**ME451: Control Systems**

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[http://www.egr.msu.edu/classes/me451/jchoi/](http://www.egr.msu.edu/classes/me451/jchoi/)

**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/](http://www.egr.msu.edu/classes/me451/jchoi/)
- **Laboratory website:** [http://www.egr.msu.edu/classes/me451/radcliffe/lab](http://www.egr.msu.edu/classes/me451/radcliffe/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
- **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

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

**Open-Loop System**

- Signal Input: $y_d$
- Manipulated variable: $u$
- Output: $y$

**Closed-Loop System**

- Signal Input: $y_d$
- Error: $e$
- Manipulated variable: $u$
- Output: $y$

**Calibration is the key!**
- Can be sensitive to disturbances
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 $u(t)$

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

where

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

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

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

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

- Output signal

$$y(t) = H[u(t)]$$

$$= H \left[ \int_{-\infty}^{\infty} u(\tau) \delta(t - \tau) d\tau \right]$$

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

$$=: \int_{-\infty}^{\infty} u(\tau) h(t - \tau) d\tau$$

$$=: u(t) * h(t)$$

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

$$= \int_{0}^{\infty} u(t - \tau) h(\tau) d\tau$$

Superposition!

**def: impulse response**

**def: convolution**

**def: causality**