Advanced Feedforward 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 Control
Mechatronics Training Curriculum

Premium

Advanced Motion Control
Advanced Feedforward Control
Passive Damping for High Tech Systems
Masterclass Design Principles

Workshop Mechatronics System Design
On request

Advanced

Mechatronics System Design – part 2
5 days

Advanced Mechatronic System Design
6 days

Standard

Motion Control Tuning
Dynamics and Modelling
Design Principles for Precision Eng.
Basics & Design for Ultra Clean Vacuum
Design for Additive Manufacturing
Experimental Techniques in Mechatronics
Metrology & Calibration of Mechatronic Systems
Actuation and Power Electronics
Machine Vision for Mechatronic Systems
Thermal Effects in Mechatronic Systems

Mechatronics System Design – part 1
5 days

Basic

Mechatronics System Design – part 2
5 days

Summer School Opto Mechatronics
On request

Start

www.mechatronics-academy.nl

Relevant partner trainings:
Applied Optics, Electronics for non-electrical engineers, System Architecture, Soft skills for technology professionals, …
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)**
- Prof.dr.ir. Maarten Steinbuch
- Dr.ir. Tom Oomen

**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

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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 $C^\text{eff}$
   - more iterations?

Convergence Analysis

ILC example again

Enforcing Robustness

Basic ILC scheme

ILC algorithm
- introduce $Q$
- learning update:
  $f_{j+1} = f_j + Q e_j$
- exploit freedom in $Q$ to ensure robustness
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

![Graphs showing different setpoints for AFC and ILC](image-url)
Day 3 (afternoon): Applications/Research

- Model free ILC using FRFs
- Research outlook: printer applications, basis functions, and extensions
Sign-up for this training

Via the website of our partner
High Tech Institute