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Model Predictive Control in two days: Educating a new way of thinking

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Abstract: In this paper, a two-day workshop on Model Predictive Controllers (MPC) is developed and practiced. The goal is to introduce the concept of MPC in an easy and motivating fashion, so that at the end of the second day not only the students are familiar with the basics of the MPC, but also are capable of indipendently program, tune and observe the performance of the MPC for their various applications. The course is mainly designed for the students with basic control engineering background and elementary Matlab/Simulink experience.

Keywords: Workshop, Model Predictive control, Process Control, Kalman Filter, Education, Tutorial

1. INTRODUCTION

Model Predictive Controllers (MPC) are a highlight in academia as well as in industry. A high number of defined subjects for master and bachelor theses in the research groups and university institutes involve MPCs. These subject is not only a compulsory for the researchers, but also an essential topic for the students, who seek to promote their job opportunities. On the other hand, there are a huge number of publications in this field. Most of them are either highly theoretical or specifically focused on an application of MPC on certain systems. For many students the first step towards understanding the MPC is confusing and demanding. To overcome these problems and ease the begining phase in understanding the MPC, the Institute of Automatic Control of RWTH Aachen university has offered a two-days workshop for the students and Ph.D. candidates. The workshop contains basic lectures where the theoretical background of MPC is presented, several tutorials, in which the students must improve and complete a template run the program, retune it and observe the results in a well-posed graphical representation. Within the workshop the students are provided with a simple in-house MPC-toolbox containing linear MPCs for stable and unstable plants with linear models. There are many approaches to introduce MPC depending on the audience and the goal of the course. One of the most practical references in MPC is Borrelli et al. (2013), where the authors start the basics of Optimization and introduce Linear and Quadratic optimization. Another approach is chosen by Maciejowski (2002), in which the main elements of MPC, its advantages and elements are first described. A similar flow is introduced by Rossiter (2014), which is a series of videos. The first video is entirely dedicated to what is supposed to be designed in MPC above the formulations and equations. The main idea in these set of videos is that the model predictive controllers are mainly a way of thinking and approaching the problem rather than a specific strategy. Next, different scenarios are introduced, in which an obvious analogy between human reaction to daily events and the process of decision making in MPC is depicted. This analogy is tangible and prompting for the students to be mentored placidly in the subject of optimization based control.

2. REQUIREMENTS

The workshop is designed for master students and PhD candidates, who have a background of control engineering. The prerequisite for the workshop are the courses *Control Engineering* for the students from mechanical engineering, *Process Automation* for the students from chemical engineering and *System and signals Theory* for students from Electrical Engineering. It is mainly because being familiar with the feedback mechanism in the conventional control loops ease the understanding of the role of the MPC in a control loop.

Additionally, being familiar with state space representations of the systems is required, as this workshop mainly involves the Dynamic Matrix Controller(DMC), which uses the state space model of the system. However, the students from applied physics, who have enough overview about analytical modeling and Ordinary Differential Equations (ODE) are also eligible to attend the course. Yet at the enrollment these students are advised to get familiar individually with the state space representation of the systems.

The workshop takes place in a computing site of RWTH Aachen university with around fifty workstations. Students are provided with Matlab 2014b, Mex-Compiler, which is required for online optimization, and a shared network, in which the template of the tutorials and the course materials are available.

3. CONTENTS

This Workshop is consisting of six capital lectures and four tutorials depicted in Fig. 1. The last lecture focuses on the

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introduction of different types of MPC, such as Stochastic, Nonlinear, Distributed and Hybrid MPC, unlike the other lectures which are concentrated directly on the linear MPC.

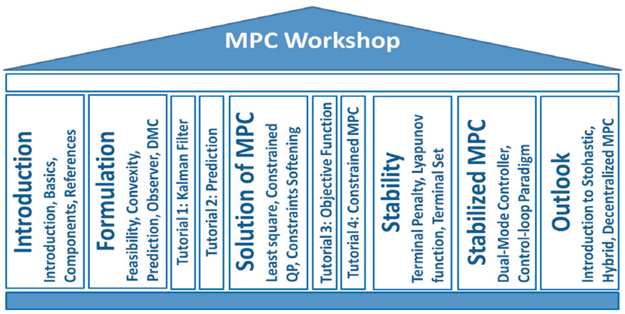

Fig. 1. The content of the MPC workshop.

3.1 Lecture 1: What is MPC?

A similar approach to Maciejowski (2002) and Rossiter (2014) is used to help the participants to understand on one hand the logic of MPC and on the other hand how different elements of MPC are structured to follow its concept. The introduction of the mathematical definitions and basics of the optimization, as introduced in Borrelli et al. (2013), is put off to the second lecture to avoid the students of being overwhelmed with excessive amount of theoretical definitions. In the following the main elements of the MPC is introduced (Fig. 2)

(1) Prediction
(2) Model
(3) Performance Index
(4) Constraints
(5) Degrees of freedom
(6) Receding Horizon

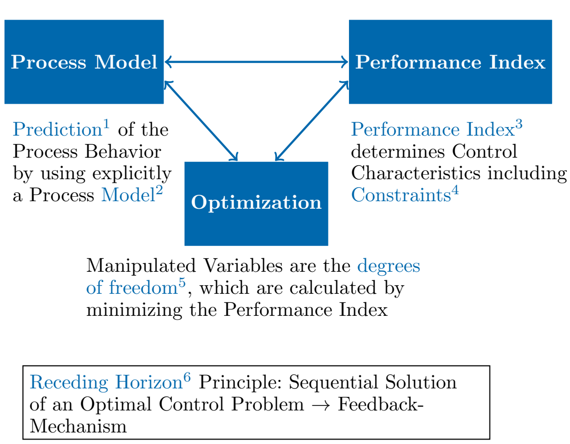

Fig. 2. The general structure of the workshop

Graphical Example As an example, a three-thank system with nonlinear valves is introduced. The system is simulated in a virtual reality environment (Fig. 3).

Using the VR-Toolbox in Matlab, the important variables of the system are connected to the model in Matlab/Simulink. The nonlinear system is then modelled in Matlab/Simulink 4. The model and simulation is available for the students to observe the controller performance graphically.

3.2 Lecture 2: MPC in practice and formulation

In introducing the objective function of a typical MPC-DMC, it is essential to convince the students that the quadratic objective function, which is widely used as the objective function, is fulfilling all the requirements. In practice, the objective function should satisfy the following requirements:

(1) At least one time differentiable, with a linear first derivative.
(2) Form a convex optimization problem.

Convexity and feasibility The student should be convinced that the combination of a quadratic cost function, a linear model and a set of linear constraints, forms an optimization problem which is convex and has a unique optimizer. Here, it is important to introduce some basics definition of the convexity and feasibility. In introducing these definitions, the approach of (Borrelli et al., 2013) is followed. It is of importance that the students have a graphical understanding of how a linear or quadratic objective function looks like, when subject to the set of constraints. (Borrelli et al., 2013) have provided a solid stage for optimization , which is followed in this workshop.

Prediction Prediction is the first step in MPC implementation. In order to understand how the future behavior of the system is predicted, the students should be familiar with the state space representations of linear systems. In most of the common control theory lectures the state space representations of the system is thoroughly explained. Therefore, this workshop is designed based on the assumption that the students are familiar with the following presentation:

$$x_{k+1} = Ax_k + Bu_k \tag{1}$$
$$y_k = Cx_k \tag{2}$$

The augmented state-space representation with the disturbance model is a MPC/DMC compatible representation, which is the basic of the linear offset-free MPC. In this representation, a constant output disturbance is added to the vector of states, which represents the model mismatch and not measured disturbances. Rawlings (2000) tutorial overview of model predictive control is a recommendable tutorial for the beginners on offset-free-MPC formulation with disturbance model.

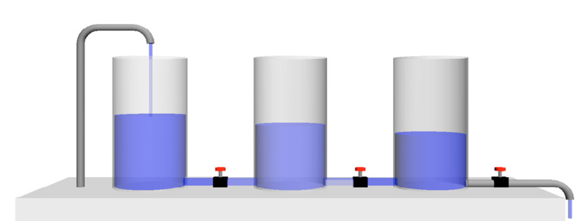

Fig. 3. The system is simulated in a virtual reality environment.