

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, Assistant 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

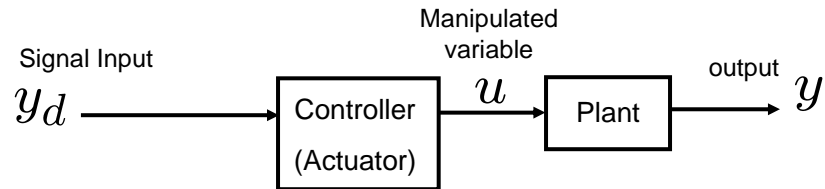
- A **control system** is an interconnected system to manage, command, direct or regulate some quantity of devices or systems.
 - Some quantity: temperature, speed, distance, altitude, force

y

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

Open-Loop vs. Closed-Loop Control

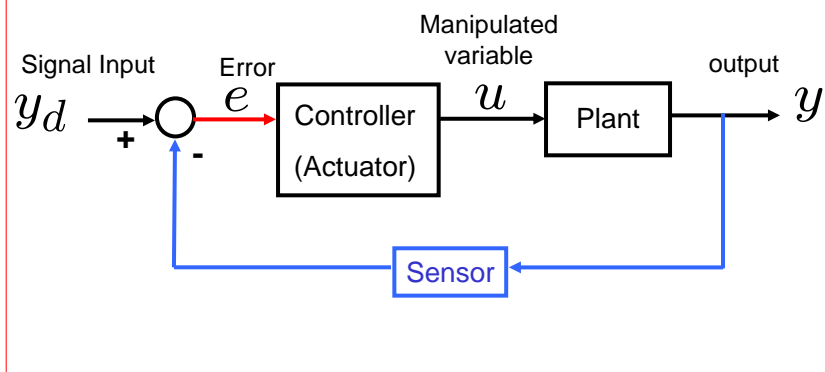
- Open-loop Control System
 - Toaster, microwave oven, shoot a basketball



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

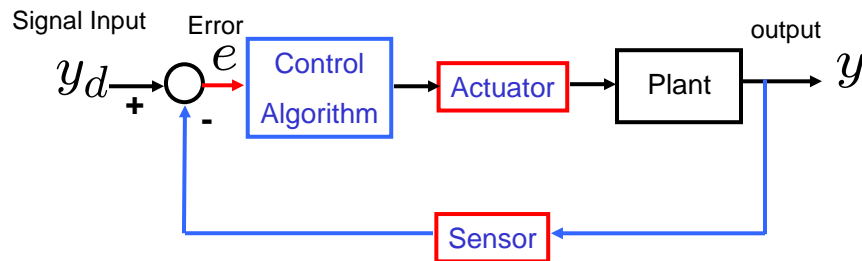
Open-Loop vs. Closed-Loop Control

- 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**



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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

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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**

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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

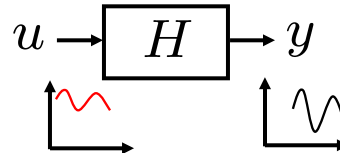
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Linear (Dynamical) Systems

- 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 $u(t)$

$$\Delta\tau \rightarrow 0$$



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

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

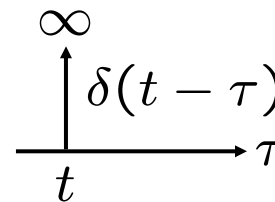
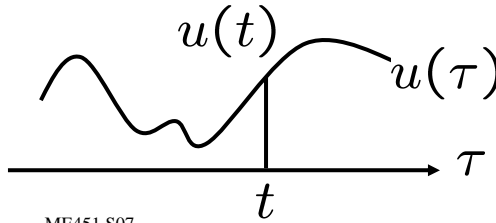
where

where

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

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

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



Output Signal of a Linear System

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

$$\begin{aligned}
 y(t) &= H[u(t)] && u \rightarrow \boxed{H[\cdot]} \rightarrow y \\
 &= H\left[\int_{-\infty}^{\infty} u(\tau)\delta(t-\tau)d\tau\right] \\
 &= \int_{-\infty}^{\infty} u(\tau)H[\delta(t-\tau)]d\tau && \leftarrow \boxed{\text{Superposition!}} \\
 &=: \int_{-\infty}^{\infty} u(\tau)h(t-\tau)d\tau && \leftarrow \boxed{\text{def: impulse response}} \\
 &=: u(t) * h(t) && \leftarrow \boxed{\text{def: convolution}} \\
 &= \int_{-\infty}^{\infty} u(t-\tau)h(\tau)d\tau \\
 &= \int_0^{\infty} u(t-\tau)h(\tau)d\tau && \leftarrow \boxed{\text{def: causality}}
 \end{aligned}$$