System-Level Simulation of MEMS by Means of Model Order Reduction

Tamara Bechtold

Institute of Electronic Appliances and Circuits, Department of Computer Science and Electrical Engineering, Rostock University, Albert Einsteinstr. 2, 18059 Rostock, GERMANY

KURZFASSUNG/ABSTRACT:

The rapid progress in microelectromechanical systems (MEMS) and the evolution from a limited set of well-established applications, examples, in automotive industry, print heads, and digital light projection, to other fields mainly driven by consumer applications opens a new market for these devices. It simultaneously creates the need for fast, efficient, and adequate design and optimization tools not only for stand-alone devices, but also for entire multiphysics microsystems comprising the MEMS component, the attached control and read-out circuitry and the package, while additionally considering environmental impacts potentially affecting the system functionality.

1 EINLEITUNG

Owing to their nature as transducing elements, an inherent feature of many MEMS devices is that multiple energy domains and their couplings determine their operation. A sampling of coupling between a subset of physical energy domains of major importance in microsystems is illustrated in Figure 1.

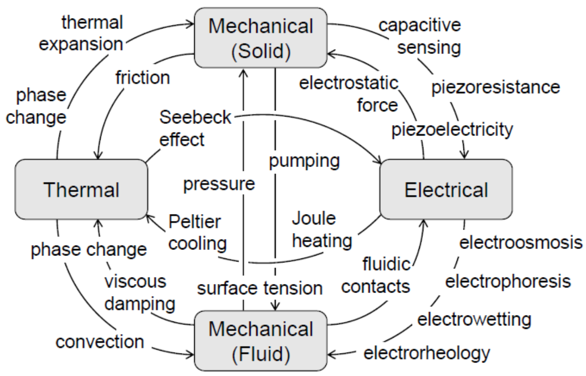

Figure 1. A sampling of multiple couplings between different energy domains in microsystems [1]

Furthermore, MEMS often exhibit complex geometrical structures. Modelling these features on continuum level (by partial differential equations) and numerically simulating them by e. g. the finite element method may be feasible for a single device. However, it becomes prohibitive when its interplay with the package, the surrounding electronics or other transducers has to be taken into account. Hence, compact modelling methods, which are able to reduce the number of degrees of freedom (DOF) and hence, to make these device models tractable, are sought after.

When speaking about the compact models of MEMS components, one differs between two main technologies: lumped-element modelling and reduced-order modelling. A good overview of the state-of-the-art in this field is given in [1]. A lumped-element model specifies a compact-modelling approach where spatially distributed physical behaviour is ‘‘lumped’’ into a finite set of ‘‘elements’’ that approximate behaviour at discrete points in space. A reduced-order model is a compact model formed by mathematically reducing the order of a high-DOF model, which typically emerges from numerical continuum simulations. Mathematical methods involved are known under the common name of model order reduction (MOR). Through MOR, the smaller systems of ordinary differential equations (ODEs) are derived, as schematically represented in Figure 2.

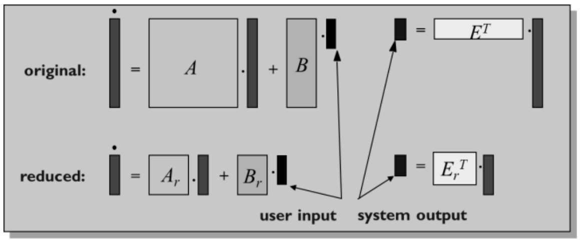

Figure 2. Schematical representation of model order reduction for an ODE system in the right-hand-side representation with system matrix $\boldsymbol{A} \in \boldsymbol{R}^{n \times n}$ and input and output distribution arrays $\boldsymbol{B}, \boldsymbol{E} \in \boldsymbol{R}^{n \times 1}$. Dimension of the reduced system is $\boldsymbol{r} \ll \boldsymbol{n}$.

This paper provides an overview of system-level modelling methodologies for MEMS and reviews some recent results [2],[3] on mathematically-based reduced order modelling.

LITERATURVERWEISE

[1] T. Bechtold, G. Schrag, L. Feng (eds), "System-Level Modeling of MEMS", (Wiley-VCH Verlag GmbH & Co. KGaA, ISBN: 978-3527319039, (2013).

[2] M. Kudryavtsev, E. B. Rudnyi, J. G. Korvink, D. Hohlfeld, T. Bechtold, "Computationally Efficient and Stable Order Reduction Methods for a Large-Scale Model of MEMS Piezoelectric Energy Harvester", accepted for publishing in Elsevier Journal of Microelectronics Reliability, 2015.

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