Introduction to TEMPO Summer School on Numerical Optimal Control and Embedded Optimization

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Systems Control and Optimization Laboratory
Faculty of Engineering, University of Freiburg
and
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Freiburg, July 27, 2015

Overview

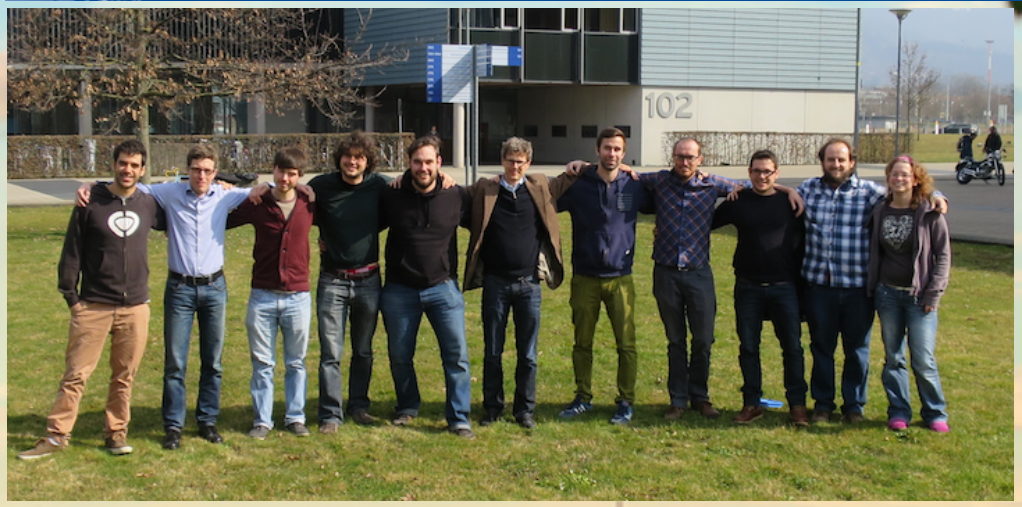
- The University of Freiburg and TEMPO
- Optimal Control Applications and Software
- Overview of the Course
- Introduction of Teachers

University of Freiburg:

- founded in 1457 by Archduke Albert VI of Western Austria, as a comprehensive university
- today, 24 000 students (52% female, 14% international), all faculties (humanities, sciences, medicine, *engineering*)

Systems Control and Optimization Laboratory

IMTEK, Faculty of Engineering, University of Freiburg



This course's sponsor: the EU Project TEMPO

TEMPO

Training in Embedded Predictive Control and Optimization

A Marie Curie Initial Training Network (ITN)

14 PhD fellows (all here)

Hosted and trained by TEMPO partner universities and companies:

NTNU Norwegian University of Science and Technology

KU LEUVEN

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

STU SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA

CentraleSupélec

Imperial College London

Ampyx Power airborne wind energy

RENAULT

UNI FREIBURG

UNIVERSITY OF OXFORD

ABB

NATIONAL INSTRUMENTS

STANFORD UNIVERSITY

ETH zürich

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

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

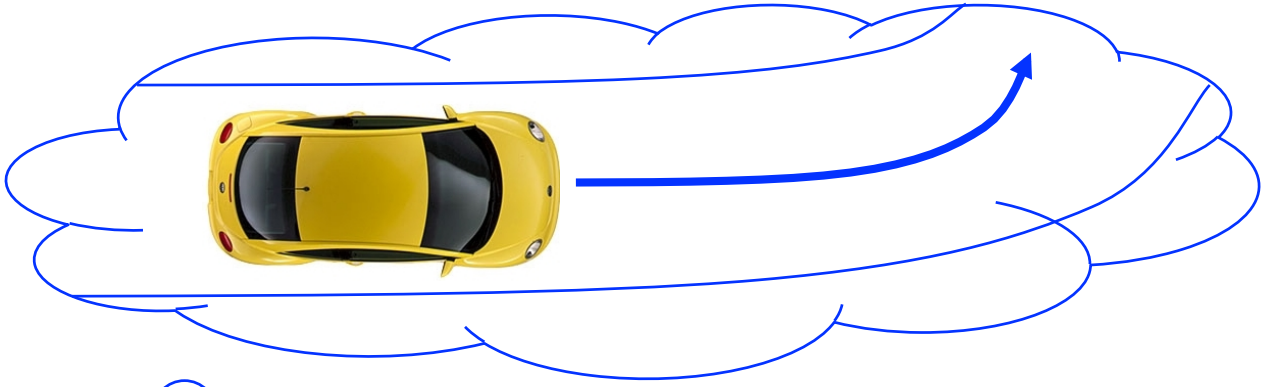
Control aims:

- 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)

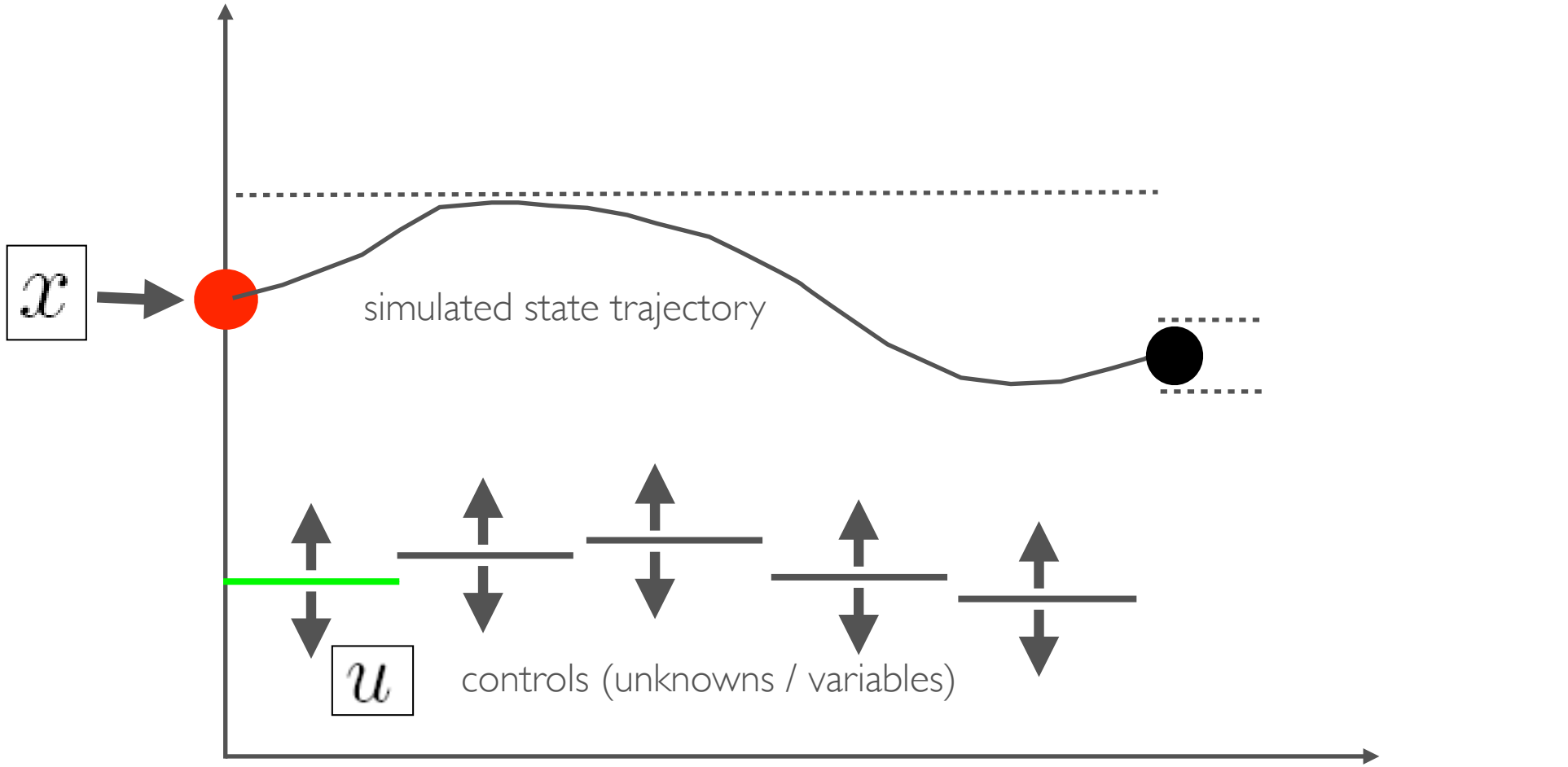
Always look a bit into the future



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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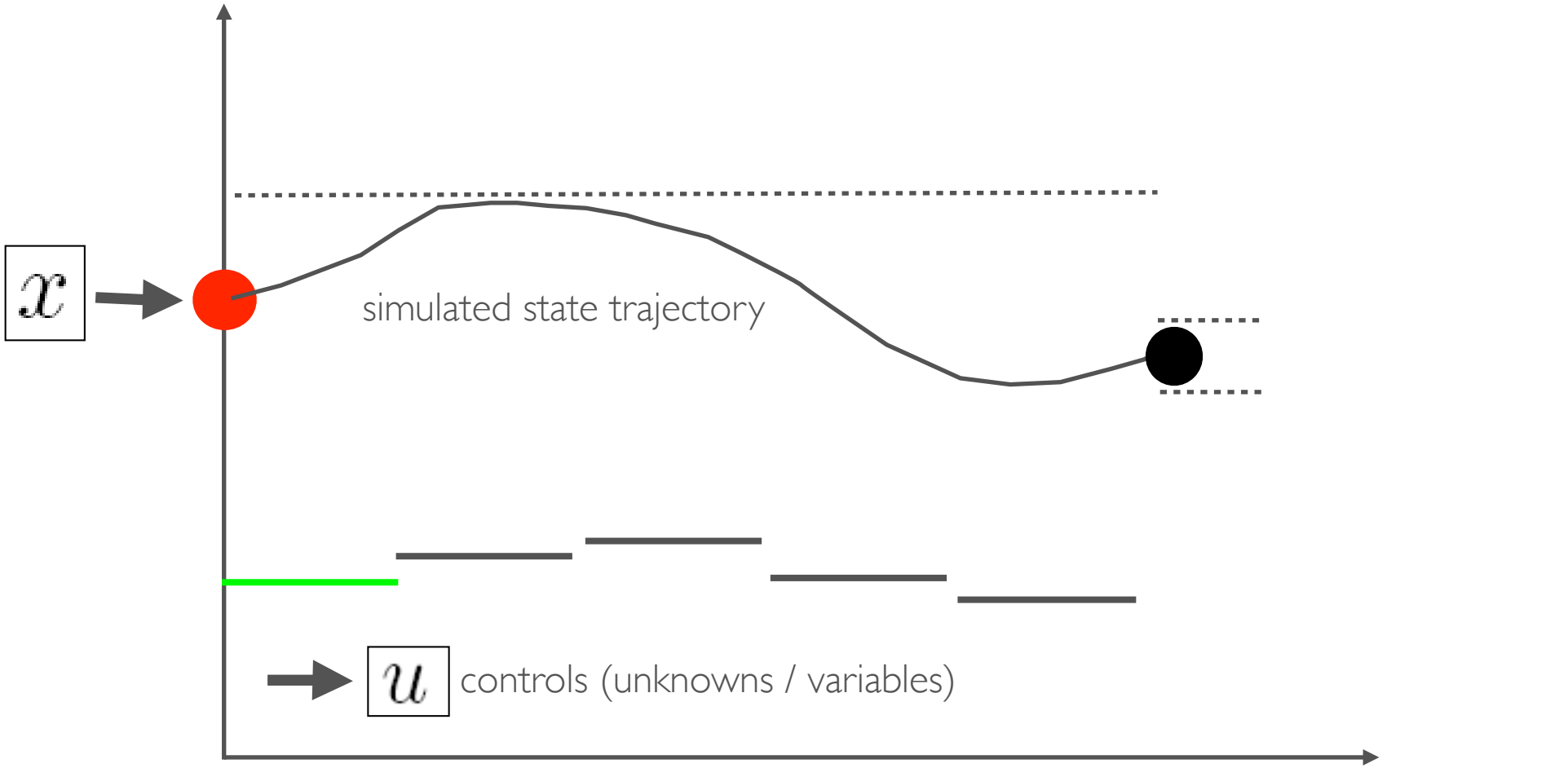


Time Optimal MPC of a Crane

SENSORS

- line angle
- cart position

MPC

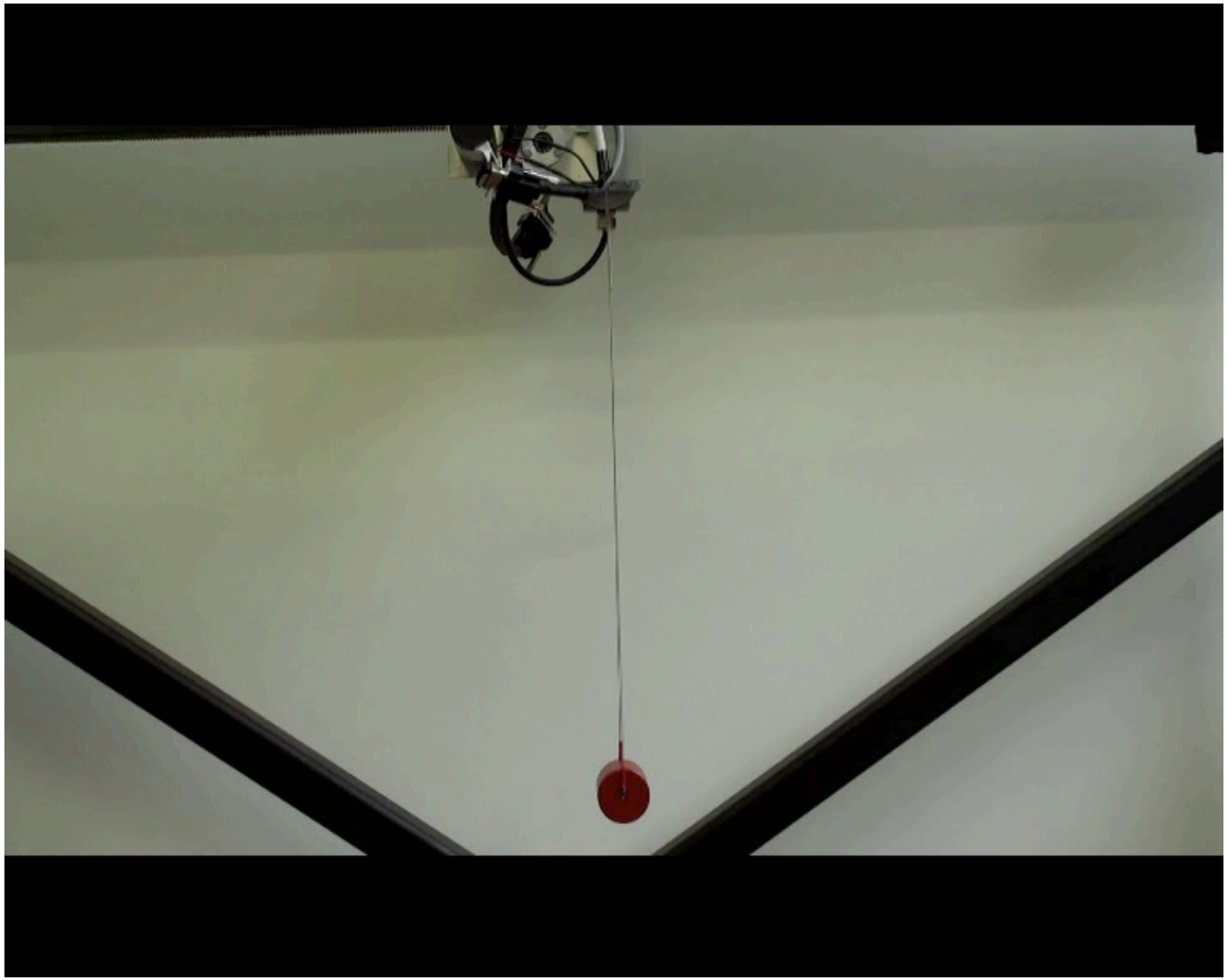
ACTUATOR

- cart motor

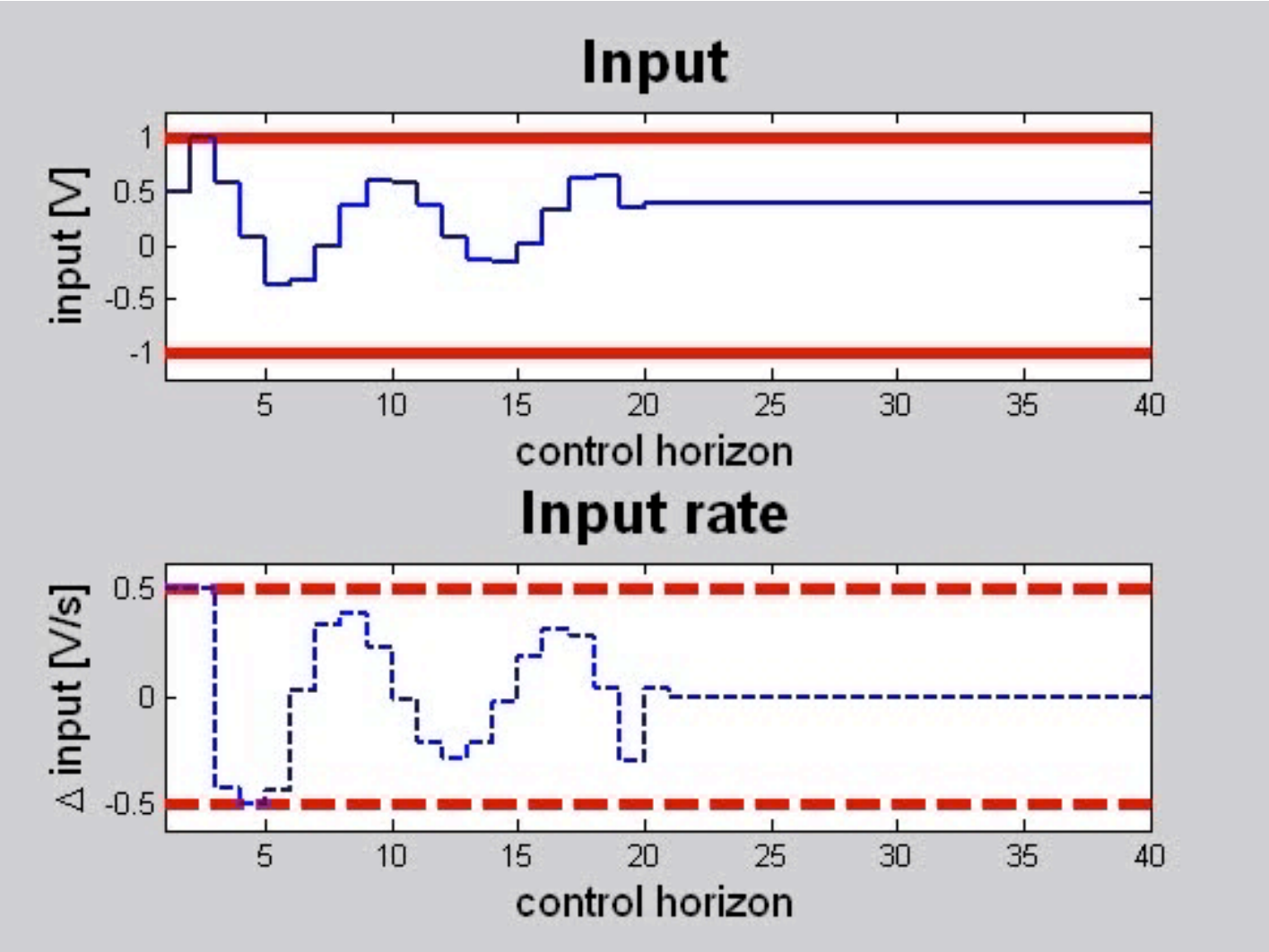
Hardware: xPC Target. Software: qpOASES [Ferreau, D., Bock, 2008]

Time Optimal MPC of a Crane

Univ. Leuven [Vandenbrouck, Swevers, D.]



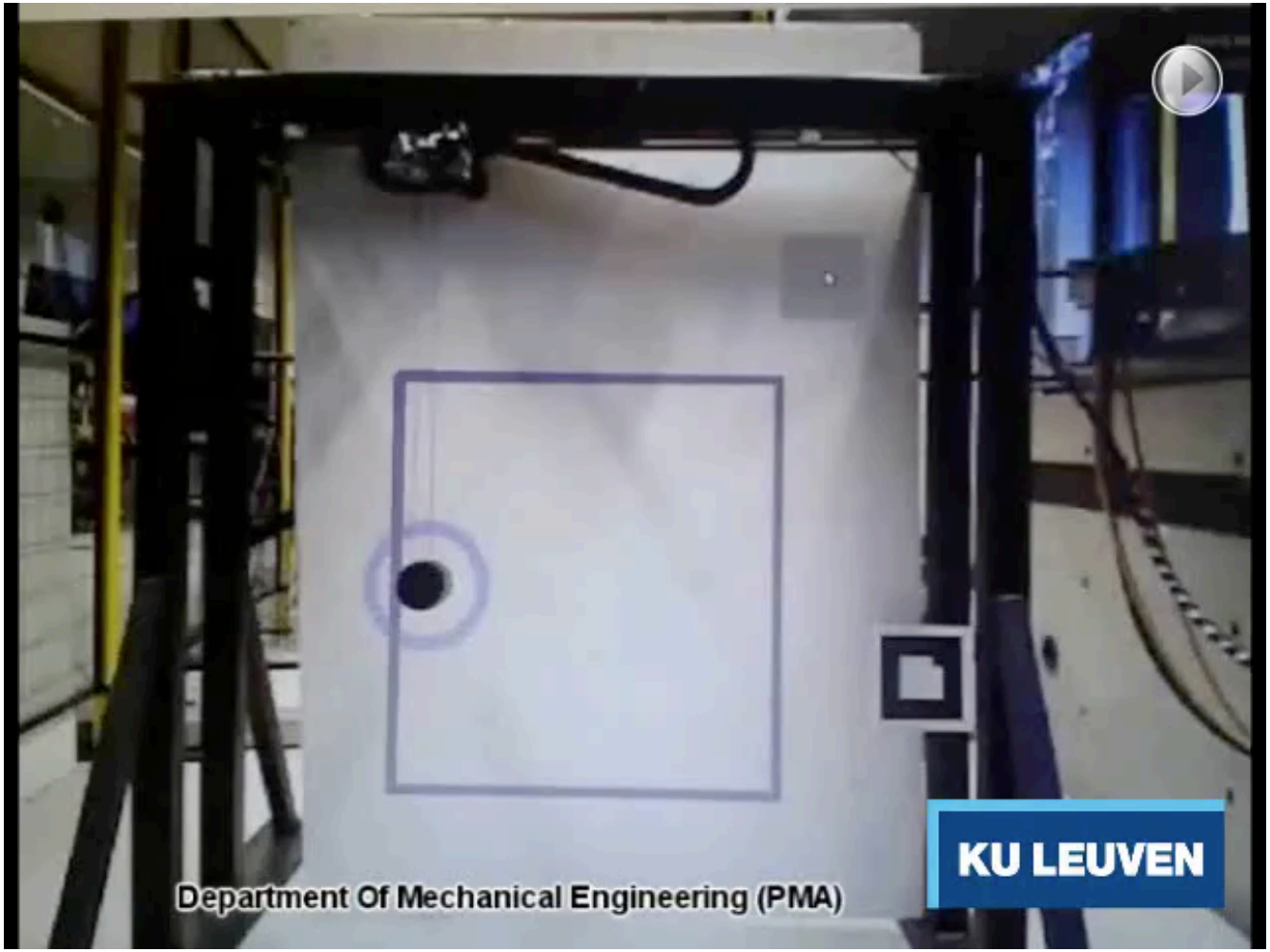
Embedded Optimization: Solutions Varying over Time



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

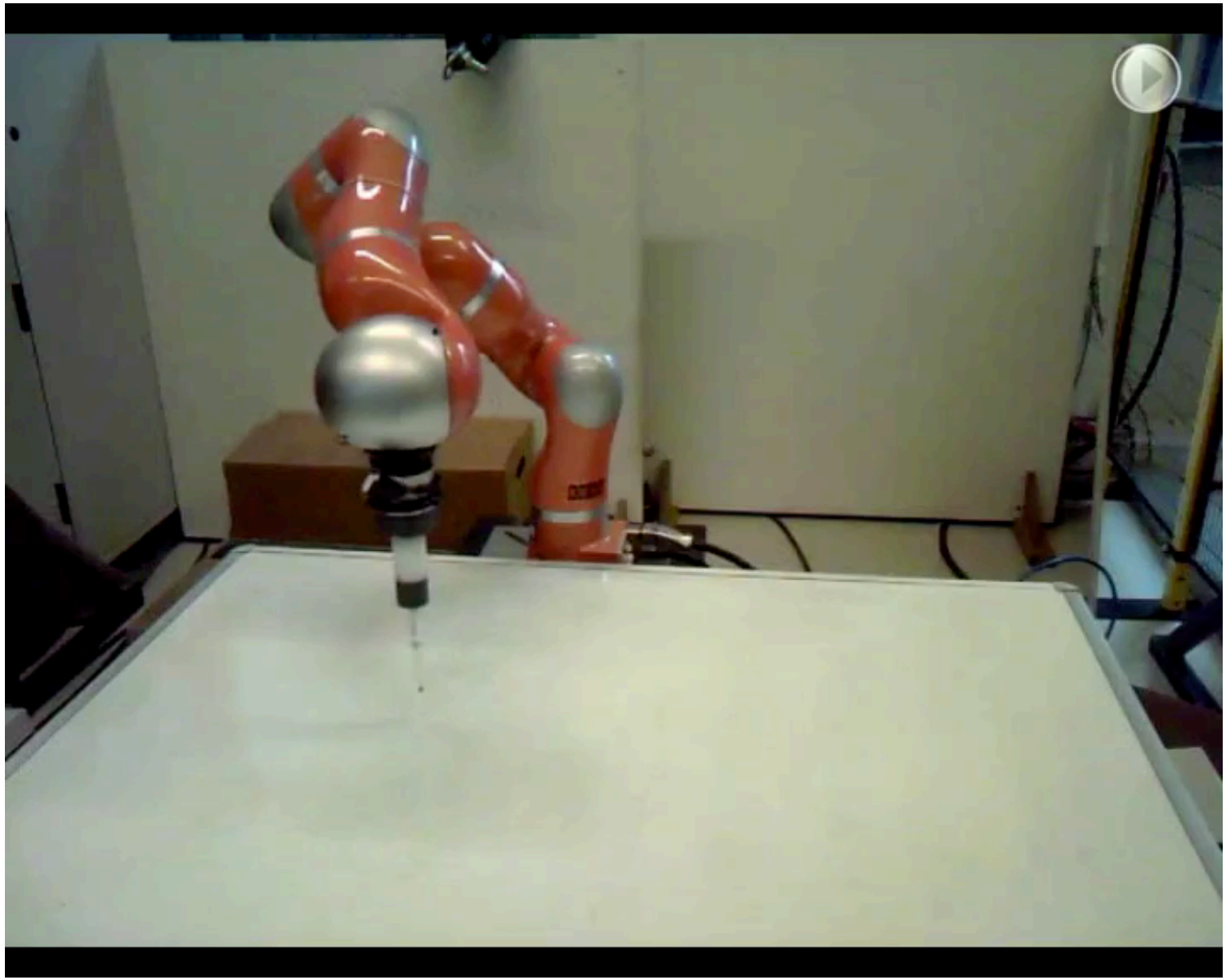
Time Optimal “drawing” by crane

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



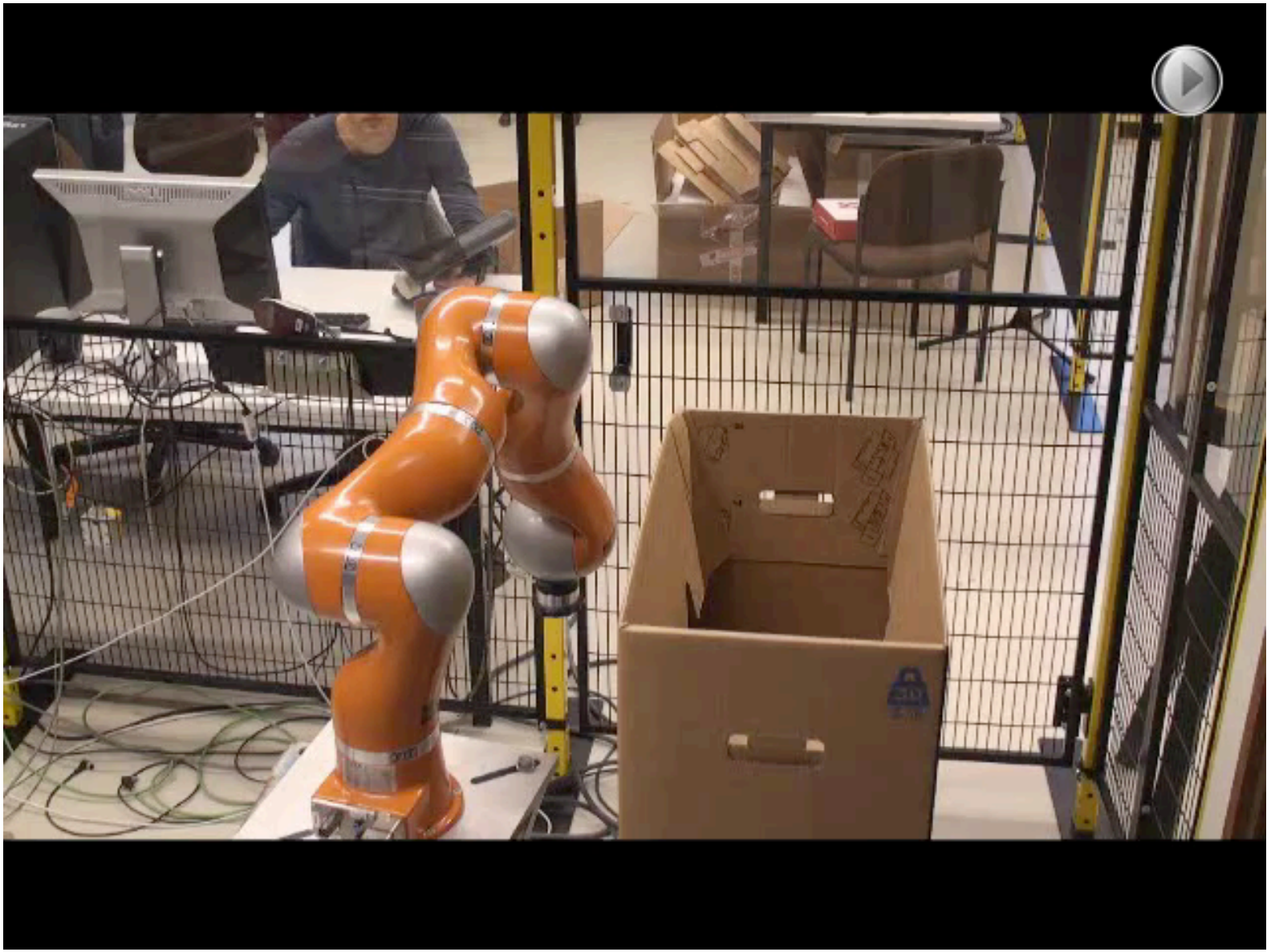
Time-optimal “hand writing” by robot

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



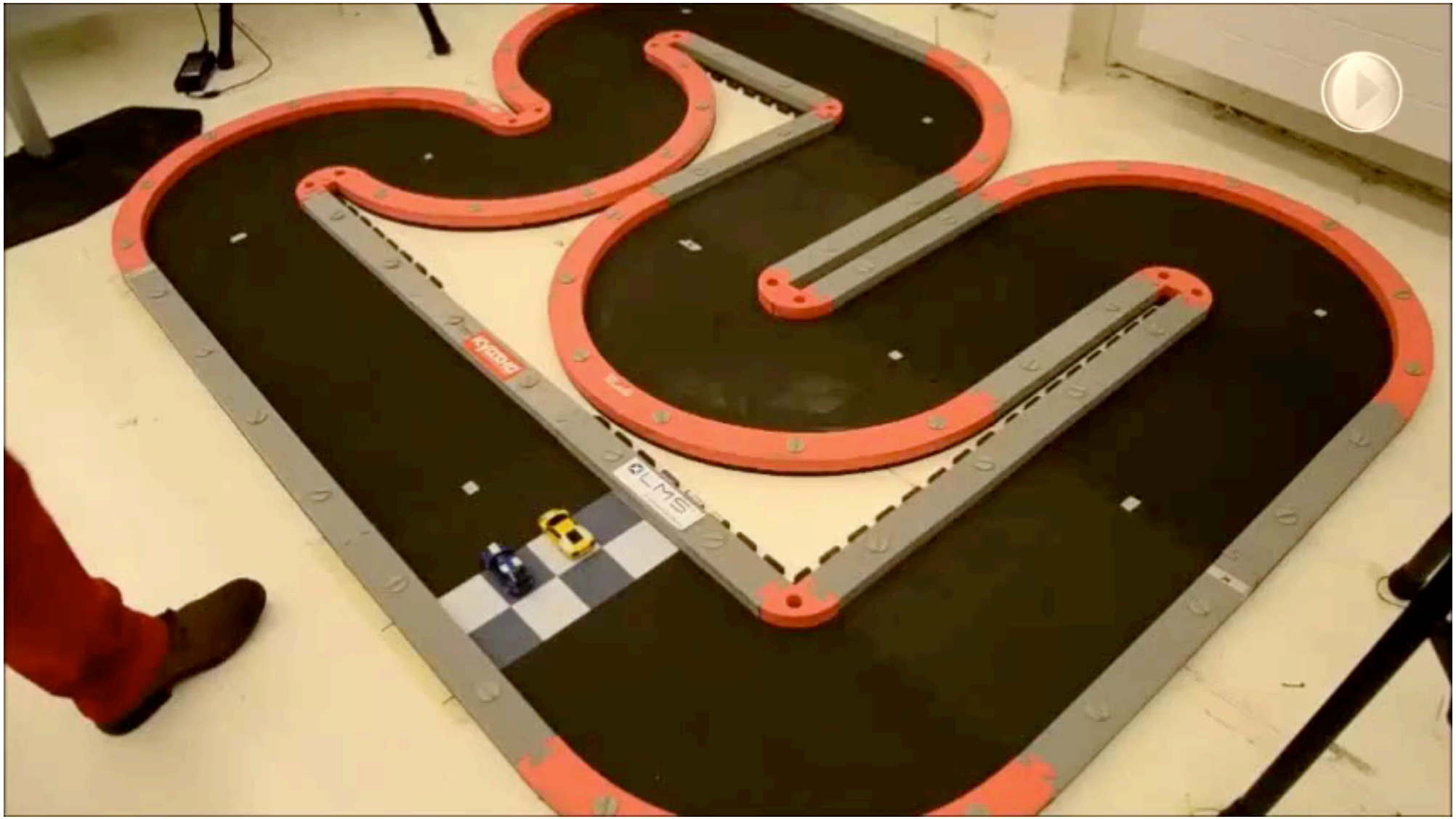
Robot avoiding a box while moving time optimally

Univ. Leuven [Swevers et al.]



Time-optimal “racing” of model cars

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



Software Tools treated in this course

All usable from MATLAB, most open-source

- YALMIP
- qpOASES (LGPL)
- FORCES / FORCES Pro
- ECOS (GPL)
- ACADO (LGPL)
- MPT Toolbox (GPL)
- qpDUNES (LGPL)

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TEMPO Summer School on

Numerical Optimal Control and Embedded Optimization

University of Freiburg, July 27 – August 7, 2015

Room 1098, Ground Floor Kollegiengebäude 1 (KG1), Platz der Universität 3, 79098 Freiburg

- two full weeks with lectures, computer exercises, exam, projects, ...
- 60 participants from 13 countries
- 15 organizers and teachers, coordinated by Colin Jones from EPFL (arriving next week), Moritz Diehl and Rien Quirynen

First week

TEMPO Summer School on Numerical Optimal Control and Embedded Optimization, First Week from July 27-31, 2015							
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Su**
9:00	Introduction: Systems, Control and Optimization	Nonlinear Simulation and Optimization	Convex Optimization and Sparsity	Alexander Domahidi: Interior Point Methods	Newton Type Optimization	**Black Forest Hike**	
10:30	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**		
11:00	Exercise 1 Linear-Quadratic Regulator	Exercise 3 Newton's Method	Exercise 5 YALMIP	Exercise 7 FORCES	Exercise 9 Gauss-Newton		
12:30	**Lunch Break**	**Lunch Break**	**Lunch Break**	**Lunch Break**	**Lunch Break**		
13:30	Optimal Control Overview	Direct Optimal Control	Joachim Ferreau: qpOASES	Alexander Domahidi: Interior Point Methods	Real-Time Iterations and ACADO		
15:00	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**		
15:30	Exercise 2 Dynamic Programming	Exercise 4 Shooting Methods	Exercise 6 qpOASES for MPC	Exercise 8 ECOS	Exercise 10 ACADO Code Generation		
17:00	**Break**	**Break**	**Break**	**Break**	**Break**		
17:20	Review Session	Review Session	Review Session	Review Session	Review Session		
18:00	**End**	**End**	**End**	**End**	**End**		
	18:30 Reception**		18:00 Guided City Tour	18:30 Dinner Reservation (self-payment)*			

Second week

TEMPO Summer School on Numerical Optimal Control and Embedded Optimization, Second Week from August 3-7, 2015					
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
9:00	Exam	Alternating Direction Method of Multipliers	Block Condensing for qpDUNES	Project Work	Project Presentations
10:30	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**
11:00	Explicit MPC	Exercise 12 ADMM	Project Work	Project Work	Project Presentations
12:30	**Lunch Break**	**Lunch Break**	**Lunch Break**	**Lunch Break**	Project Presentations
13:30	Explicit MPC	Project Work	Project Work	Project Work	**End**
15:00	**Coffee Break**	**Coffee Break**	**Coffee Break**	**Coffee Break**	
15:30	Exercise 11 Explicit MPC	Project Work	H. G. Bock Efficient Methods for Inverse Optimal Control Problems	Project Work	
17:00	**Break**	**Break**	**Break**	**Break**	
17:20	Review Session and Project Commitments	Systems Control and Optimization Lab Tour	Project Work	Project Work	
18:00	**End**	**End**	**End**	**End**	
			18:30 Dinner**		

List of Organizers and Teachers

Name	Institution
Prof. Dr. Dr. h.c. mult. Hans Georg Bock	Heidelberg University, Germany
Prof. Dr. Moritz Diehl	University of Freiburg, Germany
Dr. Alexander Domahidi	Embotech, Switzerland
Dr. Joachim Ferreau	ABB, Switzerland
Jean Hours	EPFL, Switzerland
Prof. Dr. Colin Jones	EPFL, Switzerland
Milan Korda	EPFL, Switzerland
Dimitris Kouzoupis	University of Freiburg, Germany
Dr. Michal Kvasnica	Slovak University, Slovakia
Adeleh Mohammadi	KU Leuven, Belgium
Christine Paasch	University of Freiburg, Germany
Rien Quirynen	University of Freiburg, Germany
Georgios Stathopoulos	EPFL, Switzerland
Pu Ye	EPFL, Switzerland
Mario Zanon	University of Freiburg, Germany