Deep Learning assisted analysis of Microwave-Plasma interaction and its Applications

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Microwave-plasma interaction has been extensively researched for decades due to its diverse applications. The propagation of electromagnetic (EM) waves into plasma, a complex dispersive medium, mainly depends on the spatial distribution of plasma density and the frequency of the incident EM wave. Numerous theoretical, numerical, and experimental studies have explored EM wave propagation characteristics in unmagnetized collisional plasma. When an EM wave such as a microwave is incident on a weakly ionized unmagnetized plasma it is subjected to scattering as well as absorption. This interplay of transmission, reflection, and absorption of an EM wave propagating in an inhomogeneous plasma leads to complex EM scattering patterns.

Several theoretical and computational methods exist for the study of EM wave propagation in a plasma. However, most of the traditional Computational Electromagnetics (CEM) approaches whether iterative or direct are computationally challenging due to stringent numerical criteria that lead to high memory usage and longer simulation time as the problem size increases. The first part of the talk will present a convolutional neural network (CNN)-based deep-learning (DL) model, inspired from UNet with a series of encoder and decoder units with skip connections, for the simulation of microwave–plasma interaction. The DL technique proposed in our work [1] is significantly fast when compared to the existing computational techniques and can be used as a new, prospective, and alternative computational approach for investigating microwave–plasma interaction.

In the second part of the talk, a novel DL-based non-invasive plasma diagnostics approach will be discussed where the combination of microwave-plasma interaction physics, existing plasma diagnostics techniques, and DL to train neural networks for plasma density prediction with high accuracy and minimal efforts are proposed. The electric field pattern due to microwave scattering from plasma is utilized to estimate the density profile. The proof of concept is tested for a simulated training data set comprising a low-temperature, unmagnetized, collisional plasma. Different types of symmetric (Gaussian-shaped) and asymmetrical density profiles, addressing a range of experimental configurations have been considered in our study [2]. The DL-based technique has the capability to determine the electron density profile within the plasma and can be used as a new alternative approach to address some of the challenges associated with existing plasma density measurement techniques. The performance of the proposed DL-based approach has been evaluated using several metrics and affirms the potential of the proposed machine learning-based approach in plasma diagnostics.

[1] Deep-Learning Architecture-Based Approach for 2-D-Simulation of Microwave Plasma Interaction. IEEE Transactions on Microwave Theory and Techniques, volume 70, issue 12, 2022.
[2] Deep Learning assisted microwave-plasma interaction based technique for plasma density estimation, Journal of Physics D: Applied Physics, volume 57, number 1, 2024.