Goals:
• Give an overview of CDS 101/110; describe course structure, administration
• Define feedback systems and learn how to recognize main features
• Describe what control systems do and the primary principles of feedback

Reading (available on course web page):
• Åström and Murray, *Analysis and Design of Feedback Systems*, Ch 1
  (available from course web page)
What is Feedback?

Miriam Webster:

the return to the input of a part of the output of a machine, system, or process (as for producing changes in an electronic circuit that improve performance or in an automatic control device that provide self-corrective action) [1920]

Feedback = mutual interconnection of two (or more) systems

- System 1 affects system 2
- System 2 affects system 1
- Cause and effect is tricky; systems are mutually dependent

Feedback is ubiquitous in natural and engineered systems

Terminology

Closed Loop

Open Loop
Example #1: Flyball Governor

“Flyball” Governor (1788)
- Regulate speed of steam engine
- Reduce effects of variations in load (disturbance rejection)
- Major advance of industrial revolution

Balls fly out as speed increases,
Valve closes, slowing engine

Boulton-Watt steam engine

http://www.heeg.de/~roland/SteamEngine.html
Other Examples of Feedback

Biological Systems
- Physiological regulation (homeostasis)
- Bio-molecular regulatory networks

Environmental Systems
- Microbial ecosystems
- Global carbon cycle

Financial Systems
- Markets and exchanges
- Supply and service chains
Control = Sensing + Computation + Actuation

In Feedback “Loop”

Actuate
Gas Pedal

Sense
Vehicle Speed

Compute
Control “Law”

Goals
• Stability: system maintains desired operating point (hold steady speed)
• Performance: system responds rapidly to changes (accelerate to 6 m/sec)
• Robustness: system tolerates perturbations in dynamics (mass, drag, etc)
Two Main Principles of Feedback

Robustness to Uncertainty through Feedback

- Feedback allows high performance in the presence of uncertainty
- Example: repeatable performance of amplifiers with 5X component variation
- Key idea: accurate sensing to compare actual to desired, correction through computation and actuation

Design of Dynamics through Feedback

- Feedback allows the dynamics (behavior) of a system to be modified
- Example: stability augmentation for highly agile, unstable aircraft
- Key idea: interconnection gives closed loop that modifies natural behavior
Example #2: Speed Control

\[ m \ddot{v} = -bv + f_{\text{engine}} + f_{\text{hill}} \]

\[ f_{\text{engine}} = k(v_{\text{desired}} - v) \]

**Stability/performance**
- Steady state velocity approaches desired velocity as \( k \to \infty \)
- Smooth response; no overshoot or oscillations

**Disturbance rejection**
- Effect of disturbances (e.g., hills) approaches zero as \( k \to \infty \)

**Robustness**
- Results don’t depend on the specific values of \( b, m \) or \( k \), for \( k \) sufficiently large
Example #3: Insect Flight

**SENSING**
- neural superposition eyes
- gyroscope (halteres)

**ACTUATION**
- two wings (diptera)
- specialized “power” muscles

**COMPUTATION**
- ~500,000 neurons

**More information:**
- M. D. Dickinson, Solving the mystery of insect flight, *Scientific American*, June 2001
- CDS 101 seminar: Friday, 10 Oct 03
Control Tools

Modeling
- Input/output representations for subsystems + interconnection rules
- System identification theory and algorithms
- Theory and algorithms for reduced order modeling + model reduction

Analysis
- Stability of feedback systems, including robustness “margins”
- Performance of input/output systems (disturbance rejection, robustness)

Synthesis
- Constructive tools for design of feedback systems
- Constructive tools for signal processing and estimation (Kalman filters)

MATLAB Toolboxes
- SIMULINK
- Control System
- Neural Network
- Data Acquisition
- Optimization
- Fuzzy Logic
- Robust Control
- Instrument Control
- Signal Processing
- LMI Control
- Statistics
- Model Predictive Control
- System Identification
- μ-Analysis and Synthesis
# Overview of the Course

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<td>Introduction to Feedback and Control</td>
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<td>System Modeling</td>
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<td>Control of cavity oscillations, T. Colonius</td>
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<td>Piloted flight, D. McRuer (tentative)</td>
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<td>Loop Analysis of Feedback Systems</td>
<td>Stability in Electronic Circuits, A. Hajimiri</td>
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<td>Limits on Performance</td>
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Summary: Introduction to Feedback and Control

Control = Sensing + Computation + Actuation

Feedback Principles
- Robustness to Uncertainty
- Design of Dynamics

Many examples of feedback and control in natural & engineered systems: