Passivity-Preserving Model Reduction for Interconnected Systems

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1 Introduction

Physical systems, such as RLC networks or structural dynamics systems, can often be modeled appropriately as an interconnection of several subsystems. These subsystems are often naturally passive, i.e., the systems do not generate energy internally, leading to complex, passive, coupled models. The complexity of these models typically prevents efficient dynamic analysis. Model reduction is thus required to attain an accurate low-order model. Usually, this is performed on subsystem level, for example by Component Mode Synthesis (CMS). Unfortunately, subsystem reduction does not explicitly ensure accuracy of the interconnected system. While there exist reduction methods to focus on the accuracy of the reduced, interconnected model, passivity and stability of this model are generally not retained.

2 Research approach

We introduce the Passive Interconnected Balancing (PIB) method to reduce models of interconnected subsystems, approximating the input-output behaviour of the interconnection, while preserving both the interconnection structure and passivity of the model. Equivalently, this new method reduces the individual subsystems, based on the input-output behaviour of the interconnection, while preserving passivity of the subsystems and interconnection.

Our approach is based on the concept of balancing, where typically the controllability and observability Gramians of a system are equalized and diagonalized to sort states by their importance to input-output behaviour. Instead of the observability Gramian, we use the available storage per subsystem, as in Positive-Real Balancing (PRB), to guarantee passivity of the reduced subsystem model [1]. Moreover, instead of the subsystem controllability Gramian, we use a partition of the controllability Gramian of the interconnected system, as with Interconnection Structure-preserving Balancing (ISB) [2]. This combination of available storage and a partition of the coupled controllability Gramian provides both passivity guarantees and accuracy of the coupled system.

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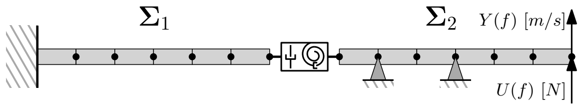

Figure 1: Schematic drawing of the coupled beam model.

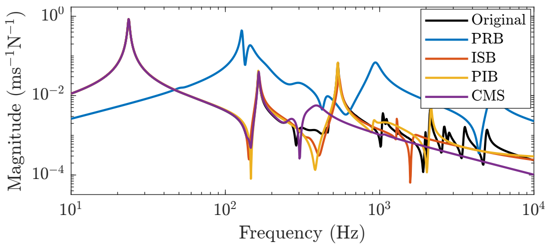

Figure 2: Magnitude plot of $|Y/U|$.

3 Numerical example

Observe the SISO system of two lightly damped Euler beams, in Figure 1, which are coupled by a translational and rotational damper. Both beam nodels consist of 24 states each and are reduced to 10 states each. Reduction is performed using (i) PRB, (ii) ISB, (iii), Craig-Bampton CMS reduction and (iv) the new PIB method. The resulting magnitudes of the collocated FRF is shown in Figure 2. PIB and ISB both show superior accuracy compared to the other methods. However, ISB does not preserve stability, whereas PIB preserves stability and passivity.

4 Conclusion and outlook

Passive Interconnected Balancing (PIB) both guarantees passivity preservation, interconnection-structure preservation and results in an accurate reduced coupled model. Further extensions will make it more computationally efficient, to also allow application to industry-relevant benchmarks.

References

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[2] A. Vandendorpe and P. Van Dooren, “Model Reduction of Interconnected Systems,” in *Model Order Reduction: Theory, Research Aspects and Applications*, 2008, pp. 305–321.