Robust control applied to a continuous bioreactor of purple bacteria

Matheus C. R. Nunes, Laurent Dewasme, Alain Vande Wouwer
Systems, Estimation, Control and Optimization (SECO), University of Mons, Belgium
Email: matheus.camargoromanonunes@umons.ac.be

1 Introduction

This study investigates the application of a tube-based nonlinear model predictive controller (tube-MPC) to a continuous bioreactor with constant volume (chemostat) for the production of purple non-sulfur bacteria (PNSB). The mathematical model is derived using limited data due to economic restrictions, leading to large parameter uncertainties despite the satisfactory fitting of the experimental data. To limit this drawback, a robust control scheme is implemented based on tube MPC. This approach is validated by a Monte-Carlo study, which tests 100 different scenarios.

2 Mathematical model

Based on the work of (1), a four-state mechanistic model is established to predict the growth of PNSB biomass (X) on glucose (G) and fructose (F), associated with protein (P) formation. The model is defined by Monod-like equations, and the estimation of 4 stoichiometric and 4 kinetic parameters, presented in Table 1, is achieved using a weighted least squares method. The root-mean-square errors (RMSE) are satisfactory with values of 0.0133, 0.0270, 0.123, and 0.125 for F, P, G, and X, respectively. However, the calculation of 95% confidence intervals (CI) shows high parameter variability, up to more than 4000% in the worst case.

Table 1: Estimated parameter values and confidence intervals.

Parameter	Estimated value	CI (%)
μ_{max_1} (h^{-1})	0.0838	636
μ_{max_2} (h^{-1})	0.0198	95.0
K_1 (g L^{-1})	0.181	4514
K_2 (g L^{-1})	1.40	150
Y_f (g g^{-1})	2.37	31.0
Y_g (g g^{-1})	0.925	17.0
Yp_1 (g g^{-1})	0.496	0
Yp_2 (g g^{-1})	0.269	985

3 Robust control design and validation

Tube MPC proceeds in two steps (2): first, a nominal MPC computes the optimal state and input trajectories, considering the nominal model parameter set. Then, an ancillary controller uses the latter results, combined with the process measurements, to compute the optimal disturbed state and input trajectories. To assess the robustness performance of the tube MPC, a standard MPC is first applied to regulate the glucose concentration at two different levels. The results consider a Monte Carlo analysis, in which random parameter sets are generated within their confidence intervals. Standard MPC yields a considerable spread of the trajectories while the tube MPC maintains the trajectories in tighter corridors (or tubes), as illustrated in Fig. 1.

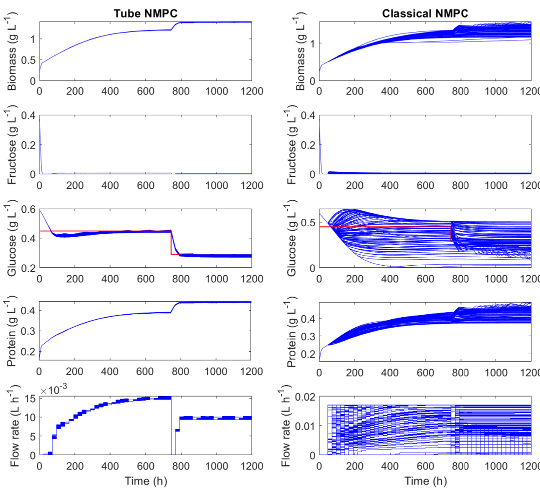

Figure 1: Monte Carlo simulation results for the tube MPC (left column) and classical MPC (right column).

References

[1] Fekih-Salem, R., Dewasme, L., Castro, C.C., Nobre, C., Hantson, A.L., and Vande Wouwer, A. (2019). Sensitivity analysis and reduction of a dynamic model of a bioproduction of fructo-oligosaccharides. *Bioprocess and biosystems engineering*, 42, 1793–1808.

[2] Mayne, D.Q., Kerrigan, E.C., Van Wyk, E., and Falugi, P. (2011). Tube-based robust nonlinear model predictive control. *International journal of robust and nonlinear control*, 21(11), 1341–1353.

Acknowledgment The research leading to these results has been funded by the Public Service of Wallonia (Economy, Employment and Research), under the FoodWal agreement n°2210182 from the Win4Excellence project of the Wallonia Recovery Plan.