Data-driven rational LPV controller synthesis for unstable systems using frequency response functions

Data-Driven Rational LPV Controller Synthesis for Unstable Systems using Frequency Response Functions

Tom Bloemers[1], Roland Tóth[1] and Tom Oomen[2]
[1]Department of Electrical Engineering, Eindhoven University of Technology
[2]Department of Mechanical Engineering, Eindhoven University of Technology
Email: {t.a.h.bloemers, r.toth, t.a.e.oomen}@tue.nl

1 Introduction

The current state-of-the-art control design techniques for Linear Parameter-Varying (LPV) systems rely on the availability of parametric models of the to be controlled system. In practice, these models can be difficult to obtain and are often too complex for control design. Although data-driven controller synthesis based on Frequency Response Functions (FRF) enables a systematic design approach within the LTI framework, at present these methods are limited when applied to LPV systems. In [1], first steps towards data-driven frequency domain controller design for LPV systems have been presented. Here an LPV finite impulse response controller is synthesized, where stability is characterized in terms of a Nyquist constraint.

2 Problem formulation

Many control systems are operating condition dependent, for example a nonlinear system that operates along a trajectory. This dependency is here represented by a scheduling variable $p[k] \in \mathbb{P}$, where $\mathbb{P}$ is the scheduling domain. The goal is to synthesize a data-driven fixed-order rational LPV controller $K = RS^{-1}$, depicted in Figure 1, for which the signal relations are as follows:

$$u[k] = \sum_{j=0}^{n_r} r_j(p[k])e[k-j] - \sum_{i=1}^{n_s} s_i(p[k])u[k-i], \quad (1)$$

where the controller coefficient functions r and s are evaluated along the trajectory of p.

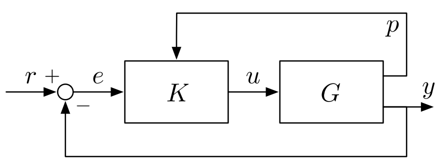

Figure 1: LPV representation of the closed-loop interconnection. K is the LPV controller and G is a nonlinear system.

3 Methodology

Inspired by [1, 2], the main contribution of this paper is a synthesis procedure for rational LPV control design for unstable systems, based on so-called frozen FRFs. The main idea is to factorize the plant and controller as coprime factorizations over $\mathcal{RH}_\infty$ and utilize the main-loop theorem to derive convex conditions on local stability and $\mathcal{H}_\infty$ performance.

This work has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement nr. 714663).

4 Results

The resulting approach is applied to an inverted pendulum, where the angular position of the pendulum introduces nonlinear dynamics. A 5th order controller is designed where the coefficient functions r and s are chosen to have affine static dependence on the scheduling p. The proposed method results in a stabilizing controller that achieves sufficient performance around the operating points, for which the step responses are shown in Figure 2.

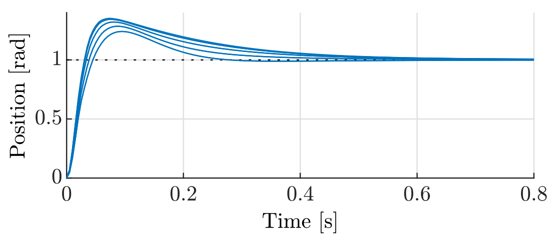

Figure 2: Local step responses of the inverted pendulum using 5th order rational data-driven LPV control design. The step responses are evaluated on a grid $\mathcal{P} \subset \mathbb{P}$ consisting of 9 grid-points.

5 Outlook

Currently, the proposed data-driven LPV synthesis guarantees performance and stability locally. Future work aims at the development of global performance and stability guarantees based approach.

References

[1] T. Bloemers, R. Tóth, and T. Oomen,"Towards Data-Driven LPV Controller Synthesis Based on Frequency Response Functions," In Proc. of the 58th IEEE Conference on Decision and Control, Nice, France, December 2019.

[2] A. Karimi, A. Nicoletti, and Y. Zhu,"Robust $\mathcal{H}_\infty$ controller design using frequency-domain data via convex optimization," International Journal of Robust and Nonlinear Control, vol. 28, no. 12, pp. 3766-3783, 2018.