

Rapid analysis model and extrapolation method of neural network in spectral diagnostic

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A robust and interpretable neural network (NN)-based model has been developed for analyzing charge exchange spectra on the HL-2A tokamak, achieving high accuracy in ion temperature (T_i) and toroidal rotation velocity (v_t) estimation. Trained and tested on around 122 thousand spectra, the model achieves a coefficient of determination (R^2) of 0.948 for T_i and 0.973 for v_t , with an inference time of less than 1 ms per spectrum. Its robustness against novel data eliminates the need for human intervention, enabling real-time plasma feedback control. Interpretability analysis using Integrated Gradients (IG) reveals that the model estimates T_i and v_t by detecting Gaussian spectral line features, aligning with fundamental physical principles. To extend the model's applicability, a method is proposed to generate synthetic high-temperature spectral data based on low-temperature experimental data. A new NN-based model is trained on data with $T_i < 2$ keV, which performs poorly when extrapolated to $T_i > 2$ keV. By adding 5% synthetic high- T_i data, the model's extrapolation capability is extended to $T_i < 4$ keV, reducing the mean relative error in the 3–4 keV range from 35% to below 15%.

This work bridges the gap between NN-based models and traditional methods, establishing a reliable alternative for spectral analysis in fusion research. The use of synthetic data to enhance AI algorithms demonstrates significant potential for real-time ion temperature measurement and feedback control in future high-parameter fusion devices.

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