Structure-preserving Model Reduction of Interconnected Systems

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Structure-preserving model reduction of interconnected systems

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1 Introduction

Many complex models of (multi-)physical systems are naturally based on an interconnection of subsystems. These dynamics models of interconnected systems often have high order, which makes analysis computationally expensive or unfeasible. This motivates the need for model order reduction (MOR) techniques. For such interconnected systems, we aim to capture the dynamics in a model that preserves the topology of the system such that we can understand the influence of individual subsystems on this system. This work introduces a potential method that can 1) evaluate the contribution of errors introduced by individual subsystem reduction to the overall model accuracy, and 2) use this knowledge to determine a model accuracy specification distribution for the individual subsystems guaranteeing a certain overall system accuracy and which, in turn, allows for an overall reduction of model complexity.

2 Problem statement

In this work, we study systems of k interconnected linear time-invariant (LTI) subsystems $G = \mathrm{diag}(G_1, \ldots, G_k)$ with input $u = [u_1^T, \ldots, u_k^T]^T$ and output $y = [y_1^T, \ldots, y_k^T]^T$. The systems are interconnected via an interconnection matrix K. The external inputs $\mathbf{u}$ and outputs $\mathbf{y}$ are connected to the subsystems via external input and output matrix H and R, respectively. The complete interconnected system $\mathcal{G}$ is then given by

$$\mathcal{G} = RG(I - KG)^{-1}H \tag{1}$$

and represented as block-diagram in Figure 1. Structure-preserving MOR computes a reduced-order model $\hat{\mathcal{G}}$ while preserving the interconnection topology of the system $\mathcal{G}$. This can be achieved by computing reduced-order models for the separate subsystems $\hat{G} = \mathrm{diag}(\hat{G}_1, \ldots, \hat{G}_k)$ [1]. These reduced-order subsystems can be interconnected to find a structure-preserved, reduced-order interconnected system $\hat{\mathcal{G}}$ given by

$$\hat{\mathcal{G}} = R\hat{G}(I - K\hat{G})^{-1}H \tag{2}$$

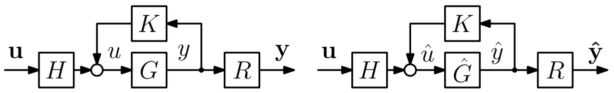

Figure 1: Block-diagram representation of the system $\mathcal{G}$ (left) and structure-preserved MOR system $\hat{\mathcal{G}}$ (right).

and also represented as block-diagram in Figure 1. In order to determine the contribution of approximation errors of individual subsystems to the complete interconnected system, we seek to find the relation between the error dynamics $E_j := G_j - \hat{G}_j$ and the error dynamics $\mathcal{E} := \mathcal{G} - \hat{\mathcal{G}}$ of the interconnected system. For the given class of interconnected systems, this relation is far from trivial.

3 Proposed approach

Robust control is a field of study that has been dealing with system uncertainties. We can model our subsystem error dynamics E_j as an additive uncertainty to our subsystem G_j. By modeling the error dynamics as $\mathcal{H}_\infty$-norm bounded uncertain systems, we can use a powerful tool, μ-analysis, to compute the L_2-gain bounds on uncertain systems [2]. We then aim to find the relation between such bounds σ_j on the subsystem error dynamics

$$\|E_j\|_\infty \leq \sigma_j, \; j = 1, \ldots, k, \tag{3}$$

and a bound γ on the interconnected system error dynamics

$$\|\mathcal{E}\|_\infty \leq \gamma. \tag{4}$$

Efficient methods to find this relation could lead to the ability to evaluate the propagation of subsystem accuracy to overall model accuracy (a bottom-up approach). Applying this evaluation could then lead to methods to determine accuracy specifications for subsystems that leads to the best overall model accuracy (a top-down approach).

References

[1] Sandberg, H., & Murray, R. M. (2009). Model reduction of interconnected linear systems. Optimal Control Applications and Methods, 30(3), 225-245.

[2] Packard, A., & Doyle, J. (1993). The complex structured singular value. Automatica, 29(1), 71-109.

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