New Subject Proposal (PG-Elective)

Model Predictive Control with Applications

Designer: Dr. Ashish Ranjan Hota, Department of Electrical Engineering.

Introduction: *Predictive Control* is a framework for optimization-based control of constrained dynamical systems. Predictive control repeatedly solves a finite-horizon optimal control problem relying on the prediction of future trajectory of the system states and uncertainty, primarily based on an underlying model. The first of the sequence of inputs computed by solving a look-ahead (or feedforward) optimization problem is applied, the system is allowed to evolve to the next time step, and the process is repeated. Due to the reliance on models, this framework is popularly known as *Model Predictive Control (MPC)* or *Receding Horizon Control (RHC)*. This framework has several advantages of over dynamic programming (DP) based optimal control approaches, including explicit constraint handling, computational tractability (MPC does not suffer from the curse of dimensionality that are inherent in DP based techniques), and guarantees on closed-loop stability.

While MPC has traditionally seen widespread applications in the process control industry, recent years have witnessed the application of MPC schemes in a wider set of domains such as *transportation* (e.g., air traffic control, energy management of hybrid electric vehicles), *energy* (e.g., control of micro-grids, advanced building energy management), *power electronics* and *robotics* [Mesbah, 2016].

In parallel, there has been substantial progress in the theory of MPC in the past decade, particularly in the context of uncertain systems leading to the sub-fields of robust and stochastic MPC. Recent research has also focused on computational tractability, data-driven algorithms, and distributed MPC.

Learning Objectives: This subject is proposed as a **post-graduate** level **elective** subject. It is relevant for both M.Tech. and Ph.D. students from the Department of Electrical Engineering as well as the Department of Chemical Engineering, Department of Aerospace Engineering, Department of Mechanical Engineering, Advanced Technology Development Center and School of Energy Science and Engineering. Both classical as well as the above mentioned recent developments in this field will be covered. The detailed content of the proposed subject is presented in Table 1. At the end of the subject, it is expected that the students will

(i) have a thorough grasp on the theory of MPC for both deterministic as well as uncertain systems,

(ii) be able to formulate and compute various MPC schemes in MATLAB,

(iii) demonstrate the application of this control technique in an application via a group project,

(iv) have an exposure to the recent literature and open problems in this field, and

(v) be able to compare and contrast with DP-based methods and determine which method is appropriate for a given problem.

Proposed hours: 3-0-0. In addition to the theory component, MATLAB demonstrations will be an essential part of this course. In the first half of the course, the working principle of MPC will be demonstrated. In the second half, a case study on any one of the application domains mentioned above will be carried out where both classical as well as advanced predictive control methods will be demonstrated.

Project Component: The group project is an essential component of the subject in order to enable the students to formulate and solve problems they encounter in their research via MPC. It is expected that the students will choose the project in their own research field in consultation with their research supervisors.

Pre-requisites: Control Theory (EE60011), Estimation of Signals and Systems (EE60013) or permission from the instructor. Familiarity with MATLAB is essential to make the most of this course. Background in optimization will be beneficial, but not strictly required.

Topics to be covered	Duration
Module 1: Review of (Convex) Optimization	**2 weeks**
Introduction to Optimization, Convex Sets and Functions, Linear Programming (LP) Quadratic Programming, Convex Optimization, Lagrangian Duality. **Demonstration:** Familiarity with CVX/YALMIP environment in MATLAB.	2 weeks
Module 2: Deterministic Model Predictive Control (MPC)	**3 weeks**
Review of State-Space Model of Linear Dynamical Systems, Motivating applications, Introduction to deterministic MPC, Quadratic Programming (QP) formulation for linear dynamical systems, quadratic cost functions and polyhedral constraints. Comparison with Dynamic Programming and Linear Quadratic Regulation.	2 weeks
Choice of time-horizon and terminal cost, Closed-loop stability	1 week
Demonstration: Deterministic MPC for linear systems and quadratic cost. The effects of horizon length, and choice of terminal cost.	
Module 3: MPC with Output Feedback and Moving Horizon Estimation	**2 weeks**
Study of MPC with output feedback and moving horizon estimation Closed-loop stability considerations **Demonstration:** Formulate an application as a MPC problem.	2 weeks
Module 4: Robust Model Predictive Control (RMPC)	**2 weeks**
Open-loop vs. (affine disturbance) feedback policy, Worst-case or min-max MPC	1 week
Tube-based RMPC, Closed-loop stability	1 week
Demonstration: Demonstrate both RMPC approaches in the application.	
Module 5: Stochastic Model Predictive Control (SMPC)	**3 weeks**
SMPC via Chance constraints, Direct reformulation, Data-Driven and Scenario optimization	2 weeks
Stochastic Tube-based MPC, Stability	1 week
Demonstration: Demonstrate the above SMPC approaches in the application.	
Module 6: Advanced Topics	**2 weeks**
Computational challenges, Explicit control laws	1 week
Discussion on MPC for Hybrid (switched linear) and Nonlinear systems.	1 week
Demonstration: Demonstrate a selection of the above approaches via MATLAB. Group project presentations.	

Table 1: Detailed Content of the Proposed Subject

Related Subjects: The proposed subject is complementary to the courses: *Optimal Control (EE60012)*, *Convex Optimization in Control and Signal Processing (EE61012)*, and *Process Dynamics and Control (CH61016)*. Less than 15% overlap with each of them.

Instructors: Dr. Ashish Ranjan Hota, Dr. Arun Ghosh and Dr. Sourav Patra, all from the Department of Electrical Engineering.

References: Textbooks [Borrelli et al., 2017, Camacho and Bordons, 2016, Rawlings et al., 2019] as well as relevant research papers.

References

Francesco Borrelli, Alberto Bemporad, and Manfred Morari. *Predictive Control for Linear and Hybrid Systems*. Cambridge University Press, 2017.

Eduardo F Camacho and Carlos Bordons. *Model Predictive Control: Classical, Robust and Stochastic*. Springer International Publishing, 2016.

Ali Mesbah. Stochastic model predictive control: An overview and perspectives for future research. *IEEE Control Systems*, 36(6):30–44, 2016.

James B. Rawlings, David Q. Mayne, and Moritz M. Diehl. *Model Predictive Control: Theory, Computation, and Design*. Nob Hill Publishing, LLC, 2019.