Nonlinear model order reduction of explicit finite element simulations for crash analysis

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ABSTRACT

The Finite Element Method is a popular technique for solving PDEs, particularly in structural mechanics. However, large and complex models still require long computation times. These issues are often encountered in the automotive, aerospace or medical industry, and they can render design space exploration, optimization and robustness studies impracticable.

Reduced-order models can significantly decrease simulation times by reducing the dimensionality of the problem. Many advances in nonlinear model order reduction have been made very recently, e.g. [1-4]. One advantage over established data-fit meta-modeling approaches is that reduced-order models preserve the information on the underlying PDE, and hence the physical nature of the problem. Model reduction of crash simulations poses a set of additional challenges. The structural behavior is highly nonlinear due to plasticity, contact and failure [5]. The process of generating reduced-order models is often intrusive, making the interaction with commercial finite element solvers difficult. Building the reduced-order models also requires efficient and scalable algorithms for processing large amounts of snapshot data.

We present an intrusive method for generating parametric hyper-reduced models for nonlinear FEM simulations. It is based on POD and the snapshot method [6], the DEIM and GNAT hyper-reduction approaches [1-3] and enhanced techniques for reduced basis generation, index selection, contact treatment and interfacing with the FEM solver, within the context of a nonlinear explicit FEM problem setting. The methods are applied to an example problem. Results show that significant speed-ups are possible in the online phase. This is achieved by operating in the reduced space (thus no longer scaling with the dimensionality of the full model), and by eliminating high-frequency contributions so that larger time steps can be used. Contact treatment and the interaction with the FE solver remain sources of inefficiencies, and further work needs to be done to improve accuracy for varying parameters.

REFERENCES

[1] Chaturantabut S, and Sorensen D C. *Nonlinear Model Reduction via Discrete Empirical Interpolation*. SIAM Journal on Scientific Computing, vol. **32**(5), pp. 2737–2764 (2010).

[2] Carlberg K T, Farhat C, Cortial J, and Amsallem D. *The GNAT method for nonlinear model reduction: Effective implementation and application to computational fluid dynamics and turbulent flows*. Journal of Computational Physics, vol. **242**, pp. 623–647 (2013).

[3] Farhat C, Avery P, Chapman T, and Cortial J. *Dimensional reduction of nonlinear finite element dynamic models with finite rotations and energy-based mesh sampling and weighting for computational efficiency*. International Journal for Numerical Methods in Engineering, vol. **98**, pp. 625–662 (2014).

[4] Vallaghé S, Huynh P, Knezevic D J, Nguyen L, and Patera A T. (2015). *Component-based reduced basis for parametrized symmetric eigenproblems*. Advanced Modeling and Simulation in Engineering Sciences, vol. **2**(7) (2015).

[5] Duddeck F. *Multidisciplinary optimization of car bodies.* Structural and Multidisciplinary Optimization, vol. **35**(4), pp. 375-389 (2008).

[6] Sirovich L. *Turbulence and the dynamics of coherent structures, part I-III.* Quarterly of Applied Mathematics, vol. **XLV**(3), pp. 561–571 (1987).