Model Predictive Control II

Dates and time

05-04-2027
12-04-2027
19-04-2027
10-05-2027
from 10:15 – 12:30 hrs

Course location

Cursus- en vergadercentrum Domstad, Utrecht

ECTS

3 ECTS if the homework is completed successfully

1 ECTS for auditing the course

Lecturers

Dr. M. Lazar, Eindhoven University of Technology, EE

Dr. Chanfreut Palacio, Eindhoven University of Technology, ME

Objective

This course will teach advanced theory, design methods, and computational techniques for model predictive control (MPC) at the level of PhD or PostDoc researchers, with a focus on nonlinear systems. MPC relies on three main building blocks:

(i) multi-step prediction models, (ii) cost function and constraints, and (iii) dynamic (receding horizon) optimization.

At each time instant, an MPC controller predicts the future behavior of the system over a finite time horizon, and computes a sequence of control inputs by solving a constrained optimization problem based on measured data. However, it applies only the first input of this sequence to the system, and the process is repeated again at the next time instant. Model predictive control design for nonlinear systems faces several challenges: how to derive accurate but low complexity prediction models for dynamical systems with complex, nonlinear behavior, how to achieve stability, tracking and recursive feasibility, and how to solve nonlinear MPC problems in real-time with under millisecond time budget. In the 4 lectures of this course we will teach solutions to this challenges as follows: we introduce a universal modeling theory based on Koopman operators for deriving simple, quasi-linear models for nonlinear systems and we will presents methods for integrating Koopman operator models and MPC. Robust tube-based methods for guaranteeing stability and recursive feasibility of Koopman MPC will be presented. Additionally, we will address the challenge of constant and time-varying setpoints tracking, and their recursive feasibility and stability properties. The course will conclude by tackling the numerical and computational challenges of NMPC, covering direct transcription methods, real-time solvers, and distributed (multi-agent) optimization for large-scale systems. Examples of applications from various domains will be provided, for example, solving control problems for drones, robotic actuators, buildings, and solar energy systems.

Contents

Lecture 1: Introduction to Koopman operator theory for control

- definition of the Koopman operator for autonomous systems and extensions to systems with control (covering linear and bilinear Koopman models)
- data-driven learning of Koopman models for MPC
- Koopman MPC formulations and numerical implementation (via SQP and quasi-LPV approaches)

Lecture 2: Koopman MPC design for nonlinear systems and stability via robust tube-based formulations

- Tube-based Koopman MPC formulation with robust stability guarantees
- Construction of terminal sets and cost for tube-based Koopman MPC
- Tutorial implementation of Koopman MPC in application inspired examples

Lecture 3: Tracking and estimation in NMPC

- Setpoint stabilization (design of terminal ingredients), trajectory tracking, and economic formulations
- Nonlinear MPC for tracking (with artificial variables)
- State estimation for nonlinear systems

Lecture 4: Numerical methods and distributed NMPC

- Direct shooting and collocation methods
- Sequential quadratic programming (SQP) and interior-point methods
- Real-time iteration (RTI)
- CasADI/Acados implementation concepts.
- Distributed nonlinear MPC (Aladin)

Course materials

A full set of lecture notes and some tutorial material will be made available on the DISC course platform. Several books specializing in different MPC topics will be recommended. Code will be provided via GitHub repositories and the DISC course platform.

Prerequisites

Taking the MPC 1 course (or having equivalent background knowledge, e.g., in the form of a MPC Master Course) is strongly recommended before this course. Likewise, participants are expected to have some background knowledge in convex optimization, discrete-time state-space systems, Lyapunov functions, linear matrix inequalities, set-theoretic concepts (invariant sets and controllable sets). Experience with basic Matlab programming and simulating dynamical systems in Matlab is recommended. However, the course will also contain tutorial material about the above-mentioned subjects and will allow less familiar participants to catch up during the course.

Homework assignments

Two homework sets will be distributed via the course website. Homework is graded on a scale from 1 to 10. Homework sets will include both theoretical, open exercises and Matlab programming assignments, i.e., students will have to submit a report and software files in a zip archive. Missing sets receive the grade 1. The final grade for the course is a weighted average of the grades for the homework sets.