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Efficient Uncertainty Quantification in Computational Electromagnetics using an Adaptive Metropolis-Hastings Method with Importance Sampling

Sathya S. Ganta*, Barry D. Van Veen, and Susan C. Hagness
Department of Electrical and Computer Engineering
University of Wisconsin-Madison, Madison, WI, USA.

1 Extended Abstract

There is inherent uncertainty in the physical parameters of both naturally occurring and artificially engineered materials. Uncertainty arises due to intrinsic heterogeneity, manufacturing tolerances, inaccuracies in measurement processes, and changing ambient conditions of temperature, pressure and humidity. Uncertain physical parameters include geometric properties like shape, position and dimensions as well as electrical properties, namely dielectric constant and conductivity. These uncertainties translate to uncertainties in field values computed in computational electromagnetics (CEM) simulations of wave interactions with the materials or devices possessing uncertain properties. There is a growing need for computationally efficient uncertainty quantification (UQ) techniques given the ubiquitous role of CEM simulations in electromagnetics engineering design and analysis.

Existing sampling-based UQ techniques yield accurate results for problems in which the variability in the computed field values is sufficiently small. However, difficulty establishing a priori that the variability is small enough in a particular problem limits the applicability of existing methods. Hence, there is a need for sampling-based UQ methods that apply to problems with modest to large variability in the CEM simulated field values.

Computed field values can be used to improve the efficiency of sampling on the fly in sampling-based methods where sampling of uncertain physical parameters and execution of corresponding CEM simulations are performed sequentially. The adaptive Metropolis-Hastings algorithm [1] is one such sequential sampling algorithm. The computed field values can be used to change the target distribution and more efficiently sample the distribution of the field values. This latter approach of incorporating the variability in computed field values into the sampling procedure is called importance sampling [2].

We present a new sampling-based UQ method that is well suited for problems with arbitrary magnitude of variability in computed field values. Our method combines the adaptive Metropolis-Hastings method and the importance sampling technique to achieve significant reduction in computational cost over traditional Monte Carlo techniques. We demonstrate the effectiveness of our method using two practical CEM simulation examples: a waveguide branch and a channel drop filter implemented using 2D photonic crystals. We employ a single uncertain physical parameter in each example so that ground truth for the uncertainty of the field values can be computed. The two examples exhibit different degrees of variability. The new method and the standard Monte Carlo method are used to estimate the mean and standard deviation of a relevant field value in each example. We compare the rate of convergence of the estimated mean and standard deviation for each method and demonstrate that the new method provides more than a 20-fold decrease in computation cost.

References

[1] H. Haario, E. Saksman, and J. Tamminen, “An adaptive Metropolis algorithm,” *Bernoulli*, **7**, 2, 2001, pp. 223–242.

[2] R. Y. Rubinstein, and D. P. Kroese, *Simulation and the Monte Carlo Method*, 3rd ed., Hoboken, NJ, USA: Wiley, 2016.