Control Systems Technology

DSD info 2022

Maarten Steinbuch  Maurice Heemels
Control Systems Technology

Disciplines

• systems and control theory
• mechanical design / mechatronics
• optimization
• systems engineering

Our research focuses on understanding the fundamental system properties that determine the performance of engineering systems, and exploiting this knowledge for the design of the high-tech systems of the future in a broad range of applications.

KPIs:
50 PhDs
85 MSc/year
Application Domains

- Automated Driving & Powertrains
- Energy Systems
- Advanced Motion Systems & Mechatronics
- Medical Systems
- Robotics & Drones
- Infra: Waterlocks, Bridges, Tunnels
CST People and subprogrammes

Steinbuch, Oomen, Heertjes, Witvoet, Tiels, Vermeulen, Blancken, Vrancken, Sperling, Kappelhof, Cacace

Cyber-Physical Systems of Systems

Robotic Systems for Care, Cure & Agro-food

Automotive Powertrains & Smart Mobility

Process Control of Energy Systems

Model-based Control, Learning Control, Identification and Design of Motion Systems

Steinbuch, Oomen, Heertjes, Witvoet, Tiels, Vermeulen, Blancken, Vrancken, Sperling, Kappelhof, Cacace

Heemels, Antunes, Reniers, vd Mortel, Etman, v Beek, Chong, Fokkink, van Eekelen, Wilschut

vd Molengraft, Bruyninckx, Kappers, Elfring, Torta, Lopez Martinez

Hofman, Salazar, Silvas, Willems, v Keulen, Huisman, Katriniok

De Baar, Krishnamoorthy (from 1st of September)
• $P$ is a complex physical system
• $C$ is a (distributed, adaptable, reconfigurable) control system
Long stroke actuator unit for an EUV reticle stage

Lightweight design (20% mass reduction) with reduced force transmissibility (~50 DB) – MSc Pim Duijsens (2016)

Design of EUV reticle stage with new long stroke actuator unit

Ref: Duijsens, P.J.H., Design of a long stroke actuator unit for the EUV reticle stage, Master’s thesis report, Eindhoven University of Technology, September 17, 2016

Disturbance force transmissibility in vertical direction, baseline vs. new design

Design of the long stroke actuator unit
EUV mirror actuator with high steepness to mass ratio

Compact light-weight alternative based on non-contact reluctance actuators with significantly improved dynamics – MSc Rene v/d Meulen (2019)

Ref: Meulen, R.J.J. van der, Design of an EUV mirror actuator system with high steepness and low mirror deformation, Master’s thesis report, Eindhoven University of Technology, August 13, 2019 (patent pending)
Control for virtual stiffness and damping

Identify models for control!

\[ d^Y(P_s, P_0, s) = \left\| T(P_0, s, C_s^{exp}) - T(P_s, C_s^{exp}) \right\|_\infty \]

Advanced Motion Control for Precision Mechatronics: Control, Identification, and Learning of Complex Systems, Tom Oomen, IEEJ Journal of Industry Applications, 7(2), 1-14, 2018

Exploiting additional actuators and sensors for nano-positioning robust motion control

Robbert van Herpen a*, Tom Oomen, Maarten Steinbuch a

Create virtual stiffness through control: Compensate torsion: performance +100%
Corresponding youtube video: https://youtu.be/kj_ouy1Fnko
Digital Twinning and Reinforcement Learning

Other (ASML):
• Predictive maintenance for mechatronic systems
• Thermal-mechanical systems -- optimisation-based control (MPC)
Hyperthermia therapy in cancer treatment

- Tumor ≈ 42 °C
- Sensitizes tumor
- Enhances chemo- and radiotherapeutic effects
- Non-toxic
- No added side effects
MR-based hyperthermia

MR-RF: Magnetic-Resonance-guided Radio Frequencies (RF)

MR-HIFU: Magnetic-Resonance-guided High-Intensity Focused Ultrasound
How to optimize tumor temperature by controlling HIFU/RF based on MR thermometry?
• Hybrid Control of Motion Systems

Linear motion systems (wafer scanners, pick-and-place machines, electron microscopes) are controlled by linear strategies. How to achieve improved performance at lower cost using innovative hybrid control strategies? – beating Bode’s waterbed effect

![Wafer Scanners](Image)

![Pick and place machines](Image)

![Electron microscopes](Image)
Novel mechatronic concepts for X-ray imaging systems

Significantly improved positioning performance at reduced clinical obstruction to medical treatment – PhD Jeffrey van Pinxteren (2016-now)

Ref: Pinxteren, J.A.W. van, Vermeulen, J.P.M.B. Loon, R. van, (R)evolutionairy improvements in the design of interventional X-ray imaging systems, Proc. of the 19th euspen international conference, Bilbao, Spain, June 3-7, 2019

(patent applied 2018PF00583, 2018PF00737)
Eye surgery robots
Home robotics (robotics for care)

BOBBIE

A robot that cares

RoboEarth
TechUnited: Soccer robots and beyond....
Five times and reigning champion of the world ...
Automated driving
(world modelling, AI, sensor fusion, MPC)

Mobile and cooperative robotics
Networked control systems (CPSoS)

Mathematical tools: Hybrid Systems
From 2D to 3D: soccer robots to drones...all cyber-physical systems of systems...
Vision of farming in the future: Multi-agent systems
Powertrain system design: electrified vehicles – an integrated approach

Component specification
Storage (kWh), conversion (kW) and transmission technology (%)

Control design
Low/high level

Validation and verification
System performances

...cars, ships, machinery equipment, trucks, buses, ...

Component specification
Storage (kWh), conversion (kW) and transmission technology (%)

Control design
Low/high level

Validation and verification
System performances

...new system engineering methods & tools...

CVT design for Electric Vehicle: battery, E-drive, CVT

Compact motor design

C. Wei, PhD (i.c.w. Bosch)

Movie CVT4EV

K. Van Berkel, PhD

N. Dac Viet, PhD

V. Van Reeven, PhD

...low cost (€), energy (kWh/km), CO₂ (g)...

Theo Hofman

Mauro Salazar
(Hybrid) Electric Powertrain Design and Control for Racing

Leverage theoretical optimal control methods and optimization algorithms for real-world racing applications.
Multi-scale Design and Operation of Sustainable Mobility Systems

Artificial currencies for urgency-aware and human-centered system-optimal routing

Salazar, Paccagnan, Agazzi, Heemels, *Urgency-aware Optimal Routing in Repeated Games through Artificial Currencies*, EJC, 2021

Mauro Salazar
Maurice Heemels
Theo Hofman

Joint Design and Operation of Electric (Intermodal) Autonomous Mobility-on-Demand

Fabio Paparella, PhD Student
(NWO) NEON project: Electric Mobility concepts with Lightyear and TNO

Future: clean, autonomous, shared mobility concepts

Need for new automated CAE design tools...
Need for a larger variety of vehicles...

Enablers...

Research

PhD3
Top down
Vehicle architecture optimization

PhD4
Bottom up
Vehicle component optimization

PhD1
Vehicle fleet optimization

PhD2
Vehicle product optimization

Knowledge

Models

Automation

Optimization

Powertrains

Vehicle types

“...making complex engineering products affordable in a short time...”

CST team with

Theo Hofman
Mauro Salazar
Pascal Etman
Energy Systems

- Plasma control
  (nuclear fusion & CO2 dissociation)
- Solar fuels
- Energy transition/charging
  infrastructures / electrification
  (ZenMO)

Example of a tokamak
## CST Master Courses

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<thead>
<tr>
<th>Course</th>
<th>Code</th>
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<tbody>
<tr>
<td>Control engineering</td>
<td>4CM00</td>
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<tr>
<td>System theory for control</td>
<td>4CM10</td>
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<tr>
<td>Engineering Optimization</td>
<td>4DM20</td>
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<tr>
<td>Hybrid systems and control</td>
<td>4CM20</td>
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<tr>
<td>Supervisory control</td>
<td>4CM30</td>
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<tr>
<td>Advanced motion control</td>
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<tr>
<td>Mobile robot control</td>
<td>4SC020</td>
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<tr>
<td>Optimal control and reinforcement learning</td>
<td>4SC000</td>
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<tr>
<td>Haptics – perception and technology</td>
<td>4SC040</td>
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<tr>
<td>Physical and data-driven modelling</td>
<td>4CM40</td>
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<tr>
<td>Applications of Design principles</td>
<td>4CM50</td>
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<tr>
<td>Advanced full-electric &amp; hybrid powertrain design</td>
<td>4AT030</td>
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<tr>
<td>Advanced control for future HD powertrains</td>
<td>4AT070</td>
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<tr>
<td>Control and operation of tokamaks</td>
<td>4SC010</td>
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<tr>
<td>Control of magnetic instabilities in fusion plasmas</td>
<td>4SC030</td>
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<tr>
<td>Integrated system design</td>
<td>4CM70</td>
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<tr>
<td>Learning Control</td>
<td>4SC070</td>
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<tr>
<td>Extremum seeking control for data-based performance optimization</td>
<td>4CM80</td>
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MSc degrees:

1. Master on Mechanical Engineering (ME)
2. Master on Systems & Control (S&C)
3. Master on Automotive Technology (AT)
4. Master on Artificial Intelligence & Engineering Systems (AI&ES)
5. Master on Science and Technology of Nuclear Fusion (NF)

Further practicalities:

• Info meetings @ start in CST
• Mentoring program
• Projects: Guidance by project coaches, regular meetings (permanent) staff employee
Summarizing

CST group unites
• Science and fundamental (control) theory
• Applied research & design
• Society / Spin-offs / Impact
Combine Highest quality standards & Fun
Links CST

https://www.tue.nl/en/research/research-groups/control-systems-technology/
https://www.tue.nl/cst (also works and shorter)

Movie iterative learning control:

https://www.youtube.com/watch?v=kj_ouy1Fnko&feature=youtu.be
Program

10.00 – 10.20 General introduction division Dynamical Systems Design (DSD)

10.20 – 10.40 Dynamics and Control (D&C) Prof.dr.ir. Nathan van de Wouw

10.40 – 11.00 Control Systems Technology (CST) Prof.dr.ir. Maurice Heemels

11:00 – 12:30 lab visits DSD
Thank you for your attention