A new co-simulation approach for mechanical systems with nonlinear components

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Summary. Co-simulation is used to enable global simulation of a coupled system via the composition of simulators. Within this work, a new co-simulation approach is developed for mechanical systems with nonlinear components. Specifically, a model two-degree-of-freedom oscillator, including Duffing type nonlinearities, was investigated first by applying the method of multiple scales. This provided reliable information on its dynamics under primary external resonance. Moreover, the new co-simulation approach was presented and compared with the classical co-simulation methods from the literature. Here, the main focus is placed on mechanical subsystems. However, the new methods have general validity and can be applied to couple arbitrary solvers.

Introduction

Co-simulation or solver coupling has already been applied extensively to various engineering fields [1, 2]. The basic idea consists in a decomposition of the global model into two or more sub-models. The different subsystems are connected by coupling variables, which are exchanged only at the macro-time points (also called communication points). Between these points, the subsystems integrate independently from each other, using their own solver. Generally, the subsystems can be coupled by physical force/torque laws (applied forces/torques) or by algebraic constraint equations (reaction forces/torques) [3, 4].
Two well-known co-simulation approaches are used: a parallel and a sequential, known as Jacobi and Gauss-Seidel, respectively, as their properties are similar to the respective linear iterative solvers. Furthermore, co-simulation approaches can be subdivided into explicit, implicit and semi-implicit methods. Finally, concerning the decomposition of the overall system into subsystems, three different possibilities can be distinguished. Namely, force/force, force/displacement and displacement/displacement decomposition.

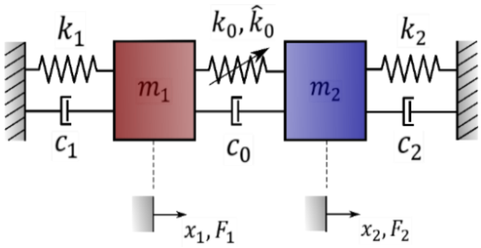

Figure 1: Example mechanical model

Description of the new co-simulation method

Within this work, emphasis is placed on the proper decomposition of the original system into two (or more) subsystems. Specifically, the decomposition takes place only at constraints of the initial model, which are artificially introduced through auxiliary bodies, in case they do not exist. The previously described procedure for the original mechanical model, shown in Figure 1, is depicted in Figure 2. Moreover, following recent work of the authors, the constraint equations and the equations of motion of each sub-model are formulated as a system of exclusively second-order ordinary differential equations (ODEs), bypassing numerical challenges associated with differential-algebraic equations [6, 7]. The distinct difference of the proposed approach, in comparison to the formerly developed co-simulation methods, lies in the dynamic nature of the master/orchestrator, which is now treated as a separate subsystem. Finally, through an appropriate weak formulation, the constraint equations and the OEMs of interface (master) model are expressed in a convenient and consistent first order ODE form, which carries over all the advantages of the corresponding second order ODE form [8].

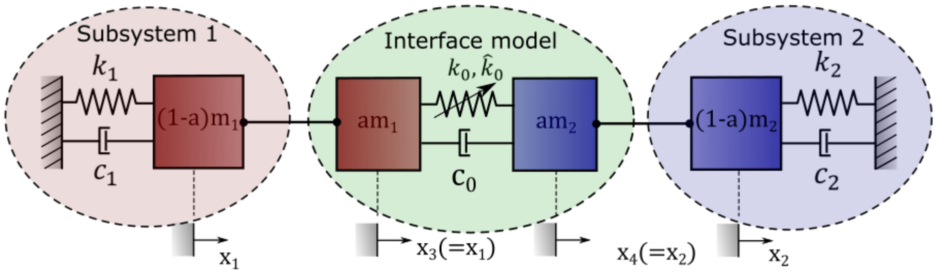

Figure 2: Equivalent model of initial mechanical model (Figure 1)

Numerical results and discussion

Here, a mechanical system with nonlinear components is examined [9, 10]. Specifically, the dynamic behavior of a two-degree-of-freedom oscillator involving stiffness characteristics modelled by linear and cubic terms is investigated by applying the method of multiple scales (see Figure 1). In the cases examined, the external forcing possesses a component with frequency close to one of the natural frequencies of the linearized model (for typical results, see Figure 3). A detailed analysis of the convergence and the numerical error behavior is carried out in order to examine the different properties of the new co-simulation scheme developed, in comparison to the already existing approaches. A set of characteristic results are presented in Figure 4. Despite the fact that the models examined are simple and purely mechanical, the techniques used can also be extended and applied to arbitrary multibody or structural dynamics systems.

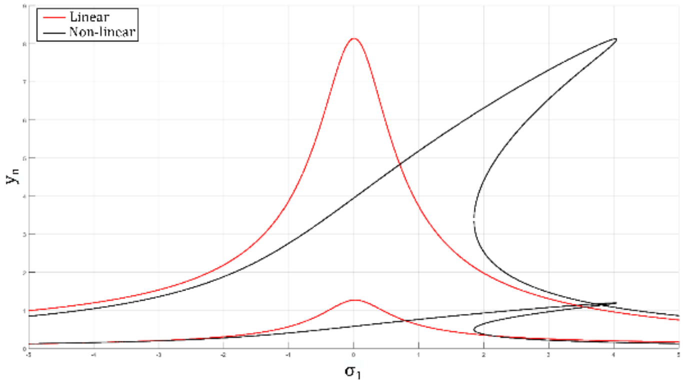

Figure 3: Normalized displacement amplitude for linear and non-linear system

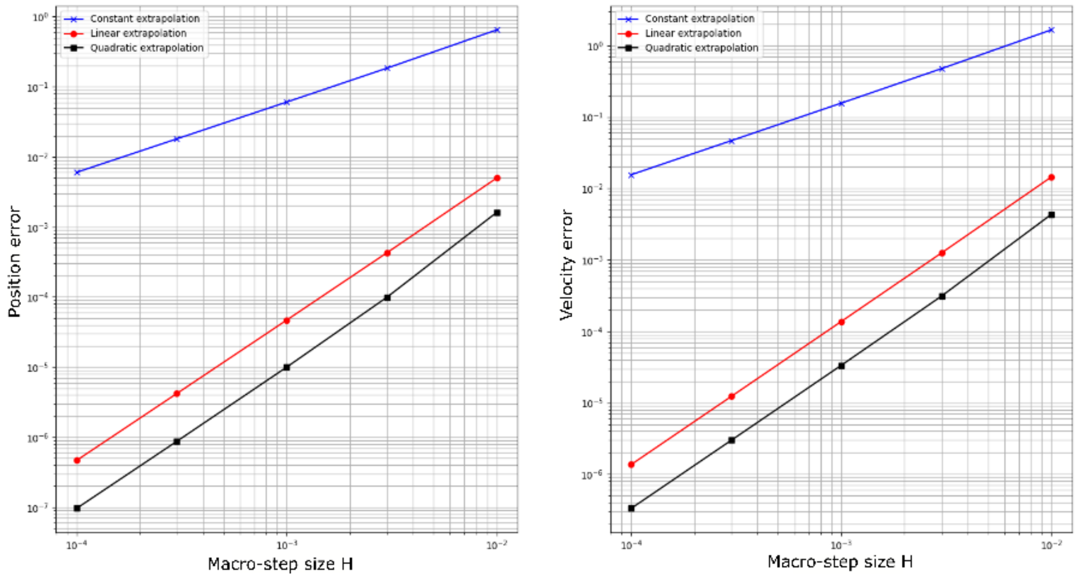

Figure 4: Convergence plots for Jacobi communication pattern, explicit scheme and force-force decomposition (classical approach)

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