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

Yang Zheng

Assistant Professor, ECE, UCSD

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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, final value theorem, 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 in the course website.

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, announcements, and updates, etc.
- Assignments:
  - **8 homework sets** (40% of grade); Please write down the number of the hours that you spend on each homework assignment!
  - **Two midterm exams** (20% of grade)
  - **Final exam** (40% 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!

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 the prerequisites are not strictly enforced
  - ECE45: Circuits and Systems or MAE 140: Linear Circuits.
  - **Ideally**: Calculus; ODE; Matrix (eigenvalues/eigenvectors);
  - **Real requirement**: High school physics, e.g., Newton 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 will be useful.
- A simple background survey (please fill it out by Tuesday night if you have not yet): `https://docs.google.com/forms/d/e/1FAIpQLSfnH919wxZrt3fj18vQs2vP5iG309S2jUIKzFR7HCB_bFXXEQ/viewform`

You will need to invest a significant amount of time, so that you will enjoy this course and learn a lot.

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: Tuesdays 4:30pm - 6:00pm PST and by appointment
- Location: Jacobs Hall Room 4506

- Dehao Dai
- Graduate student at Math Department
- Email: ddai@ucsd.edu
- Office hours: Thursdays 7:00 pm - 9:00 pm
- Location: Jacobs Hall Room 4506

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

Discussion Session and Collaboration policy

Discussion Session

- **When & Where**: CENTR 214; Monday 1:00pm - 1:50pm;
- Separated from the usual Office hours. We will mainly use it for Q&A on lectures/homework, but may also cover some background knowledge (keep an eye on announcements on Canvas).
- Week 1 (This afternoon): Review on matrices and ODEs (I).

Collaboration policy

- Collaboration on homework assignments is encouraged. You may consult outside reference materials, other students, or the instructors, but you must cite any use of material from outside references.
- All solutions that are handed in should be written up individually and should reflect your own understanding of the subject at the time of writing. It is not acceptable to copy a solution written by someone else.
- No collaboration is allowed on the midterm and final exams.

Tentative Schedule

Week	Date	Lecture	Reading Materials	Assignments
1	Mar 28	L1: Introduction & Course Logistics	Ch. 1.1 - Ch. 1.5	
	Mar 28	DI1: Matlab, Matrices, ODE		
	Mar 30	L2: ODEs and Cruise Control	Ch 1.6, Ch 4.1, Ch 6.2	
	Apr 01	L3: Feedback principles	Ch 2.1, Ch 2.3, 2.4, 2.5	Homework 1
2	Apr 04	L4: System modeling (I)	Ch 3.1, 3.2	
	Apr 04	DI2: ODE45 Examples		
	Apr 06	L5: System modeling (II)	Ch 3.3, 3.4, Ch 4.7	
	Apr 08	L6: Solutions and Phase potraits	Ch 5.1 - 5.2	Homework 2
3	Apr 11	L7: Equilibriums & Linearization	Ch 6.4	
	Apr 11	DI3: Review on complex numbers		
	Apr 13	L8: Stability (I)	Ch 5.3	
	Apr 15	L9:		Homework 3
4	Apr 18	L10:		

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

Outline

Overview and Schedule

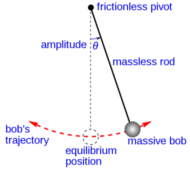
Control examples

Two live experiments

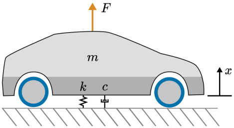
Summary

What is a dynamical system?

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

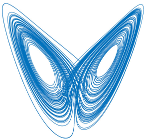


(a) Pendulum

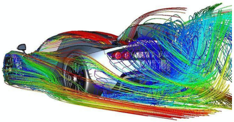


(b) Spring-mass (suspension)

(c) water flow



(d) Chaotic



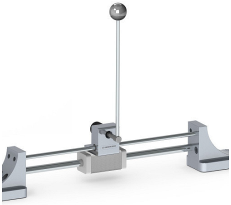
(e) fluid dynamics

(f) Sync of fishes

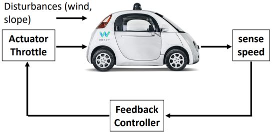
What is a control system?

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

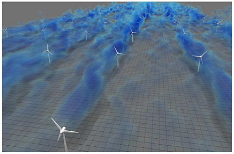
- Control is to modify the inputs to the plant (system) to produce a **desired output**.



(a) Inverted Pendulum



(b) Cruise control



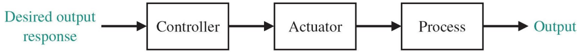
(c) Wind farm

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

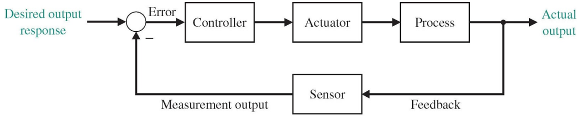


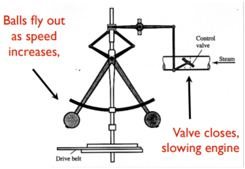
Table 1.1: Properties of feedback and feedforward.

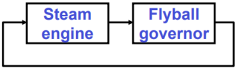
Feedback	Feedforward
Closed loop	Open loop
Acts on deviations	Acts on plans
Robust to model uncertainty	Sensitive to model uncertainty
Risk for instability	No risk for instability

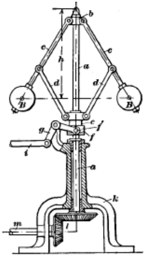
Feedback control examples (Engineering)

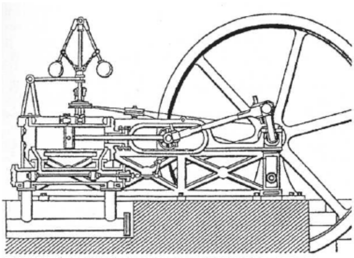
“Flyball” Governor (1788)

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









Feedback control examples (Engineering)

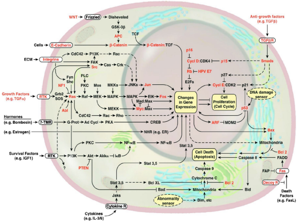
(a) Drones

(b) Autonomous vehicles

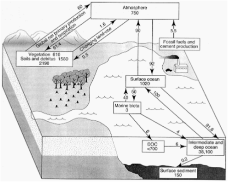
(c) SpaceX

(d) F18 Aircraft

Feedback control examples (Others)



(e) Biological Systems



(f) Environmental Systems

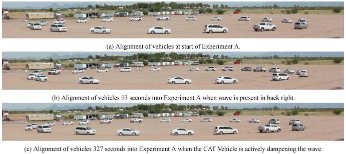
(g) Sociology

(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

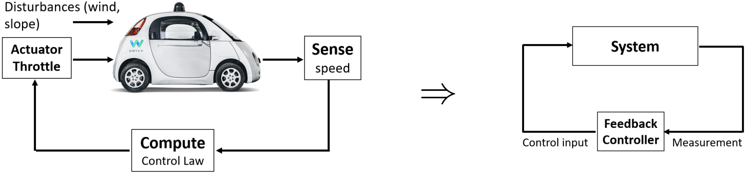
Balance a stick (Inverted Pendulum)

- 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!