Engineering Risk Analysis Group
Prof. Dr Daniel Straub

Variational Bayesian Model Updating of Nonlinear Dynamical Structures

Motivation and Objectives

Nonlinear dynamical structures are common in engineering and often control safety and performance. They exhibit behaviors such as stiffness degradation, hysteresis, contact, and large-amplitude responses that linear models cannot capture. In practice, the predictive capability of nonlinear dynamical models is limited by uncertain parameters (e.g., material properties, damping, joint/interface characteristics), imperfect knowledge of boundary and loading conditions, and noisy or incomplete measurements, so models calibrated deterministically may fit one dataset but remain unreliable for prediction. Variational Bayesian (VB) model updating offers a principled alternative by casting updating as probabilistic inference, where prior information and experimental data are fused to obtain a posterior distribution over parameters, with uncertainty quantified explicitly. At the same time, VB replaces expensive sampling with an optimization-based approximation, making Bayesian updating computationally feasible for complex nonlinear systems. This thesis aims to investigate the application of variational Bayesian model updating techniques for nonlinear dynamical structures, focusing on the integration of uncertainty quantification and model refinement. Specifically, the study will explore the optimal strategies for updating the model parameters under nonlinear conditions, incorporating both prior knowledge and observational data. The objective is to develop a robust and computationally efficient approach to update nonlinear dynamical systems, improving their predictive accuracy and reliability in the presence of uncertainties. The performance of the proposed model updating methodology will be validated using benchmark problems and compared to traditional methods to assess its effectiveness and computational advantages.

Methodology

- Literature review on variational Bayesian inference theory, model updating methodologies, nonlinear dynamical systems, and uncertainty quantification techniques in dynamic system calibration;
- Investigate the key methodological components of VB model updating when integrated with nonlinear dynamical structure modeling, including the design of structured variational distributions, adaptive step-size optimization for VB inference, and dynamic parameter calibration strategies

Requirements

What previous knowledge and skills do you expect the student to bring to the project e.g.

- Good knowledge on structural dynamics, especially the knowledge of nonlinear systems.
- Good mathematical and programming skills (Matlab)
- Strong interest in uncertainty quantification using data.

Starting date: Flexible, as soon as possible

Supervised by

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References

1. Fox, C. W., & Roberts, S. J. (2012). A tutorial on variational Bayesian inference. *Artificial intelligence review*, *38*(2), 85-95. 2.
2. Jia, X., Sedehi, O., Papadimitriou, C., Katafygiotis, L. S., & Moaveni, B. (2022). Nonlinear model updating through a hierarchical Bayesian modeling framework. *Computer Methods in Applied Mechanics and Engineering*, *392*, 114646.