

Introduction to Modern Controls

Introduction

The power of controls

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- Our internal body temperature is regulated around 37° C or 98.6° F, whether in a sauna room or outside at the north pole.
- The power of *feedback controls*: it allows us to make a precision device out of a crude one that works well even in changing environments.
- We also use *prediction and feedforward controls*: as kids, we had learned to wear T-shirts in summer, long sleeves and coats in winter. With such predictive and feedforward controls, the burden of feedback control is greatly lifted.

Analysis and control of linear dynamic systems

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- **Control System**: an interconnection of components forming a system configuration that will provide a desired response
- **Feedback**: the use of information of the past or the present to influence behaviors of a system

Why automatic control?

A system can be either manually or automatically controlled. Why automatic control?

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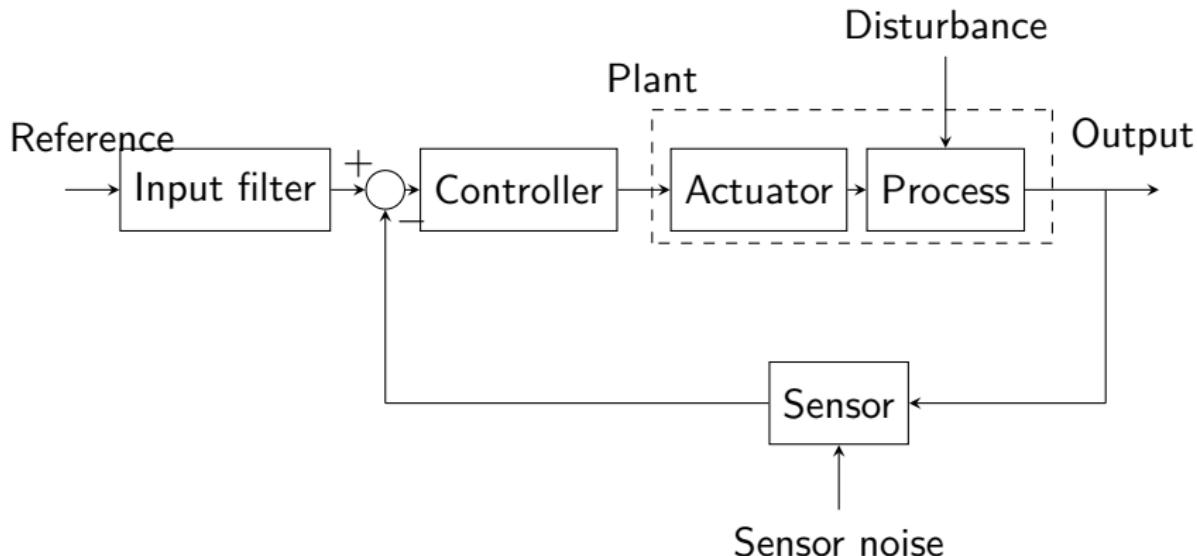
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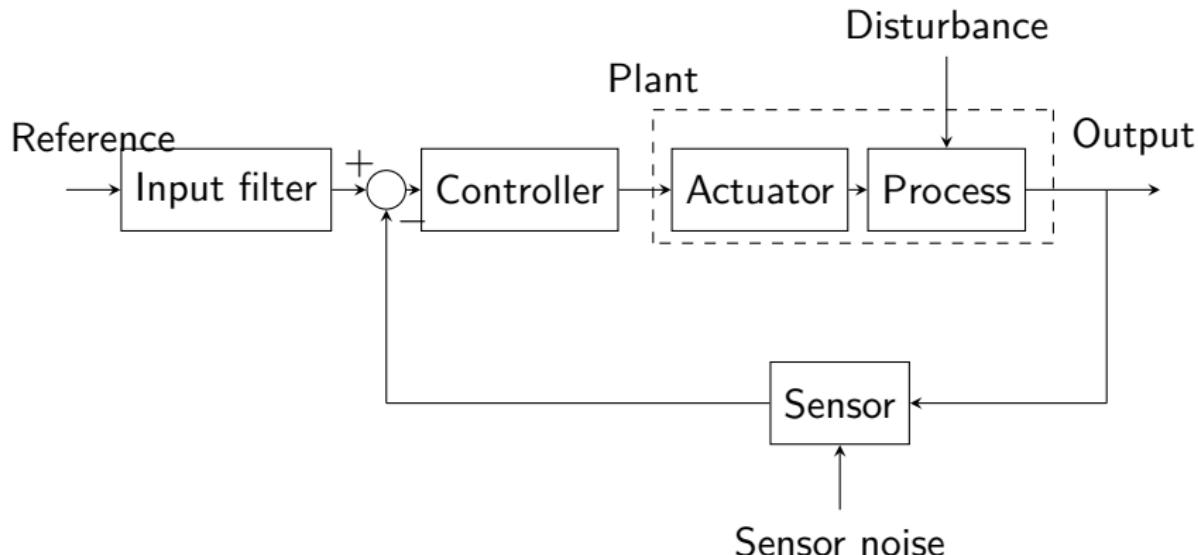
- **Stability/Safety**: difficult/impossible for humans to control the process or would expose humans to risk
- **Performance**: cannot be done “as well” by humans
- **Cost**: Humans are more expensive and can get bored
- **Robustness**: can deliver the requisite performance even if process behaves slightly differently

Terminologies



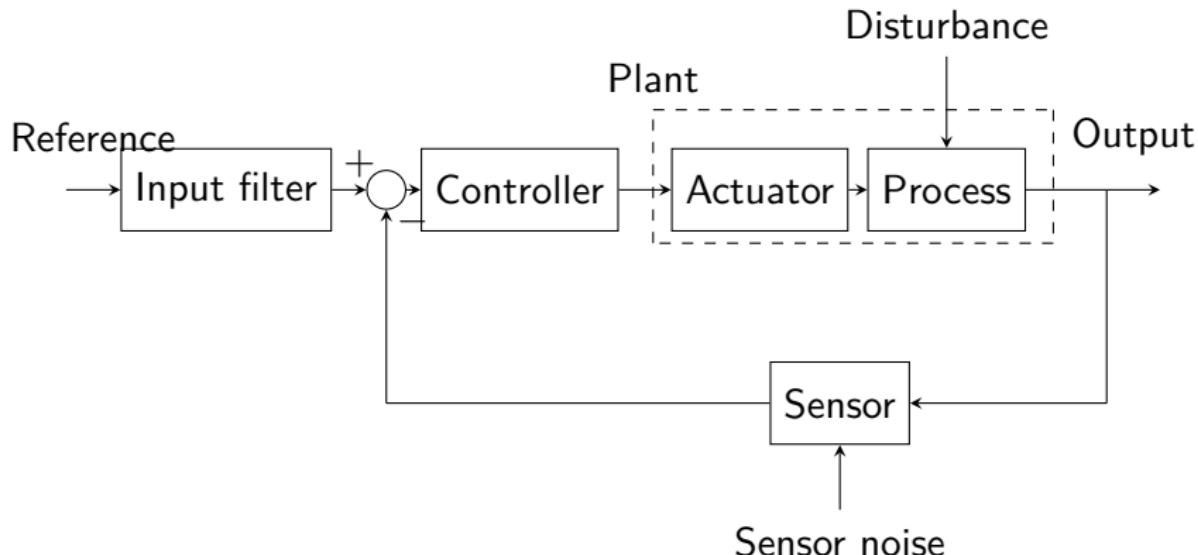
- **Process:** whose output(s) is/are to be controlled

Terminologies



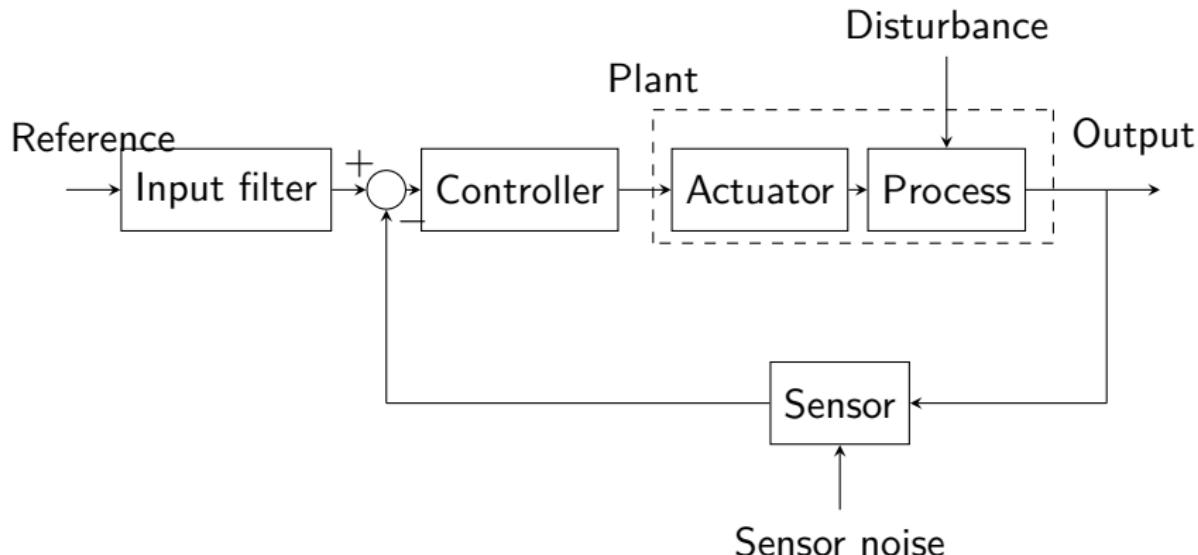
- **Process**: whose output(s) is/are to be controlled
- **Actuator**: device to influence the controlled variable of the process

Terminologies



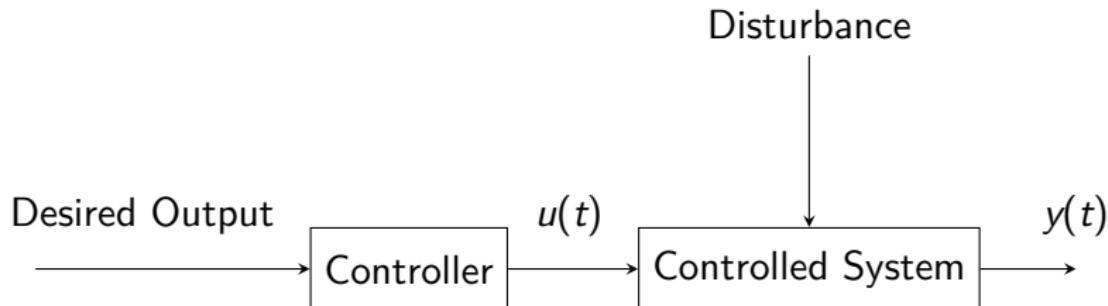
- **Process**: whose output(s) is/are to be controlled
- **Actuator**: device to influence the controlled variable of the process
- **Plant**: process + actuator

Terminologies



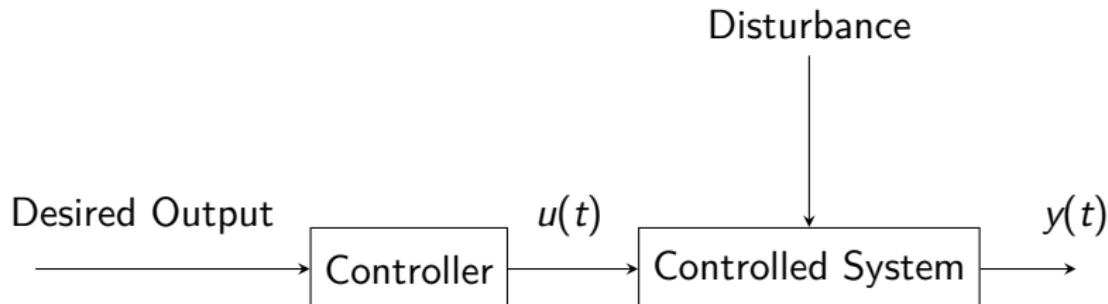
- **Process**: whose output(s) is/are to be controlled
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- **Plant**: process + actuator
- **Block diagram**: visualizes system structure and the flow information in control systems

Open-loop control v.s. closed-loop control



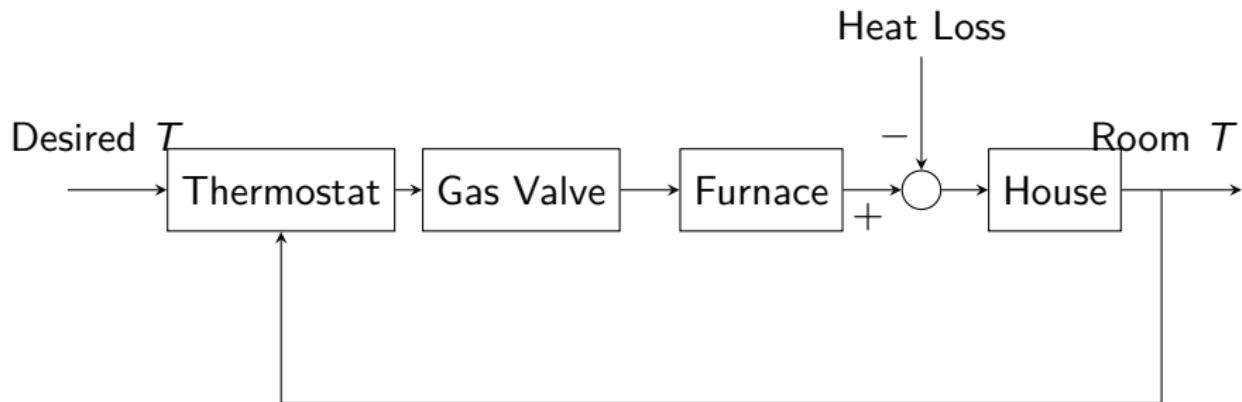
- the output of the plant does not influence the input to the controller

Open-loop control v.s. closed-loop control



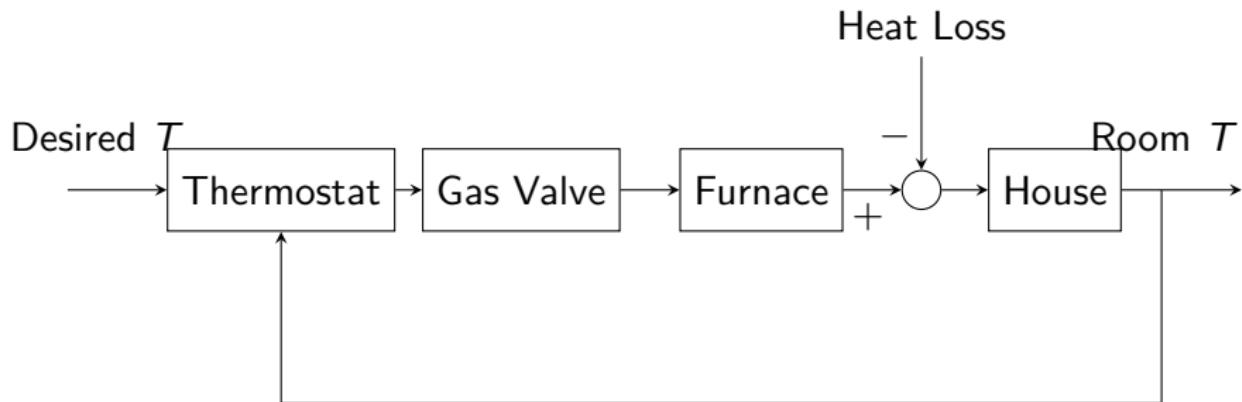
- the output of the plant does not influence the input to the controller
- input and output as *signals*: functions of time, e.g., speed of a car, temperature in a room, voltage applied to a motor, price of a stock, electrical-cardiograph, all as functions of time.

Open-loop control v.s. closed-loop control



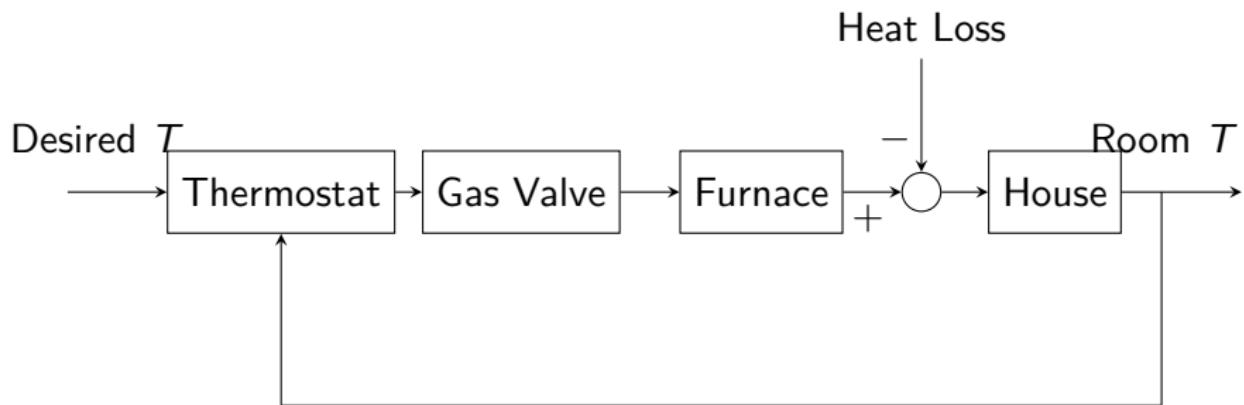
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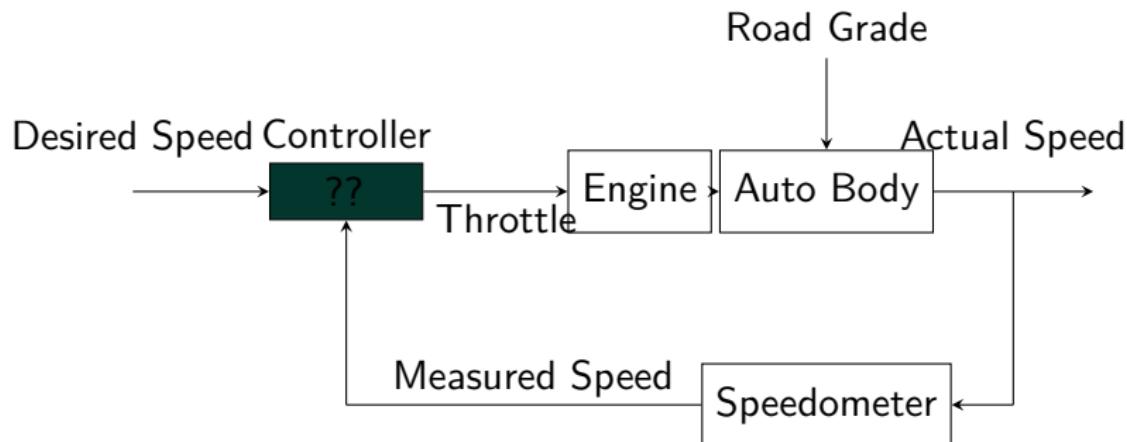


- multiple components (plant, controller, etc) have a closed interconnection
- there is always feedback in a closed-loop system

Closed-loop control: regulation example



Regulation control example: automobile cruise control



- What is the control objective?
- What are the process, process output, actuator, sensor, reference, and disturbance?

Control objectives

- Better stability

There are some aspects of control objectives that are universal. For example, we would always want our control system to result in closed-loop dynamics that are insensitive to disturbances. This is the disturbance rejection problem. Also, as pointed out previously, we would want the controller to be robust to plant modeling errors.

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- Improved response characteristics

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Control objectives

- Better stability
- Improved response characteristics
- *Regulation* of output in the presence of disturbances and noises
- Robustness to plant uncertainties
- *Tracking* time varying desired output

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Means to achieve the control objectives

- Model the controlled plant

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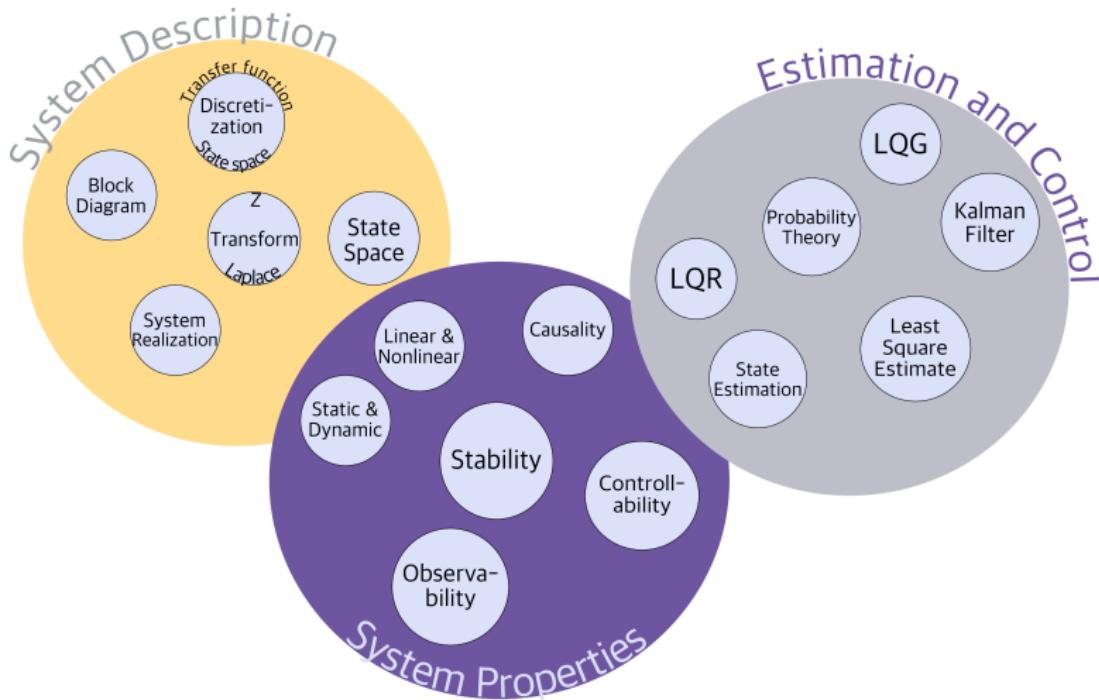
- Model the controlled plant
- Analyze the characteristics of the plant
- Design control algorithms (controllers)
- Analyze performance and robustness of the control system

Means to achieve the control objectives

- Model the controlled plant
- Analyze the characteristics of the plant
- Design control algorithms (controllers)
- Analyze performance and robustness of the control system
- Implement the controller

About this course

- a first-year graduate course on modern control systems



- a prerequisite to most advanced control courses

Textbook

Introduction to Modern Controls with Illustrations in MATLAB and Python

Xu Chen and Masayoshi Tomizuka



"Introduction to Modern Controls" uses modern computing tools such as MATLAB and Python to teach modern control systems. Teach modern control systems. You will learn how to use state-space methods to make, study, and control dynamic systems. You will explore topics like state-space models and solutions, stability, controllability, observability, state-feedback control, optimal control, observers, observer state feedback controls, least square estimation, Kalman filter, and Linear Quadratic Gaussian optimal control. You will see how these topics work in both continuous- and discrete-time settings. Substantial example codes, figures, and illustrations on physical systems supplement your learning.



Chen and
Tomizuka

Introduction to Modern Controls with Illustrations in MATLAB and Python

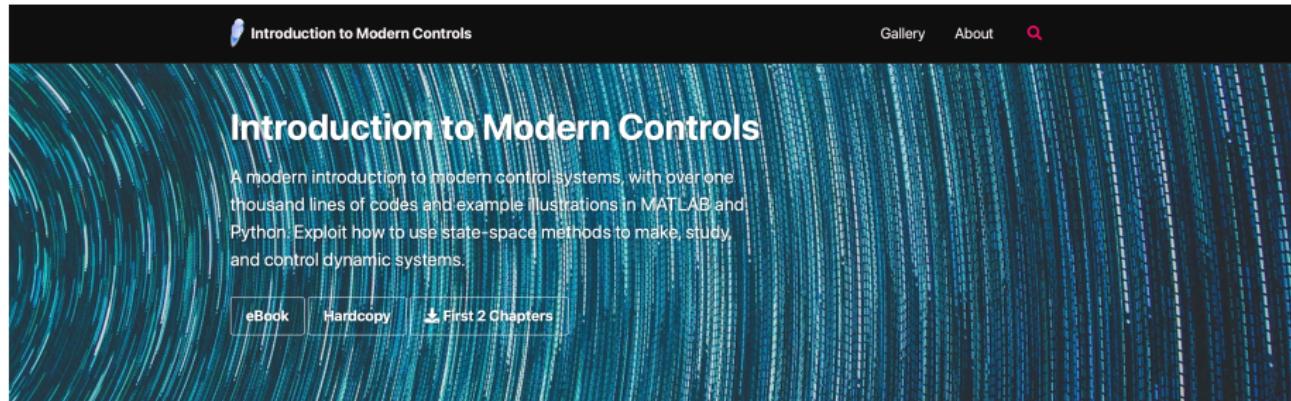


Introduction to Modern Controls with Illustrations in MATLAB and Python

This book is supported by a suite of online resources including source code, lecture slides, lecture recordings, and exercises at the end of each chapter. Read more at <https://mcimp-book.github.io/mcimp/>

Xu Chen
Masayoshi Tomizuka

Textbook



Mod Ctrl Intro (w Matlab & Python)

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Textbook

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README

Introduction to Modern Controls, with Illustrations in Matlab and Python



Codebase of the book "Introduction to Modern Controls, with Illustrations in Matlab and Python"

mcimp-book.github.io/mcimp

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Packages No packages published Publish your first package

Deployments 46

ghub-pages yesterday + 44 deployments

Languages

Python 68.0% MATLAB 31.7%

Ruby 0.1%

Written materials

- Open-source Course Notes

**University of Washington
Lecture Notes for ME547
Linear Systems**

Professor Xu Chen
Bryan T. Mitchell Student Research Fellowship
Department of Mechanical Engineering
University of Washington
Winter 2022

Aerospace ME547 - A first year graduate course on feedback control focusing on linear system theory and design, with emphasis on digital control. Content: Analysis of linear time-invariant systems, state-space representation, state-space analysis, state-space design, and implementation of controllers. Application areas include aircraft flight control, aerospace vehicle dynamics, and aerospace structures.

Coursework: The class will consist of lecture meetings for theoretical concepts of interest, problem sets, and a final project. The final project will involve the design and implementation of a controller for a real-world system.

Prerequisites: Basic knowledge of linear algebra, differential equations, and probability and statistics.

Textbook: *Feedback Control: An Introduction*, 4th edition, by G. F. Franklin, J. D. Powell, and M. L. Workman, Prentice Hall, 2007.

Contents

- 1. Introduction
- 2. Mathematical Preliminaries
- 3. State Space Representation
- 4. Linear Time-Invariant Systems
- 5. Stability
- 6. State-Space Analysis
- 7. State-Space Design
- 8. Implementation of Controllers
- 9. Applications
- 10. Final Project
- 11. References
- 12. Further Reading
- 13. Acknowledgments
- 14. Final Project Feedback
- 15. User Rights Notice

Topic:

1. Introduction of controls
2. Introduction of the course
3. Beyond the course

MES47: Linear Systems

Introduction

Bryan T. Chen
University of Washington

Open-loop control v.s. closed-loop control

- multiple components (plant, controller, actuator) have a closed loop interaction
- there is often feedback in a closed-loop system

Regulation control example: automobile cruise control

- What is the control objective?
- What are the process, process output, evaluation, sensor, reference, and disturbance?

Means to achieve the control objectives

- Model the controlled plant
- Design performance characteristics of the plant
- Design control algorithms (controllers)
- Assess performance and robustness of the control system
- Implement the controller

Closed-loop control: regulation example

- Driver stability
- Impulse response characteristics
- Regulation of output in the presence of disturbances and noises
- Disturbance rejection
- Tracking time varying desired output

These are some aspects of control objectives that are essential. For example, the furnace needs to track the desired output to reach a closed-loop dynamics that are insensitive to disturbance. This is the disturbance rejection. The tracking time varying desired output is another aspect the controller is to be robust in its modeling process.

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Resources for control education: societies

- **ASME (American Society of Mechanical Engineers)**
 - Publications: ASME Journals of Guidance, Control and Navigation
 - ASME Journals of Dynamic Systems, Measurement and Control
- **IEEE (Institute of Electrical and Electronics Engineers)**
 - IEEE Transactions on Control Systems Technology
 - IEEE Transactions on Aerospace and Electronic Systems
 - IEEE Transactions on Control Systems Technology
 - IEEE Transactions on Industrial Control
- **IFAC (International Federation of Automatic Control)**
 - Publications: Automatic Control Engineering Practice

Total listing at: [https://www.ae.washington.edu/~xchen/ME547.html](#)

IEEE Control Systems Magazine

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Introduction

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- AIAA (American Institute of Aeronautics and Astronautics)
 - ▶ Publications: AIAA Journal of Guidance, Control and Navigation
- ASME (American Society of Mechanical Engineers)
 - ▶ Publications: ASME Journal of Dynamic Systems, Measurement and Control¹
- IEEE (Institute of Electrical and Electronics Engineers)
 - ▶ www.ieee.org
 - ▶ Control System Society
 - ▶ Publications:
 - ★ IEEE Control Systems Magazine¹
 - ★ IEEE Transactions on Control Technology
 - ★ IEEE Transactions on Automatic Control
- IFAC (International Federation of Automatic Control)
 - ▶ Publications: Automatica, Control Engineering Practice

¹start looking at these, online or at library

IEEE Control Systems Magazine

