Real-time optimization and control with inaccurate models

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Modelling for simulation, modelling for optimization, and modelling for control follow the same principles, but have to meet different requirements. Simulation models should represent the behavior of the system under consideration for a predefined set of test cases faithfully, with the accuracy usually being measured in the time domain, i.e. by looking at the differences of the stationary values or trajectories of some key variables. Modelling for optimization is different in that the goal is that the computed optimum of the model and the optimum of the real system should match, and the model should support efficient global numerical optimization. This implies that the model must be accurate around the global optimum, but over the full range of the variables, a medium accuracy is sufficient. The problem for modelling of course is that without the knowledge of the region of the global optimum, it is not possible to build such a model, and hence modelling and optimization should be interleaved.

When using models for control, the relationship between model accuracy and control performance is even more intricate than for optimization. One can control a plant satisfactorily using a coarse model (in the simplest case, the sign of the gain is sufficient), while model errors can also lead to poor performance and instability. For linear time-invariant control loops, the classical robust control theory from the 1980s tells us that a good model for control is a model that describes the dynamic behavior accurately near the gain-crossover frequency, and qualitatively correctly for lower frequencies. So what a good model is for the purpose of control depends on how fast we want to control the system.

For high-performance control, techniques based on online optimization, i.e. model-predictive control (MPC) have become the dominant technology in the last decades, due to their ability to handle constraints, nonlinear systems, and economically motivated cost functions (Engell, 2007). In contrast to the classical theory of robust control, robustness to model errors for such control strategies is difficult to analyze and, similar to stability, is usually handled using a constructive approach, i.e. by building controllers that have certain robustness properties for a given description of the uncertainty of the model. min-max robust MPC in which the performance is optimized for the worst case model is the best known representative of this approach. This however comes at the price of a high conservatism.

To build good models is a costly endeavor. Therefore, both in modelling for optimization and in modelling for control, one is interested in techniques that provide good performance without huge modelling efforts. In the presentation, we discuss two recent approaches to reducing the negative effects of model errors in optimization and control. For real-time optimization, we outline the so-called modifier adaptation approach, which adds a data-based local model to a global model and updates it iteratively to ensure convergence to the true optimum of the real plant (Gao and Engell 2005, Gao, Wenzel and Engell, 2016). For control, the multi-stage MPC approach is discussed in which the future information on the realization of the model uncertainty is included in the optimization that is performed at the current time step to reduce the conservatism of the controller (Lucia, Finkler and Engell, 2013).

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