Intro. Computer Control Systems: F1

Introduction

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What is control theory?

The study of dynamical systems and their control.

System = Process = An object whose properties we wish to study/control.
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The study of dynamical systems and their control.

System = Process = An object whose properties we wish to study/control.

- The output $y$ is a signal that we can measure and/or wish to control.
- Using the input $u$ we can affect the system and its output.
Dynamical systems

- Static systems: \( y(t) = f(u(t)) \), depends on \( u \)'s current value!
- **Dynamical** systems: \( y(t) \) may depend on \( u(\tau) \) for \( \tau \leq t \).
Dynamical systems

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- Dynamical systems: \( y(t) \) may depend on \( u(\tau) \) for \( \tau \leq t \).

Consequence: Dynamical systems have ‘memory’. Current input affects the future output!
Examples
Application examples

Figure: Biomedicine and molecular interactions
Application examples

Figure: Autonomous driving and emission reduction
Application examples

Figure: Aircraft control och stabilization
Application examples

Figure: Robotics and autonomous systems
Application examples

Figure: Industrial processes and power systems
Application examples

Figure: Communication and data networks
Computer control in a nutshell
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Q: Which input $u$ to the motor such that the output $y$ stays around desired reference signal $r = 0$?

That input $u$ should be computed by a controller!

Design of the controller is the practical goal of control theory.
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*Design of the controller* is the practical goal of control theory
Computer control in a nutshell

Example

Lab exercise in Automatic Control II
Control without feedback

Determine $u(t)$ such that: $y(t)$ should follow a reference signal $r(t)$ closely, despite presence of disturbance $v(t)$.

**Open loop:** $u(t)$ predetermined by reference $r(t)$.
Control without feedback

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**Open loop:** $u(t)$ predetermined by reference $r(t)$.

**Challenges:**
- Requires accurate knowledge about the system.
- Does not take into account unknown disturbances.
Control using feedback

**Feedback:** $u(t)$ also determined by measuring $y(t)$. 

![Control System Diagram]

- **Advantages:**
  - Requires only an approximative model of the system.
  - Can mitigate unknown disturbances.

- **Challenges:**
  - Feedback controller may create instability if poorly designed.
Control using feedback

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![Control System Diagram]

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Typical design requirements

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- When reference signal changes, the output should *quickly* track it with minimal *oscillations*, using a reasonable input.
- If a disturbance occurs, the output should quickly return to the reference signal.
Typical design requirements

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- When reference signal changes, the output should *quickly* track it with minimal *oscillations*, using a reasonable input.
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**The control problem:** Design a controller such that the controlled system fulfills the desired requirements.
About the course
The course

Content

Book options:


Webpage: http://www.it.uu.se/edu/course/homepage/regsyintro/vt17
Studentportalen will also be used.
The course
Content

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Content:

- Analysis of linear dynamical systems and feedback
- Basic control principles
  - PID control
  - Forward- och cascade control
  - State feedback control
- Discrete-time models and digital control
The course
Examination forms

Labs:

▸ 3 × Computer Labs (recommended)
▸ 1 × Process Lab (mandatory)

Exam: Evaluation of each problem solution is based on:

1. demonstrating understanding of the problem using principles of the course
2. provided a reasonable and reproducible solution

Hand-in (recommended): 2 × hand-ins which help getting your hands on early and yield bonus credits for the exam.

Secret to passing course
The course

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Secret to passing course: Get hands dirty

- by taking notes
- through problem solving!
System models
Mathematical models of systems

\[ y(t) = G(u(t)) \]

**Figure**: Graphical representation of system \( G \) with input and output.

Models are neither ‘true’ nor ‘false’, but rather more or less

- accurate
- useful

representations of underlying mechanisms with measurable effects.
Build intuition from simple systems

Ex. #1: Vehicle in motion

![Figure: Force $u(t)$ och velocity $y(t)$.

Physical principles: Newton’s law

$$F = m \ddot{y},$$

where $F = u - F_{fr} = u - Cy$.

[Board: Linear differential equation]
Build intuition from simple systems

Ex. #2: Damper

Figure: Force $u(t)$ och position $y(t)$.

Physical principles: Newton’s law

$$F = m\ddot{y},$$

where $F = u - Ky$.

[Board: Linear differential equation]
Ex. #3: Inverted pendulum

Physical principles: Torque equation

\[ \frac{mL^2}{3} \ddot{y} = u + \frac{mgL}{2} \sin(y). \]

Using Taylor series around \( y = 0 \):

\[ \sin(y) \approx \sin(0) + \cos(0)(y - 0) = y \]

[Board: Linear differential equation]
Linear system models
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Linear time-invariant models are useful and sufficiently accurate in many control applications.
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\[ y(t) = G u(t) \]

Differential equation is one possible description of input-output relation, i.e. \( G \):

\[
\frac{d^n}{dt^n} y + \cdots + a_{n-1} \frac{d}{dt} y + a_n y = b_0 \frac{d^n}{dt^m} u + \cdots + b_{m-1} \frac{d}{dt} u + b_m u
\]

with initial conditions.

Often hard to interpret!
Linear system models

*Linear time-invariant* models are useful and sufficiently accurate in many control applications

\[ y(t) = G u(t) \]

Different mathematical descriptions of the input-output relation, i.e. \( G \):

1. Differential equations
2. Impulse response / weighting function
3. Transfer function / frequency response
4. State-space description

The latter descriptions are more manageable and practical!
Linear system models

Linear time-invariant models are useful and sufficiently accurate in many control applications

\[ y(t) = G y(t) \]

Revise basics:

1. Complex numbers
2. Linear ordinary differential equations
3. Laplace transform
4. Linearization using Taylor series expansion
5. Vector/matrix operations and eigenvalues

See Math Tutorial on course webpage!