Multivariable Data-Driven Uncertainty Modeling for Robust Active Vibration Isolation

Rick van der Maas and Tom Oomen
Department of Mechanical Engineering, Eindhoven University of Technology
P.O. Box 513, 5600 MB Eindhoven, The Netherlands, Email: R.J.R.v.d.Maas@tue.nl

Uncertainty Modeling

Robustness is of vital importance for any feedback controlled system. An important example of such a feedback controlled system is an active vibration isolation system (AVIS), which is used to isolate highly accurate systems from external disturbances in multiple degrees-of-freedom. The underlying idea of vibration isolation is based on the concept of skyhook damping, see [1]. Model-based robust control designs based on $\mathscr{H}_\infty$-optimization/μ-synthesis provides a structured approach for controller design for uncertain systems.

The performance of robust control designs hinges on the quantification of model uncertainty Δ. Essentially, this amounts to determining the model uncertainty size $\gamma = \|\Delta\|_\infty$. If γ is too small, then no guarantees can be provided when the resulting controller is implemented on the true system. Conversely, if γ is too large, then the resulting controller is guaranteed to stabilize the system but the resulting performance is poor due to conservatism.

Existing model-error-modeling techniques are typically based on several prior assumptions, *e.g.,* related to damping of the system or the model error being of a particular model order. The goal of this work is to develop a model-error-modeling technique that estimates the $\mathscr{H}_\infty$-norm directly from data.

Data-Driven Uncertainty Modeling

The goal in this work is to estimate $\gamma = \|\Delta\|_\infty$, where Δ is a multivariable dynamic system. Hereto, the following property of the $\mathscr{H}_\infty$-norm is an induced norm, *i.e.,*

$$\|\underline{\Delta}\|_{i2} = \sup_{u_\Delta \in \ell_2 \setminus 0} \frac{\|\underline{y}_\Delta\|_2}{\|\underline{u}_\Delta\|_2} = \sup_{u_\Delta \in \ell_2 \setminus 0} \sqrt{\frac{\underline{u}^T \Delta^T \Delta \underline{u}}{\underline{u}^T \underline{u}}}, \qquad (1)$$

is employed, where in addition the signals are assumed of finite length $N \in \mathbb{Z}$. The main contribution of this work is a new approach to estimate the $\mathscr{H}_\infty$-norm of the multivariable system Δ by iteratively determining the optimal $\underline{u}_\Delta$ in (1) for the identification of $\|\Delta\|_\infty$ and subsequently use this in an estimator which is again based on (1). The basic principle of the iterative procedure is depicted in Figure 1. Importantly, the proposed approach exhibits global convergence, *i.e.,* when the number of iterations $n \to \infty$, then $\gamma \to \|\Delta\|_\infty$, see [2] for a detailed analysis.

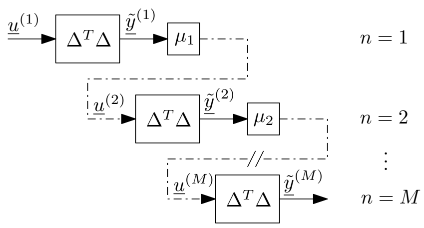
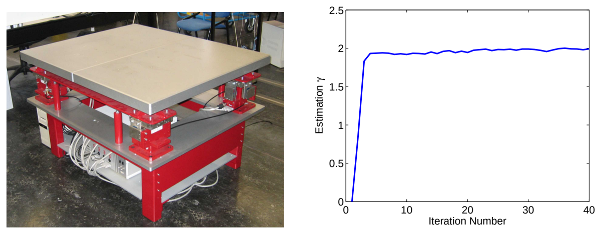


Figure 1: Data-driven $\mathscr{H}_\infty$-norm norm estimation procedure.

Experimental Results

The introduced procedure is applied on an industrial AVIS, see Figure 2a. The estimation for each iteration is shown in Figure 2b, which results after 40 iterations in $\gamma = 1.997$. Interestingly, this is more accurate than earlier results based on FRF identification, leading to 1.95. A new FRF identification using an increased grid density verifies the obtained result of the newly introduced procedure.



(a) Industrial AVIS setup (b) Convergence of the estimation γ

Figure 2

Outlook

The new data-driven model-error-modeling procedure in this paper is embedded in a identification and robust control framework, leading to significant enhancements in robust vibration isolation of an industrial AVIS, see [3] for results in this direction.

References

[1] D. Karnopp, "Active and Semi-Active Vibration Isolation," Trans. AMSE, vol. 11, pp. 177–185, 1995

[2] C. Rojas, T. Oomen, Håkan Hjalmarsson and Bo Wahlberg, "Analyzing Iterations in Identification with Application to Nonparametric $\mathscr{H}_\infty$-norm Estimation, Automatica, vol. 48, no. 11, pp. 2776–2790, 2012

[3] T. Oomen, R. van der Maas, C. Rojas and Håkan Hjalmarsson, "Iteratively learning the $\mathscr{H}_\infty$-norm of Multivariable Systems Applied to Model-Error-Modeling of a Vibration Isolation System", Proc. of the 2013 American Control Conference, Washington, DC, USA, 2013, *submitted*

Acknowledgments

The authors would like to thank Cristian Rojas and Håkan Hjalmarsson for their contribution to this work. In addition, Okko Bosgra, Robbert van Herpen, and Bo Wahlberg are acknowledged for valuable discussions.