Some Advances of Machine Learning as Applied to Computational EM, Remote Sensing, and Medical Diagnostics

Branislav M. Notaroš, Cam Key, Hein Thant, and Stephen Kasdorf

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

Machine learning algorithms have made huge strides in the past decade, and have a massive community invested in improving and expanding existing algorithms. This talk presents several major advancements in computational electromagnetics (CEM), namely in efficiency, accuracy, and versatility of solutions and in uncertainty quantification; remote sensing and characterization of winter precipitation; and medical diagnostics – taking advantage of the recent developments in artificial intelligence (AI) and machine learning algorithms and tools.

The talk presents data-enabled advancement of computation in engineering by robustly applying machine learning to accelerate the method of moments (MoM) and finite element method (FEM). This approach couples far-reaching predictive capabilities of deep neural networks (DNNs) with the robustness and rigor of MoM and FEM. Essentially, it guides MoM or FEM using DNNs to predict efficient macro basis functions for a given challenging CEM problem, leading to very substantial advancements in efficiency, accuracy, and versatility of the solution. Our approach solves CEM problems asymptotically faster than pure CEM methods and more accurately and robustly than neural networks can alone. It does not rely on direct prediction of the solution; we use DNNs to guess a highly simplified basis on which to solve the problem rigorously using available MoM or FEM techniques. The results demonstrate that the capacity of reasonably-sized neural networks is sufficient to understand complicated CEM problems with high variability, and also that the predicted basis approach achieves results nearly identical to expensive high-order variational method simulations but at a fraction of the matrix size and computational cost.

We also discuss the implementation and use of surrogate models and machine learning in uncertainty quantification (UQ) in CEM. We present the Kriging methodology, i.e., surrogate models based on Kriging interpolation, for reconstruction of probability-density function in UQ CEM problems, as very efficient alternatives to Monte Carlo simulations.

The talk also presents a comprehensive approach to characterization of winter precipitation through a synergistic use of advanced optical instrumentation and radars, with emphasis on machine learning tools for classification of snowflake types. The instrumentation includes the multi-angle snowflake camera (MASC) and snowflake measurement and analysis system (SMAS), which use many cameras to capture high-resolution photographs of snowflakes or other frozen hydrometeors in freefall from multiple views. An important analysis outcome is automatic classification of precipitation, namely, deciding to which of the several classes of winter hydrometeors the observed particles belong, based on collected MASC and SMAS images. With the use of convolutional neural networks (CNNs) as well as other AI techniques, we classify snowflakes into six geometrical categories, small particle, planar crystal, columnar crystal, combination of columnar and planar crystal, aggregate, and graupel, as well as five separate degrees of riming. We show the results from recent winter field campaigns with the networks achieving unprecedented accuracies of geometrical classification and the riming estimator of upward 95%.

Finally, we present the direct electromagnetic coupling (DEC) system for orthopaedic fracture-healing diagnostics, with a simple and effective utilization of changes of antenna resonant frequency, employing small Vivaldi-like antennas for contactless position detection of metallic implants in orthopaedic clinical practice, and the use of machine learning to improve the accuracy, resolution, efficiency, and versatility of the multi-antenna DEC system.