ME451: Control Systems

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http://www.egr.msu.edu/classes/me451/jchoi/

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Course Information (Syllabus)

- Lecture: 2205 EB, Sections: 5, 6, 7, 8, MWF 12:40-1:30pm
- Class website: http://www.egr.msu.edu/classes/me451/jchoi/
- Laboratory website: http://www.egr.msu.edu/classes/me451/radcliff/lab
- Class Instructor: Jongeun Choi, Assisntant Professor, 2459 EB, Email: jchoi@egr.msu.edu
- Office Hours of Dr. Choi: 2459 EB, MW 01:40-2:30pm, Extra hours by appointment only (via email)
- Laboratory Instructor: Professor C. J. Radcliffe, 2445 EB, Phone: (517)-355-5198
- Required Text: Feedback Control Systems, C. L. Phillips and R. D. Harbor, Prentice Hall, 4th edition, 2000, ISBN 0-13-949090-6
- Grading: Homework (15%), Exam 1 (15%), Exam 2 (15%), Final Exam(comprehensive) (30%), Laboratory work (25%)
- Note
  - Homework will be done in one week from the day it is assigned.
  - 100% laboratory attendance and 75% marks in the laboratory reports will be required to pass the course.
  - Laboratory groups for all sections will be posted on the door of 1532 EB.

About Your Instructor

- Ph.D. ('06) in Mechanical Engineering, UC Berkeley
  - Major field: Controls, Minor fields: Dynamics, Statistics
- M.S. ('02) in Mechanical Engineering, UC Berkeley
- B.S. ('98) in Mechanical Design and Production Engineering, Yonsei University at Seoul, Korea
- Research Interests: Adaptive, learning, distributed and robust control, with applications to unsupervised competitive algorithms, self-organizing systems, distributed learning coordination algorithms for autonomous vehicles, multiple robust controllers, and micro-electromechanical systems (MEMS)
- 2459 EB, Phone: (517)-432-3164, Email: jchoi@egr.msu.edu, Website: http://www.egr.msu.edu/~jchoi/

Motivation

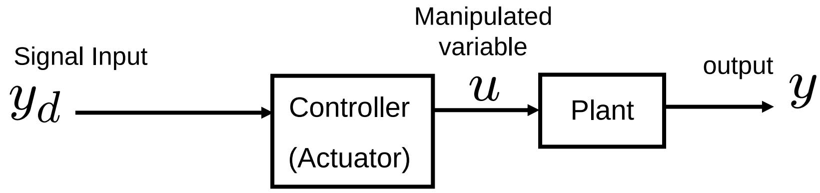
- A control system is an interconnected system to manage, command, direct or regulate some quantity of devices or systems.
  - Some quantity: temperature, speed, distance, altitude, force

$$y$$

- Applications
  - Heater, hard disk drives, CD players
  - Automobiles, airplane, space shuttle
  - Robots, unmanned vehicles,

Open-Loop vs. Closed-Loop Control

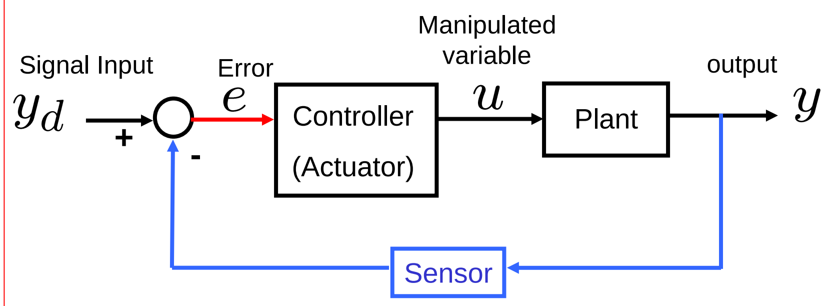
- Open-loop Control System
  - Toaster, microwave oven, shoot a basketball



  - Calibration is the key!
  - Can be sensitive to disturbances

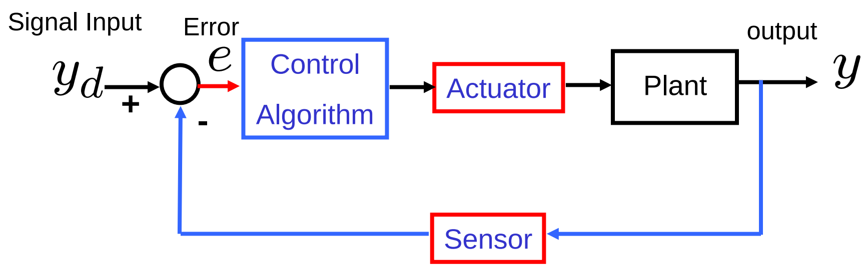
Open-Loop vs. Closed-Loop Control

- Closed-loop control system
  - Driving, cruise control, home heating, guided missile



Feedback Control

- Compare actual behavior with desired behavior
- Make corrections based on the error difference
- The sensor and the actuator are key elements of a feedback loop
- Design control algorithm



Common Control Objectives

- Regulation (regulator): maintain controlled output at constant setpoint despite disturbances
  - Room temperature control,
  - Cruise control
- Tracking (servomechanism): controlled output follows a desired time-varying trajectory despite disturbances
  - Automatic landing aircraft,
  - Hard disk drive data track following control

Control Problem

- Design Control Algorithm
  - such that the closed-loop system meets certain performance measures, and specifications
- Performance measures in terms of
  - Disturbance rejection
  - Steady-state errors
  - Transient response
  - Sensitivity to parameter changes in the plant
  - Stability of the closed-loop system

Why the Stability of the Dynamical System?

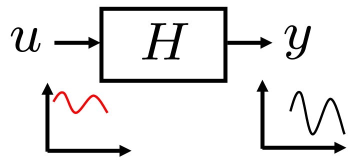
- Engineers are not artists:
  - Code of ethics, Responsibility
- Otherwise, Tacoma Narrows Bridge: Nov. 7, 1940

Wind-induced vibrations

Catastrophe

Linear (Dynamical) Systems

- H is a **linear system** if it satisfies the properties of superposition and scaling:
  - Inputs: $u_1(t),\, u_2(t)$
  - Outputs: $y_1(t) = H[u_1(t)]$
    $y_2(t) = H[u_2(t)]$



- Superposition: $H[u_1(t) + u_2(t)] = y_1(t) + y_2(t)$
- Scaling: $H[\beta u_1(t)] = \beta y_1(t)$

- Otherwise, it is a **nonlinear system**

Why Linear Systems?

- Easier to understand and obtain solutions
- Linear ordinary differential equations (ODEs),
  - Homogeneous solution and particular solution
  - Transient solution and steady state solution
  - Solution caused by initial values, and forced solution
- Add many simple solutions to get more complex ones (Utilize superposition and scaling!)
- Easy to check the Stability of stationary states (Laplace Transform)
- Even nonlinear systems can be approximated by linear systems for small deviations around an operating point

Convolution Integral with Impulse

- Input signal u(t) $\qquad \Delta\tau \to 0$

$$u(t) = \sum_{\tau=-\infty}^{\infty} u(\tau)\delta_\Delta(t-\tau)\Delta\tau,$$

where

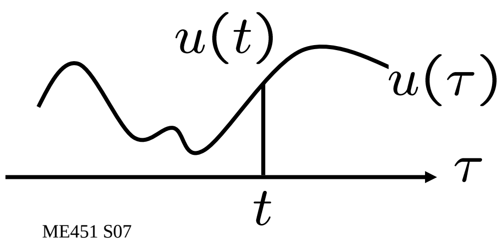
$$\delta_\Delta(y) := \begin{cases} 1/\Delta t, & \text{if } y = 0 \\ 0, & \text{if } y \neq 0 \end{cases}$$

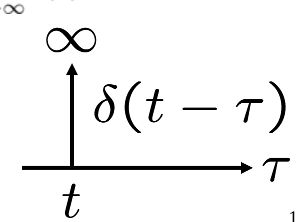
$$u(t) = \int_{-\infty}^{\infty} u(\tau)\delta(t-\tau)d\tau,$$

where

$$\delta(y) := \begin{cases} \infty, & \text{if } y = 0 \\ 0, & \text{if } y \neq 0 \end{cases}$$

$$\int_{-\infty}^{\infty} \delta(\tau)d\tau = 1$$





Output Signal of a Linear System

- Input signal $\quad u(t) = \int_{-\infty}^{\infty} u(\tau)\delta(t-\tau)d\tau,$
- Output signal

$$u \longrightarrow \boxed{H[\cdot]} \longrightarrow y$$

$$\begin{aligned} y(t) &= H[u(t)] \\ &= H\left[\int_{-\infty}^{\infty} u(\tau)\delta(t-\tau)d\tau\right] \\ &= \int_{-\infty}^{\infty} u(\tau)H[\delta(t-\tau)]d\tau && \longleftarrow \boxed{\text{Superposition!}} \\ &=: \int_{-\infty}^{\infty} u(\tau)h(t-\tau)d\tau && \longleftarrow \boxed{\text{def: impulse response}} \\ &=: u(t) * h(t) && \longleftarrow \boxed{\text{def: convolution}} \\ &= \int_{-\infty}^{\infty} u(t-\tau)h(\tau)d\tau \\ &= \int_{0}^{\infty} u(t-\tau)h(\tau)d\tau && \longleftarrow \boxed{\text{def: causality}} \end{aligned}$$