Department of Electrical Engineering and
Information Technology
Automatic Control Group
https://en.ei.uni-paderborn.de/de/rat/

Proposal for a Master's Thesis Project

Data-driven model predictive control of a flapping-wing system

Background

Deriving accurate and time-efficient models for flapping-wing flying vehicles has proven to be a difficult task. This is mainly due to the complex flight dynamics characteristics of the nonlinear and time-dependent aerodynamics and structural dynamics of flapping wings. It is shown in [1] that the whole set of trajectories, generated by a linear system, can be represented by a finite set of its past trajectories. Instead of requiring a prior identification step, we can directly use the data measured from the past trajectories to design the controller for the system. There are several works following this idea, which have proposed data-driven MPC, e.g. [2], as well as attempts to extend the framework to the case of nonlinear systems.

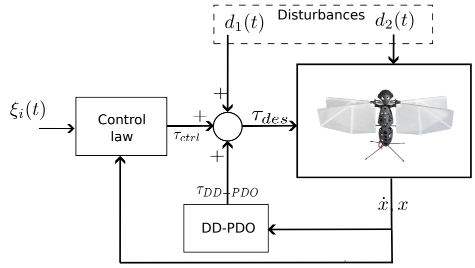

Figure 1: task i). d_1 and d_2 represent model uncertainties and external perturbations, respectively. $\xi_i(t)$ states for the desired trajectories to be tracked and $\tau_{ctrl}, \tau_{DD-PDO}$ and τ_{des} are the nominal, compensated and desired control inputs.

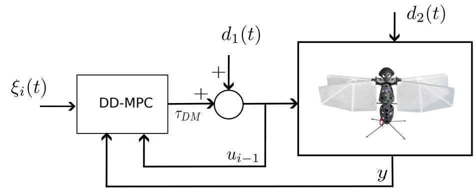

Figure 2: DD-MPC framework. u_{i-1} and y depict the past control input and the output of the system.

Thesis Goals

In this thesis, the student will investigate the data-driven approach by using Willems' lemma [1] and extend the results to design and implement a data-driven model predictive control (DD-MPC) for nonlinear MIMO systems. Different methods to cope with online data that are not persistently exciting will be addressed. The analysis will be done for the flapping-wing system.

Intermediate Goals

- Literature review of DD-MPC approache [2].
- Design the control DD-MPC framework in two steps: i) consider the case that a nominal controller stabilizes the flapping-wing system. Thus, a data-driven predictive disturbance observer should be developed to deal with the uncertainties of the model, see Fig 2. This will be investigated inspired by the work presented in [3]. ii) Consider the full control of the flapping-wing system shown in Fig. 2.
- Implementation of tasks i) and ii) in simulations.
- Real-time test of the proposed framework architecture in the flying arena.

Knowledge

Required:
- System theory, control theory, basics of optimization.
- Good programming skills (Python, ROS).
- Knowledge of MPC is a plus.
- Enthusiasm for learning.

Not required, but a big +:
- Experience in real-time experiments with drones.

References

[1] J. C. Willems, P. Rapisarda, I. Markovsky, and B. L. De Moor, "A note on persistency of excitation," *Systems & Control Letters*, vol. 54, no. 4, pp. 325–329, 2005.

[2] J. Berberich, J. Köhler, M. A. Müller, and F. Allgöwer, "Data-driven model predictive control with stability and robustness guarantees," *IEEE Transactions on Automatic Control*, vol. 66, no. 4, pp. 1702–1717, 2021.

[3] D. Müller, J. Feilhauer, J. Wickert, J. Berberich, F. Allgöwer, and O. Sawodny, "Data-driven predictive disturbance observer for quasi continuum manipulators," in *2022 IEEE 61st Conference on Decision and Control (CDC)*, pp. 1816–1822, 2022.

Contact: Julio Betancourt, julio.betancourt@uni-paderborn.de, Room: P1.7.14.5