COST TU1402: Quantifying the Value of Structural Health Monitoring

Contribution to the 1st Workshop, 04.-05.05.2015, DTU, Denmark

Structural Damage Identification by Integrating Bayesian Inference and Physics-Based Models

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Objectives

The objective of our research is to develop methodologies for identifying structural damage based on vibration measurements collected from a sensor network. Bayesian inference techniques integrated with high fidelity physics-based (finite element) models are used for quantifying and calibrating uncertainty models in structural dynamics, identifying the location, size and severity of structural damage, as well as propagating uncertainties and damage information in model simulations for updating robust predictions of system performance, reliability and safety.

The Bayesian tools are based on Laplace methods of asymptotic approximation and sampling algorithms [1]. 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 and loading parameters. They require a moderate to very large number of system re-analyses to be performed over the space of uncertain parameters. For high-fidelity finite element (FE) models required in model-based structural health monitoring applications, the use of Bayesian technique may result in excessive computations.

The computational challenges encountered in Bayesian tools for structural damage identification are addressed by integrating high performance computing techniques with Bayesian techniques to efficiently handle large-order models of hundreds of thousands or millions degrees of freedom, and nonlinear actions activated during system operation:

a) Fast and accurate component mode synthesis techniques are proposed, consistent with the finite element model parameterization, to achieve drastic reductions in computational effort in a single finite element model simulation [2].

b) Surrogate models are also used within multi-chain MCMC algorithms with annealing properties to substantially speed-up computations, avoiding full system re-analyses [3].

c) Significant computational savings are also achieved for highly-parallelized operations manifested in system simulations and sampling algorithms, by adopting the Π4U software to efficiently distribute the computations in available multi-core CPUs [1].

An application of the methodology on Metsovo bridge is illustrated in the Figures.

Figure 1. Metsovo Bridge (a) full bridge, (b) Bridge under construction)

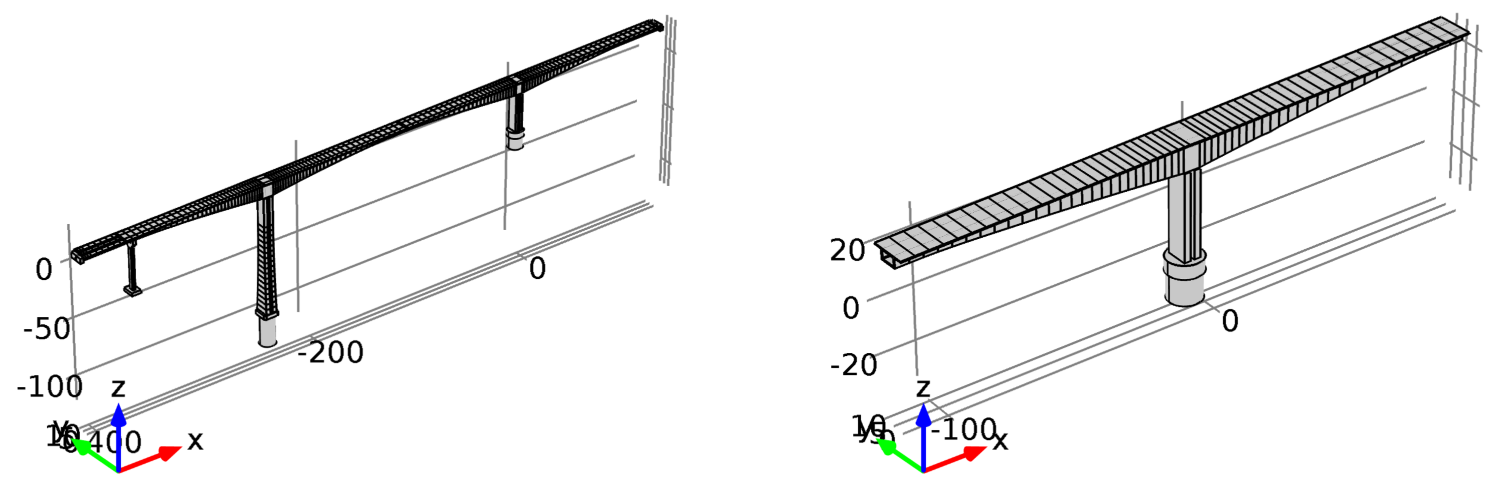

Figure 2. High fidelity finite element models (a) full bridge (830.115 DOF), (b) Construction phase (226.179 DOF)

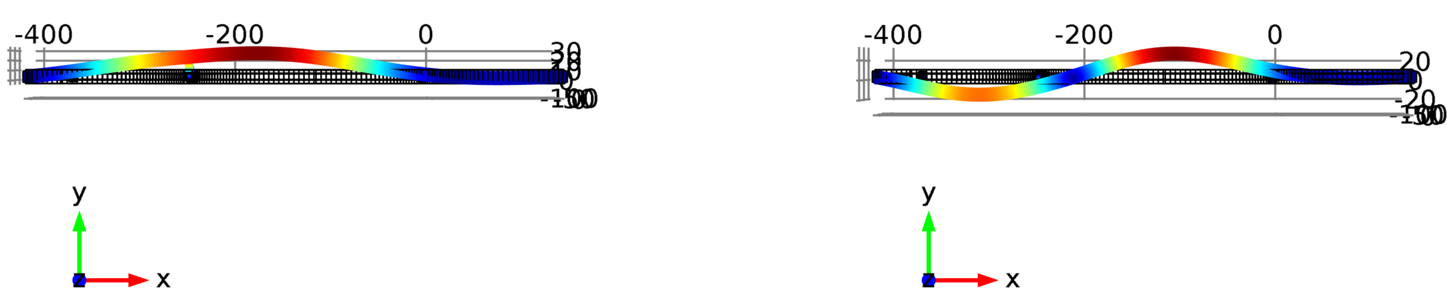

Figure 3. Mode shapes predicted by FE model

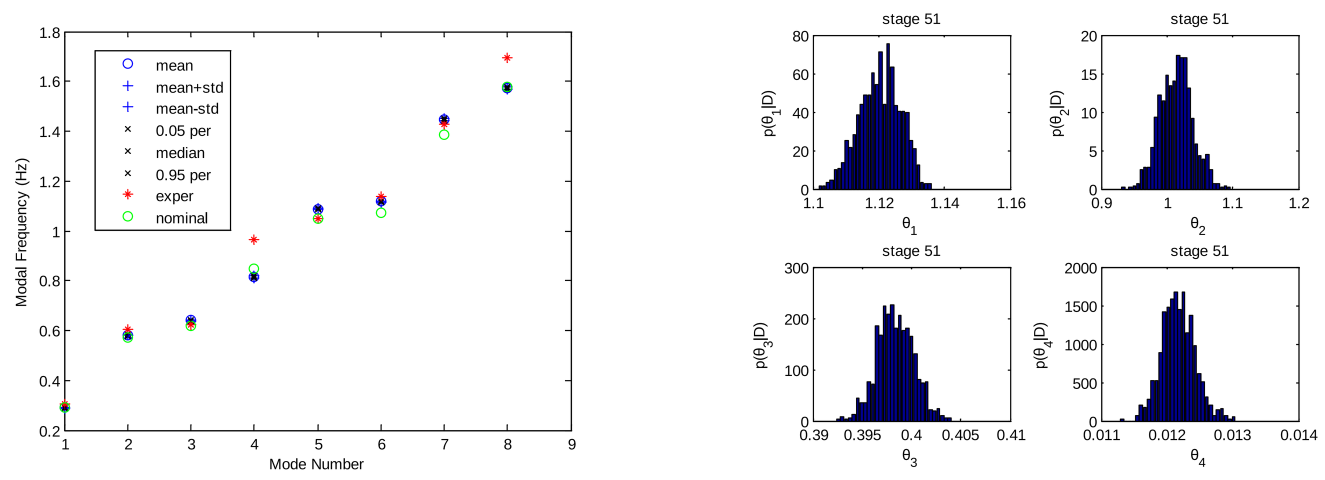

Figure 4. Bayesian parameter estimation based on vibration measurements. Modal frequency fits and posterior marginal distributions: x1= deck stiffness, x2=pier stiffness, x3=soil stiffness, x4=prediction error parameter

Conclusions

The proposed Bayesian inference tools allow one to handle detailed physics-based (linear and nonlinear) models of structural components and thus improve SHM capabilities. The effectiveness of the proposed computational framework has been demonstrated for applications on model-based structural damage identification of civil infrastructure.

References

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