Control of a Dynamic Bioreactor with Automated Back-Off Calculating Nonlinear MPC: An Easy Example for Increased Process Safety

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Abstract: In this work a case study of a dynamic continuous stirred-tank reactor (CSTR) with a multi-component system is controlled with nominal nonlinear model-predictive control (NMPC) and then compared with a robust NMPC formulation. The nominal NMPC is designed in such a way that it acts as a baseline solution. The robust NMPC will use the automatic back-off calculation NMPC (ABC-NMPC) formulation described by Krog (2024).

The goal is to showcase the robust ABC-NMPC formulation and its capability of increasing process safety by staying within critical process constraints. The ABC-NMPC features uncertainty predictions for an explicit back-off calculation based on parameter uncertainties. Herein considered are uncertainties in parameters that are most relevant for potentially safety-critical control variables of the system. As opposed to deterministic predictions with confident parameter assumptions, which is done by the nominal NMPC implementation, the ABC-NMPC respects the uncertainty in these variables, accounting for the diversity of possible outcomes under the given parameter uncertainty to predict a new safety margin (back-off) using Monte Carlo simulations of the plant model, proportional to the existing uncertainty in the system.

The ABC-NMPC formulation is chosen as robust NMPC formulation as it is a theoretically simple method with good quality of results in comparison to the added layer of complexity. The implementation iterates between a standard NMPC module and an uncertainty analysis module with MC-simulations which adds a minor amount of computational cost and complexity. This is deemed acceptable when weighed against the gain in robustness. Processes with a higher inherent risk involved than the presented case study (i.e. Hydrolysis of water for hydrogen generation) are believed to be suited to be controlled by the ABC-NMPC formulation.

Keywords: Nonlinear Model Predictive Control, Robust Model Predictive Control, Chemical Process Control, Continuous Stirred-Tank Bio Reactor

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DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work the author(s) used Claude Sonnet 4.6 in order to refine formulations and improve the structuring of the written text. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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