Aalto University

Process automation (this course)

Process Automation (CHEM-E7140), 2019-2020

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School of Chemical Engineering

Process automation

The course

Overview

We study the mathematical principles and basic computational tools of state-feedback and optimal control theory to manipulate the dynamic behaviour of process systems

- Understanding of feedback control
- Examples from process systems

- (Catchy image from the internet)

The approach is general with application domains in many (bio)-chemical technologies

People

Process control and automation at Aalto University

Francesco Corona

- ⇝ Professor of process control and automation
- Once and future chemical engineer
- Camouflaged as computer scientist

Jukka Kortela

- ⇝ Lecturer and doctor in process automation
- Invents and builds unbelievable stuff

Research developed on **computational** and **inferential thinking** of process systems

- ⇝ Automatic control and machine learning
- ⇝ Process optimisation and scheduling
- **Professor Iiro Harjunkoski**

Formal methods from statistics, control theory and optimisation, and applications

Overview

CHEM-E7140 is a set of **lectures (24h)** and **exercises (24h)** on process systems

- The prime objective is to provide a modern view on process control
- The boundary between lectures and exercises will be fuzzy

Examination (4h)

- OCT 25, 2019
- DEC 12, 2019
- FEB 20, 2020

To pass the course you need to pass the exam

- The examination pays **60%** of the final grade
- Classic pen-and-paper exam, Aalto-style

Assignments (~~3~~ 2)

- ~~SEPT 23, 2019~~
- OCT 08, 2019
- OCT 20, 2020

To pass the course you need to return them

- The assignments pay **40%** of the final grade
- We will work in randomly generated groups

Overview (cont.)

W01 (41)	**Course introduction and mathematical tools**			
11/09 (08-10)	L (KONE)	01a	Process automation (Intro, course + field)	FC/JK
12/09 (08-10)	E (A046)	02a	Matrix algebra and calculus (+ coding, 1)	FC/JK
13/09 (10-12)	L (U147)	03a	Dynamical systems as ODEs	FC/JK
W02 (42)	**Ordinary differential equations and state-space models**			
17/09 (08-10)	E (A046)	02b	Matrix algebra and calculus (+ coding, 2)	FC/JK
18/09 (08-10)	L (KONE)	03b	Dynamical systems as ODEs	FC/JK
19/09 (08-10)	E (A046)	03c	Dynamical systems as ODEs (+ coding, 1)	FC/JK
20/09 (10-12)	L (U147)	03d	Dynamical system as ODEs	FC/JK
W03 (43)	**Process dynamics using state-space models**			
~~23/09 (07:59)~~			~~Return assignment 01~~	
24/09 (08-10)	E (Y338)	03a	Dynamical system as ODEs (+ coding, 2)	FC/JK
25/09 (08-10)	L (KONE)	03a	Analysis of state-space models	FC/JK
26/09 (08-10)	E (Y338)	03b	Analysis of state-space models (+ coding)	FC/JK
27/09 (10-12)	L (U147)	03b	State feedback and controllability	FC/JK
W04 (44)	**Process control using state feedback**			
01/10 (12-14)	E (A046)	04a	Feedback control and controllability (+ coding)	FC/JK
02/10 (08-10)	L (KONE)	04a	Controllability and the linear quadratic regulator	FC/JK
03/10 (08-10)	E (A046)	04b	Linear quadratic regulator (+ coding, 1)	FC/JK
04/10 (10-12)	L (U147)	04b	The Cayley-Hamilton theorem	FC/JK
W05 (45)	**State estimation and feedback control**			
08/10 (07:59)			**Return assignment ~~02~~ 01**	
09/10 (08-10)	L (KONE)	05a	Observability and full state estimation	FC/JK
10/10 (08-10)	E (U046)		Linear quadratic regulator (+ coding, 2)	FC/JK
11/10 (10-12)	L (U147)	05b	State estimation and Kalman filtering	FC/JK
11/10 (16-18)	E (A046)	05a	Observability (+ coding)	FC/JK
W06 (46)	**State estimation and feedback control**			
15/10 (12-14)	E (A046)	06a	State estimation and Kalman filtering (+ coding)	FC/JK
16/10 (08-10)	L (KONE)	06a	Linear quadratic Gaussian regulator	FC/JK
17/10 (08-10)	E (A046)	06a	Linear quadratic Gaussian regulator (+ coding)	FC/JK
18/10 (10-12)	L (U147)	06b	Pre-examination review	FC/JK
20/10 (23:59)			**Return assignment ~~03~~ 02**	

Overview (cont.)

- ⇝ Process modelling and state-space representation
- ⇝ State-feedback and optimal control
- ⇝ Optimal state estimation

Outcome 1

- How to write and analyse a mathematical description of process system

⇝ The model will be expressed as a set of differential equations

Outcome 2

- How to design/synthetise controllers to manipulate the process system

⇝ The design will be based on optimal state-feedback control

Outcome 3

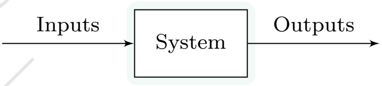
- How to design estimators to reconstruct the process state from data

⇝ The design will be based on optimal state feedback control

Trajectory

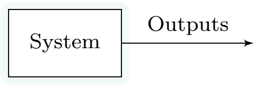
Input-output process modelling of process systems

- Controlled variables and disturbances
- Measurement variables, the data
- The system evolves in time



Ordinary differential equations and matrix algebra

- Force-free response (no inputs)
- Numerical integration
- Stability



Trajectory (cont.)

State-space process modelling

- Inputs u, outputs y and states x
- The dynamics of the states f
- From states to data g

System

$$u(t) \longrightarrow \boxed{\begin{aligned} \dot{x} &= f_t(x,u) \\ y &= g_t(x,u) \end{aligned}} \longrightarrow y(t)$$

Process dynamics (linear and time-invariant)

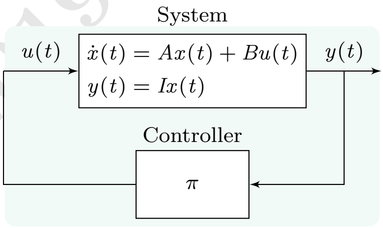
System

$$u(t) \longrightarrow \boxed{\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned}} \longrightarrow y(t)$$

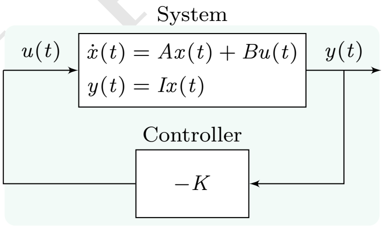
Trajectory (cont.)

From (linear) process dynamics to state-feedback control

- We can measure the states x
- We define control actions u
- The controlled system



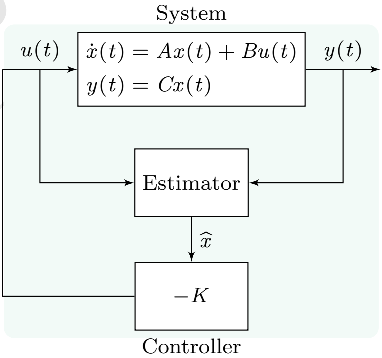
State-feedback optimal control (linear, quadratic)



Trajectory (cont.)

Optimal state-feedback estimation and control (linear, quadratic, Gaussian)

- We cannot measure the states x anymore
- We estimate them from measurements
- Then, we define control actions u



Trajectory (cont.)

Optimal state-feedback estimation and control (the general framework)