

Model Predictive Control

Dates and time

07-04-2025 (2 lectures on the same day)

14-04-2025 (2 lectures on the same day)

from 10:15 – 12:30 and from 13:45 – 16:00

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

The course will teach Model Predictive Control (MPC) theory, design methods and implementation in Matlab at the level of PhD or PostDoc researchers. The objective of the course is to provide participants with fundamental and practical knowledge of the MPC field, enabling them to conduct research in the MPC field or to apply MPC controllers to specific application domains.

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. We will teach all the aspects necessary for mastering the building blocks of MPC mainly for discrete-time linear systems, along with systematic methods for guaranteeing asymptotic stability and recursive feasibility, and ensuring robustness. Additional material for extending the developed techniques to nonlinear discrete-time systems will also be indicated, but not covered in this course. Besides the stabilization problem, we will also provide solutions to tracking MPC problems and robust tube MPC problems with recursive feasibility and robust stability guarantees.

The course will be split into two parts: the first part will focus on centralized MPC of standalone / isolated systems; the second part will focus on distributed MPC of multi-agent/interconnected systems. The second part will be built on the knowledge acquired in the first part of the course and will teach specific methods for dealing with the challenges of distributed MPC. Examples of applications from various domains will be provided.

Contents

Lecture 1: INTRODUCTION & LINEAR MODEL PREDICTIVE CONTROL (MPC).

- Principles of MPC, introduction to MPC books and toolboxes used in the course.
- Building blocks of linear MPC, QP solvers for MPC, stability and recursive feasibility, computation of terminal costs and terminal sets (refreshers on Lyapunov theory for discrete-time systems and positively invariant sets, active set methods for QP, will be included).

Lecture 2: TRACKING AND TUBE-BASED MODEL PREDICTIVE CONTROL.

- Design of linear MPC for tracking with recursive feasibility and stability guarantees.
- Computation of terminal costs and sets for tracking using lifted dynamics.
- Design of tube-based MPC for linear systems with additive disturbances bounded in a polytope.

Lecture 3: INTRODUCTION TO DISTRIBUTED MODEL PREDICTIVE CONTROL (DMPC) & LAGRANGE-BASED DMPC ALGORITHMS

- From centralized to distributed control, examples of applications.
- Cooperative/non-cooperative DMPC
- Lagrange-based DMPC algorithms: dual ascent, dual decomposition, alternating direction method of multipliers (ADMM), and introduction to ALADIN.

Lecture 4: COOPERATION-BASED DMPC (REGULATION AND TRACKING) & EMERGING TOPICS

- Cooperation-based DMPC based on Gauss-Jacobi iterations.
- DMPC for tracking
- Tube-based MPC to deal with mutual disturbances
- Other topics in DMPC: time-varying partitioning/coordination, plug-and-play, cyber-security.

For further studying numerical methods for solving nonlinear MPC problems, we recommend the DISC course Numerical Optimal Control. For further studying data-driven predictive control methods, we recommend the DISC course Data Driven Control.

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.

Prerequisites

Following the MPC course will require some background knowledge in convex optimization, discrete-time state-space systems, Lyapunov functions, linear algebra. 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.