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A Comparative Study of Sampling-Based Uncertainty Propagation with First Order Error Analysis and Percentile-Based Optimization

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Abstract : In system analysis, the information on the uncertain input variables cause uncertainty in the system responses. Different probabilistic approaches for uncertainty representation and propagation in such cases exist in the literature. Different uncertainty representation approaches result in different outputs. Some of the approaches might result in a better estimation of system response than the other approaches. The NASA Langley Multidisciplinary Uncertainty Quantification Challenge (MUQC) has posed challenges about uncertainty quantification. Subproblem A, the uncertainty characterization subproblem, of the challenge posed is addressed in this study. In this subproblem, the challenge is to gather knowledge about unknown model inputs which have inherent aleatory and epistemic uncertainties in them with responses (output) of the given computational model. We use two different methodologies to approach the problem. In the first methodology we use sampling-based uncertainty propagation with first order error analysis. In the other approach we place emphasis on the use of Percentile-Based Optimization (PBO). The NASA Langley MUQC's subproblem A is developed in such a way that both aleatory and epistemic uncertainties need to be managed. The challenge problem classifies each uncertain parameter as belonging to one the following three types: (i) An aleatory uncertainty modeled as a random variable. It has a fixed functional form and known coefficients. This uncertainty cannot be reduced. (ii) An epistemic uncertainty modeled as a fixed but poorly known physical quantity that lies within a given interval. This uncertainty is reducible. (iii) A parameter might be aleatory but sufficient data might not be available to adequately model it as a single random variable. For example, the parameters of a normal variable, e.g., the mean and standard deviation, might not be precisely known but could be assumed to lie within some intervals. It results in a distributional p-box having the physical parameter with an aleatory uncertainty, but the parameters prescribing its mathematical model are subjected to epistemic uncertainties. Each of the parameters of the random variable is an unknown element of a known interval. This uncertainty is reducible. From the study, it is observed that due to practical limitations or computational expense, the sampling is not exhaustive in sampling-based methodology. That is why the sampling-based methodology has high probability of underestimating the output bounds. Therefore, an optimization-based strategy to convert uncertainty described by interval data into a probabilistic framework is necessary. This is achieved in this study by using PBO.

Keywords : aleatory uncertainty, epistemic uncertainty, first order error analysis, uncertainty quantification, percentile-based optimization
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