Interval-Based Model-Predictive Control for Uncertain Dynamic Systems with Actuator Constraints

Andreas Rauh, Julia Kersten, Thomas Dötschel, and Harald Aschemann

Chair of Mechatronics
University of Rostock
D-18059 Rostock, Germany
{Andreas.Rauh,Julia.Kersten,Thomas.Doetschel,Harald.Aschemann}@uni-rostock.de

Abstract

Model-predictive control approaches are well-known means to stabilize dynamical systems and to compute input signals online which allow for the tracking of desired state trajectories. These control procedures, which are partially implemented by means of algorithmic differentiation, are inherently robust and can, therefore, be used to compensate unknown disturbances to some extent [1, 2]. This holds even if the disturbances are neglected during the derivation of the predictive control strategy. Besides tracking desired state trajectories, model-predictive controllers can be employed to enhance the overall system performance by the minimization of suitable cost functions in real time. These criteria typically take into account the control effort in addition to the deviation of the state variables (or system outputs) from their corresponding desired values. In such a way, it becomes possible to compute control strategies online which account for both influence factors simultaneously.

In this presentation, an overview of different verified extensions is given for the design of model-predictive control strategies. These controllers are implemented by applying interval arithmetic procedures in real time. In such a way, the influence of uncertain parameters and measurement uncertainties, which can be described by interval vectors, can be taken into account directly. This allows one to design control laws which definitely prevent the violation of predefined tolerance intervals around the desired state trajectories. Additionally, the application of interval arithmetic procedures gives the possibility for an online redesign of desired trajectories if the violation of the above-mentioned tolerance intervals cannot be avoided due to the activation of actuator saturations [3, 4].

The corresponding computational procedures are described both for a simple illustrative example and for the control of the thermal behavior of high-temperature fuel cell stacks. This application scenario is characterized by the fact that internal parameters can be determined only within certain intervals due to the necessity to use mathematical system models that can be evaluated in real time. Furthermore, temperature uncertainty due to limited measurement facilities in the interior of the fuel cell stack can be expressed by interval parameters in a natural way. Finally, interval parameters describe disturbances resulting from the variation of electrical load demands which are a-priori unknown to the controller. Under consideration of these uncertainties, a reliable control strategy has to be implemented in such a way that the range of technologically feasible input values is not violated.

Like any other interval arithmetic procedure for the evaluation of dynamic system models (either discrete-time or continuous-time initial value problems), interval-based predictive control procedures suffer from overestimation resulting from both the dependency problem and the wrapping effect. In the case of predictive control procedures, this overestimation may lead to control strategies which are more conservative than necessary. To detect overestimation in the interval evaluation of the predictive control procedure, physical conservation properties (derived on the basis of the first law of thermodynamics) can be exploited in an algebraic consistency test that can be evaluated in real time in parallel to the computation of the control law. The derivation and implementation of such consistency tests is a topic of our current research.

References

[1] Y. Cao. A Formulation of Nonlinear Model Predictive Control Using Automatic Differentiation. *Journal of Process Control*, 15:851–858, 2005.

[2] Y. Cao and W.-H. Chen. Automatic Differentiation Based Nonlinear Model Predictive Control of Satellites Using Magneto-Torquers. In *Proc. of IEEE Conf. on Industrial Electronics and Applications, ICIEA 2009*, pages 913–918, Xi'an, China, 2009.

[3] A. Rauh, J. Kersten, E. Auer, and H. Aschemann. Sensitivity Analysis for Reliable Feedforward and Feedback Control of Dynamical Systems with Uncertainties. In *Proc. of 8th Intl. Conference on Structural Dynamics EURODYN 2011*, Leuven, Belgium, 2011.

[4] A. Rauh, J. Kersten, E. Auer, and H. Aschemann. Sensitivity-Based Feedforward and Feedback Control for Uncertain Systems. *Computing*, (2–4):357–367, 2012.