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Data-driven control in the frequency-domain: From reference model selection to controller validation

Pauline Kergus, Martine Olivi, Charles Poussot-Vassal, Fabrice Demourant

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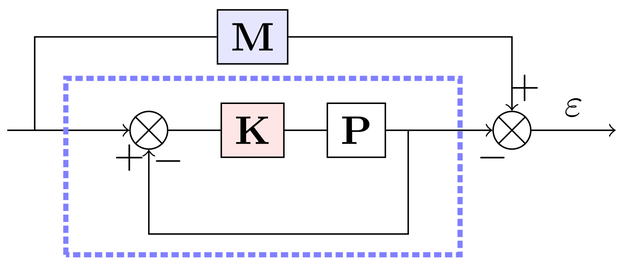
Loewner Data-Driven Control: general formulation



Input data

- Frequency-domain data from the plant $\mathbf{P}$: $\{\omega_i, \Phi_i\},\ i = 1 \dots N$.
- Reference model $\mathbf{M}$.

Proposed methodology

1. Computation of the ideal controller $\mathbf{K}^\star$ frequency-response: $\mathbf{K}^\star(\imath\omega_i) = \Phi_i^{-1}\mathbf{M}(\imath\omega_i)(I - \mathbf{M}(\imath\omega_i))^{-1}$.
2. Interpolation and reduction of the ideal controller $\mathbf{K}^\star$ through the Loewner framework.

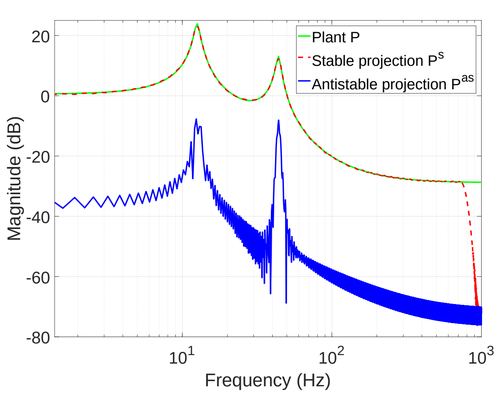
$$\left.\begin{array}{l}\mathbf{P}(s) = \frac{0.03616(s-140.5)(s-40)^3}{(s^2+1.071s+157.9)(s^2+3.172s+1936)} \\ \mathbf{M}(s) = \frac{1}{0.04s^2+0.4s+1}\end{array}\right\} \quad \mathbf{K}^\star(s) = k\frac{(s^2+1.071s+157.9)(s^2+3.172s+1936)}{s(s+10)(s-140.5)(s-40)^3}$$

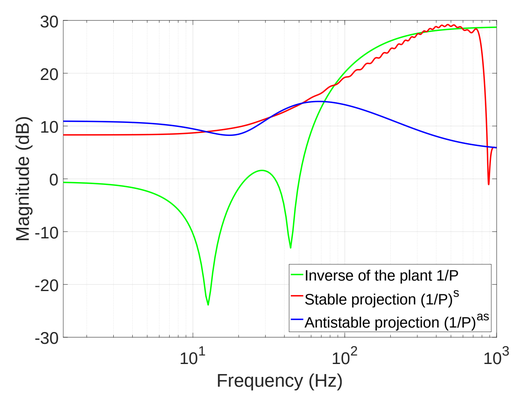
→ The reference model should be achievable by the plant.
→ A data-driven closed-loop stability analysis is needed.

Selection of an achievable reference model

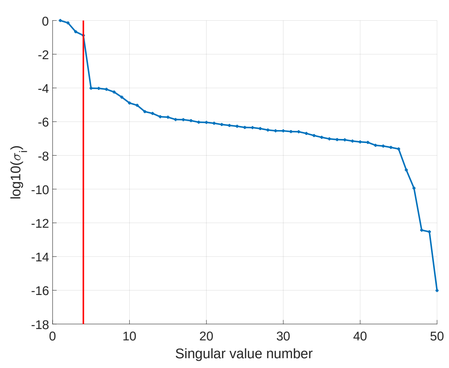
$$\begin{cases}\mathbf{y}_{z_i}^T\mathbf{P}(z_i) = 0 \\ \mathbf{y}_{p_j}\mathbf{P}(p_j) = \infty\end{cases} \Rightarrow \begin{cases}\mathbf{y}_{z_i}^T\mathbf{M}(z_i) = 0 \\ \mathbf{M}(p_j)\mathbf{y}_{p_j} = \mathbf{y}_{p_j}\end{cases}.$$

1) Projection of the available data to determine the nature of $\mathbf{P}$: 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.



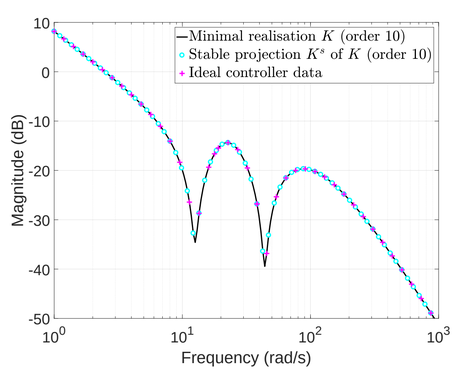
True z_i	Estimated $\tilde{z}_i$
140.5	140.58
40	41.3+2$\imath$
40	41.3+2$\imath$
40	37.4

3) Construction of an achievable reference model $\mathbf{M}_f$.

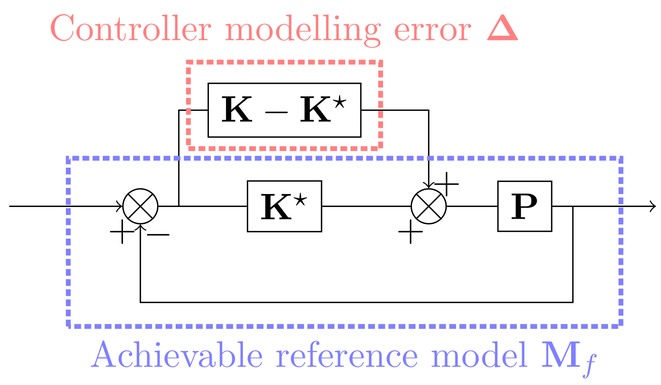
$$\mathbf{M}_f = \mathbf{M}\mathbf{B}_z$$

$$\mathbf{B}_z(s) = \prod_{i=1}^{n_z}\frac{s-\tilde{z}_i}{s+\tilde{z}_i}$$

→ No more compensation of instabilities in the open-loop!

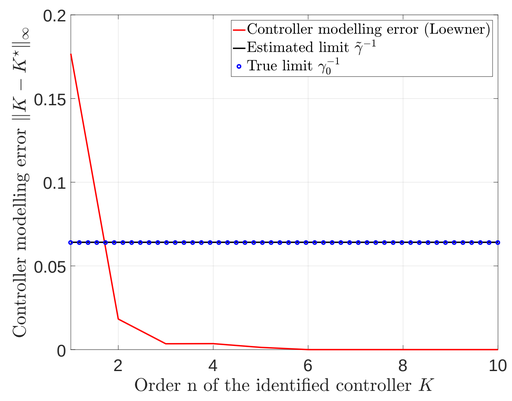


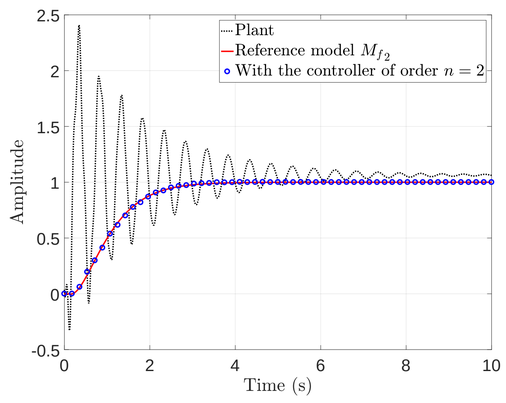
Data-driven closed-loop stability analysis



The interconnection is stable for all stable Δ such that $\|\Delta\|_\infty < \gamma$ iff $\|(1-\mathbf{M}_f)\mathbf{P}\|_\infty \leq \gamma^{-1}$.

→ Maximal controller modelling error $\tilde{\gamma}^{-1} = \max_{i=1\dots N} |(1-\mathbf{M}_f(\imath\omega_i))\Phi_i|$





Conclusions and outlooks

- Data-driven technique taking into account the inherent performance limitations of the plant.
- The reduction of the controller is performed under a stability constraint.
- Need for a better data-driven estimation of the $\mathcal{H}_\infty$-norm.
- Too conservative stability test: possibility to use other stability indicators.

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