Integration of Machine Learning approaches in spectroscopic diagnostic of nonthermal atmospheric pressure plasmas

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Real-time diagnostics of plasma are critical for the effective control and optimization of plasma-mediated processes, particularly in applications involving non-equilibrium plasmas, such as atmospheric pressure (AP) plasmas and laser-produced plasmas (LPP). These plasmas exhibit complex behaviors due to their unique environments, which include neutral atoms and molecules, radicals, excited states, ions, and electrons. The non-equilibrium nature of these plasmas, characterized by electron energies of a few electron volts (eV), enables the generation of highly reactive chemistry at near-ambient temperatures, making them suitable for a wide range of innovative applications. However, the same non-equilibrium conditions that make these plasmas so versatile also present significant challenges for diagnostics. Accurate extraction of plasma parameters necessitates coupling optical emission spectroscopy (OES) measurements with appropriate collisional radiative (CR) models. However, the real-time analysis of these parameters using traditional CR models alone is often infeasible due to the computational complexity involved.

In this study, we explored the integration of advanced ML algorithms with a non-invasive CR model-based optical diagnostic framework to enhance the real-time diagnostics of nonthermal atmospheric pressure plasmas (NAP) [1] and LPP. Specifically, we employed Random Forest regression (RFR) to analyze and predict plasma parameters based on simulated intensity data generated from a fine-structure resolved CR model. This model was developed using consistent cross-section data obtained from the Relativistic Distorted Wave method [2, 3]. The results showed that the plasma parameters obtained from the ML models were in excellent agreement with those derived from the CR model.

Additionally, Optical emission spectroscopy (OES) measurements were collected from an Ar-Nonthermal MultiJet system across various operating conditions. The dataset was initially complex, with high dimensionality due to numerous spectral peaks from Ar I, N_2, O, and OH species. To streamline the analysis, principal component analysis (PCA) was applied to reduce the dimensionality, making the data more manageable. This reduced data was then input into a Deep Neural Network (DNN) for regression analysis, which successfully generated synthetic spectra and accurately predicted the key emission intensities. Further optimization of the DNN allowed us to identify the optimal operating parameters for achieving desired peak values. This work highlights the effectiveness of ML, particularly RFRs, and DNNs, in real-time diagnostics and modeling the relationship between operating conditions and spectral outputs, offering a practical alternative to complex physical models in plasma diagnostics. Further insights will be presented at the conference.

References

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