Workshop on Embedded Optimization and Learning for Robotics and Mechatronics

October 10-11, 2022
University of Freiburg, Kollegiengebäude I, Room 1098,
Platz der Universität 3, 79098 Freiburg, Germany

Programme

Monday, October 10, 2022

10:30 Welcome Coffee

11:00 Opening of the Workshop

11:15 Real-Time Optimization Algorithms for Nonlinear Model Predictive Control of Nonsmooth Dynamical Systems - Toshiyuki Ohtsuka (Kyoto University, Japan)

12:00 Lunch

14:00 Paths towards Open World Generalization in Computer Vision - Thomas Brox (University of Freiburg)

14:45 Interactive Learning for (Mobile) Manipulation - Abhinav Valada (University of Freiburg)

15:30 Break

16:00 Embedded Learning, Optimisation and Predictive Control for Autonomous Systems - Rien Quirynen (Mitsubishi Electric Research Laboratories, USA)

16:45 End of Talks

18:10 Transit from seminar location to Waldsee (joint walk or tram)

19:00 Welcome reception at Gaststätte Waldsee (Waldseestrasse 84, 79117 Freiburg)

Tuesday, October 11, 2022

09:00 The unreasonable effectiveness of Predictive Control and the tools to harness it - Yuval Tassa (Google Deepmind, UK)

9:45 Contact-Implicit Model-Predictive Control - Taylor Howell (Stanford University, USA)

10:30 Break

11:00 Autonomous, Vision-based Agile Flight - Davide Scaramuzza (University of Zürich, Switzerland)

12:00 MPC@Bosch: from Control of Electric Drives to Robot Navigation (Part 1) - Maximilian Manderla, Niels van Duijkeren, Ozan Demir, and Stefan Gering (Bosch Research, Renningen, Germany)

12:30 Lunch break

14:00 MPC@Bosch: from Control of Electric Drives to Robot Navigation (Part 2)

15:30 Break

16:00 Learning for Predictive Control and Vice Versa - Melanie Zeilinger (ETHZ, Switzerland)

16:45 Optimal Adaptive Droop Design via a Modified Relaxation of the OPF - Silvia Mastellone (FHNW, Switzerland)

17:30 End of Workshop

https://www.syscop.de/events, https://elo-x.eu/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 953348

Abstracts

Monday, October 10 at 11:15

Real-Time Optimization Algorithms for Nonlinear Model Predictive Control of Nonsmooth Dynamical Systems

Toshiyuki Ohtsuka (Kyoto University)

In this talk, we discuss numerical computation techniques for model predictive control (MPC) of robotic systems with rigid contacts, which is a special but important class of nonsmooth dynamical systems. We deal with the whole-body model of a robot without simplification, and we optimize not only a trajectory but also switching times due to contact of the robot with the environment. We introduce structure-exploiting algorithms and demonstrate that real-time optimization is possible in a hardware experiment of a quadrupedal robot. We will also introduce a numerical solution method for optimal control problems with equilibrium constraints, which is a general framework for optimal control of nonsmooth dynamical systems. We demonstrate that a non-interior-point method can generate optimal solutions with fewer iterations than an interior-point method. This talk is based on joint work with Sotaro Katayama and Kangyu Lin.

Monday, October 10 at 14:00

Paths towards Open World Generalization in Computer Vision

Thomas Brox (University of Freiburg)

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Monday, October 10 at 14:45

Interactive Learning for (Mobile) Manipulation

Abhinav Valada (University of Freiburg)

Learning to solve complex manipulation tasks from visual observations is a dominant challenge for real-world robot learning. In this talk, I will first present our CEILing (Corrective and Evaluative Interactive Learning) framework that combines both corrective and evaluative feedback from a human to train a stochastic policy in an asynchronous manner, and employs a dedicated mechanism to trade off human corrections with the robot's own experience. I will then present our reinforcement learning approach for multi-object search that combines short-term and long-term reasoning in a single model while avoiding the complexities arising from hierarchical structures. Finally, I will present our mobile manipulation approach to learn feasible dynamic motions for a mobile robotic base while the end-effector follows a trajectory in task space generated by an arbitrary system to fulfill the task at hand. I will conclude the talk with our on-going work on fairness-aware learning for safe human-robot interaction.

Monday, October 10 at 16:00

Embedded learning, optimization and predictive control for autonomous vehicles

Rien Quirynen (Mitsubishi Electric Research Laboratories)

Mitsubishi Electric Research Laboratories (MERL) is a leading research organization located in Cambridge, MA, USA that conducts fundamental research for industrially motivated problems. In this talk, I will present three projects at MERL related to machine learning and optimal control. First, I describe a stochastic nonlinear model predictive control technique and its integration with tire-friction model learning for autonomous vehicles. Second, I will present a safe reinforcement learning algorithm for fast multi-agent motion planning, including results from hardware experiments. The third project concerns the use of deep learning to accelerate the solution of mixed-integer convex programs for real-time optimal control applications.

Tuesday, October 11 at 9:00

The unreasonable effectiveness of Predictive Control and the tools to harness it

Yuval Tassa (Google Deepmind)

Predictive Control is a powerful technique that is used extensively in industry and academia. However, it is currently not very accessible to beginners and amateurs due to lack of convenient tools and the complexity of the algorithms involved. We will present Trajectory Explorer, a new, open-source tool based on the MuJoCo simulator, that provides a simple, easy to use interface for exploring Predictive Control problems. Specifically, we will describe an almost-trivial, derivative-free shooting method that works surprisingly well on multiple difficult problems, and requires no understanding of "proper" optimisation techniques.

Tuesday, October 11 at 9:45

Contact-Implicit Model-Predictive Control

Taylor Howell (Stanford University)

We present a general approach for controlling robotic systems that make and break contact with their environments. Contact-implicit model-predictive control (CI-MPC) generalizes linear MPC to contact-rich settings by relying on linear complementarity problems (LCP) computed using strategic Taylor approximations about a reference trajectory and retaining non-smooth impact and friction dynamics, allowing the policy to not only reason about contact forces and timing, but also generate entirely new contact mode sequences online. To achieve reliable and fast numerical convergence, we devise a structure-exploiting, path-following solver for the LCP contact dynamics and a custom trajectory optimizer for trajectory-tracking MPC problems. We demonstrate CI-MPC at real-time rates in simulation, and show that it is robust to model mismatch and can respond to disturbances by discovering and exploiting new contact modes across a variety of robotic systems, including a pushbot, hopper, and planar quadruped and biped.

Tuesday, October 11 at 11:00

Autonomous, Vision-based Agile Flight

Davide Scaramuzza (University of Zürich)

Autonomous drones: I will summarize our latest research in learning deep sensorimotor policies for agile vision-based quadrotor flight. Learning sensorimotor policies represents a holistic approach that is more resilient to noisy sensory observations and imperfect world models. However, training robust policies requires a large amount of data. I will show that simulation data is enough to train policies that transfer to the real world without fine-tuning. We achieve one-shot sim-to-real transfer through the appropriate abstraction of sensory observations and control commands. I will show that these learned policies enable autonomous quadrotors to fly faster and more robustly than before, using only onboard cameras and computation. Applications include acrobatics, high-speed navigation in the wild, and autonomous drone racing.

Tuesday, October 11 at 12:00

MPC @ Bosch: from Control of Electric Drives to Robot Navigation

Maximilian Manderla, Niels van Duijkeren, Ozan Demir, Stefan Gering (Bosch Research)

In this talk, we will present recent MPC applications at Bosch Corporate Research.

We showcase positive examples, in which MPC has proven advantages, but also touch on common obstacles and open points arising in applied research, being at the intersection of academia and series production.

Presented applications will be from the fields of mobile robotics, electric drive systems and hydraulic systems, showing benefits in terms of efficiency-improvement, constraint handling and reduction of application effort.

At the same time, all examples comprise remaining challenges in terms of real-time criticality, non-convexity of the underlying optimization problem, adaptivity of data-based models, and general safety issues when having MPC algorithms interact with complex software architectures.

In this regard, the talk might inspire to improve next-gen MPC algorithms.

Tuesday, October 11 at 16:00

Learning for Predictive Control and Vice Versa

Melanie Zeilinger (ETH Zürich)

Automation is transforming our society through technological advances in robotics, transportation, manufacturing, energy and medical systems. As ubiquitous sensing and communication is turning these systems into large data generators, learning is becoming a central element of automatic control systems to address new levels of system complexity, variability and user interaction. While this paradigm shift offers tremendous opportunities, it also raises fundamental questions of learning in real-time in a closed-loop dynamical control system.

In this talk, I will present our research towards predictive controllers that enable even safety-critical systems to leverage the potential of data and to learn during operation. I will particularly highlight our results for using learning for automatic controller design to reduce development time while pushing the performance envelope, as well as a novel modular framework that can equip any learning-based controller with safety guarantees. The underlying theory and concepts will be illustrated with examples of applications from robotics.

Tuesday, October 11 at 16:45

Optimal Adaptive Droop Design via a Modified Relaxation of the OPF

Silvia Mastellone (FHNW)

The ever-increasing penetration of Renewable Energy Resources (RESs) in power distribution networks has brought, among others, the challenge of maintaining the grid voltages within the secure region. Employing droop voltage regulators on the RES's inverters is an efficient and low-cost solution to reach this objective. However, fixing droop parameters or optimizing them only for overvoltage conditions does not provide the required robustness and optimality under changing operating conditions. In this paper, a convex optimization approach is proposed for reconfiguring P-V and Q-V droop regulators during on-line operation. The objective is to minimize power curtailment, power losses, and voltage deviation subject to electrical security constraints. This enables to optimally operate the grid with high RES penetration under variable conditions while preserving electrical security constraints (e.g., current and voltage limits). As a first contribution, a mixed-integer linear model of the droop characteristics is developed. According to this model, a droop-regulated generation unit is represented as a constant-power generator in parallel with a constant-impedance load. As a second contribution, a Modified Augmented Relaxed Optimal Power Flow (MAR-OPF) formulation is proposed to guarantee that the electrical security constraints are respected in the presence of constant-impedance loads in the network. Sufficient conditions for the feasibility of the MAR-OPF solution are provided. Those conditions can be checked a priori and are valid for several real distribution networks. Furthermore, an iterative approach is proposed to derive an approximate solution to the MAR-OPF that is close to the global optimal one. The performance of the MAR-OPF approach and the accuracy of the proposed model are evaluated on standard 34-bus and 85-bus test networks.