Model Reduction of Assemblies: Improving Accuracy while Preserving Modularity and Passivity

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Machines are typically an interconnection of components, i.e., they are assemblies. To analyze the dynamics of these assemblies, their components are generally modeled by large structural, finite element models. The large order of these component models, and of their interconnection, necessitates the use of model reduction techniques to allow further analysis.

Model reduction of the assembly is often performed by reduction of the individual components, because direct reduction of the assembly is not computationally tractable. Component mode synthesis, for example, is one such popular method for component-level reduction. However, by reducing the individual components, the dynamics that is retained in the reduced component model might not be relevant to the assembled model. Stated differently, if the reduction of a component model does not take the dynamics of the component's environment into account, the accuracy of the interconnected, reduced-order model, cannot be guaranteed.

In this work, we propose a new model reduction method called Passive Interconnected Balanced Truncation (PIBT). PIBT can improve the accuracy of the assembly model with respect to component-level reduction, while guaranteeing passivity and stability of both the components and the assembly.

PIBT is based on the reduction method of Balanced Truncation (BT), which focuses on the accurate description of (selected) input-output behavior. BT consists of two steps: first the coordinates are transformed to a balanced realization, where states are sorted by their 'importance', followed by a truncation of the least important states. This `importance' of the balanced states is determined based on two so-called Gramians, which depend on the realization of the model.

To aim for higher accuracy, while guaranteeing passivity, PIBT is based on a combination of one local (component-level) and one global (assembly-level) Gramian. The local Gramian is the minimal solution to the Positive Real Lemma and relates to passivity. The global Gramian is the controllability Gramian of the assembly and relates to its input-output behavior. By using this combination of Gramians, both the reduced component and reduced assembly models are guaranteed to be passive, while the assembly's input-output behavior tends to be approximated accurately.

To validate PIBT, it is tested on a numerical example of two interconnected Euler beam models. In a comparison to two existing methods from literature, reduction with PIBT results in a superior reduced order model, showing both passivity preservation and an accurate approximation of the assembly.