Economic Multi-stage Output Feedback Nonlinear Model Predictive Control based on the Innovations Sampling using Unscented Kalman Filter

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Abstract: Nonlinear Model predictive control (NMPC) is a popular control strategy for highly nonlinear chemical processes. The ability to handle safety and environmental constraints along with the use of an economic objective makes NMPC highly appealing to industries. The performance of the NMPC depends highly on the accuracy of the model. In reality, there is plant-model mismatch and estimation error. Hence the NMPC controller must be robust to uncertainties in the model as well as the estimation error. Among the several approaches presented in the literature, the scenario-tree based multi-stage NMPC approach is a non-conservative alternative. In this approach, the evolutions of the plant for different realizations of the uncertainties are considered as different scenarios and this formulation results in multi-stage stochastic programming. This can be solved in real-time using efficient numerical tools.

In this work, we propose an output feedback multi-stage NMPC approach using Unscented Kalman Filter (UKF) where the nonlinearities are represented using deterministically chosen sigma points. In this output-based method, we consider the UKF estimation equations to predict the future evolution of the system. The innovations are the new information from the measurement used to update the predicted state using the system model. The innovations for the properly tuned filter can be represented as White Gaussian Noise (WGN). We model the samples of innovations as new scenarios in the scenario tree in addition to the parametric uncertainties and we use the UKF estimation equations for the evolution of the future states along with the covariance information. In this approach, we explicitly take into account that the measurements are available at later time-stages and the future control actions at those stages can make use of the then available measurement information. This feedback information not only makes the approach less conservative but also helps in the propagation of covariance information along the possible future realization of the states for all possible scenarios. Based on the covariance of the state estimate along the prediction horizon for all scenarios, the prediction of the Kalman gain at all time-stages is possible leading to a good predicted state estimate. The proposed approach is thus robust to plant-model mismatches and to estimation errors. The proposed approach is illustrated by simulation results of fed-batch nonlinear chemical reactor with an economic cost function.

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