Efficient reliability analysis by combining uncertain measurement data, Bayesian model updating and reduced order modeling

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Abstract

One of the main challenges regarding our civil infrastructure is the efficient operation over their complete design lifetime while complying with standards and safety regulations. Thus, costs for maintenance or replacements must be optimized while still ensuring specified safety levels. This requires an accurate estimate of the current state as well as a prognosis for the remaining useful life (RUL). Currently, this is often done by regular manual or visual inspections within constant intervals. However, the critical sections are often not directly accessible or impossible to be instrumented at all. In this case, model-based approaches can be used where a numerical model of the structure is set up. Based on this numerical model, a prognosis of the future performance of the structure, e.g. the failure probability, can be computed. The main challenge in this approach is the calibration and validation of the model based on uncertain measurement data. Therefore, model updating approaches which are inverse optimization processes are applied. This requires a huge number of computations of the same numerical model with slightly different model parameters. In reliability analyses, the failure probability of a structure is estimated. The failure probability is defined as an integral of a n-dimensional density function over the failure domain. Usually, it cannot be computed analytically. It is estimated by evaluating the integral function at a huge number of sample points. Thereby, each sample evaluation includes the computation of the numerical model with again slightly different model parameters. For that reason, model updating as well as reliability analyses become computationally very expensive for real applications.

The aim of this contribution is to increase the efficiency of structural model updating and the subsequent reliability analysis by using the advantages of reduced order models. Model reduction is a popular concept to decrease the computational effort of complex numerical simulations. Coupling a reduced model of the structure of interest with a Bayesian model updating approach or a reliability analysis to estimate the failure probability can reduce the computational cost of such analyses drastically. First, the reduced order model of the investigated mechanical structure (a cross-section of a T-beam bridge) is derived. In this contribution, the Proper Generalized Decomposition (PGD) method [1, 2] is used to bypass the curse of dimensionality. The key idea of this method is to use a separated representation for the unknown coordinates

including also model parameters. In this case, a numerical abacus is obtained, providing the structural response for all parameter congurations.

Secondly, the PGD reduced model is used in the Bayesian model updating procedure. Measurement data as well as numerical models suffer from different kinds of errors. For a given prior distribution as well as a likelihood function, samples of the a posterior distribution are drawn using a Metropolis-Hasting algorithm [3]. At each sample, the deviation between numerical model and measurement is computed by the computationally inexpensive evaluation of the PGD solution function instead of the expensive computation of a full order model.

Third, a reliability analysis with the PGD surrogate model and the identified distributions of the random model parameters is developed. For that purpose, an importance sampling [4] using the subset idea [5] for a proper choice of the importance density is applied. Using such a variance-reducing sampling algorithm reduces the number of sample points in general. By evaluating the computationally inexpensive PGD solution at each sample point instead of a full order model, a computationally efficient reliability analysis is carried out. The influences of using a PGD reduced order model in Bayesian model updating and reliability analyses is discussed by means of a numerical example of a bridge model. The main influences on the accuracy of the solution are the mode truncation and mesh discretization. Furthermore, the convergence of the identication is demonstrated and estimation of the failure probability is provided.

References

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