

Utilization of Adaptive Sampling in Gradient Enhanced Taylor Kriging for Uncertainty Quantification in FEM Radar Cross Section Computations

Christopher Erickson, Stephen Kasdorf and Branislav M. Notaroš

Electrical & Computer Engineering Department, Colorado State University, Fort Collins, CO 80523, USA (Christopher.Erickson@colostate.edu, notaros@colostate.edu)

The typical approach to uncertainty quantification (UQ) in computational electromagnetics (CEM) as well as many other computational sciences is via a Monte Carlo simulations approach. These simulations take significant time and computational resources as they usually require an extremely large number (>1000) of samples to be collected to obtain proper representation of the parameter space. As the design space grows larger so do these requirements. Furthermore, the convergence rates of these solutions are restricted and limited by a rate proportional to the square root of the number samples.

Contemporary approaches to solving the UQ problem have been via adjoint analysis to calculate the solution gradient and use this to enhance and inform surrogate models. These surrogate models can use fewer samples to achieve nearly indistinguishable results compared to that of a high-quality Monte Carlo simulation, making it an attractive alternative. The reduced sampling requires fewer simulations to be solved and, by extension, time and computational resources.

Surrogate models have been adopted for analysis of UQ problems, with fairly good results. A typical surrogate model approach is polynomial chaos expansion (PCE). It offers high accuracy and high convergence rates, meaning a fairly accurate solution for small sample sizes. It is often considered the best general approach to UQ in CEM and other computational fields.

Gradient enhanced Taylor kriging (GETK) has emerged as a contender to these two methods, offering significant increases in convergence rates and accuracy. With as little as 9 points offering magnitudes higher accuracy in comparison to PCE. GETK uses the adjoint solution to augment the typical kriging methods, allowing it to use information about the gradient in its regression scheme. A hidden benefit of GETK outside of its already impressive results, is its ability to give information about the estimated uncertainty of the reconstructed points, or variance from the observed data. In this presentation we present a methodology for adaptive sampling and refinement using this untapped information to further improve the results of GETK.

The addition of adaptive sampling shows an improvement in convergence rates at a higher number of sampling points in comparison to a typical latin hyper cube (LHS) sampled approach for GETK, and a dramatic improvement over PCE in both accuracy, stability, and convergence rates.

Adaptive sampling methods for GETK show a further increase in efficacy of the surrogate model methods. This approach only requires a sampling of 15 points from the parameter space to achieve an RMSE of 1.74×10^{-5} , a 98.2% improvement to the PCE RMSE of 9.58×10^{-4} , and an 81.8% improvement to the non-adaptive sampled GETK method of 9.57×10^{-5} . These results show the impressive effects that adaptive sampled GETK has on UQ in CEM, especially in comparison to the standard Monte Carlo method.