

Utilizing the Power of AI and ML in Applied EM: From CEM, UQ, and Snow Scattering to MRI, Antenna Design, and Noninvasive Orthopaedic Monitoring

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Advancements in the methods and applications of artificial intelligence (AI) and machine learning (ML) have been a major focus in the past decade. In particular, AI and ML utilizing deep neural networks (DNN) have been of recent interest. This talk presents recent advancements in the utilization of AI/ML and DNNs in applied electromagnetics, for a very broad range of state-of-the-art topics and applications.

We present the improvement and use of gradient-enhanced-Taylor-Kriging (GETK) based ML in uncertainty quantification (UQ) for computational electromagnetics (CEM). We present surrogate functions based on the Kriging methodology for interpolation of an unknown function, in the case of a dielectric scatterer. These results show dramatic improvements in efficiency in comparison to Monte Carlo simulations. Furthermore, we show advancements of these results utilizing various techniques to further optimize the Kriging method such as basis function selection and adaptive refinement.

Classification of precipitation, namely, deciding to which of the predefined classes of winter hydrometeors the observed particles belong, can enhance understanding, characterization, and quantification of other geometrical, microphysical, and scattering properties of snowflakes, as well as enrich our understanding of polarimetric radar signatures of snow. The high-resolution photographs of snowflakes collected by multicamera instruments are especially suitable for snowflake classification. Obviously, classifying particle types by visual inspection is not practical. There have been dramatic recent developments in AI and ML, including techniques based on Convolutional Neural Networks (CNNs), enabling methods for accurate and fast automatic classification of snowflakes using images. We present our new results of the use of CNNs in geometrical classification, riming degree estimation, and wet/dry state estimation of snowflakes with record-breaking accuracies reaching upwards of 98.4%.

Additionally, within medical magnetic resonance imaging (MRI), we present the use of CNNs to build a fast and efficient method for patient personalized specific absorption rate (SAR) estimation of arbitrary transmit antennas at clinical ($B_0 < 3T$) and high ($B_0 > 3T$) field strengths, based on a single MRI scan at low power. We show the flexibility of the neural network design to various antenna types, and imaging systems. This system offers a dramatic increase in SAR estimation speed for patients when compared to standard CEM methods.

We also present a novel approach to parametric antenna design using AI/ML and CNNs, together with CEM simulations to produce arbitrarily shaped antennas with specific characteristics such as S parameters and radiation patterns. We show the ability for this system to achieve a near optimal design in a matter of hours that then can be rapidly prototyped and implemented into a new or existing system.

Finally, we present a noninvasive orthopaedic fracture monitoring method using direct electromagnetic coupling (DEC) enhanced by DNNs. Utilizing several Vivaldi-like antennas, positional variations of a metal fixation plate are wirelessly detected via antenna resonant frequency shifts and are used to determine orthopaedic healing rates. A neural network is used to efficiently and accurately interpret the frequency shifts at multiple frequencies over multiple antennas to determine millimeter distances at the Fresnel region. Furthermore, an additional neural network is utilized to determine the effective permittivity of a patient's limb composition, to account for variation in material parameters of the patient, to improve accuracy of the overall system.