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Topology optimization under uncertainty using adaptive Monte Carlo simulation

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Abstract

Topology optimization is a computational tool for designing high-performance structures. Solutions obtained by performing the optimization in a deterministic setting, however, are typically suboptimal or impractical when considering the inherent variability in manufacturing processes and operating conditions. There is increasing interest in accounting for these variabilities formally in the design process to create topologies that are more robust or reliable in the presence of such uncertainties. Regardless of the underlying uncertainty quantification method, recently developed approaches, including both Robust Topology Optimization and Reliability-Based Topology Optimization design algorithms, are typically verified against results obtained via Monte Carlo simulation, widely considered the benchmark for stochastic computational methods in terms of flexibility, accuracy and robustness. Monte Carlo methods, however, are well-known to be computationally expensive. This work attempts to leverage the advantages of Monte Carlo simulation in a computationally efficient manner through a new sample size extension methodology, termed Refined Stratified Sampling (RSS), for highly space-filling stratified samples. The RSS technique is placed into a general uncertainty quantification context in which statistical convergence is evaluated after each sample in order to minimize the required sample size and further reduce the computational cost. This work also demonstrates a new Monte Carlo concept, referred to as Targeted Random Sampling (TRS), that is rooted in the developed RSS method. TRS enables the selection of random samples from specific strata of the space (with known probability of occurrence) that are identified, based on statistical information available from existing samples, as being particularly important to estimation of the statistical quantity of interest (such as probability of failure). The presented approaches are coupled with topology optimization to solve benchmarkproblems in topology optimization under uncertainty. Results are compared to existing approaches as well as other variance reduction techniques (Latin hypercube samples, importance sampling, subset sampling and line sampling), and relative advantages and disadvantages are discussed.