Sensors and Actuators

- Avionics, Software, and Simulation design project
- Sensors for space systems
- Actuator components and design
AVSS Project

• Due Tuesday 12/11
• Submit electronic files to Dropbox on Blackboard site
• I would prefer PDF, but Powerpoint or Keynote files are fine, too
AVSS Design Problem – Overview

• Perform the avionics design for a lunar program crew cabin
• Select one of your crew cabin designs from first two problems, or create a hybrid of two or more designs (state clearly what was selected and why)
• As before, submission will be in the form of presentation slides with high information bandwidth
AVSS Design Problem – Crew Cabin

• Calculate communications link budgets for the following links
  – Ku band direct to Earth
  – S band direct to Earth
  – Ka band to L2 relay satellite
  – Ku relay satellite direct to Earth
  – UHF omni to EVA suits

• Compile a sensor list for all systems in the cabin
  – Type and number of sensors for each signal
  – Criticality of sensor
  – Frequency of sampling
AVSS Problem - 484 Simulation Planning

• Develop a list of possible Design/Build/Test/Evaluate (DBTE) projects for ENAE 484 next term

• For each concept, briefly discuss
  – Research objective (what do we learn/why do we care?)
  – Required mockup/test apparatus
  – Concept of test operations (include simple sketches)

• Rank your top three concepts in priority order, based on importance and feasibility

• Keep in mind overall 484 goal of lunar exploration architecture!
Design Problem Submissions

• Create “Preliminary Design Review” slide package for your design
• Follow guidelines from Engineering Graphics lecture, especially in maximizing information transfer
• Grade will reflect both content from AVSS lectures and quality of presentation created
### Team Assignments for AVSS Project

<table>
<thead>
<tr>
<th>Team D1</th>
<th>Team D2</th>
<th>Team D3</th>
<th>Team D4</th>
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<tr>
<td>Bilyk, Stephanie</td>
<td>Astler, Douglas</td>
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<td>Black, James</td>
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<td>Foust, Rebecca</td>
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<td>Paruchuru, Siddharth</td>
<td>Sanchez, Dennis</td>
<td>Yalamanchili, Rajesh</td>
<td>Smyth, Brendan</td>
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<td>Zarbo, Nicholas</td>
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<td>Hamilton, Michael</td>
<td>Gewirtz, Simon</td>
<td>Cunningham, Michael</td>
<td>Marcus, Matthew</td>
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<td>Johnson, Samantha</td>
<td>Kang, Sukhjohn</td>
<td>Rich, Matthew</td>
<td>Flood, Christopher</td>
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<td>Nwachuku, Calvin</td>
<td>Lee, Kevin</td>
<td>Sultzman, Michelle</td>
<td>Patel, Kiran</td>
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<td>Slafkosky, Alex</td>
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<td>Wingate, Scott</td>
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<tr>
<td>Burr, Jason</td>
<td>Doeren, Christine</td>
<td>Block, Peter</td>
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<td>Klimchenko, Vera</td>
<td>Noyes, Thomas</td>
<td>Henninger, Mark</td>
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<td>McLaughlin, Grant</td>
<td>Robert, Sean</td>
<td>Rotunda, Nicholas</td>
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<td>Pino, Johnathan</td>
<td>Sloane, Joshua</td>
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**Sensors and Actuators**

**ENAE 483/788D - Principles of Space Systems Design**
Proprioceptive Sensors

- Measure internal state of system
- Rotary position
- Linear position
- Velocity
- Accelerations
- Temperature
**Absolute Encoders**

- Measure absolute rotational position of shaft
- Should produce unambiguous position even immediately following power-up
- Rovers typically require continuous rotation sensors
- General rule of thumb: never do in analog what you can do digitally (due to noise, RF interference, cross-talk, etc.)
Potentiometers

Diagram showing a potentiometer with labels:
- Wiper turns with dial
- Resistive material
- Points A, B, W
Potentiometers

• Advantages
  – Very simple (three wires)
  – Unambiguous absolute position readout
  – Generally easy to integrate
  – Low cost

• Disadvantages
  – Analog signal
  – Data gap at transition every revolution
  – Accuracy limited to precision of resistive element
  – Wear on rotating contactor
  – Liable to contamination damage
Resolvers

Maximum influence on the SINE winding

Minimum influence on the COSINE winding

Equal influence on both windings

Less of an influence on the SINE winding

More of an influence on the COSINE winding

Shaft Angle $\theta$

Excitation Reference $E_x$

1 speed sin output

1 speed cos output
Resolvers

• Advantages
  – Non-contact (inductively coupled)
  – Unambiguous absolute position reading
  – Similar technology to synchros

• Disadvantages
  – AC signal
  – Analog
  – Requires dedicated decoding circuitry
  – Expensive
Rotary Binary Encoder

Fig 1. A rotary optical encoder
Binary Absolute Position Encoders

Fig 3: 4-Bit binary code absolute encoder disk track patterns
Gray Code Absolute Position Encoders

Fig 2. 4-Bit gray code absolute encoder disk track patterns
Optical Absolute Encoders

- Advantages
  - No contact (low/no friction)
  - Absolute angular position to limits of resolution
    - 8 bit = 256 positions/rev = 1.4° resolution
    - 16 bit = 65,536 positions = 0.0055° resolution
- Require decoding (look-up table) of Gray codes
- Number of wires ~ number of bits plus two
Magnetic Absolute Encoders

- Advantages
  - No contact (low/no friction)
  - Absolute angular position to limits of resolution
    - 8 bit = 256 positions/rev = 1.4° resolution
    - 16 bit = 65,536 positions = 0.0055° resolution
  - Robust to launch loads
- Require decoding (frequently on chip)
- Choice of output reading formats (analog, serial, parallel)
Incremental Encoders

• Measure change in position, not position directly
• Have to be integrated to produce position
• Require absolute reference (index pulse) to calibrate
• Can be used to calculate velocities
• Generally optical or magnetic (no contact)
Quadrature Incremental Encoder

Fig 5. Incremental encoder disk track patterns
Quadrature Direction Sensing

Forward (CW)

A

B

CW

CCW

Reverse (CCW)

1X

2X

4X

1X
Velocity Measurement

- Number of bits/unit time
  - High precision for rapid rotation
  - Low resolution at slow rotation
  - For n bit encoder reading k bits/interval
    \[
    \omega = \frac{k}{2^n} \frac{2\pi}{\Delta t_{CLK}} \left( \frac{\text{rad}}{\text{sec}} \right)
    \]

- Amount of time between encoder bits
  - High precision for rapid rotation
  - Low resolution for slow rotation
    \[
    \omega = \frac{1}{2^n} \frac{2\pi}{\Delta t_{pulses}} \left( \frac{\text{rad}}{\text{sec}} \right)
    \]
Sensor Guidelines for Flight Systems

• Instrument every flight-critical activity

• Provide sufficient sensor redundancy to differentiate between sensor failure and system failure
  – Redundant sensors
  – Reinforcing sensors

• Interrogate sensors well beyond Shannon’s limit (cannot reconstruct data without at least two samples/cycle)
Exterioceptive Sensors

- Measure parameters external to system
- Pressure
- Vision (saved for a future lecture)
- Active ranging
  - Sonar
  - Lidar
  - Radar
Sonar Rangefinder Systems

Note: The displayed beam width of (D) is a function of the specular nature of sonar and the shape of the board (i.e. flat mirror like) and should never be confused with actual sensor beam width.

beam characteristics are approximate
Laser Rangefinders
Scanning Laser Rangerfinder FOV
LIDAR Types
SpaceX DragonEye Flash LIDAR

- DragonEye DTO Flight Unit
- ISS docking port as viewed from Space Shuttle
- DragonEye LIDAR Range Readings
- DragonEye LIDAR Intensity Readings
Prime Mover Taxonomy

• Electrical
  – Direct Current
  – Alternating Current

• Non-Electrical
  – Hydraulics
  – Pneumatics
  – Chemical
  – Thermal
  – Stored Energy
DC Brushed vs. Brushless Motors

- DC Brushed Motor:
  - Magnet
  - Shaft
  - Windings
  - Laminations
  - Case

- Brushless Motor:
  - Multi-pole Magnet
  - Shaft
  - Windings
  - Laminations
  - Case
DC Brushless Motor Schematic
Stepper Motor Schematic
Standard DC Motor Characteristics

a) Speed vs. Torque

b) Current vs. Torque
DC Motor Power and Efficiency

(a) Power Out

(b) Efficiency
Speed as a Function of Torque
## Standard Motor Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Typical Symbols</th>
<th>Tolerance</th>
<th>Typical Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque Constant</td>
<td>( K_T ), TPA</td>
<td>( \pm 15% )</td>
<td>oz \cdot in \over A, N \cdot m \over A</td>
</tr>
<tr>
<td>Back emf Constant</td>
<td>( K_e ), BEF</td>
<td>( \pm 15% )</td>
<td>volts \over 1000 \text{rpm}, volts \over \text{rad/s}</td>
</tr>
<tr>
<td>Terminal Resistance</td>
<td>( R_T ), RTR</td>
<td>( \pm 15% )</td>
<td>ohms, milliamperes</td>
</tr>
<tr>
<td>Inductance</td>
<td>( L ), DUK</td>
<td>( \pm 10% )</td>
<td>oz \cdot in \cdot s^2, kg \cdot m^2, N \cdot m \cdot s^2</td>
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<tr>
<td>Inertia</td>
<td>( J ), ERT</td>
<td>( \pm 10% )</td>
<td>oz \cdot in, N \cdot m</td>
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<tr>
<td>Motor Torque losses</td>
<td>( T_m )</td>
<td>( +30% )</td>
<td>oz \cdot in, N \cdot m</td>
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<tr>
<td>Motor Friction</td>
<td>( T_F ), TOF</td>
<td>( +50% )</td>
<td>oz \cdot in, N \cdot m</td>
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<tr>
<td>No Load Current</td>
<td>( I_0 ), IINL</td>
<td>( +30% )</td>
<td>amperes</td>
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</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbols</th>
<th>Tolerance</th>
<th>Derivation</th>
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<tbody>
<tr>
<td>Stall Torque</td>
<td>( T_p ), TPK</td>
<td>Reference</td>
<td>( \frac{E \times K_T - T_F}{R_T} )</td>
</tr>
<tr>
<td>No Load Speed</td>
<td>( S_0, SNL, \omega_{nl}, \omega_{NL} )</td>
<td>( \pm 15% )</td>
<td>( \frac{E - \text{INL} \times R_T}{K_e} ) \frac{E}{R_T} )</td>
</tr>
<tr>
<td>Stall Current</td>
<td>( I_p ), AMP</td>
<td>( \pm 15% )</td>
<td>( \frac{K_T}{\sqrt{R_T}} )</td>
</tr>
<tr>
<td>Motor Constant</td>
<td>( K_M ), PKO</td>
<td>Reference</td>
<td>( \frac{K_T \times K_e}{R_T} )</td>
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<tr>
<td>Damping Constant (zero source impedance)</td>
<td>( K_D ), DPO</td>
<td>Reference</td>
<td>( \frac{\sqrt{V \cdot W}}{\text{INL}(\text{rad/s})}, \frac{N \cdot m}{\text{rad/s}} )</td>
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<tr>
<td>Electrical Time Constant</td>
<td>( T_E ), TCE</td>
<td>Reference</td>
<td>( \frac{L}{R_T} )</td>
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<tr>
<td>Mechanical Time Constant</td>
<td>( T_M ), TCM</td>
<td>Reference</td>
<td>( \frac{J \times R_T}{K_T \times K_e} ), \frac{J}{K_D} )</td>
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</table>
### Typical DC Motor Specification

<table>
<thead>
<tr>
<th>Winding types</th>
<th>-206P</th>
<th>-216P</th>
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<tbody>
<tr>
<td>Measured values</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>1 Measuring voltage</td>
<td>3.0</td>
<td>6.0</td>
</tr>
<tr>
<td>2 No-load speed</td>
<td>rpm</td>
<td>rpm</td>
</tr>
<tr>
<td>3 Stall torque</td>
<td>mNm (oz-in)</td>
<td>mNm (oz-in)</td>
</tr>
<tr>
<td>4 Average no-load current</td>
<td>mA</td>
<td>mA</td>
</tr>
<tr>
<td>5 Typical starting voltage</td>
<td>V</td>
<td>V</td>
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<tr>
<td>Max. recommended values</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>6 Max. continuous current</td>
<td>1.50</td>
<td>0.83</td>
</tr>
<tr>
<td>7 Max. continuous torque</td>
<td>mNm (oz-in)</td>
<td>mNm (oz-in)</td>
</tr>
<tr>
<td>8 Max. angular acceleration</td>
<td>62</td>
<td>102</td>
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<tr>
<td>Intrinsic parameters</td>
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<tr>
<td>9 Back-EMF constant</td>
<td>V/1000 rpm</td>
<td>V/1000 rpm</td>
</tr>
<tr>
<td>10 Torque constant</td>
<td>mNm/A (oz-in/A)</td>
<td>mNm/A (oz-in/A)</td>
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<tr>
<td>11 Terminal resistance</td>
<td>ohm</td>
<td>ohm</td>
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<tr>
<td>12 Motor regulation R/k^2</td>
<td>10^3/Nms</td>
<td>10^3/Nms</td>
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<tr>
<td>13 Rotor inductance</td>
<td>mH</td>
<td>mH</td>
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<tr>
<td>14 Rotor inertia</td>
<td>kgm^2. 10^-7</td>
<td>kgm^2. 10^-7</td>
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<tr>
<td>15 Mechanical time constant</td>
<td>ms</td>
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Basic Gear Parameters

Figure 1.1 Basic Gear Geometry
Gear Forms

Figure 1.22

Figure 1.38 Typical Worm Mesh

Figure 1.41 Typical Right Angle Bevel Gear

Figure 1.31 Gear Rack

Figure 1.39 Central Section of a Worm and Wormgear
Types of Bearings

- Type A—Angular Contact
- Type C—Radial Contact
- Type X—Four Point Contact
Ideal Bearing Applications

Back-to-back Mounting

Face-to-face Mounting