ECE 171A: Linear Control System Theory
Lecture 1: Introduction

Yang Zheng

Assistant Professor, ECE, UCSD

April 01, 2024

Reading materials: Ch. 1.1 - Ch. 1.5

Outline

Outline

Course Overview

- **ECE 171A: Linear Control System Theory** focuses on modeling and analysis of single-input single-output linear control systems emphasizing frequency domain techniques.
- A **tentative** list of topics include
  - **Part I: System modeling** (2 weeks): ODEs, linear time-invariant systems, first-order and second-order systems, mechanical systems, RLC circuits, etc.
  - **Part II: System analysis** (4 weeks): Phase portraits, stability, Laplace transform, transfer functions, block diagram, Steady-State Error, Transient Response, Stability, etc.
  - **Part III: Feedback control** (4 weeks): PID control, Bode plots, Nyquist plots, stability margin, root locus, Loop analysis/shaping, etc.
- **Primary Textbook**: Karl J. Astrom and Richard M. Murray, *Feedback Systems: An introduction for Scientists and Engineers*, Available at:

  `http://www.cds.caltech.edu/~murray/books/AM08/pdf/fbs-public_24Jul2020.pdf`

  Other references are listed on the course website.

Prerequisites

- This is an undergraduate-level course in classical control theory;
- Control engineering is fascinating. I want everyone to learn a little bit about control theory, so that the prerequisites are not strictly enforced
  - ECE45: Circuits and Systems or MAE40: Linear Circuits.
  - **Ideally**: Calculus; ODE; Matrix (eigenvalues/eigenvectors);
  - **Real requirement**: High school physics, e.g., Newton's law, Kirchoff's circuit law, One-dimension calculus (integral, derivative, exponential function, first-order Taylor expansion.)
  - Some coding experience with MATLAB, Python, or similar software is expected.
  - Please install Matlab, if you haven't yet.
- A simple background survey (please fill it out by Tuesday night if you have not yet): https://forms.gle/iZhw8rQqhfk1bQmD7

Logistics

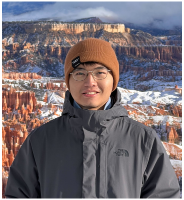
- Course website: `https://zhengy09.github.io/ECE171A/ece171a`
- Includes links to:
  - **Canvas**: Course materials, slides, lecture recordings (if available) etc.
  - **Gradescope**: homework submission and grades
  - **Piazza**: Q&A discussions; check Piazza regularly for class discussions and updates, etc.
- Assignments:
  - **8 homework sets** (35% of grade); Please write down the number of hours that you spend on each homework assignment!
  - **Two midterm exams** (20% of grade)
  - **Final exam** (40% of grade)
  - **Class attendance & participation** (5% of grade)
- Grading:
  - A standard grade scale (e.g., 93%+ = A) will be used with a curve based on the class performance (e.g., if the top students have grades in the 83%-86% range, then this will correspond to letter grade A)
  - **no late policy**: HW submitted past the deadline will receive 0 credit. Start each homework early!

Logistics

- **Class attendance & participation is very important.** (5% of grade)
  - Two simple in-class quizzes; unannounced (2.5% each);
  - You're encouraged to ask and answer questions on Piazza
  - If you miss one in-class quiz, then your active participation in this course (e.g., answering questions on Piazza) can be used to account for up to 2.5% of your grade.
- **Software**
  - You will use Matlab to write simple scripts for homework questions. Please install it as soon as possible.
- **Collaboration policy**
  - Collaboration on homework assignments is encouraged. You may consult outside reference materials, other students, or the instructors.
  - All solutions that are handed in should be written up individually and should reflect your own understanding of the subject. It is unacceptable to copy a solution written by someone else.
  - No collaboration is allowed on the midterm and final exams.

Instructors

- Yang Zheng, Assistant Professor at ECE
- I have been here since 2021, after Phd from Oxford, 1.5 years postdoc at Harvard, and 1 year postdoc at Imperial College London
- Office hours: TBA
- Location: TBA



- Chih-Fan (Rich) Pai
- Graduate student, ECE
- Email: cpai@ucsd.edu
- Office hours: TBA
- Location: TBA

Ideally, I would like most of you, if not all, to go to the office hours together even if you don't have questions. You can even help us answer questions from others. It is important to have a supportive community for this class!

Office hours and Discussion Session

Office hours

- *"going to office hours is something I actually look forward to. I've been able to make some friends in the class while in office hours"*
- *"Office hours and letting us work together in group really fostered a good community. I have never went to office hours so much and enjoyed the people as I did in this class. I felt challenged in the material, supported by my professor, TA, and peers."*

It is important to have a supportive community for this class! Come to office hours!

Discussion Session

- **When & Where**: FAH 1101; Wednesday 1:00 pm - 1:50 pm;
- Separated from the usual Office hours. We will use it to cover some background knowledge and also for Q&A on lectures/homework.
- Week 1 (Wednesday afternoon): Review on matrices and ODEs (I).

Tentative Schedule

ECE171A, Spring 2024 – Linear Control System Theory

Tentative Schedule

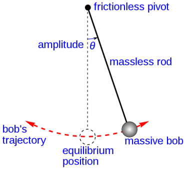
Week	Date	Lecture	Reading Materials	Assignments
1	Apr 01	L1: Introduction & Course Logistics	Ch. 1.1 - Ch. 1.5	
	Apr 03	D1: Matlab, Matrices, ODE		
	Apr 03	L2: ODEs and Cruise Control	Ch 1.6, Ch 4.1, Ch 6.2	
	Apr 05	L3: Feedback principles	Ch 2.1, Ch 2.3, 2.4, 2.5	Homework 1
2	Apr 08	L4: System modeling (I)	Ch 3.1, 3.2	
	Apr 10	D2: 2nd-order ODE and ode45		
	Apr 10	L5: System modeling (II)	Ch 3.3, 3.4, Ch 4.7	
	Apr 12	L6: Solutions and Phase potraits	Ch 5.1 - 5.2	Homework 2
3	Apr 15	L7: Equilibriums & Stability	Ch 5.3	
	Apr 17	D3: Eigenvalues & Eigenvectors		
	Apr 17	L8: Linearization	Ch 6.1, Ch 6.4	
	Apr 19	L9: Review		Homework 3
4	Apr 22	L10: Input/output system response (I)	Ch 6.1, 6.2	

Check the course website for updates:
`https://zhengy09.github.io/ECE171A/schedule.html`

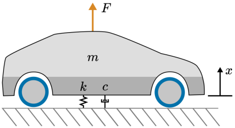
Outline

What is a dynamical system?

A **dynamical system** is a system whose behavior changes over **time**, often in response to external stimulation or forcing.

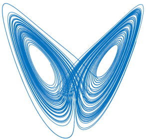


(a) Pendulum

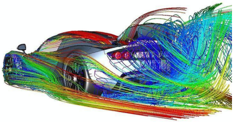


(b) Spring-mass (suspension)

(c) water flow



(d) Chaotic



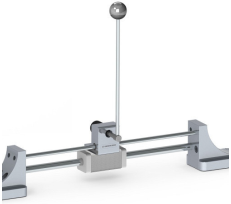
(e) fluid dynamics

(f) Sync of fishes

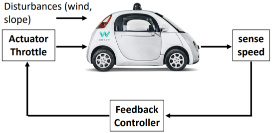
What is a control system?

A **control system** is an interconnection of two or more dynamical systems that provides a **desired response**.

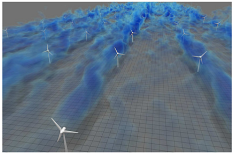
- Control is to modify the inputs to the plant (system) to produce a **desired output**.



(a) Inverted Pendulum



(b) Cruise control



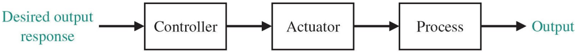
(c) Wind farm

What is a control system?

- Modern control systems include physical and cyber components
- A **physical component** is a mechanical, electrical, fluid, or thermal device acting as a *sensor*, or *actuator*
  - A **sensor** is a device that provides measurements of a signal of interest (*output*)
  - An **actuator** is a device that alters the configuration of the system or its environment (*input*)
- A **cyber component** is a software node that executes a specific function
- **Control system engineering** focuses on:
  - **Modeling** cyber-physical systems;
  - **Analyzing** the system behavior;
  - **Designing** controllers that achieve desired system performance characteristics,
    - such as stability, transient and steady-state tracking, rejection of external disturbances, and robustness to modeling uncertainties etc.

Open-loop vs Closed-loop Control Systems

- An **open-loop (Feedforward) control system** utilizes a controller without measurement feedback of the system output



- A **closed-loop (Feedback) control system** utilizes a controller with measurement feedback of the system output

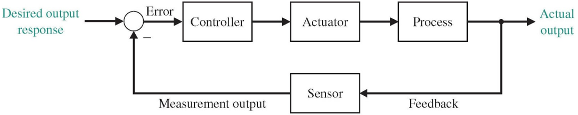


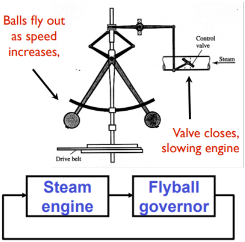
Table 1.1: Properties of feedback and feedforward.

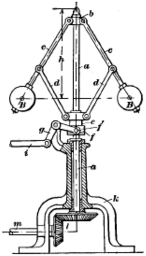
Feedback	Feedforward
Closed loop	Open loop
Acts on deviations	Acts on plans
Robust to model uncertainty	Sensitive to model uncertainty
Risk for instability	No risk for instability

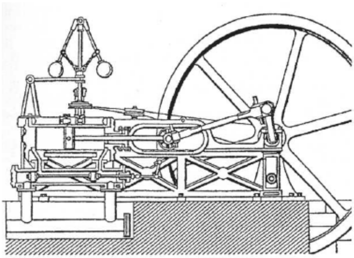
Feedback control examples (Engineering)

“Flyball” Governor (1788)

- Regulate speed of steam engine
- Reduce effects of variations in load (disturbance rejection)
- Major advance of industrial revolution







Feedback control examples (Engineering)

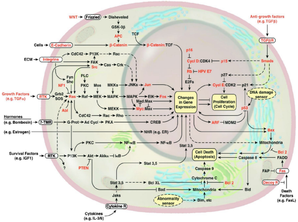
(a) Drones

(b) Autonomous vehicles

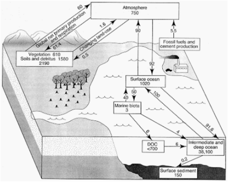
(c) SpaceX

(d) F18 Aircraft

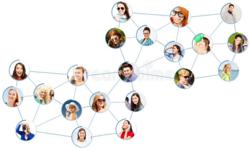
Feedback control examples (Others)



(e) Biological Systems



(f) Environmental Systems



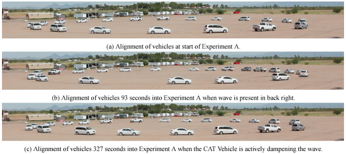
(g) Sociology

(h) Finance Market

Some of my favorite engineering examples

See another PPT for very fancy video demonstrations

(a) Boston dynamics



(b) Stabilizing traffic wave

(c) Flying Machine

Outline

Experiment 1

- Now, stand on one foot
- Then, close your eyes

Experiment 2

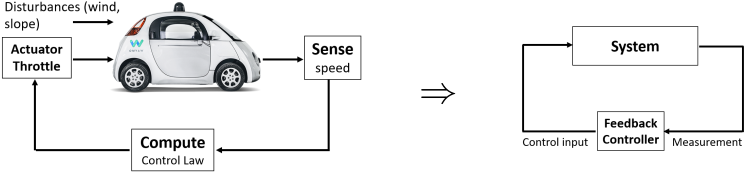
Balance a stick (Inverted Pendulum)

- Different lengths
- Different focus points
- Close eyes

Outline

Summary

Feedback control = Sensing + Computation + Actuation



Three main topics in this class

- **Modeling**: Use physics to build a mathematical model that relates the inputs to the outputs
- **Analysis**: Use the model to predict and/or simulate the dynamical response /performance; Use both mathematical and numerical (Matlab) approaches
- **Control**: how to change the dynamic response by using feedback control; learn about trade-offs, what is actually possible?

Emphasizing the classical frequency-domain methods.

Thank you & Enjoy the Spring quarter!