CDS 101/110a: Lecture 1.1
Introduction to Feedback & Control

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Goals:
• Give an overview of CDS 101/110: 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:
• Åström and Murray, Feedback Systems: An Introduction for Scientists and Engineers, Chapter 1 [30 min]

CDS 101/110 Course Sequence

CDS 101 – Introduction to the principles and tools of control and feedback
• Summarize key concepts, w/ examples of fundamental principles at work
• Introduce MATLAB-based tools for modeling, simulation, and analysis

CDS 110 – Analytical understanding of key concepts in control
• Detailed description of classical control and state space concepts
• Provide knowledge to work with control engineers in a team setting

CDS 112 – Detailed design tools for control systems
• Optimization-based control (LQR, RHC/MPC, Kalman filters)

CDS 212/213 – Modern (robust) control design
• Operator-based approach to control; linear and nonlinear systems
• 212 = analysis, 213 = synthesis

CDS 140 – Introduction to Dynamical Systems
• Introduction to tools in dynamical systems

CDS Minor
• Undergrads: CDS 110, CDS 112, CDS 140, senior thesis
• Grad students: 54 units in CDS - usually CDS 110/112, CDS 140/240 + 2 electives
Course Administration

Course Syllabus

- CDS 101 vs 110
- Lectures, recitations
- Office hours
- Grading
- Homework policy (+ grace period)
- Course text and references
- Class homepage
- Software
- Course outline

It is the policy of the California Institute of Technology that all Caltech courses be open to all students. Therefore, there will be no prerequisite checks, and you can take this course even if you have not completed any of the prerequisite courses.

What is Feedback?

Merriam 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
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

Example diagram:
- Balls fly out as speed increases,
- Valve closes, slowing engine

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

X-29 experimental aircraft (NASA)
Example #2: Speed Control

\[ m \dot{v} = -a v + F_{\text{eng}} + F_{\text{hill}} \]
\[ F_{\text{eng}} = k_p (v_{\text{des}} - v) \]

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

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

**Robustness**
- Results don’t depend on the specific values of \( a, m \) or \( k_p \), for \( k_p \) sufficiently large

Example #3: Insect Flight

**SENSING**
- neural superposition eyes
- hind wing gyroscopes (halteres)

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

**COMPUTATION**
- \(~500,000\) neurons

More information:
- M. H. Dickinson, Solving the mystery of insect flight, *Scientific American*, June 2001
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 Logic
- Signal Processing
- LMI Control
- Statistics
- Model Predictive Control
- System Identification
- μ-Analysis and Synthesis
- Systems biology (SBML)

Python Toolboxes
- scipy/numpy
- python-control

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: