Attitude Determination

- AMR (Anisotropic Magnetoresistance)
  - Null-field offsets
1) Attitude Determination

- AMR (Anisotropic Magnetoresistance)
  - Temperature drift
1) Attitude Determination

- AMR (Anisotropic Magnetoresistance)
  - Set/reset procedure
    - Reduces null-field offset and temperature drift offset
1) Attitude Determination

- Magnetometer main parameters
  - Sensitivity [μT or Gauss] (1 gauss = 100 μT)
  - Noise [μT]
  - Bandwidth [Hz]
  - Full-scale [μT]
  - Zero drift [μT]
  - Temperature drift [μT/°C]
  - Sensitivity drift [%/°C]
  - Cross-axis [%]
1) Attitude Determination

- Earth sensor
  - 16x4 px thermopile
  - Detects earth-space horizon based on the temperature difference
1) Attitude Determination

- Sun sensor
  - Detects position of the Sun
  - Types:
    - PSD detector
    - QUAD detector
1) Attitude Determination

- PSD detector
  - measure a position of a light spot in one or two-dimensions on a sensor surface
  - High precision
1) Attitude Determination

- Quad photodiode detector
  - Incoming light is focused on the detector as a spot
  - Comparing of the output currents received from each of the four quadrants = position of light source
1) Attitude Determination

Calibration
1) Attitude Determination

- Sun-sensors orthogonality

![Sun-sensors orthogonality graph](image)
1) Attitude Determination

• Star tracker
  – Optical device that measures the position(s) of star(s) using photocell(s) or a camera.
# 1) Attitude Determination

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Gyroscopes</td>
<td>Drift rate: 0,003°/hr-1°/hr</td>
<td>1 - 25</td>
<td>5 - 200</td>
</tr>
<tr>
<td>Sun sensor</td>
<td>0,2 - 1</td>
<td>0,04 - 0,5</td>
<td>&lt; 1</td>
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<tr>
<td>Star tracker/sensor</td>
<td>0,0002 - 0,08</td>
<td>3 - 7</td>
<td>4 - 32</td>
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<tr>
<td>Horizon sensor</td>
<td>0,02 - 0,1</td>
<td>0,6 - 5</td>
<td>1 - 8</td>
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<tr>
<td>Magnetometer</td>
<td>0,5 - 1,0</td>
<td>0,2 - 0,7</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>GPS-Receiver</td>
<td>-</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

1) Attitude Determination

- Sensor fusion
  - Gyroscope
    - Drift
    - Low-pass noise
    - Poor response
  - Magnetometer
    - Noisy
    - low-drift
2) Attitude control

• Passive systems

• Magnetic stabilization
  – B-dot algorithm
  – Testing with 3D helmholtz coils system

• Reaction wheel
2) Attitude control

- Passive magnetic stabilization
  - Uses permanent magnet
  - 2-axis stabilization
2) Attitude control

- Gravitation Gradient Stabilization
  - Different distance of the two masses $m_1$ and $m_2$ to the center of gravity -> $F_1 > F_2$
  - Centrifugal forces $Fz_1$ and $Fz_2$ also different
2) Attitude control

- Gravitation Gradient Stabilization
  - Example of a Gravitational Stabilized Satellite (UoSat-12)
2) Attitude control

• Spin-Stabilization
  – Rotating mass has an inherent stability (just like a spintop)
  – Long duration stability around the spinning axis
  – Antenna and instruments are rotating
  – Solar arrays must be body mounted
  – **Examples:** INTELSAT I, II und III, METEOSAT, MSG
2) Attitude control

• Reaction wheels
  – Implemented as special electric motors
  – rotation speed is changed - counter-rotate proportionately through conservation of angular momentum
2) Attitude control
2) Attitude control

• Active magnetic stabilization
  – Complexity (Actuators, Sensors, Software)
  – Not for interplanetary missions (require external magnetic field)
2) Attitude control

• Magnetorquer
  – Small coercivity is required
  – Higher permeability = lower energy
2) Attitude control

Magnetic stabilization
2) Attitude control

- B-dotequation

\[ m = -k \dot{B} \]
2) Attitude control

- B-dot algorithm

- Magnetorquers

Magnetic stabilization
2) Attitude control

- Testing of ADCS
  - 3D hemholtz coils system
    - Generates an external magnetic field
  - Air bearing
    - Creates conditions of microgravity
2) Attitude control

Magnetic stabilization
2) Attitude control

Magnetic stabilization
2) Attitude control

Magnetic stabilization

![Graph showing B-dot axis Y-Z with angular velocity in degrees per second (°/sec) vs. time in seconds (s) with the equations for the curves: y = 29.838e^{-0.019x} and y = 30.506e^{-0.029x}.](image)
• Thank you for your attention 😊