Regeltechniek

Lecture 1 – Introduction

Robert Babuška

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Lecture Outline

- Information about the course.
- Why is control essential.
- Basic elements of feedback.
- Modeling dynamic systems.

Teaching Staff

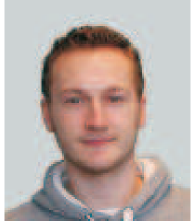
Lecturer:	Prof.Dr. Robert Babuška, M.Sc.
Assistants:	Ir. Ivo Grondman
	Dr.ir. Mernout Burger

Robert Babuška

Research:
– Artificial intelligence methods for nonlinear control, robotics

Teaching:
– Knowledge-Based Control Systems (M.Sc. course)
– Integration Project (M.Sc. course, Systems and Control)

Course Assistant: Ivo Grondman



Office hours:	ask appointment by email
Room:	3ME, E-3-310
Phone:	(015-27) 83371
Email:	I.Grondman@TUDelft.NL

PhD student: Reinforcement Learning.

Learning optimal control strategy by interaction with the process.
Applications to nonlinear systems in robotics and mechatronics.

Course Assistant: Mernout Burger

Office hours: ask appointment by email

Room: 3ME, E-3-310

Phone: (015-27) 83371

Email: M.Burger@TUDelft.NL

Postdoc: Model-Based Predictive Control for Intelligent Micro-Transportation Systems.

Scheduling small autonomous water-taxis, optimizing energy efficiency while respecting transportation demand and charging.

Goals of the Course

- Represent dynamic systems as transfer function and state-space models.
- Analyze closed-loop dynamics by using:
  - the root-locus method,
  - Bode plots,
  - Nyquist plots
- Design controllers by using the above methods.
- Design state-feedback controllers by pole placement.
- Use effectively Matlab and Simulink for analysis, design and simulation.

Course Organization

Please, enroll in the course via Blackboard!

Course Structure

- Two lectures every week:
  - Monday 13:45 – 15:30, 3mE lecture room A and C
  - Friday 13:45 – 15:30, 3mE lecture room A and C
- Instruction (problem-solving) sessions:
  - week 3 (calendar week 38)
    – Thursday 10:45 – 12:30, Aula – lecture room A
  - week 5 (calendar week 40)
    – Thursday 10:45 – 12:30, Aula – lecture room A
  - week 7 (calendar week 42)
    – Friday 13:45 – 15:30, Aula – lecture room A

Course Structure - contn'd

- Matlab computer sessions:
  - week 4 (calendar week 39) - introduction to Matlab
  - week 6 (calendar week 41) - root locus and freq. domain
  - week 7 (calendar week 42) - experimental setup (lab)

  Week 4 and 6 in computer room 020 (CT), week 7 in Meetshop. See Blackboard for the schedule.
- Guest lecture – robotics and wind turbines
  - week 3 (calendar week 38)
    Wednesday 13:45 – 15:30, 3mE - lecture room A and C
- Examination: check Blackboard for dates and times

Practical Matlab Sessions

I hear and I forget. I see and I remember. I do and I understand."
– Confucius

- Get hands-on experience, learn to use Matlab and Simulink.
- Compulsory for everyone who has not passed yet.
- Work in groups of two students (you choose your partner).
- Assignment in the second and third Matlab session – written report (deliver 1 report per group).
- Report is graded (1 – 10).
- Final grade = 0.75*exam grade + 0.25*assignment grade, If final grade $<$ 6 or exam grade $<$ 5 Then resit;
  If assignment grade $<$ 5 Then additional assignment.

Organization of Matlab Sessions

In weeks 4, 6 four sessions in the week are scheduled in computer room 020 (CT). Each group only comes once in week 4 and once in week 6.

In week 7 in meetshop – DC motor setup
14 sessions are scheduled
and again each group only comes once in week 7.

For space reasons, you cannot come whenever you wish.
Instead, please, register (= indicate your non-availability and your group partner) via Blackboard and we will assign you to a time slot.
Registration open: September 10 through 16 (24:00), 2012.

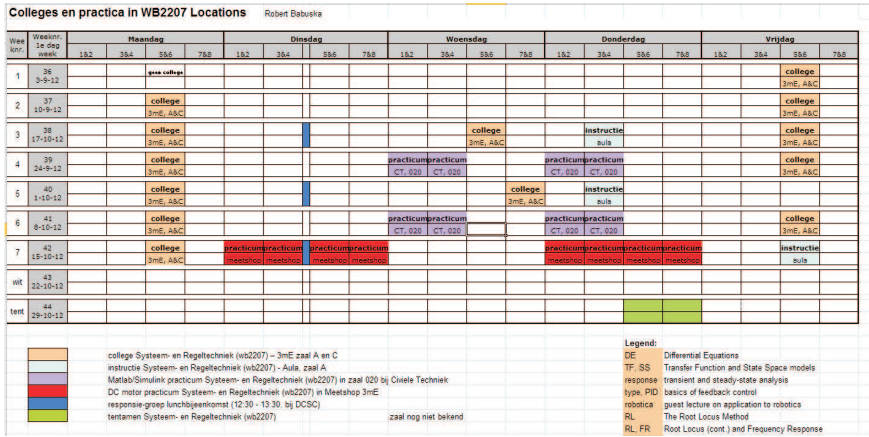
Organization of Matlab Sessions

All students following this course must register for the practical Matlab sessions via Blackboard (next week).

Two exceptions:

- Students who already passed the Matlab practical in one of the past years (grade for the report $>$ 5) and who do not wish to improve their grade must NOT register for the Matlab sessions.
- Students who follow this course as a part of the Robotics Minor (lecturer Dr. Martijn Wisse) must NOT register for the Matlab sessions (they are already assigned to a time slot).

Complete Schedule



Colleges en practica in WB2207 Locations Robert Babuska

Wee knr.	Weeknr. 1e dag week	Maandag				Dinsdag				Woensdag				Donderdag				Vrijdag			
		1&2	3&4	5&6	7&8	1&2	3&4	5&6	7&8	1&2	3&4	5&6	7&8	1&2	3&4	5&6	7&8	1&2	3&4	5&6	7&8
1	36 3-9-12			geen college																college 3mE, A&C	
2	37 10-9-12			college 3mE, A&C																college 3mE, A&C	
3	38 17-10-12			college 3mE, A&C								college 3mE, A&C			instructie aula					college 3mE, A&C	
4	39 24-9-12			college 3mE, A&C						practicum CT, 020	practicum CT, 020			practicum CT, 020	practicum CT, 020					college 3mE, A&C	
5	40 1-10-12			college 3mE, A&C									college 3mE, A&C		instructie aula						
6	41 8-10-12			college 3mE, A&C						practicum CT, 020	practicum CT, 020			practicum CT, 020	practicum CT, 020					college 3mE, A&C	
7	42 15-10-12			college 3mE, A&C		practicum meetshop	practicum meetshop	practicum meetshop	practicum meetshop					practicum meetshop	practicum meetshop	practicum meetshop	practicum meetshop			instructie aula	
wit	43 22-10-12																				
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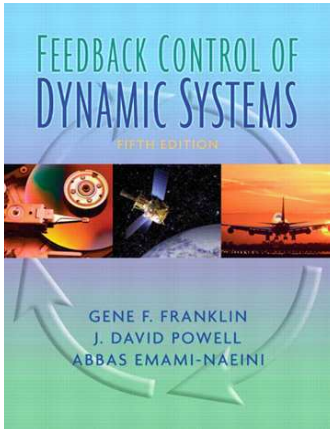
college Systeem- en Regeltechniek (wb2207) – 3mE zaal A en C
instructie Systeem- en Regeltechniek (wb2207) - Aula, zaal A
Matlab/Simulink practicum Systeem- en Regeltechniek (wb2207) in zaal 020 bij Civiele Techniek
DC motor practicum Systeem- en Regeltechniek (wb2207) in Meetshop 3mE
responsie-groep lunchbijeenkomst (12:30 - 13:30, bij DCSC)
tentamen Systeem- en Regeltechniek (wb2207) zaal nog niet bekend

Legend:

DE	Differential Equations
TF, SS	Transfer Function and State Space models
response	transient and steady-state analysis
type, PID	basics of feedback control
robotica	guest lecture on application to robotics
RL	The Root Locus Method
RL, FR	Root Locus (cont.) and Frequency Response

Course Material



Book:
Feedback Control of Dynamic Systems.
Franklin, Powell, and Emami-Naeini.
Fifth Edition, Prentice Hall.

Transparencies:
available through Blackboard

MATLAB/Simulink software
available through Blackboard

Recommended Prerequisites

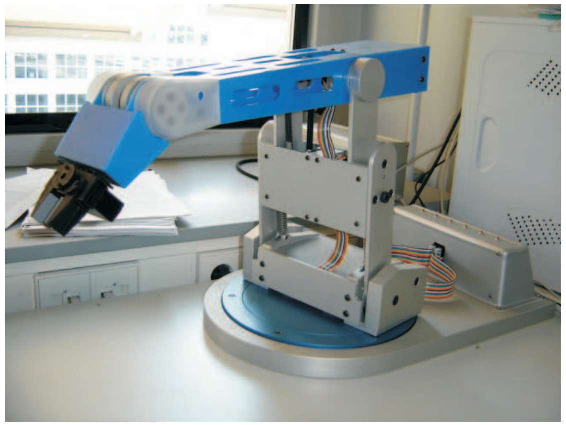
Regeltechniek I (WB 2104) or similar

Brush up (at least) the following concepts:

- Differential equations, Laplace transform.
- Transfer functions, block diagrams.
- Poles and zeros, stability, dynamic response.
- Basic properties of feedback.
- PID controller, system type.

Chapters 1 through 4 of the course book.

Link With the Mechatronics Project



Module P2-6: Controller Design for Ed-Ro.

Examination

- Closed-book exam – no books are allowed
- You may bring only
  - your own hand-written notes
- It is not allowed to bring any printouts or copies.
- Open questions (answers in dedicated boxes).

Note: not everything will be discussed in the lectures, some parts of the book are left for self-study.

See "Exam demands" in the download section of the course website.

Course Information on the Web

Blackboard (mirrored also at www.dcsc.tudelft.nl/~wb2207)

- Basic course information.
- Important dates, messages.
- Lecture sheets handouts.
- Sample exams (representative for difficulty degree).
- Matlab and Simulink examples.

Enroll! Check the page regularly!

Final Remarks

Where to Run Matlab:

- Your own computer (download from Blackboard).
- Computer rooms at the faculty, meetshop.

Response group: a group of 4–5 students meeting with the lecturer and assistants 3 times (on 18-9, 2-10 and 16-10) at the lunch time – to give feedback on the course, discuss possible improvements, etc. Interested students, please, come to the lecturer during the break.

Purpose of Control

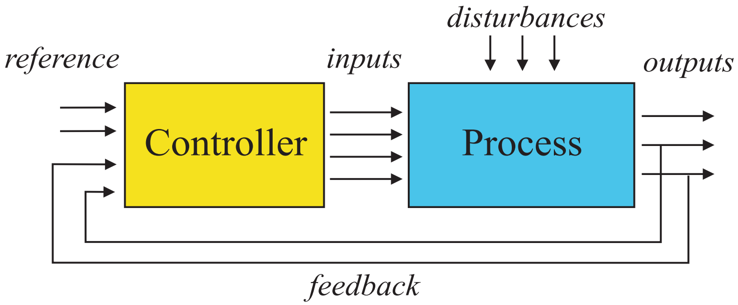
Design systems that

- maintain desired performance (or optimize performance),
- despite disturbances and
- changes in the controlled system or its environment

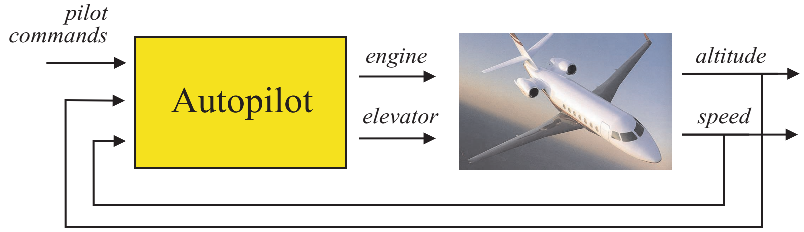
Basic principle:
– feed back a measured quantity
– influence system behavior through actuation

By means of control, we can modify system's behavior!
Main interest is in dynamic systems.

Elements of a Control System

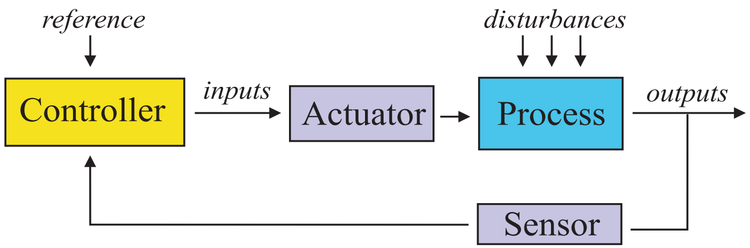


Example: Aircraft Autopilot



+ less workload for pilot
+ improved comfort, handling, safety
+ lower fuel consumption

Elements of the Feedback Loop



Make distinction between:

- Signals (lines) – physical quantities, information
- Systems (blocks) – process information

Applications of Control

Control systems are invisible, but omnipresent in a tremendous range of processes and products ("from steam engine to space station"):

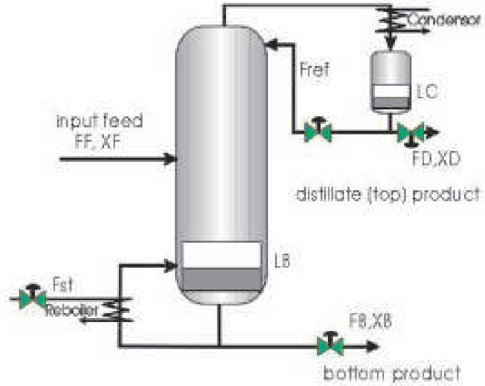
- electronics, home appliances, CD players
- industrial processes, manufacturing, robots
- computers, networks, communication systems
- transportation systems: cars, planes, spacecraft (our safety often depends on a controller!)

Feedback is also one of the important basic mechanisms in living organisms.

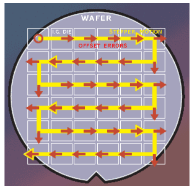
Robotics

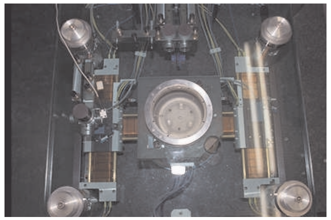


Process Industry



Manufacturing Systems

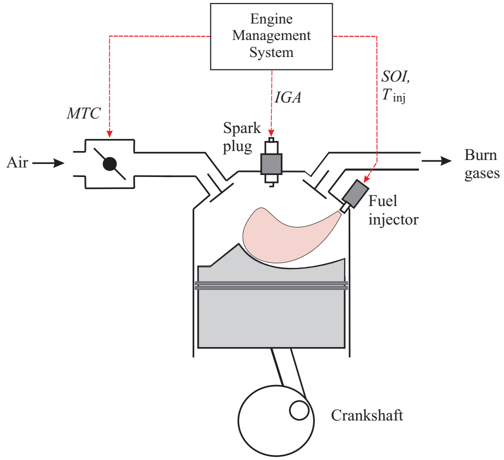



Traffic and Transport

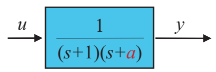
- Traffic flow control
- In-car driver assistance systems
- Autonomous vehicles

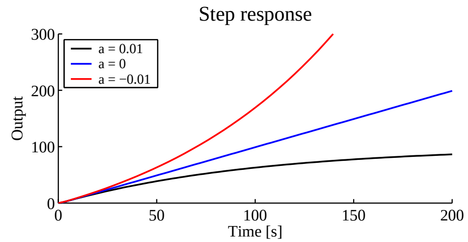
Car Engine Management Systems



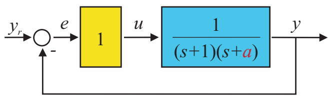
Feedback can make things better . . .

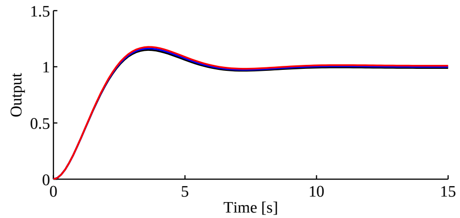
Open loop





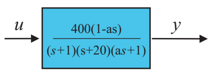
Closed loop

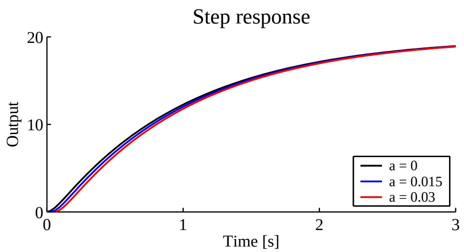




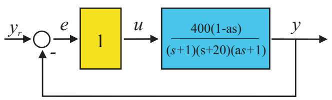
. . . but also worse!

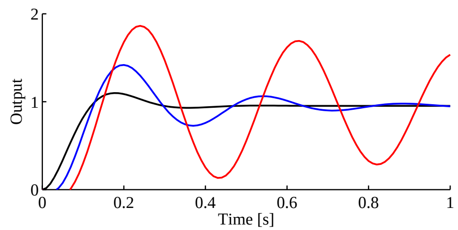
Open loop





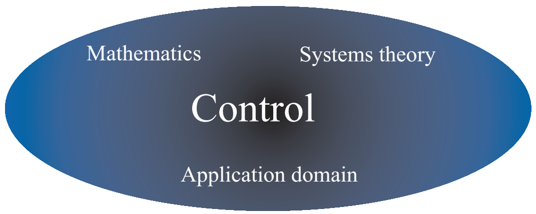
Closed loop



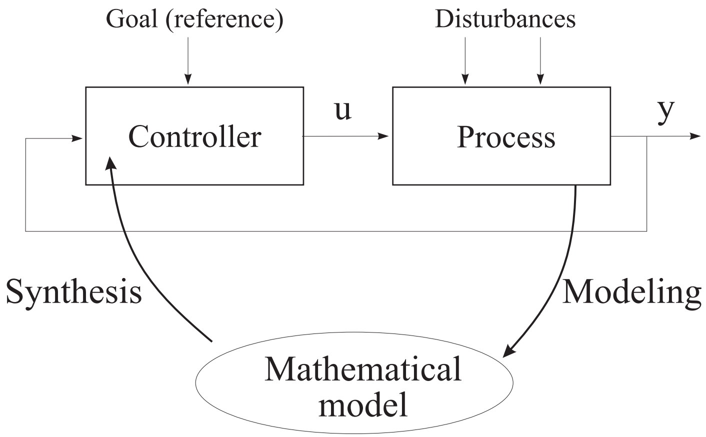


Key Ingredients of Control Engineering

- need to understand dynamics, analyze complex systems
- use provably correct techniques for the design
- based on mathematics and understanding of the physics
- "systems-oriented approach" is essential



Control Design Procedure



Main Steps

- Model the process (using insight in the physics, etc.)
- Analyze the model (stability, response, etc.)
- Design a controller, meeting given performance criteria
- Implement the controller (usually on a digital computer)

Dynamic Process Modeling

Three alternative frameworks:

1. Time domain (differential equations).
2. Laplace transform (transfer function, s-domain).
3. State-space representation (set of 1st-order DE).

2. and 3. are the two main options for control design, each with its own pro's and con's – this course will give you insight in both.

Linear Differential Equations

$$a_n y^{(n)}(t) + a_{n-1} y^{(n-1)}(t) + \cdots + a_o y(t) =$$

$$b_m u^{(m)}(t) + b_{m-1} u^{(m-1)}(t) + \cdots + b_o u(t)$$

Example 1: Motion Under Viscous Friction

$$ma(t) = F_n(t)$$

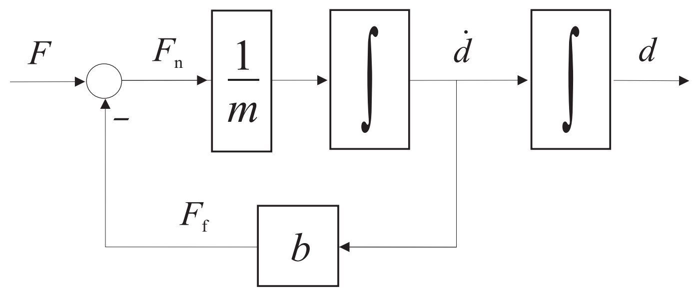
$$ma(t) = F(t) - F_f(t)$$

$$m\ddot{d}(t) = F(t) - b\dot{d}(t)$$

- Linear differential equation
- Not directly suitable for analysis or control design
- Can be used to simulate the process

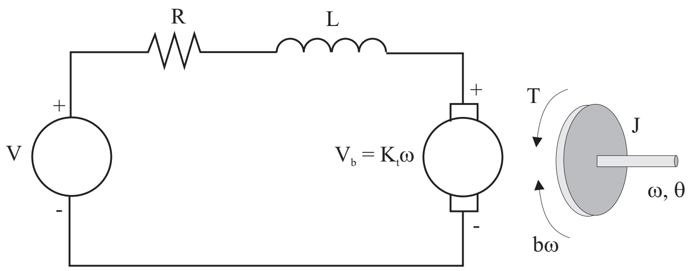
Solution either by hand (tedious in general) or by numerical integration (use, e.g., Matlab or Simulink).

Example 1 (cont'd): Block Diagram



Implementation and simulation in Simulink.

Example 2: DC Motor



$$L\frac{di}{dt} + Ri = V - V_b \quad , \quad V_b = K_t\omega = K_t\frac{d\theta}{dt}$$

$$J\frac{d^2\theta}{dt^2} + b\frac{d\theta}{dt} = T \quad , \quad T = K_t i$$

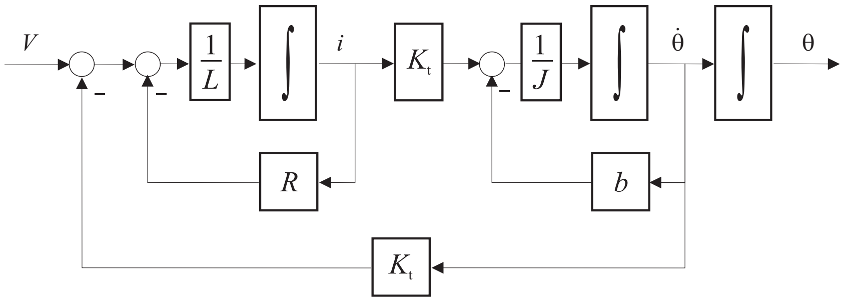
Example 2 (cont'd): Differential Equations

$$L\frac{di(t)}{dt} + Ri(t) = V(t) - K_t\frac{d\theta(t)}{dt}$$ electrical part

$$J\frac{d^2\theta(t)}{dt^2} + b\frac{d\theta(t)}{dt} = K_t i(t)$$ mechanical part

Inductance often negligible – we can assume $L = 0$.

Example 2 (cont'd): Block Diagram



Summary

- Control design: modeling, analysis, synthesis, implementation.
- Modeling dynamic systems: the basis are differential equations.
- Representation of a DE as a block diagram.
- Simulation in Simulink (or other software).