ECE 388 – Automatic Control

Basics and Plant Modeling

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Compulsory Course in Electronic and Communication Engineering
Credits (2/2/3)

Course Webpage: http://ECE388.cankaya.edu.tr

Content and Structure

Content

- Linear State Space and Transfer Function Models
- Model Analysis
- Basic Control Concepts
- Control Loop Analysis
- Control Loop Design
- Matlab/Simulink Laboratory

Structure

- 2 lecture hours: Monday 13:20 – 15:10
- 2 Lab hours: Tuesday 13:20 – 15:10; Tuesday 15:20 – 17:10
- Office hours: Tuesday 10:20 – 11:00

Grading and Literature

Grading

- 13 Laboratories (30%)
- 1 Midterm Exam (30%)
- 1 Final Exam (40 %)

Literature

- Ogata, Katsuhiko: "Modern Control Engineering (5th Edition)", Prentice-Hall, Inc., 2009 (ISBN: 0-13-615673-8) (Main Textbook)
- Goodwin, Graham, Graebe Stefan, Salgado, Mario: "Control System Design", Prentice-Hall, Inc., 2001 (ISBN: 0-13-958653-9)
- Astrom, Karl and Murray, Richard: "Feedback Systems: An Introduction for Scientists and Engineers", Princeton University Press, 2008 (ISBN: 0-691-13576-2)

Motivation: Basics

Control

Control is a discipline that is concerned with the automatic manipulation of a dynamic system's behavior

Dynamic System

System that shows dynamic dependency between input and output signals

- Signal is a time-varying physical quantity (e.g. position, velocity, temperature, voltage, current, . . .)
- Usually, dynamic systems possess memory
- Dynamic systems are for example modeled by differential equations, difference equations, transfer functions

Motivation: Dynamic System in Control

Detailed Graphical Representation

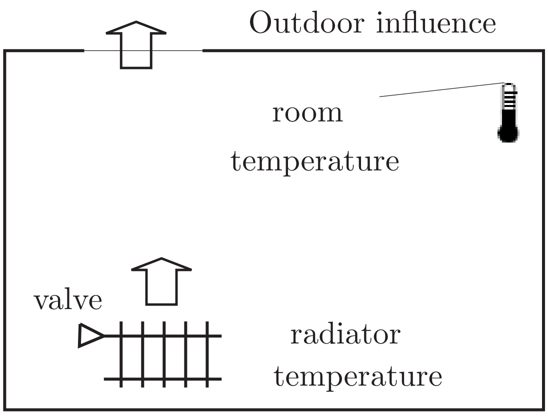
Gap 1

Manipulation of a Dynamic System

Application of appropriate inputs such that the system state/output behaves as desired even in the presence of disturbances

Examples: Room Temperature System

Schematic



Graphical Representation

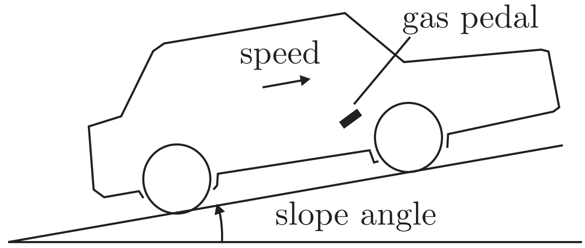
Gap 2

Control Task

- Desired (specified) behavior: keep room temperature constant
- Manipulation: automatically adjust valve position

Examples: Vehicle Speed

Schematic



Graphical Representation

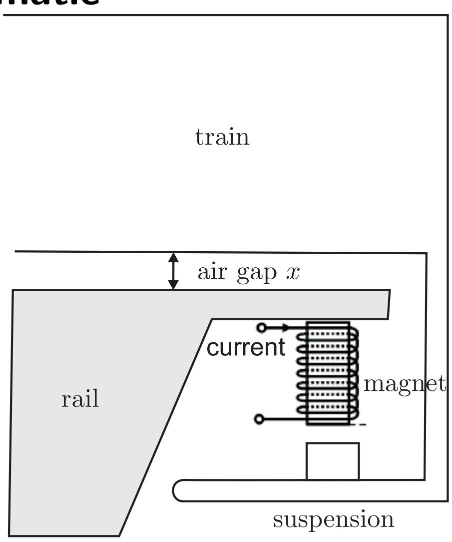
Gap 3

Control Task

- Desired (specified) behavior: keep vehicle speed constant
- Manipulation: automatically adjust pedal position

Examples: Magnetic Suspension

Schematic



Graphical Representation

Gap 4

Control Task

- Desired (specified) behavior: Move to/keep specified position
- Manipulation: automatically adjust current in the coil

Examples: Movies

Inverted Pendulum

- Desired (specified) behavior: Keep pendulum upright
- Manipulation: horizontally move cart

⇒ http://www.rt.eei.uni-erlangen.de/FGnls/video/inverted_pendulum.wmv

Automatic Parking

- Desired (specified) behavior: Reach parking position (without collision)
- Manipulation: automatically adjust speed and steering angle

⇒ http://www.rt.eei.uni-erlangen.de/FGnls/video/automatic_parking.wmv

Ball on Plate

- Desired (specified) behavior: follow path/keep position
- Manipulation: automatically change orientation of plate

⇒ http://www.rt.eei.uni-erlangen.de/FGnls/video/ball_on_plate.wmv

Control Engineering: Basic Task

Main Task of Control Engineering

Design and realize technical appliance – controller – that enforces the desired output behavior of the plant when connected to the plant

Feedforward Control

Gap 5

⇒ Feedforward controller provides appropriate input such that the plant follows a given reference signal

Control Engineering: Basic Principles

Feedback Control

Gap 6

⇒ Feedback controller tries to compensate the difference between a reference signal and the measured output signal

Remarks

- Control problems occur in many subject areas
- Examples: process engineering, electrical engineering, communication networks, automotive applications, medicine, chemistry, biology, . . .
  ⇒ Mathematical abstraction of control problems to enable interdisciplinary application

Control Engineering: General Solution Procedure

Procedure

1. Mathematical modeling of plant
   ⇒ Abstraction from the physical problem
2. Analysis of the plant behavior
   ⇒ Determine basic properties of the plant and their implications on the design
3. Controller design
   ⇒ Achieve desired plant behavior
4. Simulation and test on the real system
   ⇒ Verify if design goals are achieved

Plant Modeling: Basic Idea

A plant model is a mathematical description of the cause-effect relationship between the plant signals that are relevant for the design task

Remarks

- The same system can have different plant models
  $\rightarrow$ We focus on models for control tasks
- There are models in different domains
  - Time-domain: we will use state space models
  - Laplace domain: we will use transfer function models
- We consider as relevant signals
  - Input signals (signals that we can directly influence)
  - Output signals (signals that we want to manipulate)
  - Disturbance signals (signals that cannot be directly influenced and that can have a negative effect on the system)

Linear State Space Models: Definitions

System State

The state $x(t_0)$ of a dynamic system at time t_0 is the information at time t_0 that is needed together with the input signal $u(t)$ for $t \geq t_0$ to determine the output signal $y(t)$ for $t \geq t_0$

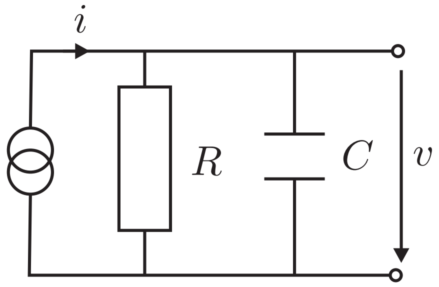
Example

Gap 7

Linear State Space Models: RC-Circuit Example

Computation

Gap 8



- Input: $u = i$
- Output: $y = v$
- State: $x = v$

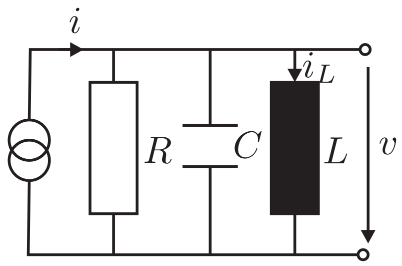
Model

$$\dot{x} = -\frac{1}{R\,C}x + \frac{1}{C}\,u$$
$$y = x$$

Linear State Space Models: RLC-Circuit Example

Computation

Gap 9



- Input: $u = i$
- Output: $y = v$
- State: $x_1 = i_L$, $x_2 = v$

Model

$$\dot{x}_1 = \frac{1}{L}x_2$$
$$\dot{x}_2 = -\frac{1}{C}x_1 - \frac{1}{R\,C}x_2 + \frac{1}{C}u$$
$$y = x_2$$

Linear State Space Models: Definitions

State Space Equations

$$\dot{x}(t) = A\,x(t) + b\,u(t)$$
$$y(t) = c^T\,x(t) + d\,u(t)$$

Signals

- State vector: $x(t) \in \mathbb{R}^n$
- State vector derivative: $\dot{x}(t) \in \mathbb{R}^n$
- Input: $u(t) \in \mathbb{R}$
- Output: $y(t) \in \mathbb{R}$

Constant Matrices and Vectors

- Dynamics matrix: $A \in \mathbb{R}^{n\times n}$
- Input vector: $b \in \mathbb{R}^{n\times 1}$
- Output vector: $c^T \in \mathbb{R}^{1\times n}$
- Feed-through: $d \in \mathbb{R}$

$\Rightarrow$ We focus on Single-Input Single-Output (SISO) systems

Linear State Space Models: Circuit Examples

State-Space Models

Gap 10