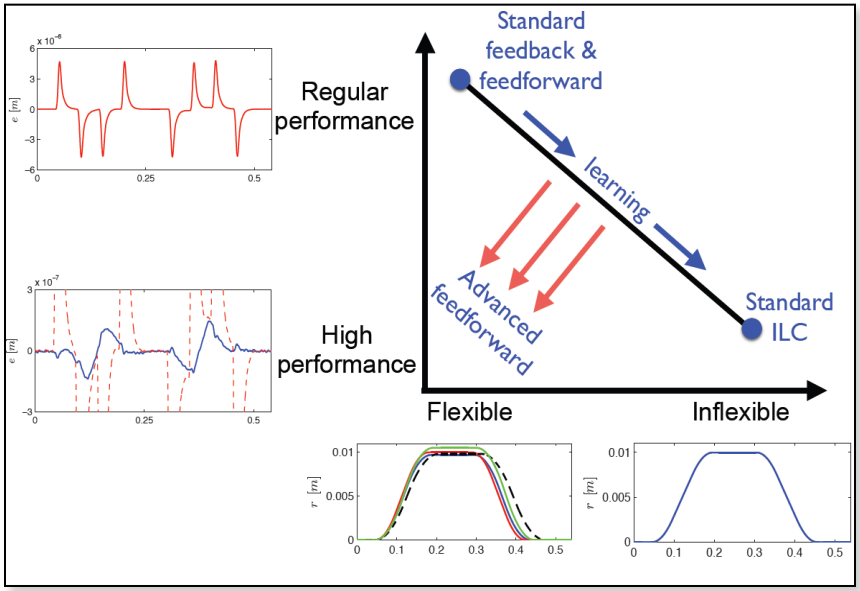
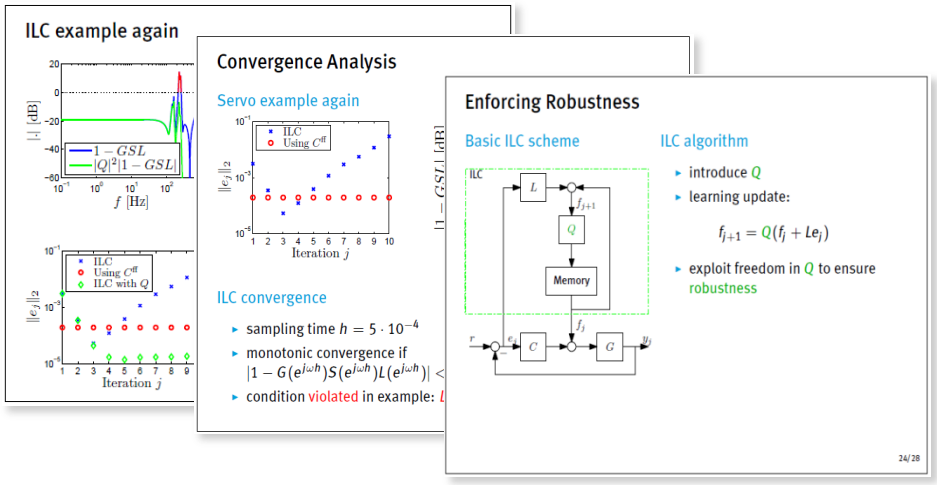
Advanced Feedforward & Learning Control



TOPICS

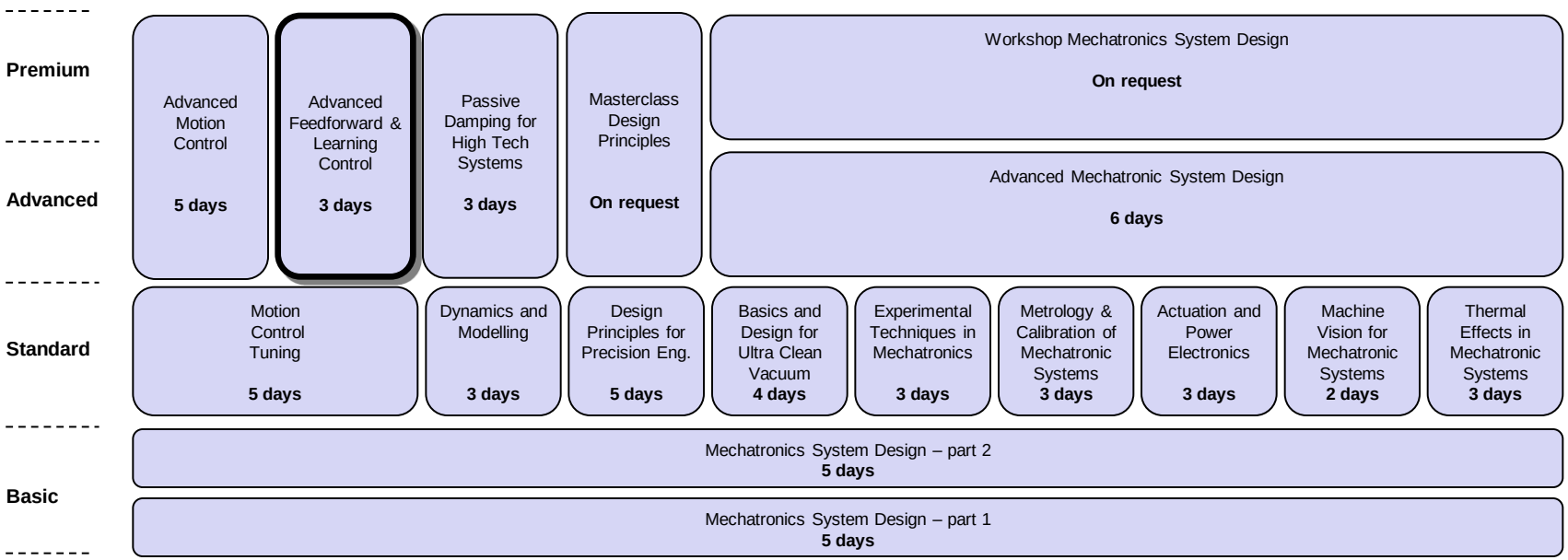
- Feed-forward design for high-precision motion systems: velocity, acceleration, jerk, snap feedforward
- Iterative learning control (ILC): basics, frequency domain approach, convergence/robustness analysis, design
- Lifted iterative learning control
- Automated FF tuning using identification-based approach
- Input shaping and rational feedforward
- Repetitive control
- Simulation and design using Matlab and SIMULINK
- Hands-on experience with real-time implementation on HP printer setup.



Contents

- Mechatronics Training Curriculum
- Details of Course *Advanced Feedforward & Learning Control*

Mechatronics Training Curriculum



Relevant partner trainings:
Applied Optics, Electronics for non-electrical engineers, System Architecture, Soft skills for technology professionals, …

www.mechatronics-academy.nl

Mechatronics Academy

- In the past, many trainings were developed within Philips to train own staff, but the training center CTT stopped.
- **Mechatronics Academy B.V.** has been setup to provide continuity of the existing trainings and develop new trainings in the field of precision mechatronics. It is founded and run by:
  - Prof. Maarten Steinbuch
  - Prof. Jan van Eijk
  - Dr. Adrian Rankers
- We cooperate in the **High Tech Institute** consortium that provides sales, marketing and back office functions.

Advanced Feedforward Control

Topics

- Overview application areas
- Feed-forward design for high-precision motion systems: velocity, acceleration, jerk, snap feedforward
- Iterative learning control: basic principles, frequency domain approach, convergence and robustness analysis, and design
- Lifted iterative learning control: basic principles, analysis, optimal design
- Basis functions in iterative learning control
- Automated feedforward tuning through identification-based approach
- Input shaping and rational feedforward
- Repetitive control: basic principles
- Simulation and design of systems using Matlab and SIMULINK
- Hands-on experience with real-time implementation on HP printer setup.

Course Directors / Trainers

Course Director(s)

- Dr.ir. Tom Oomen (TU/e)
- Dr.ir. Adrian Rankers (Mechatronics Academy)

Teachers

- TU/Eindhoven:
  - Prof.dr.ir. Maarten Steinbuch,
  - Dr. ir. Tom Oomen
  - Ir. Robin de Rozario
  - Ir. Lennart Blanken
- Invited experts from industry
  - Dr.ir. Joost Bolder (ASML)
  - Dr.ir. Sjirk Koekebakker (Océ)

Program

Day	Timing	Topic	Trainers
1	Morning	• Introduction & (Advanced) Feedforward • Frequency Domain ILC	Oomen Oomen
	Afternoon	• Frequency Domain ILC (continued) • Hands-on experiments	Oomen
2	Morning	• Repetitive Control • Hands-on experiments	Blanken
	Afternoon	• Lifted ILC • Hands-on experiments	Oomen
3	Morning	• Research overview • Automated Feedforward Tuning • Hands-on experiments	Steinbuch Bolder
	Afternoon	• Model-free ILC using FRFs • Hands-on experiments • Invited industry research presentation	De Rozario Koekebakker

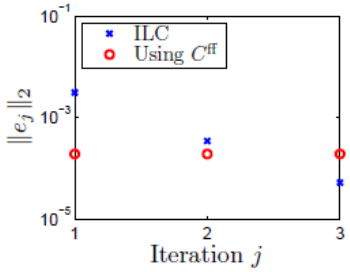
Day 1 (morning):

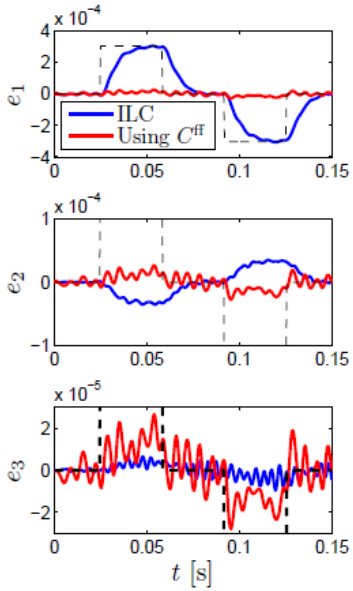
- Introduction / Goals
- Advanced Feedforward
- Frequency Domain ILC

ILC example

ILC iterations

1. Initial error
2. After one iteration:
   - error reduced
3. After two iterations:
   - error further reduced
   - outperforms C^{ff}!
   - more iterations?





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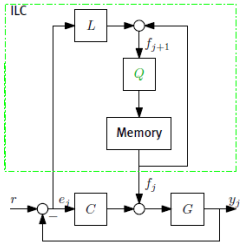
Enforcing Robustness

Basic ILC scheme



ILC algorithm

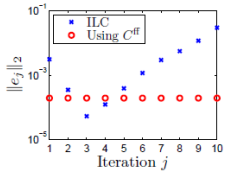
- introduce Q
- learning update:

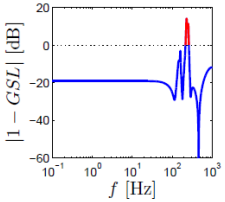
$$f_{j+1} = Q(f_j + Le_j)$$

- exploit freedom in Q to ensure robustness

Convergence Analysis

Servo example again

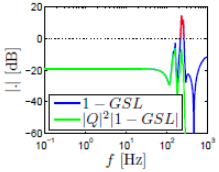


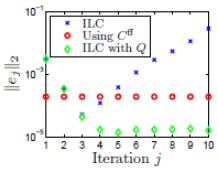


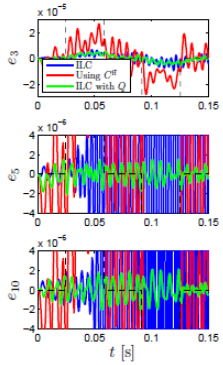
ILC converge

- sampling
- monoton
  $|1 - G(e$
- condition

ILC example again







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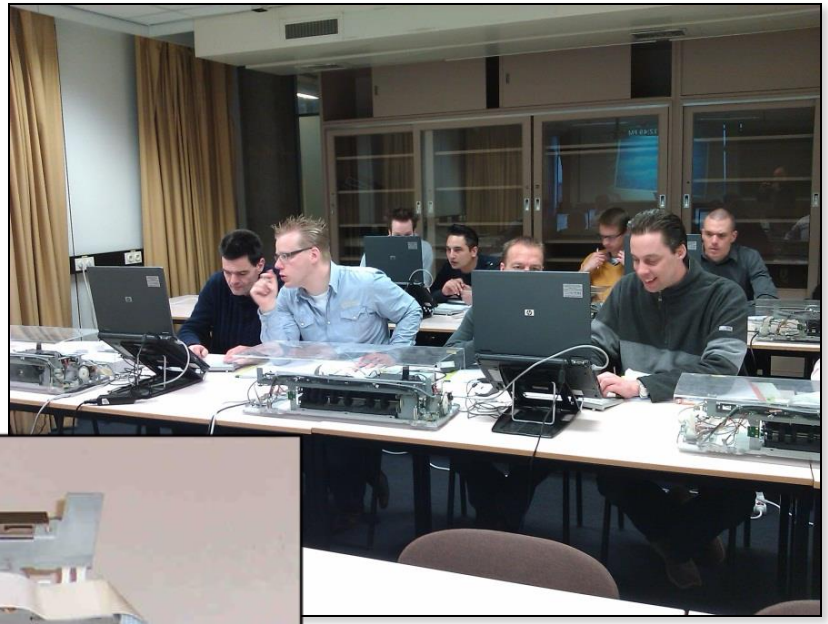
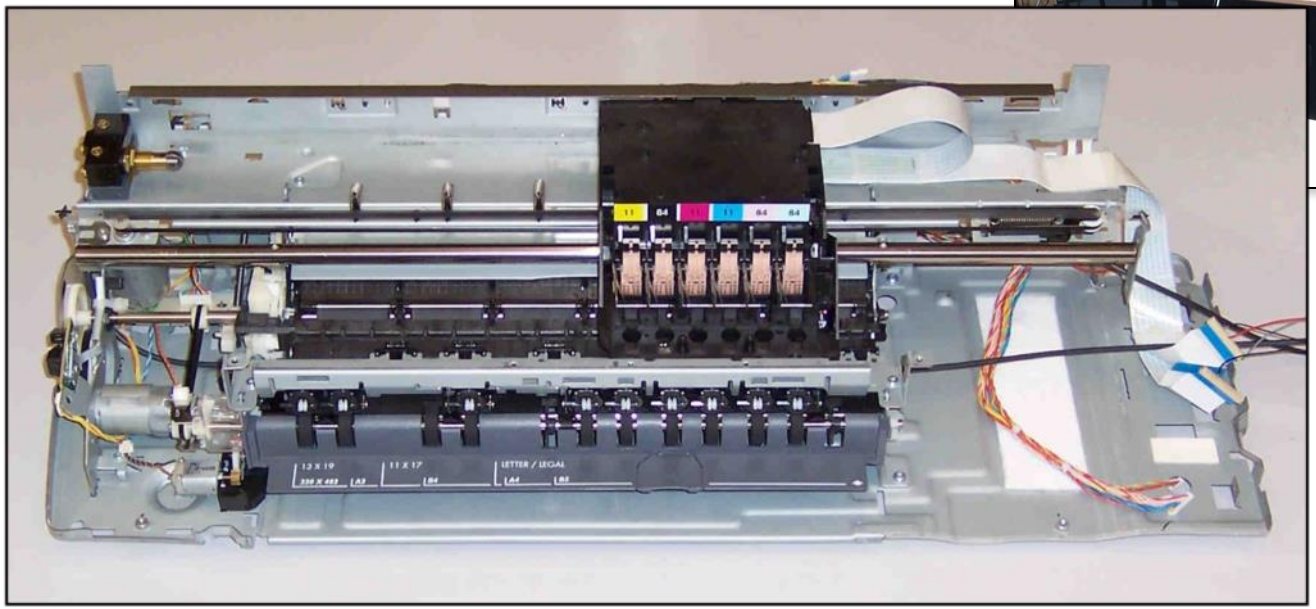
Day 1 (afternoon):

- Frequency Domain ILC
- Hands-on experiments



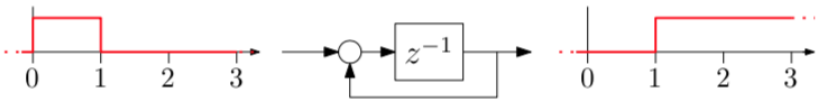


Day 2 (morning):

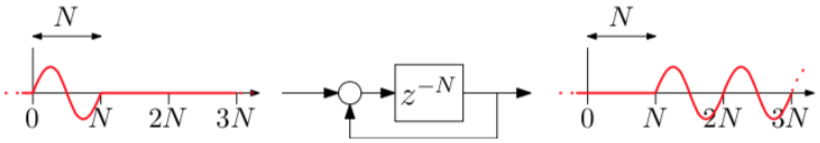
- Repetitive Control
- Experiments

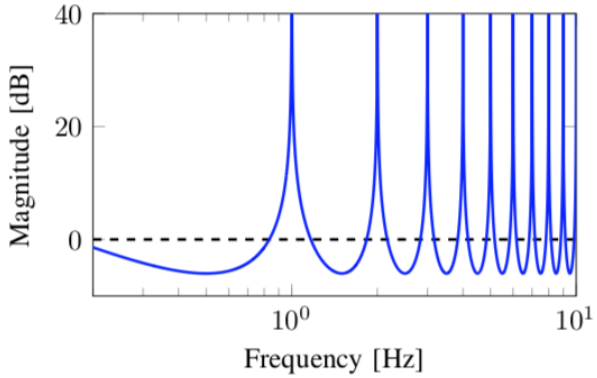
Periodic signal models

- Step disturbance: integrator



- General N-periodic disturbance: memory loop (N integrators)



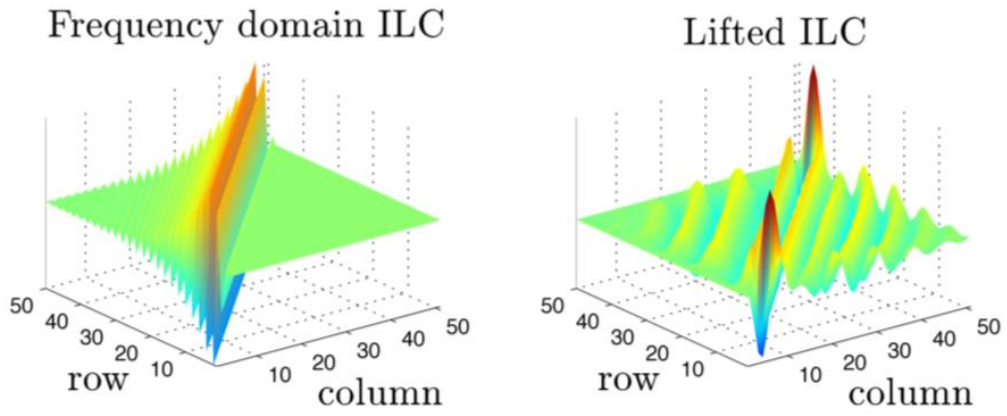


Day 2 (afternoon):

- Lifted ILC
- Experiments

Example revisited: frequency domain ILC

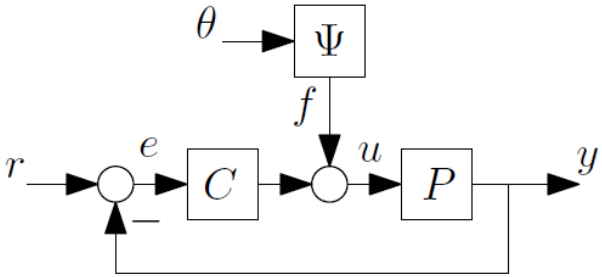
Toeplitz matrix of L:

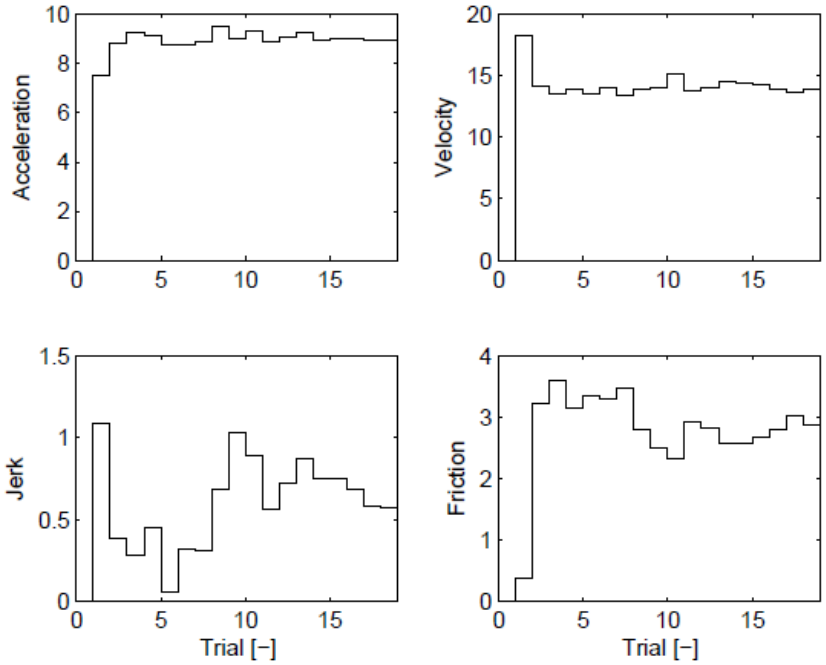


- Important difference: edge effects in red and blue
- Note: frequency domain ILC uses ZPETC

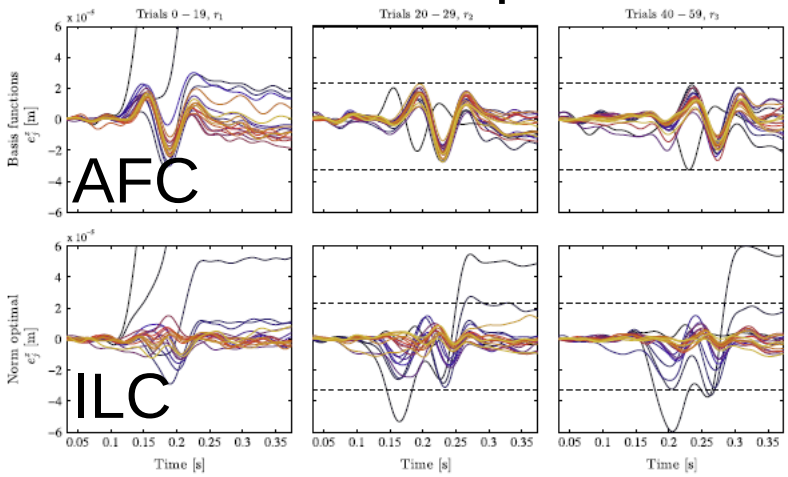
Day 3 (morning):

- Research outlook
- Automated Feedforward tuning
- Experiments



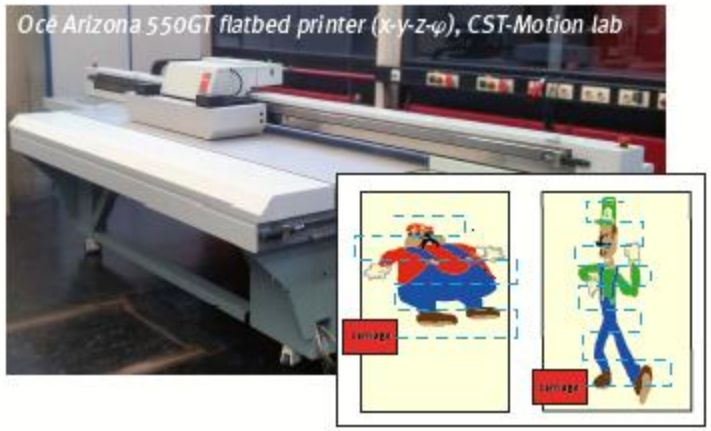


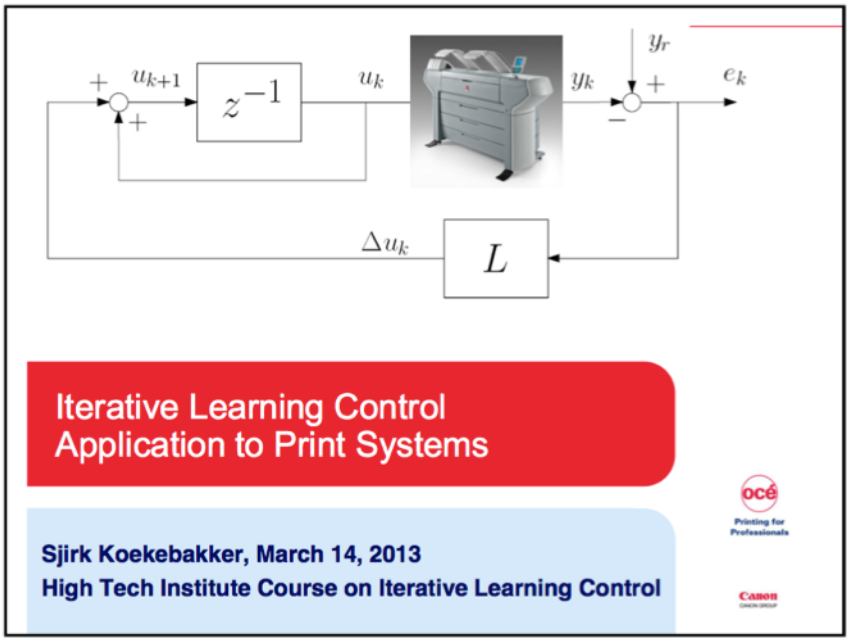
Different setpoints

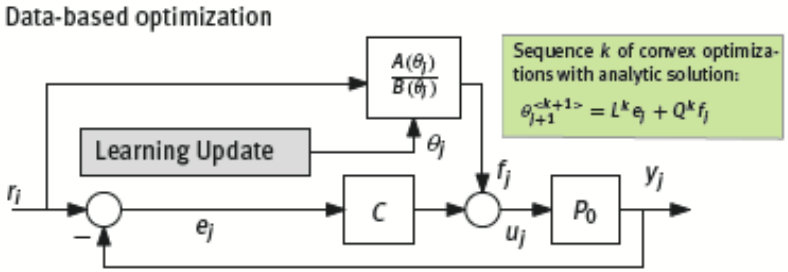


Day 3 (afternoon): Applications/Research

- Model free ILC using FRFs
- Research outlook: printer applications, basis functions, and extensions







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