Review of dissertation:
Eva Žáčeková, "Identification for Model Predictive Control under Closed-loop Conditions".

Overall positioning of the research

This thesis contributes to the area of data-driven modeling and model-based model-predictive control (MPC) of industrial dynamic processes. It connects to an important and highly relevant development that was started in the 1990s, of relating the modeling and model-based control problems to each other. In other words: to define and utilize performance criteria for modeling that are derived from the goal of the modeling step, i.c. the design of model-based controllers. One of the central phenomena in this connection of problems, is the observation that process data are typically obtained in closed-loop circumstances, with the controller being active, and that models should accurately represent the control-relevant aspects of the dynamical systems. While the research in this domain has started more than 25 years ago, some basic contributions have been made, but also important questions still remain open. I consider the research in this domain to be highly relevant both from a scientific and from a technological point of view. The MPC technology is a well-spread technology in many domains of applications; however the question how to maintain appropriate dynamic models during real-time MPC operation is still a challenge.
In this thesis the candidate connects to the two important problem aspects:

(1) The identification of (MPC) control-relevant models, and

(2) The design and operation of controllers while guaranteeing enough excitation in the control-loop for appropriate model re-identification.

In both aspects a particular and principle line of reasoning is selected that is further elaborated. For aspect (1) this is the attention for multi-step ahead prediction error models, that are claimed to be more appropriate for use as a basis for MPC control. For aspect (2) this is a formulation of the (receding horizon) optimal control problem under additional constraints on the informativeness of the data for identification purposes, translated into a full rank condition on the (incremental) empirical information matrix. In this latter line of reasoning, different types of algorithms are developed (one sample algorithm, gradient algorithm, semi-receding horizon principle algorithm) to further explore operational and computational aspects of the approach.
Although the breadth of both mentioned aspects is not really exploited in its full terms, the two chosen lines of reasoning are worked out well, analyzed and exploited in real-life modeling and control problems.

Main goal of the research

The main goal of the thesis has been formulated as: "to provide a methodology for obtaining the mathematical models in real life conditions in such a way that *i)* the identified models are appropriate for use with MPC (i.e. they have bounded complexity and attractive prediction behavior; and *ii)* considering economical, operational and time aspects, the whole identification process is as modest as possible."

Given the particular chosen lines of reasoning in both aspects mentioned above, the goal of the research has been addressed.

Strengths of the presented work

The candidate has developed effective and innovative algorithms for both control-relevant identification and for MPC with guaranteed excitation, and has paid proper attention to real-time implementability of these methods. Additionally real-life application of some of the techniques in

a building climate control system show the validity of the developed approaches. The thesis, and the papers on which it is based, are well structured and well-written.
The technical part of the thesis is based on three journal publications in *Applied Energy, Control Engineering Practice*, and *Journal of Process Control.* Since the latter two are in my domain of expertise, I can state that these journals are among the highly ranked journals in the field. In addition, there are conference papers in IEEE CDC, IEEE CAA (both being highly ranked international conferences), and one journal paper (Franklin Institute) under review.

Limitations and connections
As mentioned above, the two major aspects of the research have been developed along rather particular and somehow narrow lines. While the research deals with data-driven identification on the basis of closed-loop data, the consequence of this for the chosen identification methods seems to be left undiscussed, giving priority to the control-relevance of models in terms of the multi-step ahead prediction. This is e.g. reflected in the limited attention for the considered noise models. In the second aspect (2), informativeness of the data, presumably leading to model identifiability, is not related to the control-relevance of the models that are required for updating the MPC controller. In both aspects it seems that there is a "system in the model set" type of reasoning, rather than a philosophy of the model being an approximation of the underlying system; this is however not extensively discussed (if I am correct).
Relevant connections of this work could be made to the work on least-costly experiment design for control (X. Bombois et al., 2006) and also to the work of Larsson et al. (2013, 2016) on MPC-x. Given the timing of the work of the candidate, and observing that her main publications on MPC with guaranteed persistent excitation are from 2013 and 2014, the work of Larsson may have come too late to connect to in a more extensive way.

Additional Review questions

- To what extent the subject of the thesis is relevant to the current needs of the scientific community?
  The research is highly relevant both from a scientific and a technological point of view. Properly maintaining models and controllers in an MPC setting is a highly challenging and most important research question.
- To what extent the main objectives of the work have been fulfilled?
  The main objectives have definitely been addressed, including aspects of real-time operability, as witnessed by the real-life applications.
- To what extent the methods used in the thesis are appropriate?
  The methods are appropriate, but there may still be room for further developments in this domain.
- What the main results and contributions of the work are?
  See my earlier text.
- To what extent the work is important for the further development of science?
  See my earlier text.
- Whether the thesis satisfies the conditions of a creative scientific work.
  Yes it does.

The author of the thesis has proved to have an ability to perform research and to achieve scientific results. I do recommend the thesis for presentation with the aim of receiving a Ph.D. degree.

Paul M.J. Van den Hof, 14 January 2019.