



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

Douglas G. MacMartin

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]

9/29/2014

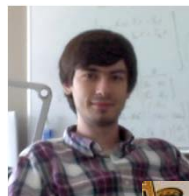
D. MacMartin, CDS 101/110 2014

1



CDS 101/110 Instructional Staff

- Instructor:
 - Doug MacMartin (CMS/CDS)
- TAs (cds110-tas@cds.caltech.edu)
 - Jerry Cruz
 - Ivan Papusha
 - David Flicker
 - Ioannis Filippidis



9/29/2014

D. MacMartin, CDS 101/110

2

Course Administration

- CDS 101 vs 110
- Class homepage
- Lectures, recitations
- Grading:
 - 50% HW, 20% midterm, 30% final
- Homework policy
 - Due Wed 5pm, 3 free 2-day grace period
 - Typically need Matlab or Python
- Piazza
- Office hours:
 - Mon 3-5pm, TBD
 - Tues 6-8pm, TBD
- Course text and references
- Course outline

- Signup sheet
- Lecture MP3s
- Course load: keep track of hours
- Course ombuds: send e-mail by Thurs evening to volunteer

Piazza: Website for Questions

- Please use Piazza to ask questions!
- Please answer questions!



Course Outline

1. Introduction to feedback, modeling
 2. Dynamic behavior and stability
 3. Linear systems
 4. Transfer functions
 5. Loop analysis; Nyquist and stability under feedback
 6. PID control (Proportional, integral, derivative)
 7. Loop-shaping
 8. Control design and robustness
 9. State feedback, reachability and observability
 10. Observability, introduction to modern control
- Monday lecture: 101 and 110, typically powerpoint, overview for the week
 - Wednesday lecture: 101 and 110; blackboard, more detail & math
 - Friday lecture or recitation for 110: problem solving, examples, matlab...
 - Some weeks may provide more depth, some more focused on matlab

9/29/2014

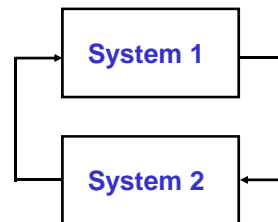
D. MacMartin, CDS 101/110 2014

5

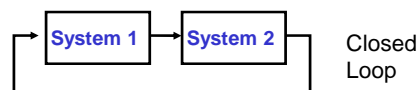


What is Feedback?

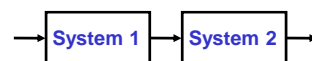
- Merriam Webster:
 - The return to the input of a part of the output of a machine, system, or process (as for producing changes in an electronic circuit that improve performance or in an automatic control device that provide self-corrective action) [1920]
- Feedback = mutual interconnection of two (or 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
- **Control: we get to design feedback!**



Terminology



Closed Loop




Open Loop

9/29/2014

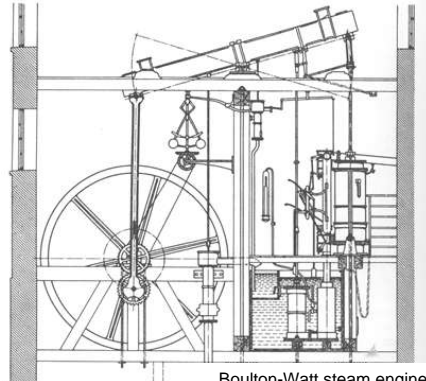
D. MacMartin, CDS 101/110 2014

6

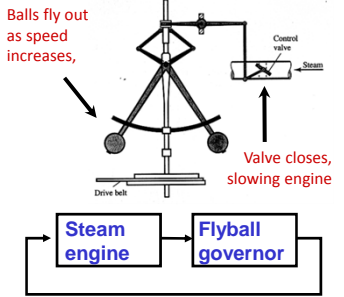


Example #1: Flyball Governor

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




Boulton-Watt steam engine




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

Steam engine

Flyball governor

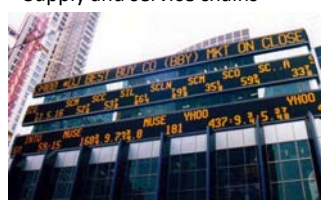


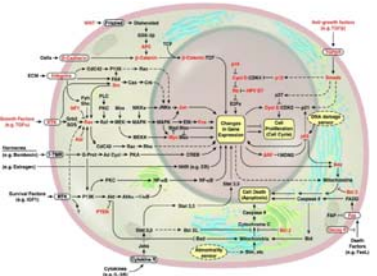
7

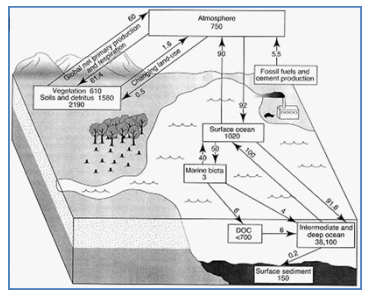


Other Examples of Feedback


- Biological Systems
 - Physiological regulation (homeostasis)
 - Bio-molecular regulatory networks
- Environmental Systems
 - Microbial ecosystems
 - Global climate change
- Financial Systems
 - Markets and exchanges
 - Supply and service chains





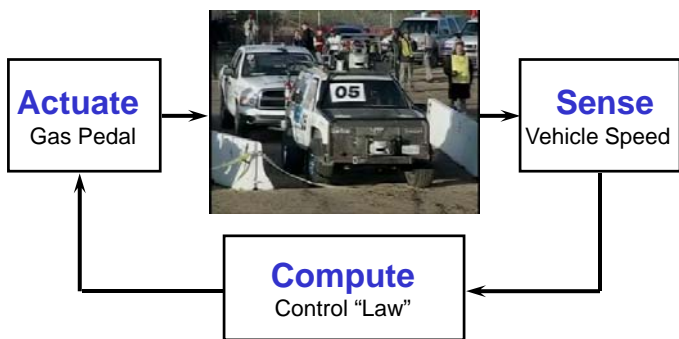


9/29/2014
D. MacMartin, CDS 101/110 2014
8



Control = Sensing + Computation + Actuation

In Feedback "Loop"




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)

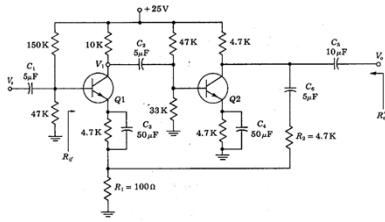

(Note: this class will only deal with *feedback* or *closed-loop* control)

9/29/2014 D. MacMartin, CDS 101/110 2014 9




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)

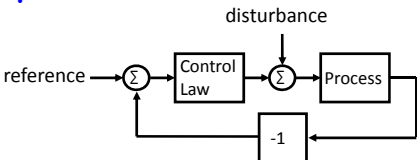
9/29/2014 D. MacMartin, CDS 101/110 2014 10



Example #2: Speed Control

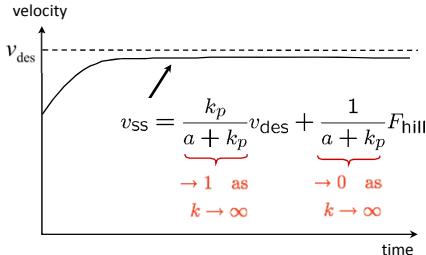


“Bob”



$$m\dot{v} = -av + F_{\text{eng}} + F_{\text{hill}}$$

$$F_{\text{eng}} = k_p(v_{\text{des}} - v)$$




$$v_{ss} = \underbrace{\frac{k_p}{a + k_p}}_{\rightarrow 1 \text{ as } k \rightarrow \infty} v_{\text{des}} + \underbrace{\frac{1}{a + k_p}}_{\rightarrow 0 \text{ as } k \rightarrow \infty} F_{\text{hill}}$$

- **Stability/performance**
 - Steady state velocity approaches desired velocity as $k \rightarrow \infty$
 - Smooth response; no overshoot or oscillations
- **Disturbance rejection**
 - Effect of disturbances (eg, hills) approaches zero as $k \rightarrow \infty$
- **Robustness**
 - Results don't depend on the specific values of a , m or k_p , for k_p sufficiently large

9/29/2014

D. MacMartin, CDS 101/110 2014

11

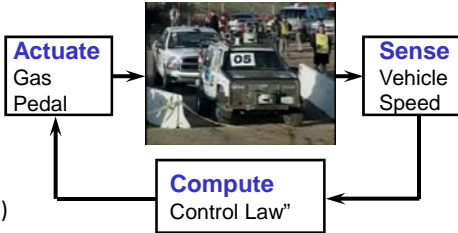


Modeling

- Control design is based on *models* of the system
 - Model does not need to be perfect, but “good enough”
 - Capture input-output behaviour
- Describe time evolution
 - Continuous-time (ODE)

$$\dot{x} = \frac{dx}{dt} = f(x, u)$$
 - Discrete-time (difference equation)

$$x_{k+1} = x[k + 1] = x(t_{k+1}) = f_d(x_k, u_k)$$




- “Classical control” is based on frequency-domain analysis:
 - What is the response of the system to sinusoidal inputs?
- “Modern control” stays in time-domain (end of 101/110, and 112, 212...)

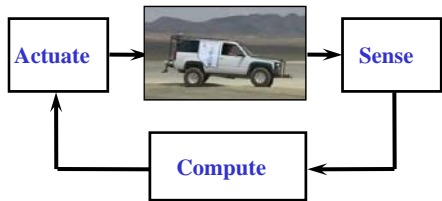
9/29/2014

D. MacMartin, CDS 101/110 2014

12

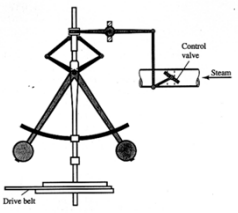


Summary: Introduction to Feedback and Control

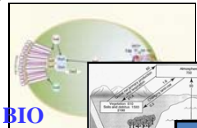


- Control =
 - Sensing + Computation + Actuation
- Feedback Principles
 - Robustness to Uncertainty
 - Design of Dynamics

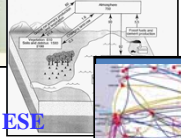
Many examples of feedback and control in natural & engineered systems:




9/29/2014



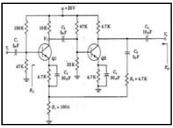
BIO

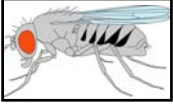


ESE



CS





D. MacMartin, CDS 101/110 2014

13