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Dr. Costas Papadimitriou

Bayesian Uncertainty Quantification Framework for Complex Models in Structural Dynamics

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ENG1 288

Abstract

Bayesian inference is used for quantifying and calibrating uncertainty models in structural dynamics based on vibration measurements, as well as propagating these uncertainties in simulations for updating robust predictions of system performance, reliability and safety. The Bayesian tools for identifying system and uncertainty models as well as performing robust prediction analyses are Laplace methods of asymptotic approximation and sampling algorithms. These tools involve solving optimization problems, generating samples for tracing and then populating the important uncertainty region in the parameter space, as well as evaluating integrals over high-dimensional spaces of the uncertain model parameters. They require a moderate to very large number of system re-analyses to be performed over the space of uncertain parameters. Consequently, the computational demands depend highly on the number of system analyses and the time required for performing a system analysis.

A computational framework for Bayesian uncertainty quantification and propagation for complex models in structural dynamics will be presented. The model complexity is due to the very high number (hundreds of thousands or millions) of degrees of freedom arising in developing high-fidelity structural models, the localized nonlinear actions activated during system operation, and the applied stochastic loads. High performance computing techniques are integrated with Bayesian techniques to efficiently handle such complexities. Fast and accurate component mode synthesis (CMS) techniques are proposed, consistent with the finite element model parameterization, to achieve drastic reductions in computational effort. Surrogate models are also used within multi-chain sampling algorithms with annealing properties to substantially speed-up computations, avoiding full system re-analyses. Significant computational savings are achieved for stochastic simulation algorithms by adopting parallel computing algorithms to efficiently distribute the computations in available GPUs and multi-core CPUs. Important issues related to the computational efficiency of the asymptotic approximations versus the stochastic simulation algorithms for serial or parallel computing environments are discussed. Applications of the framework to structural health monitoring, damage identification and updating the remaining structural reliability are emphasized. The proposed approach is demonstrated using applications in civil infrastructure and vehicle dynamics.

Bio Sketch

Costas Papadimitriou is Professor of Structural Dynamics in the Department of Mechanical Engineering of the University of Thessaly and Director of the System Dynamics Laboratory. He was born in Nafpaktos (Lepanto), Greece, in 1961. He graduated from the Department of Mechanical Engineering of the University of Patras (Greece) in 1984 and pursued graduate studies in the California Institute of Technology (Caltech), where he was awarded the degrees of M.S. and Ph.D. in Applied Mechanics in 1985 and 1990, respectively.

He is associate editor for the ASCE Journal of Engineering Mechanics and the International Journal of Reliability and Safety, member of the editorial board for the International Journal of Structural Control and Health Monitoring, member of several international technical and scientific committees, and a reviewer for more than 35 international scientific journals.He holds the position of the Executive Vice President (2011-2017) of the European Association of Structural Dynamics (EASD) and he is coordinator of the Subcommitte on "Identification and Model Updating with Experiments and Inverse Problems" of the EASD. He has organised more than 15 symposia, mini-symposia and technical sessions for ASCE, ASME and other international conferences. He has published more than 44 refereed journal articles, 1 book chapter and more than 110 conference articles. He served as guest editor for two special journal issues on Structural Identification, SHM and Reliability published in "International Journal of Reliability and Safety" and in "Structural Safety". He is a member of the Technical Chamber of Greece and the American Society of Civil Engineers (ASCE).