Towards Model Order Selection in View of Robust Control for Motion Systems with Dominant Flexible Dynamics

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Background

Next-generation high-precision positioning systems tend to become lightweight. Generally, lightweight systems exhibit pronounced flexible dynamical behavior in relevant frequency ranges. These flexible dynamics typically are not aligned with the motion degrees-of-freedom, leading to an inherently multivariable dynamical behavior. As a consequence, multivariable controllers are essential to achieve the limits of performance. Model-based control enables a systematic design of such multivariable controllers.

The need for robust-control-relevant model sets

Any physical system is too complex to be represented exactly by a mathematical model. For example, identification of highly complex models of lightly damped flexible dynamical systems is numerically infeasible, as is confirmed in [4]. Hence, any model is approximate. This has two important implications for control design: i) model imperfections should be addressed in a robust control design to guarantee that the designed controller performs adequately when implemented on the physical system and ii) the model should accurately describe those phenomena that need to be compensated explicitly by control, since the quality of approximate models depends on their purpose. Recently, a novel coordinate frame has been presented [1] that transparently connects control-relevant identification of a nominal model, as developed in, e.g., [2], [3], with uncertainty modeling and robust control design.

Re-evaluating model order selection

Although the transparent connection between nominal model identification, uncertainty modeling, and robust control enables a non-conservative multivariable control design to the limits of performance, the desire to construct *control-relevant model sets* requires a re-evaluation of model order selection procedures. Indeed, the separate steps of nominal model identification and uncertainty modeling both involve the parametrization and order selection of a dynamical system. A selection procedure should be developed that i) involves both the model order corresponding to the nominal model and to the uncertainty model and ii) evaluates these model orders in light of the control criterion.

First experimental results

Application of the robust-control-relevant identification framework to a next-generation wafer stage for various nominal model orders yields Fig. 1 and Fig. 2. The resulting model sets i) encompass the true system behavior and ii) accurately describe those phenomena that need to be compensated to achieve high performance indeed. (Note that, instead of modeling consecutive control-relevant system artifacts, conventional modeling approaches typically focus on the representation of low-frequent system behavior.) Non-conservative robust control design requires for a dynamical bound on the uncertainty characterization shown. Clearly, an important interplay exists between order selection for the nominal model and the uncertainty bound.

References

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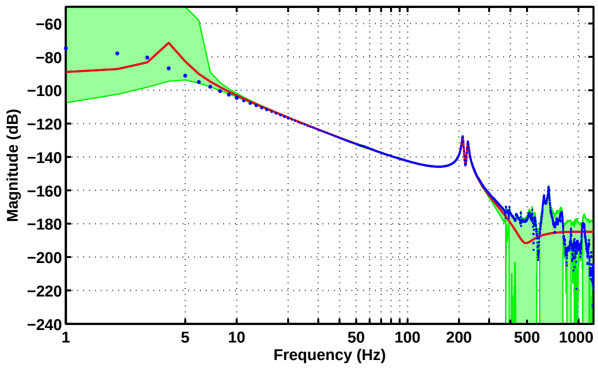

Figure 1: Bode magnitude plot of the true system (dotted), control-relevant 7th order model (solid) and candidate plant set, tight around dominant resonances (shaded).

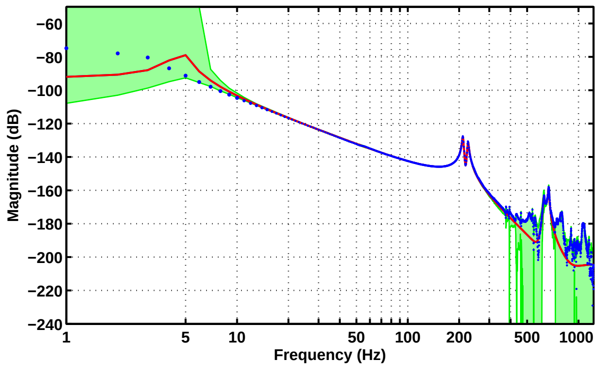

Figure 2: Inclusion of consecutive control-relevant system artifacts in an 11th order model, enabling explicit compensation the high-frequent resonances at 600 Hz.