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Non-intrusive Model Reduction via Spectral Submanifolds in Structural and Fluid Dynamics

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Reduced-order modelling is among the leading theoretical and computational challenges in structural dynamics and in fluid mechanics. Direct extraction of nonlinear footprints (e.g., backbone curves, frequency responses, bifurcations, state transitions) in such complex, high-dimensional systems are computationally demanding, if not unattainable. Advanced nonlinear model reduction methods are under constant development, but most require explicit knowledge of the nonlinearities of the governing equations as multi-variable polynomials. This information, however, is not available from commercial finite-element codes or DNS solvers.

Here we present an approach that extracts explicit nonlinear models from data leveraging the recent theory of spectral submanifolds (SSMs) [1]. From numerical simulations, we collect data on a small number of decaying (unforced) trajectories with initial conditions selected to be close to slow spectral submanifolds that govern the asymptotic dynamical behavior. Our method then identifies low-dimensional attracting SSMs whose reduced dynamics reveals geometric and/or damping nonlinearities. These SSM-reduced models turn out to be highly accurate in predicting decaying trajectories outside their training range or even forced response.

We illustrate our method on applications coming from structural and fluid dynamics. Specifically, we discuss vibrations of beams, plates and complex geometries, for which SSM-based models trained on decaying vibrations data predict the harmonically forced frequency response of the system, as well as its behavior under quasi-periodic forcing. On examples from fluid dynamics, we show how SSM-based models inferred from trajectories capture vortex shedding behind a cylinder and transitions among equilibrium states in Couette flow.

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