Gateway To Space

ASEN 1400 / ASTR 2500

Class #19

Colorado Space Grant Consortium
Today:

- Announcements

- Guest Lecture - ADCS

- Launch is in 18 days
Announcements:

- Still working getting next round of grades posted

- DD Rev A/B are graded
  - Comments given to those teams I met with
  - Combining Crawford’s comments with mine
  - New grade sheet will have grades
  - Overall most teams did well
Next Class...

In-Class Team Time

Bring all hardware and be prepared for in-class inspections

Ready For Flight Cards

Colorado Space Grant Consortium
Tuesday 11/04...

In-Class Mission Simulations

Payloads turned on beginning of class and off at end

Spider

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Questions?

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Spacecraft ADCS

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Colorado Space Grant Consortium
Spacecraft Attitude Determination and Control

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November 28th, 2014
What is ADCS?
[Attitude Determination and Control Subsystem]
“It’s all about orientation”

• “Attitude” is the relative orientation of one frame to another
  – With spacecraft, it always starts with a spacecraft-body-fixed frame relative to an inertially-fixed frame
  – Anything “pointing” typically falls to the ADCS team to control

• Acronym varies: ACDS, ACS, ADC,…

“It’s all about orientation”
Why ADCS is the Best Spacecraft Subsystem

• Interconnected with all other subsystems
  – Must point payloads at targets, COM antennas at ground stations, solar arrays at the sun…

• Interesting work in all mission phases
  – Mission design, S/C design, I&T, commissioning, operations, mission extensions

• Nice balance of academic and production-oriented activities
  – Analysis deeply rooted in theory, but hardware still has to fly!

• Interpretive dance in the workplace
Part 1: Attitude Determination

“Where Am I?”
Describing Pointing

- Usually comes down to a unit vector in a common frame
  - Example: “The camera’s boresight is \([x, y, z] \) in the ECI frame”
- Assign convenient coordinate frames to instruments of interest
- Then it’s just linear algebra to transform vectors from one frame to the next

\[
\begin{bmatrix}
T_{11} & T_{12} & T_{13} \\
T_{21} & T_{22} & T_{23} \\
T_{31} & T_{32} & T_{33}
\end{bmatrix}
\begin{bmatrix}
x \\
y \\
z
\end{bmatrix}_N
= \begin{bmatrix}
1 \\
0 \\
0
\end{bmatrix}_B
\]

The 3x3 matrix \([T]\) is a Direction Cosine matrix, a common way to represent attitude.

\(X_B = [x, y, z]_N\)
Describing an Attitude

• Use your right hand!
• There are many ways to represent an attitude:
  – Euler angles (roll, pitch, yaw)
  – Direction cosine matrices (“DCMs”)
  – Quaternions
  – Modified Rodriguez Parameters & others
• Attitude is always relative! Always frame-A-to-frame-B.
• Very common for attitudes to be nested:
  A-to-C = A-to-B, then B-to-C
The Human Star Tracker Game

*Comparing the landmarks seen by your sensors against their known locations*

- One vector isn’t enough information
- Two vectors is too much information
- “Triad” is the most simplistic reconciliation: declare one measurement to be true, then “swivel” about it to make the other measurement as close as you can
AD In Practice

• We almost always collect more data than we need

• **Estimation**: getting a small amount of quality information out of a large quantity of noisy measurements

• Least Squares Fitting is used everywhere
  – Ex: Q-method, Kalman Filter
AD Hardware: Sensors

- **Earth Sensors / Horizon Sensors**
  - Optical instruments that scan for the CO$_2$ in Earth’s atmosphere

- **Sun Sensors**
  - When illuminated, report vector to sun

- **Magnetometer**
  - Detects Earth’s magnetic field as a 3D vector

- **Star Trackers / Star Cameras**
  - Takes pictures of the sky and maps stars against a catalog

- **Angular Rate Sensors**
  - Directly measure rate & direction of rotation vs. inertial space
  - Iron gyros, Ring Laser Gyros, Fiber Optic Gyros
  - “Relative” position measurements, suffer from drift over time
Part 2: Attitude Control

“Get a Move On!”
Common Attitude Targets

- Inertial
- Orbit-fixed
- Spin about an axis (old school)
- Nadir Pointing
- Earth-target tracking
Most Generic Block Diagram

Automotive Example

Target

"I want to go 50 mph."

Error

"Need to go 5 mph faster"

Controller

The flight computer and control law

Command

"Open throttle 10 degrees!"

Plant

"State"

"Now going 46 mph"

Sensor

"The speedometer reads 45 mph"
Control Laws

*The brains of the operation*

- **PID control is by far the most common**
  - **Proportional:** based on displacement from target (like a spring)
    - Good for responding quickly to disturbances
  - **Integrator:** based on *accumulated* displacement from target
    - Good for removing constant “DC” biases
  - **Derivative:** based on rate of change (like a damper)
    - Good for stability
  - Frequency domain analysis techniques
    - Bode plots, Nichols plots, …

- **Multiple control loops are common**
  - Coarse vs. fine pointing systems
  - Pointing vs. momentum management
AC Hardware: Actuators

- Thrusters
- Electromagnetic Torque Rods
- Reaction wheels
- Control-Moment Gyros
- Passive devices: gravity gradient boom, viscous dampers, aerobrakes
Speaking the Language

**Open Loop Control:** sending commands without real-time visibility into their effect

**Closed Loop Control:** commanding that adjusts in real-time based on its measured effectiveness

**Gains** – coefficients that dictate the responsiveness of the system

**Phase Margin/Gain Margin:** measures of stability

**Bandwidth:** what range of frequencies your system responds to

**Propagation:** predicting the state of the system sometime in the future based only on the current state of the system
“GNC”

• **Guidance**
  – “Figuring out where you are”
  – The job of a sensor
  – Example: “My speedometer says I’m going 25 mph, but I’d really like to be doing 50”

• **Navigation**
  – “Your strategy for getting where you want to go”
  – The job of computers & algorithms
  – Example: “I’ll cross into the left lane and pass this dump truck”

• **Control**
  – “Getting there”
  – The job of actuators
  – Example: mash pedal to the floor, turn wheel to the left, …
Orbits

*Position and Velocity*
Orbit Types

• Low-Earth Orbit (LEO)
  – Easy to get to, see lots of parts of the Earth
  – Ex: Int’l Space Station, GEOEYE

• Geosynchronous Orbit (GEO)
  – See the same spot on the ground 24/7
  – Ex: Satellite TV

• Others:
  – MEO, HEO

• Space debris pic here
Defining Your Orbit

- You will always need 7 numbers to uniquely describe an orbit
- One of them is always time... the “epoch”
- Six orbital elements, or Position and Velocity as 3-element vectors
Maneuvers

• Hohman Transfer
  – Most fuel efficient way to increase SMA (raise orbit)
  – Burn in velocity direction at apogee

• Higher orbits do fewer “revs” per day
  – NOT intuitive for formation flying
Orbits: Speaking the Language

• J2 – The equitorial “bulge” of the Earth
• Spherical Harmonics – mathematical parameters to describe the shape of the Earth
• Geoid – the gravitational shape of the Earth. The shape of the Earth if it were uniformly dense.
• Precession – The slow rotation of the orbit plane about the Earth’s spin axis
  – Caused by the J2. Rate of precession varies with altitude, inclination
• Vernal Equinox – line formed by intersection of Earth’s equator and the plane of Earth’s orbit around the sun
Links

- http://www.youtube.com/watch?v=dmnmumuTv4pGE