



Intro. Computer Control Systems: F1

Introduction

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What is control theory?

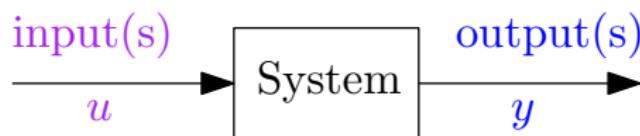
The study of dynamical **systems** and their **control**.

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

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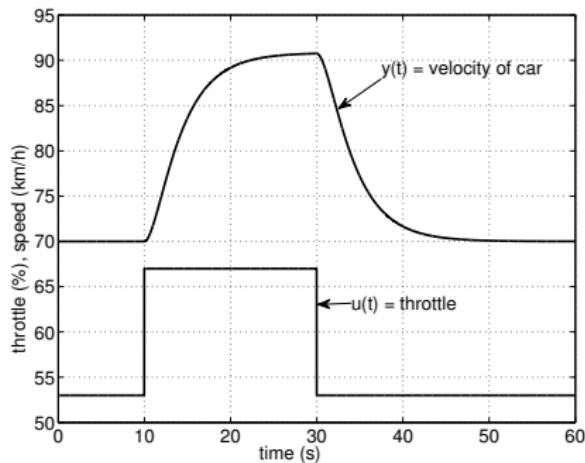
- ▶ The **output y** is a signal that we can measure and/or wish to control.
- ▶ Using the **input u** we can affect the system and its output.

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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Consequence: Dynamical systems have 'memory'. *Current* input affects the *future* output!



Examples

Application examples

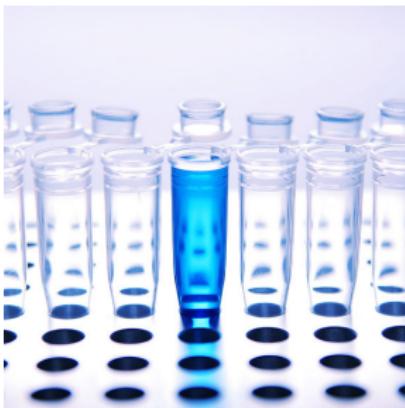


Figure: Biomedicine and molecular interactions

Application examples

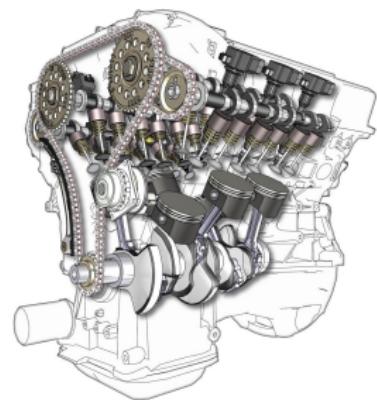


Figure: Autonomous driving and emission reduction

Application examples



Figure: Aircraft control och stabilization

Application examples



Figure: Robotics and autonomous systems

Application examples

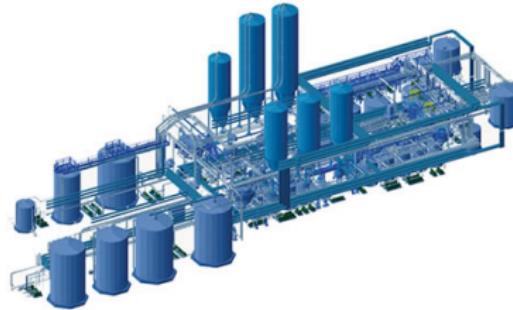


Figure: Industrial processes and power systems

Application examples

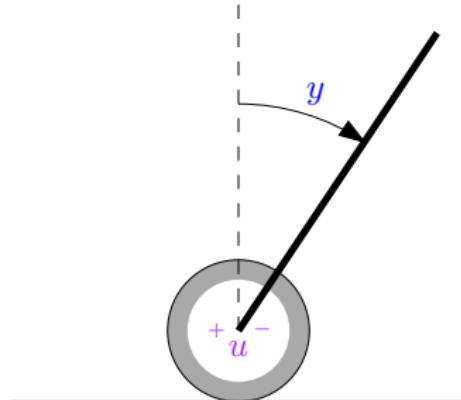


Figure: Communication and data networks

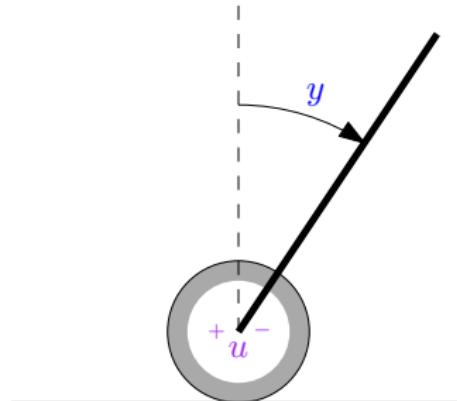


Computer control in a nutshell

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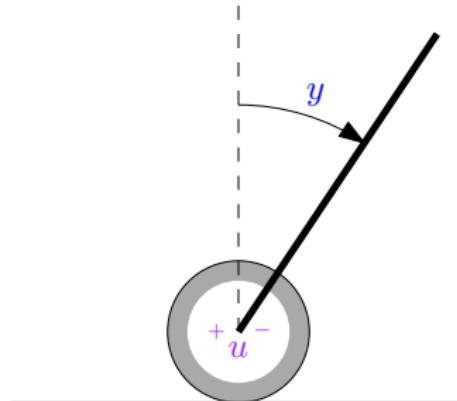


Computer control in a nutshell



Q: Which **input u** to the motor such that the **output y** stays around desired reference signal $r = 0^\circ$?

Computer control in a nutshell



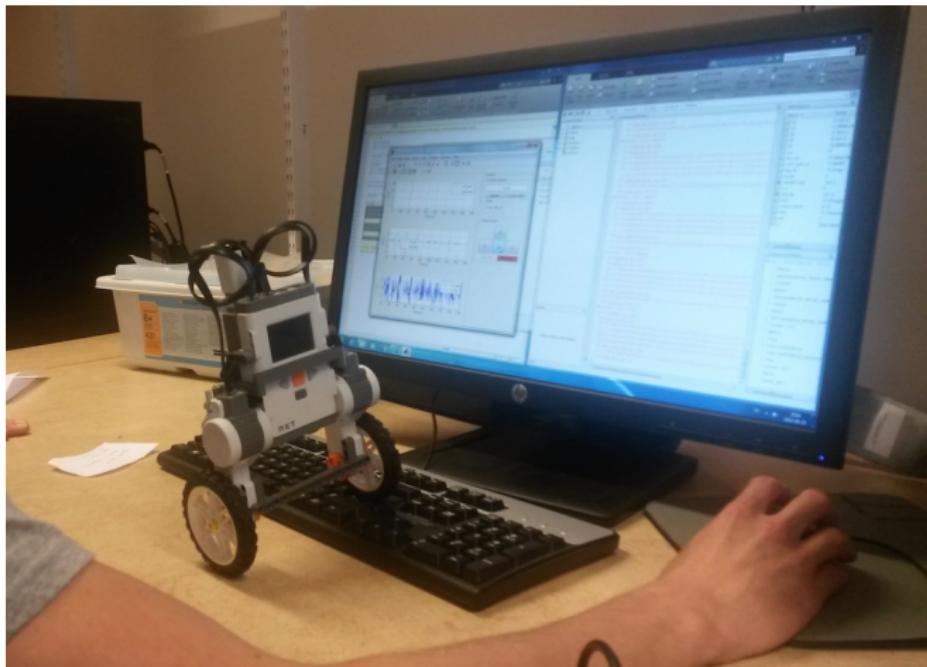
Q: Which **input u** to the motor such that the **output y** stays around desired reference signal $r = 0^\circ$?

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

Design of the controller is the practical goal of control theory

Computer control in a nutshell

Example

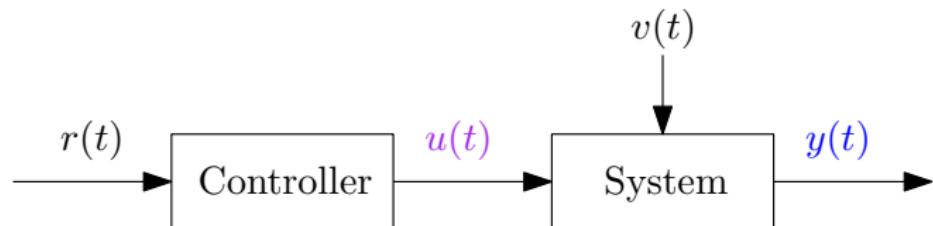


Lab exercise in Automatic Control II

Control without feedback

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

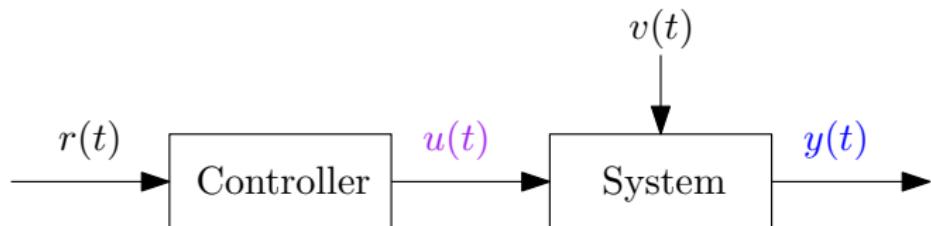
Open loop: $u(t)$ predetermined by reference $r(t)$.



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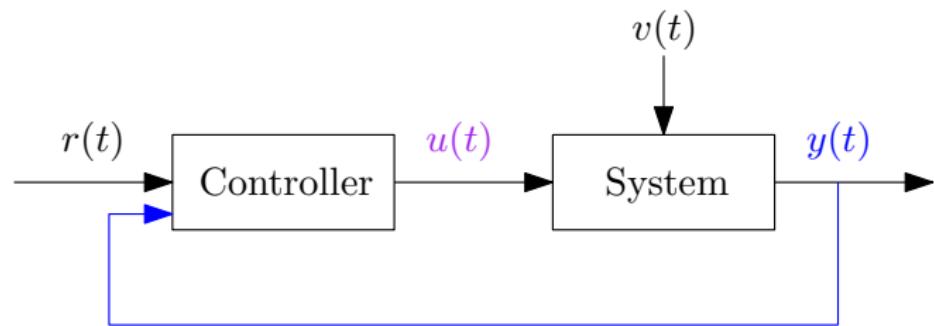


Challenges:

- ▶ Requires accurate knowledge about the system.
- ▶ Does not take into account unknown disturbances.

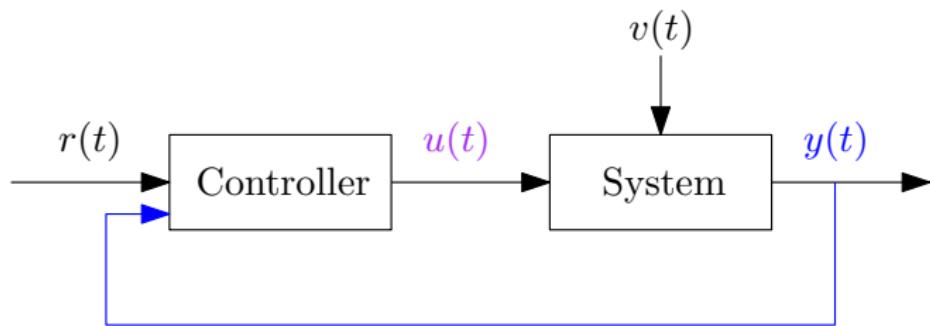
Control using feedback

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



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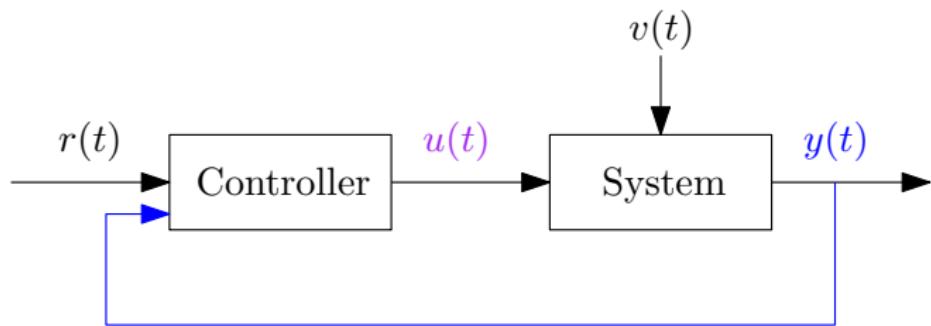


Advantages:

- ▶ Requires only an approximative model of the system.
- ▶ Can mitigate unknown disturbances.

Control using feedback

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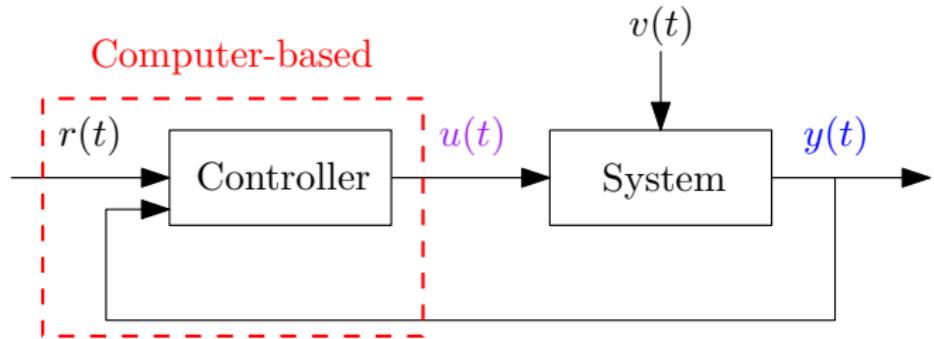
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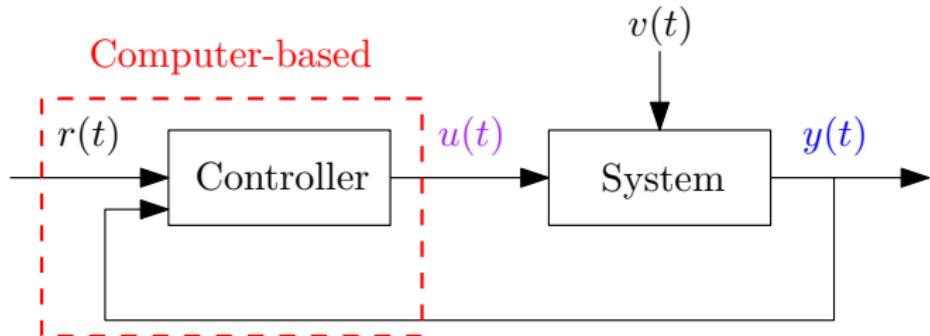
Challenges:

- ▶ Feedback controller may create instability if poorly designed.

Computer-based control using feedback



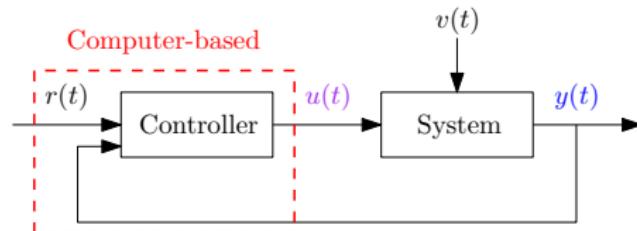
Computer-based control using feedback



Computer-based controller requires:

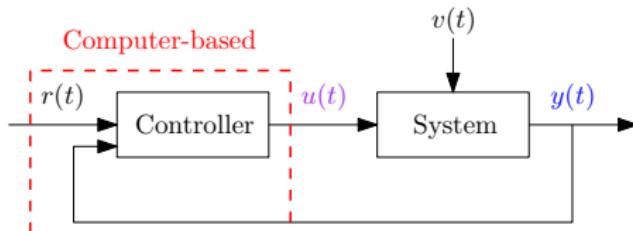
- ▶ Analog-to-digital conversion of $y(t)$
- ▶ Digital-to-analog conversion of $u(t)$

Typical design requirements



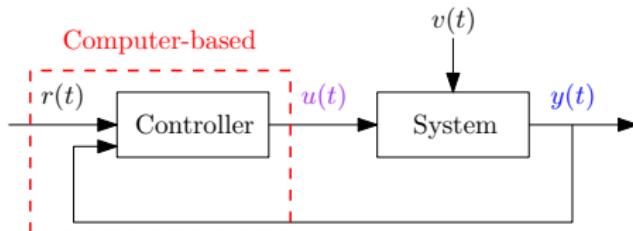
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Typical design requirements



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2. **Tracking:** $y(t)$ tracks $r(t)$ **quickly** with minimal **oscillations**
3. **Feasibility:** Controller should decide on feasible **input** $u(t)$
4. **Robustness:** If a disturbance occurs, output $y(t)$ should quickly **return** to the reference signal $r(t)$.

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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:

- ▶ Reglerteknik — Grundläggande teori, T. Glad & L. Ljung, 4th edition from 2006, Studentlitteratur.
- ▶ Feedback Control of Dynamic Systems, G.F. Franklin, J.D. Powell, A. Emami-Naeini, 7th edition, Prentice Hall.

Webpage: <http://www.it.uu.se/edu/course/homepage/regsysintro/vt18>
Studentportalen will also be used.

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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

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Secret to passing course: Get hands dirty

- ▶ by taking notes
- ▶ through problem solving!



System models

Mathematical models of systems



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

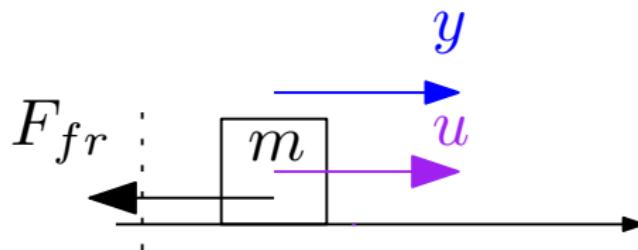


Figure: Force $u(t)$ och velocity $y(t)$.

Physical principles: Newton's law

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

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

[Board: Linear differential equation]

Build intuition from simple systems

Ex. #2: Damper

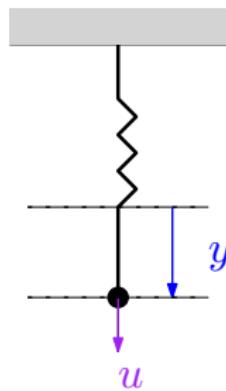


Figure: Force $u(t)$ och position $y(t)$.

Physical principles: Newton's law

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[Board: Linear differential equation]

Build intuition from simple systems

Ex. #3: Inverted pendulum

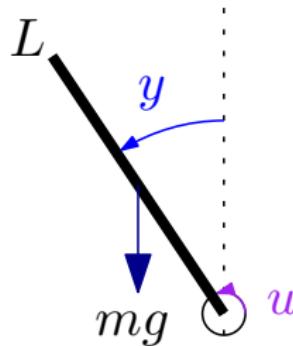


Figure: Torque $u(t)$ och angle $y(t)$.

Physical principles: Torque equation

$$(mL^2/3)\ddot{y} = u + (mgL/2) \sin(y).$$

Using Taylor series around $y = 0$:

$$\sin(y) \approx \sin(0) + \cos(0)(y - 0) = y$$

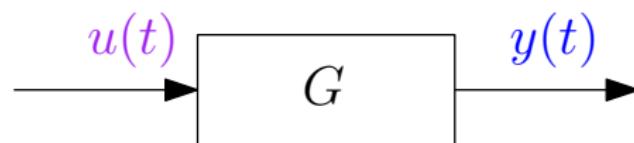
[Board: Linear differential equation]



Linear system models

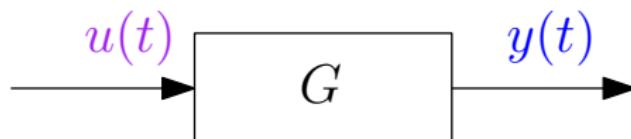
Linear system models

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



Linear system models

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



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

$$\frac{d^n}{dt^n}y + \cdots + a_{n-1}\frac{d}{dt}y + a_ny = b_0\frac{d^m}{dt^m}u + \cdots + b_{m-1}\frac{d}{dt}u + b_mu$$

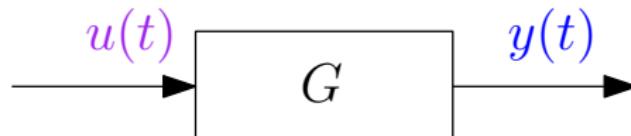
with initial conditions.

Often hard to interpret!



Linear system models

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Different mathematical descriptions of the **input-output** relation, i.e. G :

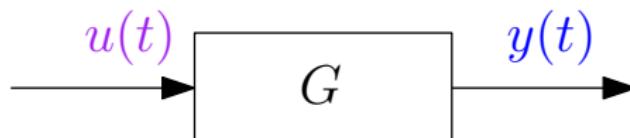
1. Differential equations
2. Impulse response / weighting function
3. Transfer function / frequency response
4. State-space description

The latter descriptions are more manageable and practical!



Linear system models

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



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!