Introduction to AWESCO Winter School on Numerical Optimal Control with Differential Algebraic Equations (NOC-DAE)

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Systems Control and Optimization Laboratory
Faculty of Engineering, University of Freiburg

Freiburg, August 4, 2014

Overview

- The University of Freiburg and AWESCO
- Optimal Control Applications and Software
- Overview of the Course
- Introduction of Teachers

History of the Team

2013 -
University of Freiburg

- founded in 1457
- 25 000 students (52% female, 14% international)
- all faculties (humanities, sciences, medicine, *engineering*)

Albert-Ludwigs University of Freiburg

University of Freiburg (since 1457)

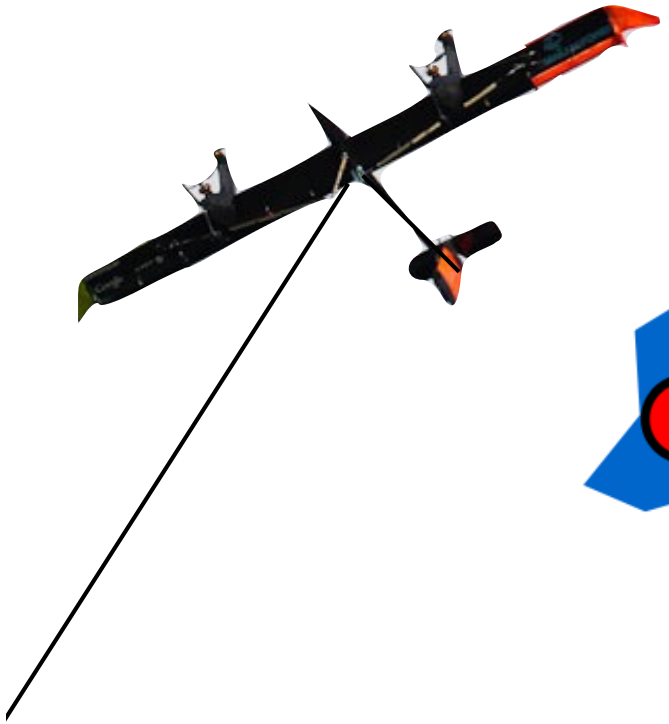
Faculty of Engineering (since 1995, 45 prof. 1700 stud.)

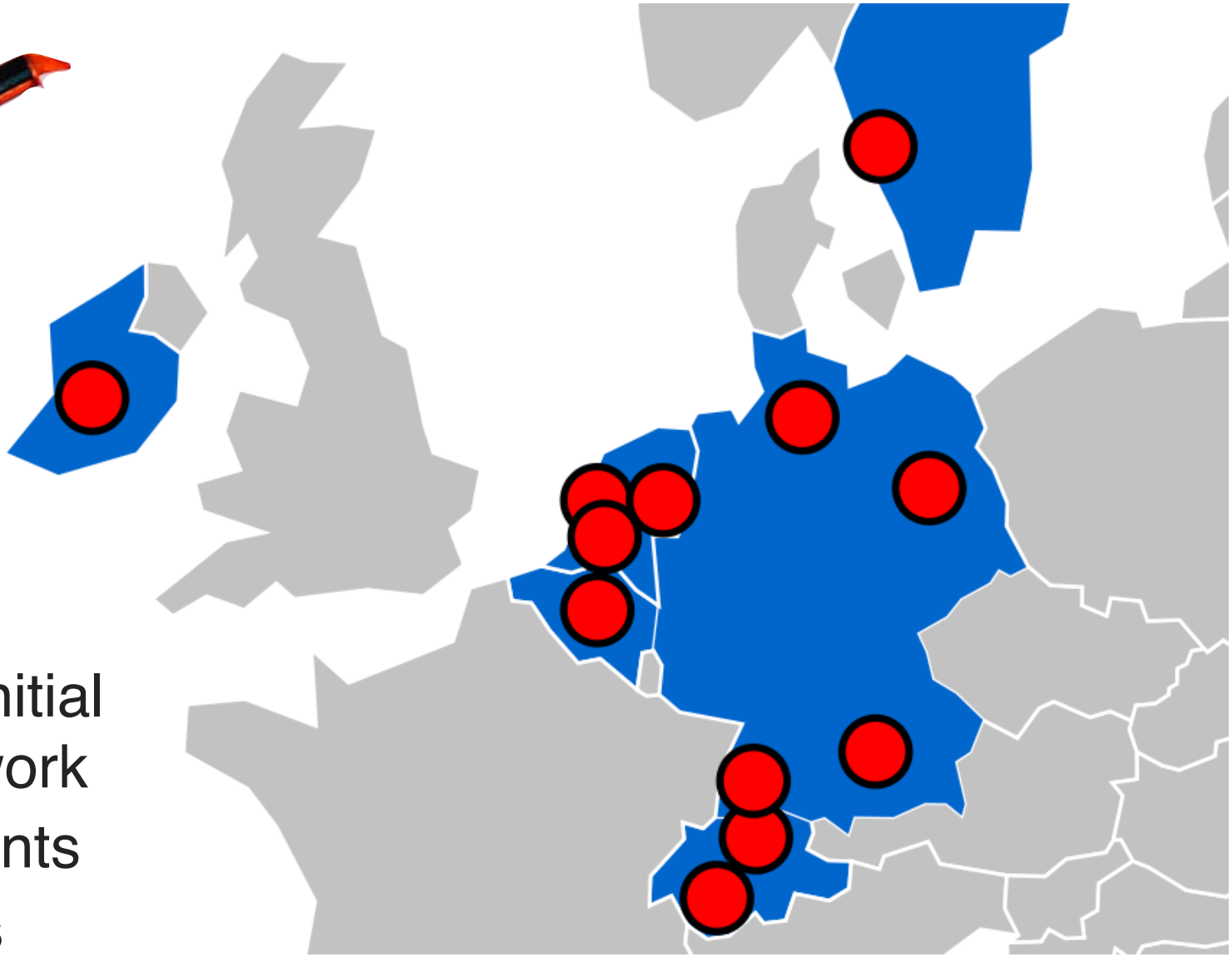
- Computer Science
- Microsystems Engineering
  - Systems Control and Optimization Laboratory
- Sustainable Systems Engineering


Systems Control and
Optimization Laboratory
syscop.de

The Sponsor: EU Project AWESCO

Airborne **W**ind **E**nergy **S**ystem Modelling, **C**ontrol and **O**ptimisation





- Marie Curie Initial Training Network
- 14 PhD students
- 12 institutions

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Time-Optimal Point-To-Point Motions [PhD Vandenbrouck 2012]

Fast oscillating systems (cranes, plotters, wafer steppers, …)

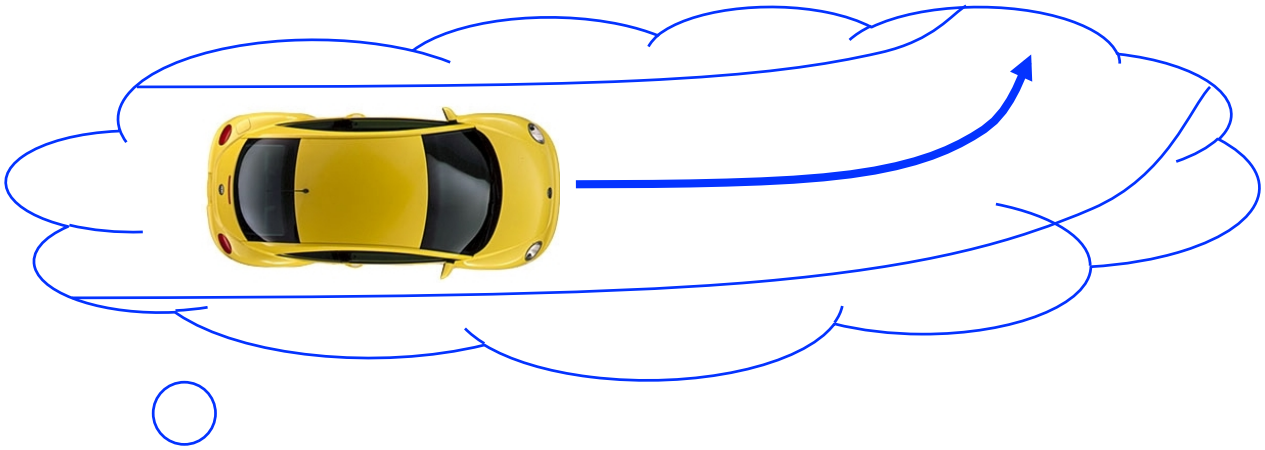
Control aims:

- reach end point as fast as possible
- do not violate constraints
- no residual vibrations

Idea: formulate as embedded optimization problem
in form of Model Predictive Control (MPC)

Model Predictive Control (MPC)

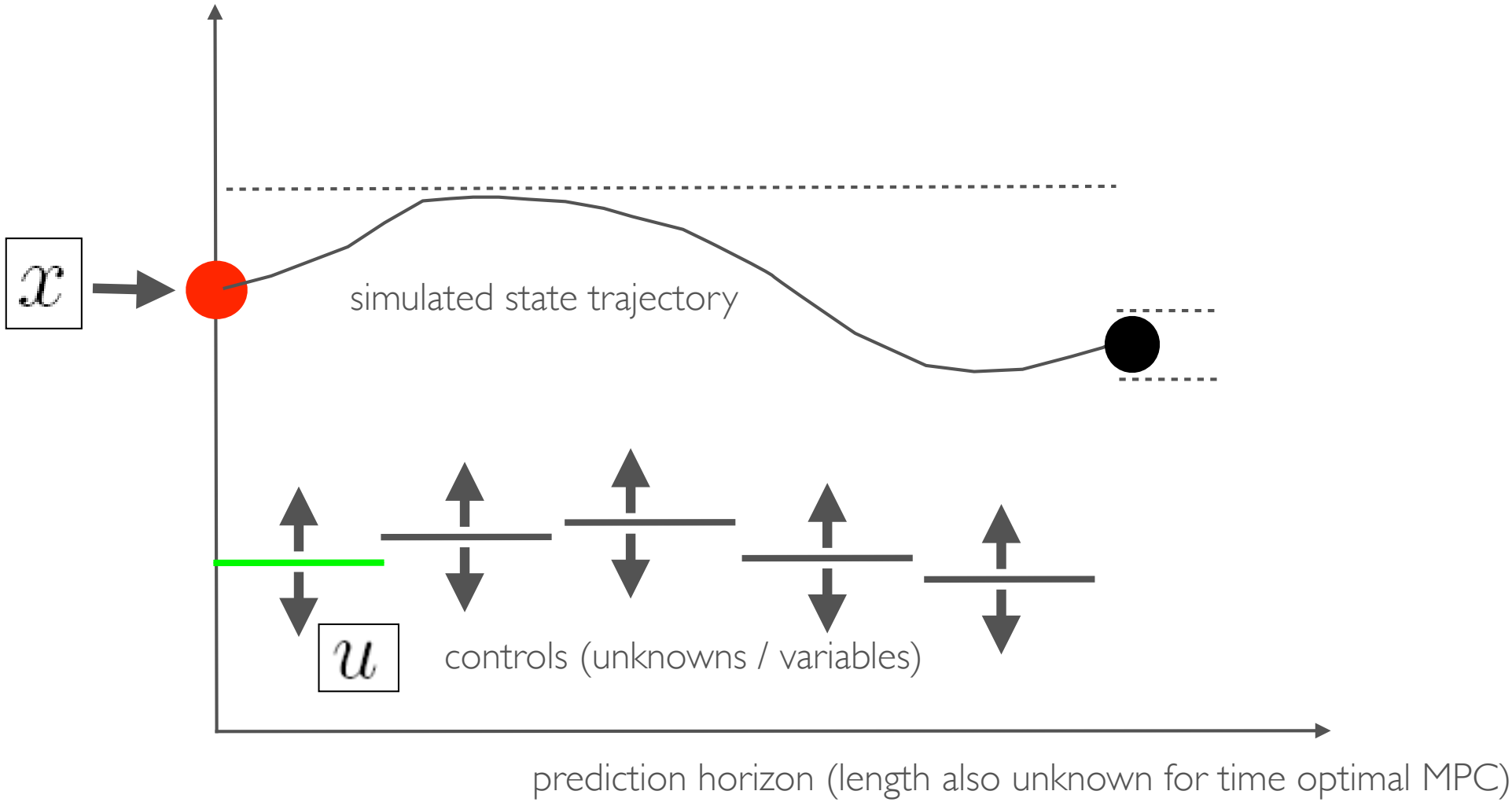
Always look a bit into the future



Example: driver predicts and optimizes, and therefore slows down before a curve

Optimal Control Problem in MPC

For given system state $\boldsymbol{x}$, which controls $\boldsymbol{u}$ lead to the best objective value without violation of constraints ?



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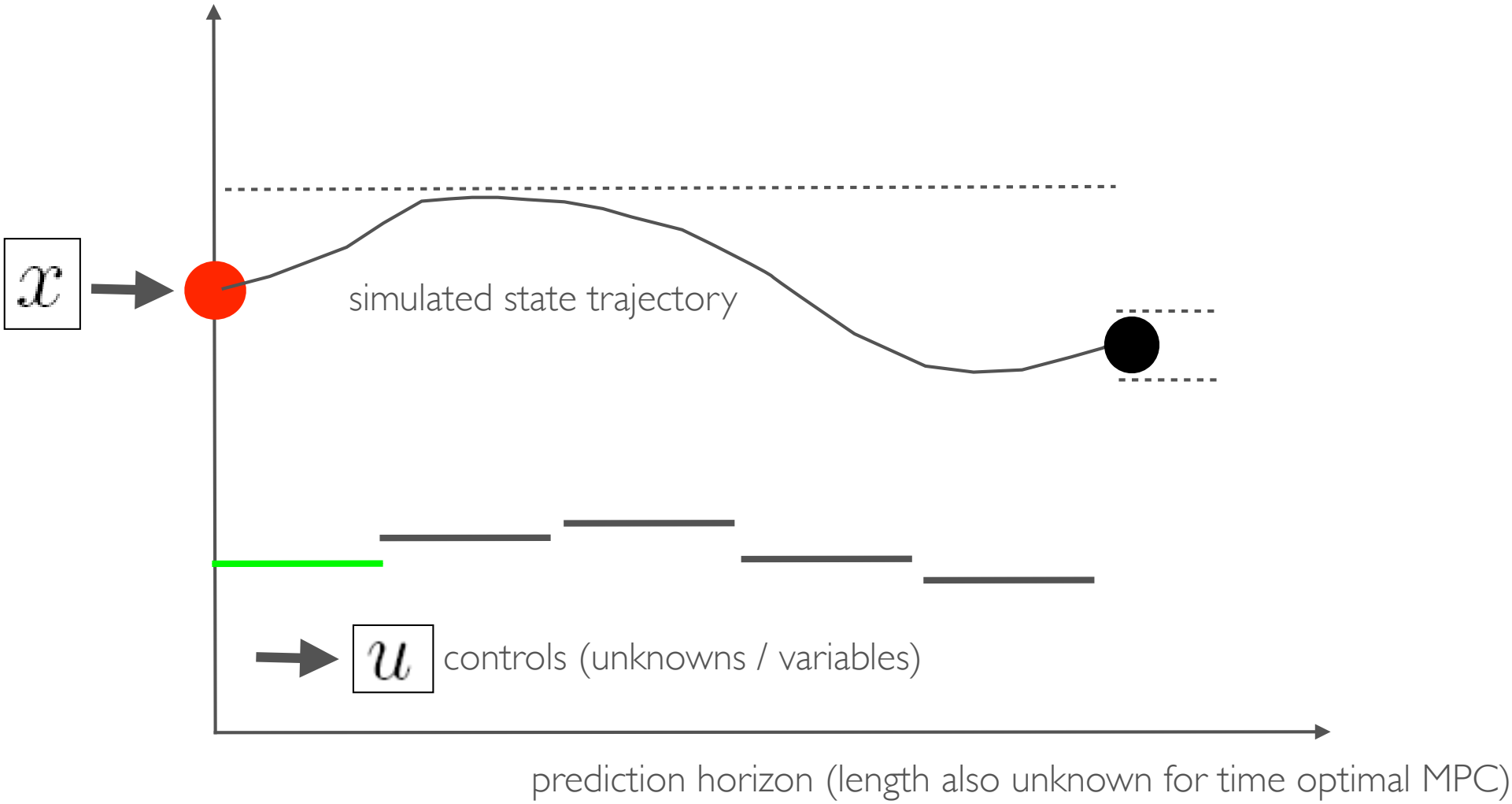


Time Optimal MPC of a Crane

SENSORS

- line angle
- cart position

MPC

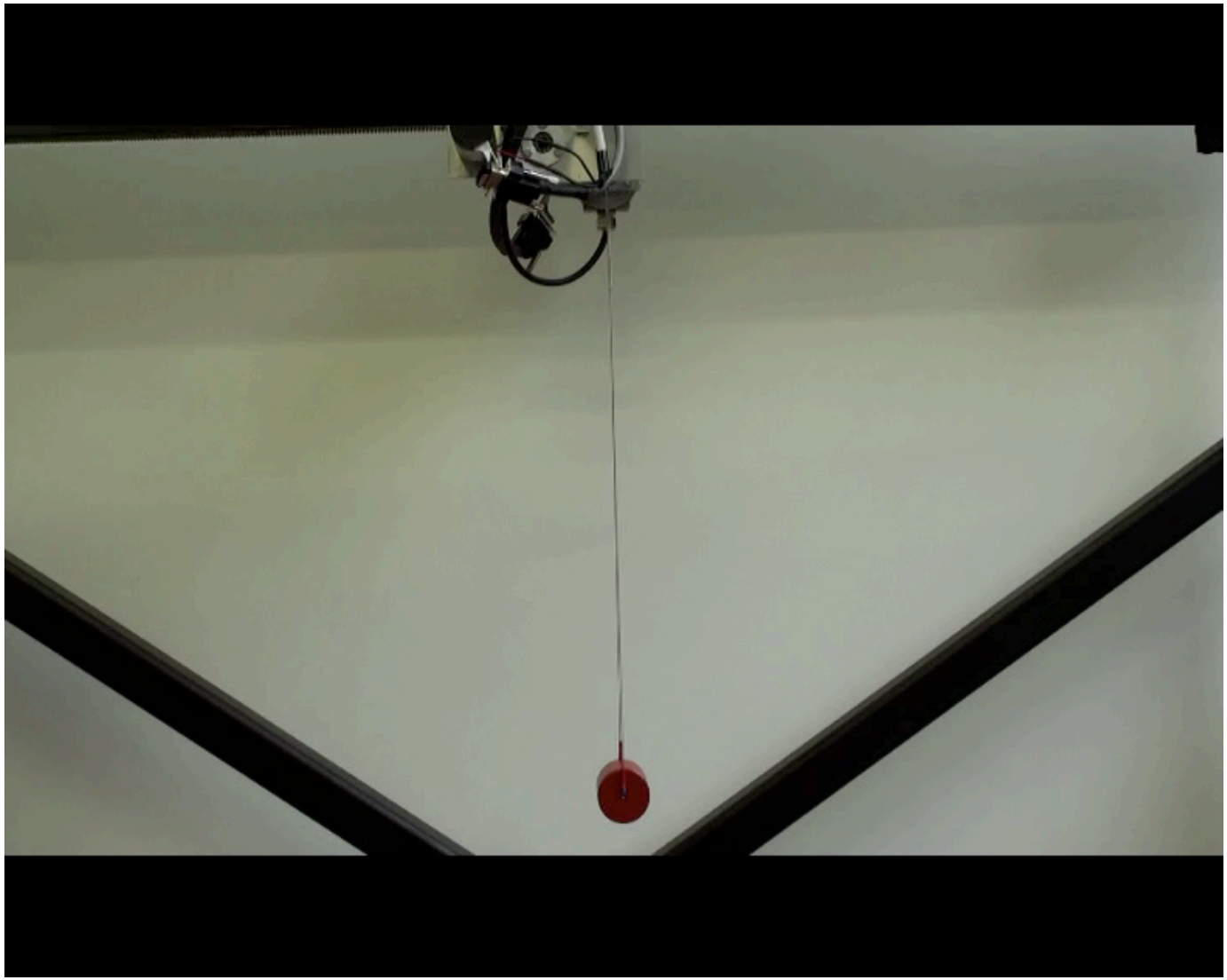
ACTUATOR

- cart motor

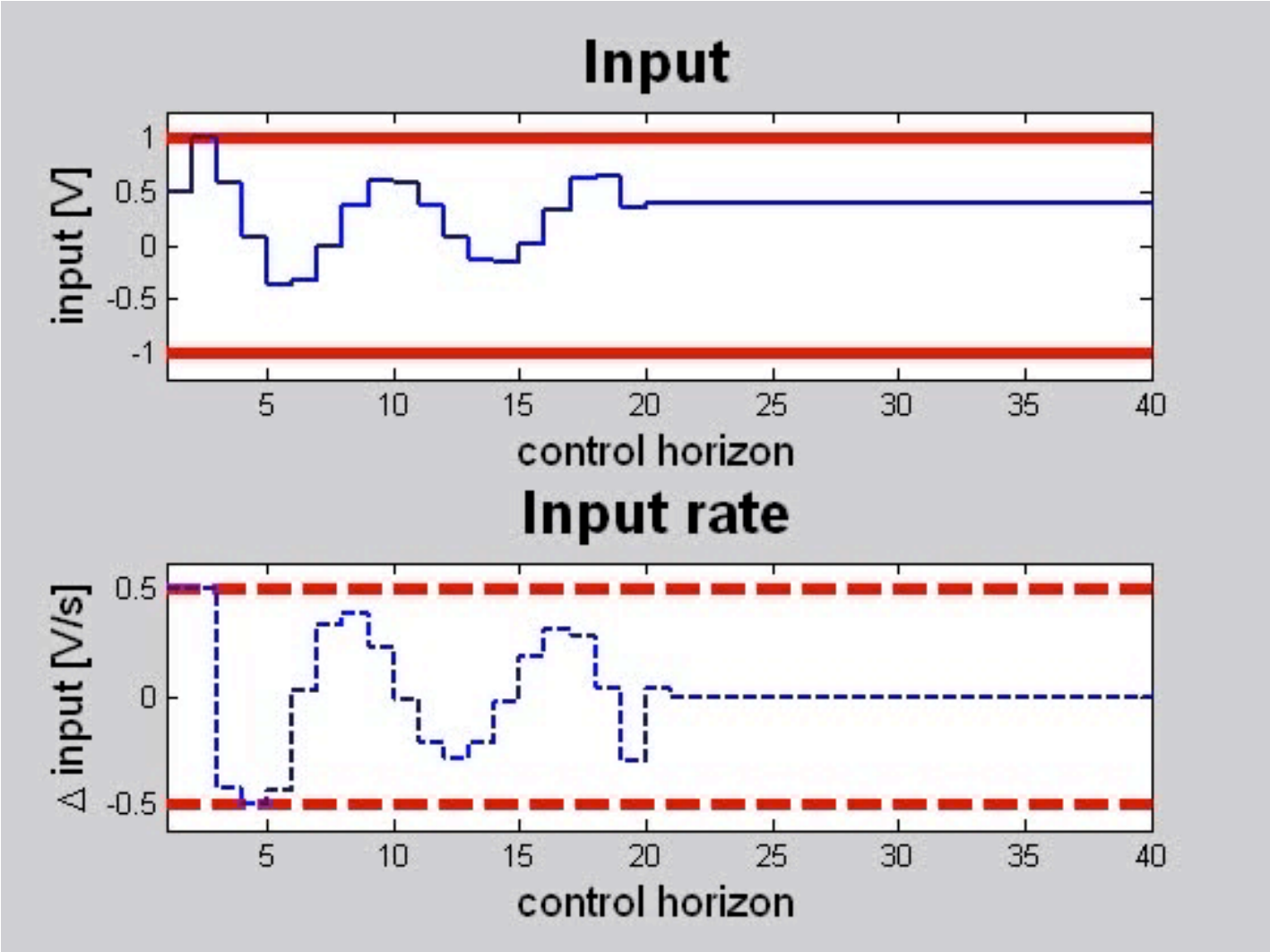
Hardware: xPC Target. Software: qpOASES [Ferreau, D., Bock, 2008]

Time Optimal MPC of a Crane

Univ. Leuven [Vandenbrouck, Swevers, D.]



Optimal Solutions in qpOASES Varying in Time



Solver qpOASES [PhD H.J. Ferreau, 2011], [Ferreau, Kirches, Potschka, Bock, D. , A parametric active-set algorithm for quadratic programming, Mathematical Programming Computation, 2014]

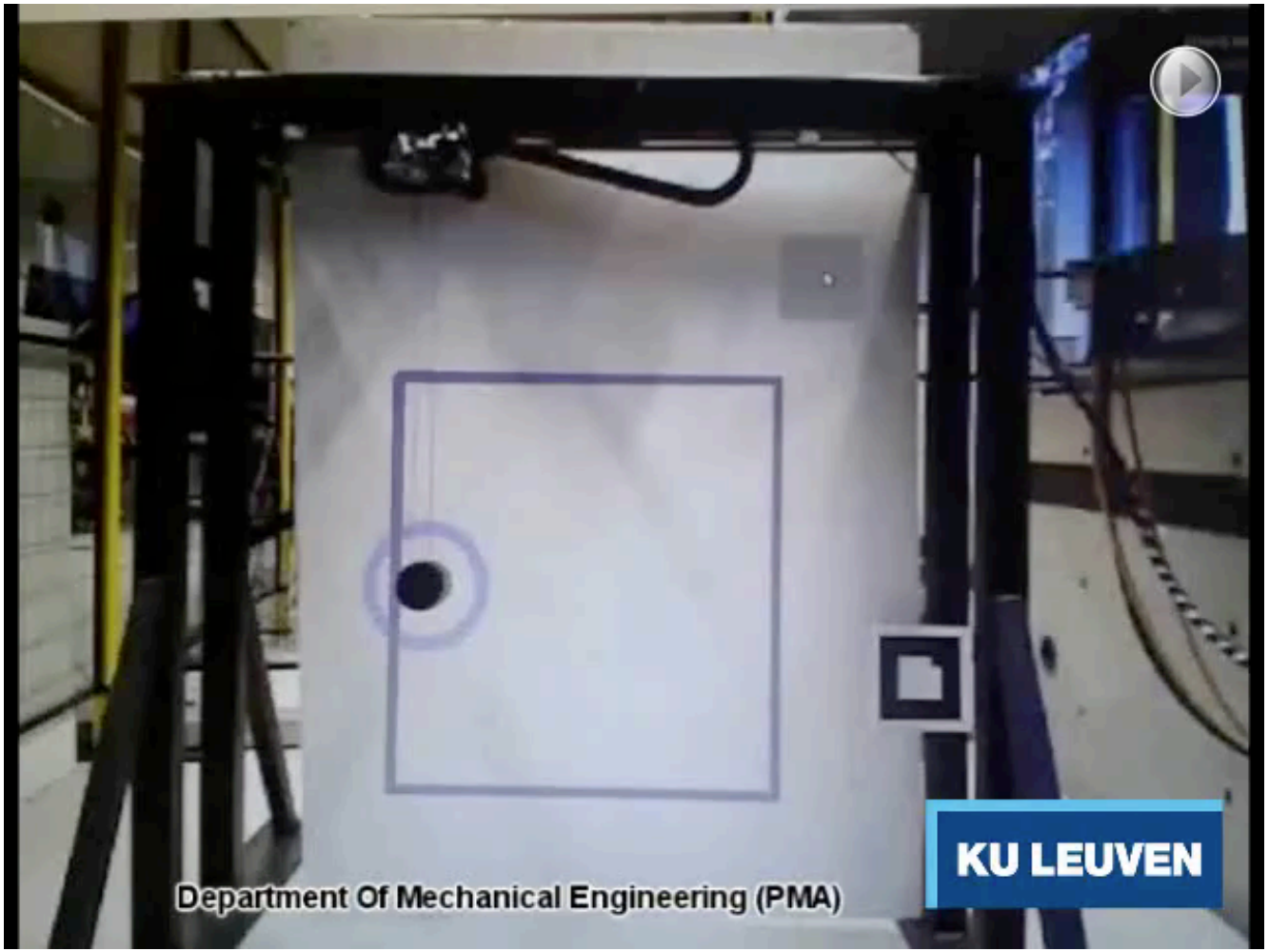
Open Source Software Tools from the Systems Control and Optimization Laboratory

under industry friendly LGPL license

- **qpOASES:** dense parametric quadratic programming [Joachim Ferreau, …]
- **qpDUNES:** sparse online quadratic programming [Janick Frasch, …]
- **ACADO:** nonlinear MPC [Boris Houska, Joachim Ferreau, Milan Vukov, Rien Quirynen, Robin Verscheuren, …]
- **CasADi:** modelling environment for dynamic optimization [Joel Andersson, Joris Gillis, Greg Horn, …]

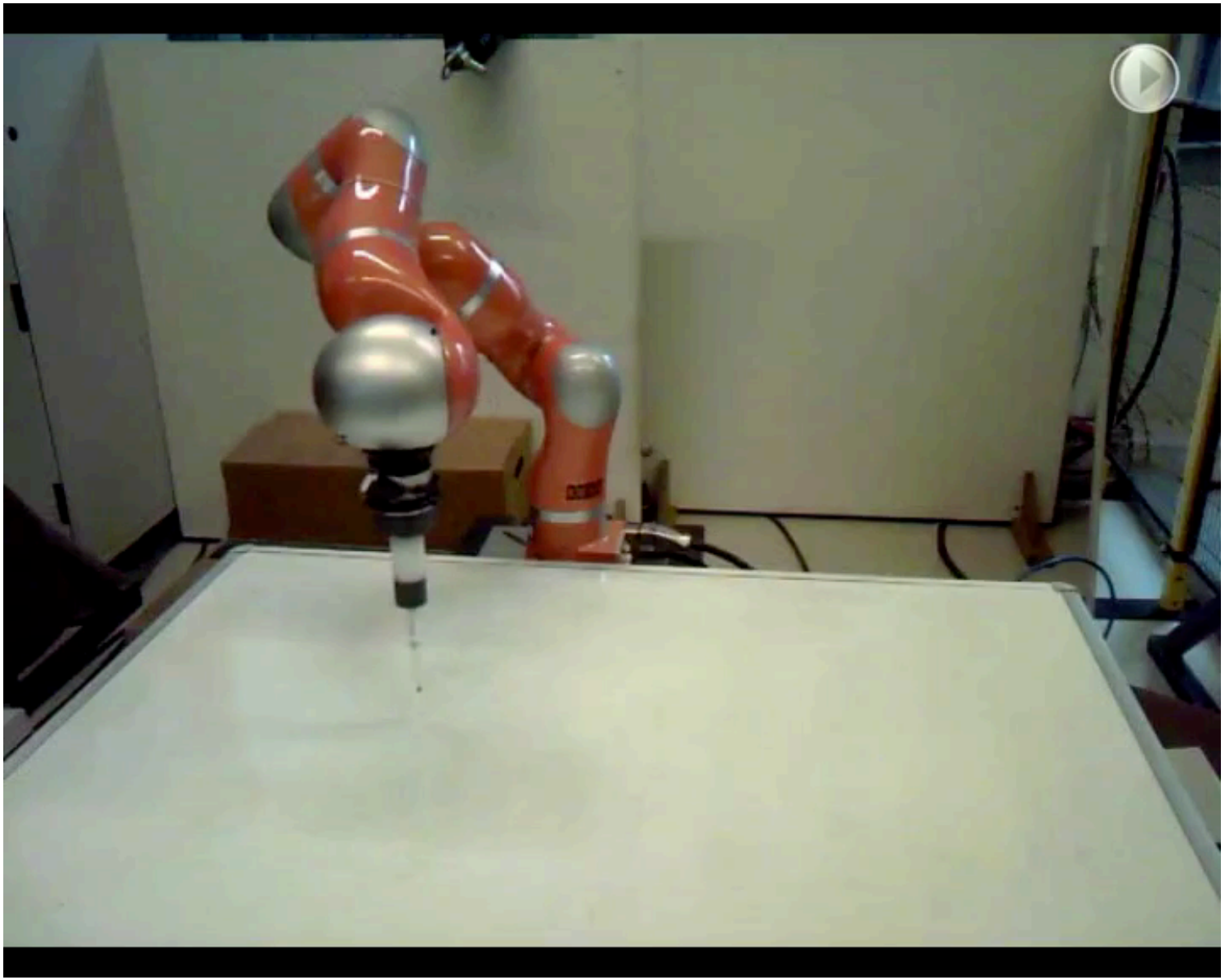
Time Optimal “drawing” by crane

Univ. Leuven [Wannes Van Loock et al.,] (CasADi)



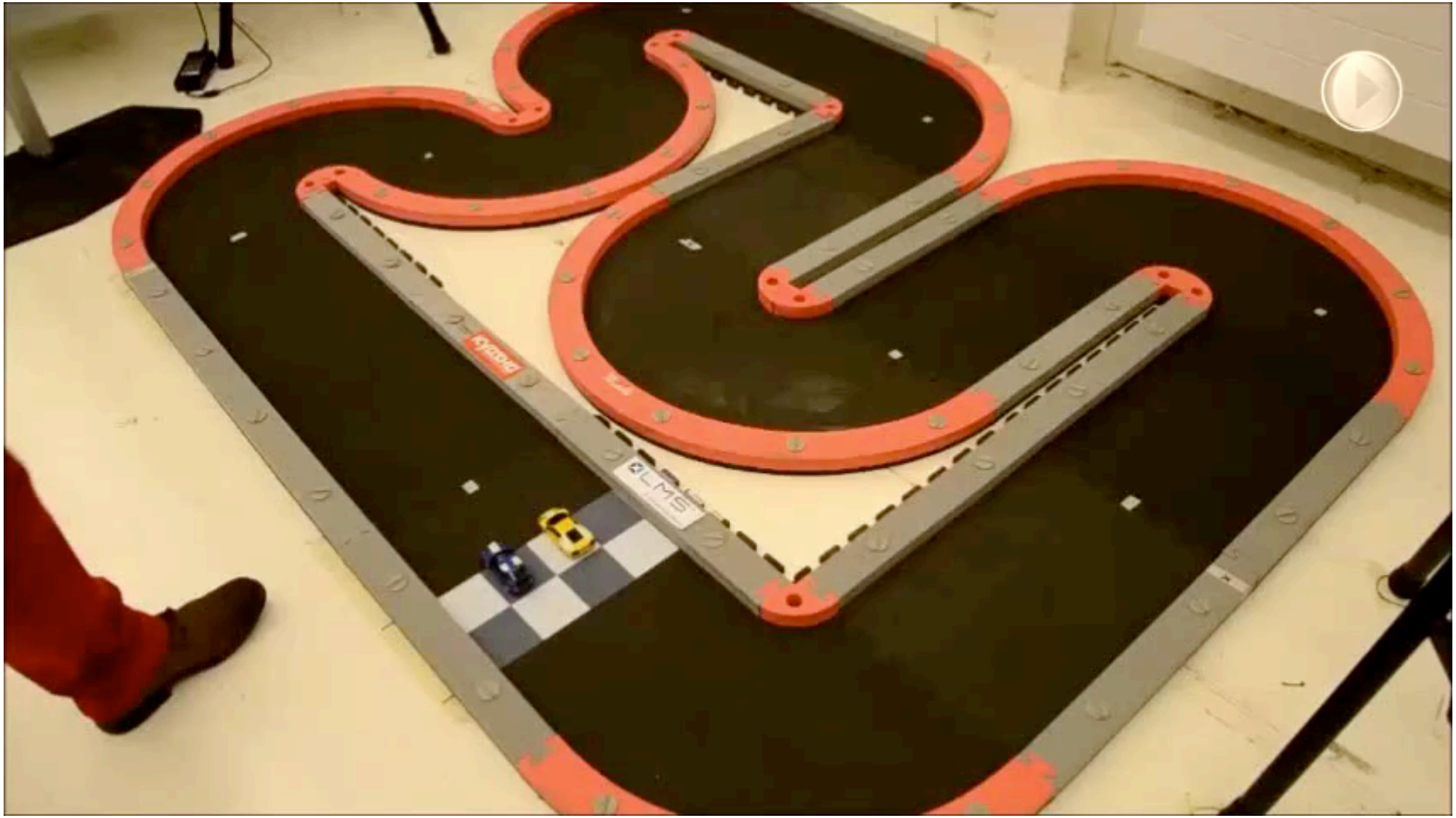
Time-optimal “hand writing” by robot

Univ. Leuven [Debrouwere, Swevers] using [Verscheure et al, IEEE TAC 2009]



Time-optimal “racing” of model cars

Univ. Leuven/ETH & LMS [Robin Verscheuren] (ACADO/qpOASES)



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Overview of the course

- 1st week:
- Optimal Control with Ordinary Differential Equations (ODE)

- 2nd week:
- Differential Algebraic Equations (DAE), Exam and Projects

Detailed Schedule of First Week

AWESCO Winter School on Numerical Optimal Control with Differential Algebraic Equations, First Week from Feb 15-21, 2016							
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
9:00	Introduction into Optimization and CasADi	Numerical Simulation and Derivatives	Newton Type Optimization: SQP	Direct Single and Multiple Shooting	The Indirect Approach and Pontryagin's Maximum Principle		**Excursion**
10:30	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**		
11:00	Exercise 1	Exercise 3	Exercise 5	Exercise 7	Exercise 9		
12:30	**Lunch Break**	**Lunch Break**	**Lunch Break**	**Lunch Break**	**Lunch Break**		
14:00	Nonlinear Programming & Convex Optimization	Optimal Control Overview	Interior Point Methods	Direct Collocation	Optimal Control with TOMLAB		
15:30	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**		
16:00	Exercise 2	Exercise 4	Exercise 6	Exercise 8	Embedded Optimal Control with ACADO		
17:30	Extra Time	Extra Time	Extra Time	Extra Time	Extra Time		
18:00	**End**	**End**	**End**	**End**	**End**		
	18:30 Reception*		18:30 Dinner Reservation (self-payment)**				

* Peterhofkeller Freiburg, Niemensstraße 10, 79098 Freiburg

** MARTIN'S BRÄU, Kaiser-Joseph-Straße 237, 79098 Freiburg

Detailed Schedule of Second Week

AWESCO Winter School on Numerical Optimal Control with Differential Algebraic Equations, Second Week from Feb 22-26, 2016					
	Monday	**Tuesday**	**Wednesday**	**Thursday*****	**Friday*****
9:00	Differential Algebraic Equation (DAEs) Models	Optimal Control with DAEs	Optimal Control of Airborne Wind Energy Systems	Exam	Project Presentations
10:30	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**
11:00	Exercise 10	Exercise 12	Stability and Robustness Optimization for Periodic Systems	Project Work	Project Presentations
12:30	**Lunch Break**	**Lunch Break**	**Lunch Break**	**Lunch Break**	Project Presentations
14:00	High Index DAEs and Index Reduction	Periodic Optimal Control with DAEs	Project Work / Study Time	Project Work	**End**
15:30	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**	
16:00	Exercise 11	Exercise 13	Project Work / Study Time	Project Work	
17:30	Project Commitments	Extra Time	Project Work / Study Time	Extra Time	
18:00	**End**	**End**	**End**	**End**	
		18:30 Dinner*			

* Peterhofkeller Freiburg, Niemensstraße 10, 79098 Freiburg

*** Room HS1015, Ground Floor Kollegiengebäude 1 (KG1), Platz der Universität 3, 79098 Freiburg

Introduction of Teachers and Organizers

Joel Andersson	UW Madison, USA
Moritz Diehl	University of Freiburg, Germany
Gianluca Frison	University of Freiburg, Germany
Joris Gillis	KU Leuven, Belgium
Sébastien Gros	Chalmers University, Sweden
Dimitris Kouzoupis	University of Freiburg, Germany
Elena Malz	Chalmers University, Sweden
Christine Paasch	University of Freiburg, Germany
Rien Quirynen	University of Freiburg, Germany
Per Rutquist	TOMLAB
Robin Verschueren	University of Freiburg, Germany
Andrea Zanelli	University of Freiburg, Germany