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# DATA-DRIVEN STABILITY ANALYSIS AND ENFORCEMENT FOR LOEWNER DATA-DRIVEN CONTROL PAULINE KERGUS LUND UNIVERSITY DEPARTMENT OF AUTOMATIC CONTROL

## LOEWNER DATA-DRIVEN CONTROL: GENERAL FORMULATION



## Input data

• Frequency-domain data from the plant **P**:  $\{\omega_i, \Phi_i\}, i = 1 \dots N$ .

## Proposed methodology

1. Computation of the ideal controller **K**<sup>\*</sup> frequency-response:

 $\mathbf{K}^{\star}(\iota\omega_{i}) = \Phi_{i}^{-1}\mathbf{M}(\iota\omega_{i})(I - \mathbf{M}(\iota\omega_{i}))^{-1}.$ 

Interpolation and reduction of the ideal controller K\* through the Loewner framework.

## A simple example

$$\mathbf{P}(s) = \frac{0.03616(s - 140.5)(s - 40)^3}{(s^2 + 1.071s + 157.9)(s^2 + 3.172s + 1936)} \quad \mathbf{M}(s) = \frac{1}{0.01s^2 + 0.25s + 1}$$

$$\mathbf{K}^{\star}(s) = k \frac{(s^2 + 1.071s + 157.9)(s^2 + 3.172s + 1936)}{s(s+10)(s-140.5)(s-40)^3}$$

 $\rightarrow$  The reference model should be achievable by the plant.

$$\begin{cases} \mathbf{y}_{z_i}^T \mathbf{P}(z_i) = 0 \\ \mathbf{y}_{p_j} \mathbf{P}(p_j) = \infty \end{cases} \Rightarrow \begin{cases} \mathbf{y}_{z_i}^T \mathbf{M}(z_i) = 0 \\ \mathbf{M}(p_j) \mathbf{y}_{p_j} = \mathbf{y}_{p_j} \end{cases}$$



• Reference model M.

 $\rightarrow$  A data-driven closed-loop stability analysis is needed.



## **CHOICE OF THE REFERENCE MODEL**

1) Projection of the available data to determine the nature of **P**:



 $\rightarrow$  The system is stable but Non-Minimum Phase (NMP).

2) Principal Hankel Components technique to determine the number of NMP zeros and obtain an estimate of the instabilities.



### **CONTROLLER IDENTIFICATION**

The objective is to obtain a rational model  $\mathbf{K} = (E, A, B, C, D)$  such that:

$$\forall i = 1 \dots N, \mathbf{K}(\imath \omega_i) = \mathbf{K}^{\star}(\imath \omega_i).$$

→ Use of the Loewner pencil  $[\mathbb{L}, \mathbb{L}_{\sigma}]$ 1. Embedded order reduction



## **CONTROLLER REDUCTION**



The resulting closed-loop is well-posed and internally stable for all stable  $\Delta$  such that  $\|\Delta\|_{\infty} \leq \beta$  if and only if  $\|(1 - \mathbf{M}_f)\mathbf{P}\|_{\infty} < \frac{1}{\beta}$ .

 $\rightarrow$  Limiting the controller modelling error allows to ensure closed-loop internal stability!







## STRUCTURED LDDC DESIGN

General structuration of the controller:



1. Kergus, P., Olivi, M., Poussot-Vassal, C., Demourant, F. (2019). *From reference model selection to controller validation: Application to Loewner Data-Driven Control.* IEEE L-CSS.



At iteration k, problem  $\mathcal{P}_k$  is solved:



where  $\mathbf{H}(\theta_k, \imath \omega_i) = (I + \Phi_i \mathbf{K}(\theta_k, \imath \omega_i))^{-1} \Phi_i \mathbf{K}(\theta_k, \imath \omega_i)$  2. Cooman, A., Seyfert, F., Olivi, M., Chevillard, S., Baratchart, L. (2017). *Model-free closed-loop stability analysis: A linear functional approach*. IEEE TMTT.

3. Cooman, A., Seyfert, F., Amari, S. (2018). *Estimating unstable poles in simulations of microwave circuits*. IEEE IMS.

4. Van Heusden, K., Karimi, A., Bonvin, D. (2009). *Data-driven controller validation*. IFAC Symposium on System Identification.