Identification of position-dependent mechanical systems

Robin de Rozario, Robbert Voorhoeve, Wouter Aangenent, Tom Oomen
Eindhoven University of Technology, Department of Mechanical Engineering, Control Systems Technology group
P.O. Box 513, 5600 MB Eindhoven, The Netherlands, Email: r.d.rozario@student.tue.nl

1 Background

Increasing accuracy and speed demands in precision applications lead to a situation where the flexible behavior of the system becomes relevant [1]. For instance, the internal deformations hamper the performance at the point of interest, which is typically not measured directly. Hence, ensuring satisfactory performance at this point can be achieved through control strategies that infer the point of interest from indirect measurements in conjunction with a model, e.g., through an observer. In general, these models are Linear Parameter Varying (LPV), since the point of interest is position-dependent. The aim of this research [2] is to develop mechanical models whose outputs are position-dependent.

2 Approach

The key step in the proposed approach is to use a local LPV identification [3] approach while exploiting physical properties of the class of mechanical systems. As such, a set of local frozen systems is estimated, where each frozen system represents a fixed mapping for a given position. The frozen systems are parametrized as modal mechanical systems,

$$\mathcal{L}[s^2 I + sD_m + \Omega^2]^{-1}\mathcal{R}, \quad (1)$$

$\mathcal{L} \in \mathbb{R}^{n_y \times n_m}$, $D_m, \Omega^2 \in \mathbb{R}^{n_m \times n_m}$, $\mathcal{R} \in \mathbb{R}^{n_m \times n_u}$, with n_y, n_m and n_u the number of outputs, mechanical modes and inputs, respectively. This nonlinear-in-the-parameters parametric model is identified from frequency response data by first estimating a Left Matrix Fraction Description (LMFD) using the Sanathanan-and-Koerner method, [4]. Then, possibly after refining this model using gradient-based techniques, this estimate is transformed to an initial estimate with the modal structure and is subsequently refined using a gradient-based approach.

The frozen system set is then interpolated to yield a system that is continuous in the position variable. By virtue of the mechanical system structure, the interpolation of the frozen systems is equivalent to the interpolation of the mode shapes of the system. Robust interpolation of these modes is achieved by using a basis-function expansion with optimal model order selection, or by using Thin Plate Splines with optimal smoothing, where optimality is defined with respect to a cross-validation measure [5].

3 Results

The developed method is successfully implemented numerically and a position-dependent model of the Over-Actuated-Test rig, a prototype next-generation wafer stage as shown in Figure 1, is estimated, thereby confirming that proposed the identification method is well-suited for practical applications.

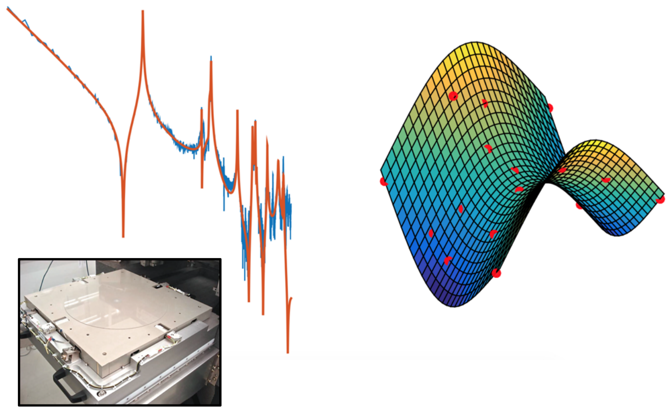

Figure 1: Lower left: OAT-chuck. Upper left: Modal model fit of one of the transfers of the OAT setup. Right: Experimental estimate of the second flexible mode of the OAT chuck.

4 Ongoing work

Further research focuses on controller synthesis using the obtained LPV-models in relation to inferential control, learning and robustness aspects.

References

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