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Probabilistic optimization of engineering system with prescribed target design in a reduced parameter space

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Abstract

A novel probabilistic robust design optimization framework is presented here using a Bayesian inference framework. The objective of the proposed study is to obtain probabilistic descriptors of the system parameters conditioned on the user-prescribed target probability distributions of the output quantities of interest or figures of merit of a system. A criterion-based identification of a reduced important parameter space is performed from the typically high number of parameters modelling the stochastically parametrized physical system. The criterion can be based on sensitivity indices, design constraints or expert opinion or a combination of these. The posterior probabilities on the reduced or important parameters conditioned on prescribed target distributions of the output quantities of interest is derived using the Bayesian inference framework. The probabilistic optimal design proposed here offers the distinct advantage of prescribing probability bounds of the system performance functions around the optimal design points such that robust operation is ensured. The proposed method has been demonstrated with two numerical examples including the optimal design of a structural dynamic system based on user-prescribed target distribution for the resonance frequency of the system.

Keywords: Bayesian inference; robust design; probabilistic optimization; uncertainty propagation; stochastic structural dynamics; sensitivity analysis;

1. Introduction

Optimal design of engineering systems under uncertainty is important to ensure their fail-safe and robust performance. It is in this context that uncertainty quantification (UQ) of engineering systems has received significant attention in the past decade due to its effectiveness and applicability in handling parameteric uncertainty in engineering systems. The uncertainty may stem from the lack of knowledge of the parameter values or randomness inherent in them or error (noise or bias) associated with model predictions. Hence design optimization under uncertainty requires identifying optimal posterior distributions on the design parameters which satisfy the target design as opposed to working with point estimates.

The forward UQ problem forms an inner loop, and is often the first step, in the problem of robust optimization under uncertainty. It considers propagation of input parametric uncertainty using efficient computational methods to create a high-dimensional stochastic response surface in the parameter space. Some of the most efficient methods which fall under this category are stochastic Galerkin method using polynomial chaos basis functions [1–5], stochastic collocation techniques [6, 7], Monte-Carlo sampling

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