A Neural Network Approach for DTT Plasma Profile Reconstruction validated on data-driven TCV kinetic surrogates

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Abstract

To surrogate the kinetic states, n_e and T_e of tokamak plasma, we present a Fully Connected Neural Network (FCNN), benchmarked against synthetic-tokamak database. A novel numerical database generation methodology is being proposed. To generate the dataset, we parameterized the nonlinear source terms of Grad Schafranov equation using a basis set of 12 distinct and experimental magnetic equilibrium reconstructions and then performed random sampling of these profiles to generate an extensive, diverse set of nonlinear equilibrium solutions. A synthetic framework, 'Tokalab', is employed for further augmentation of free boundary (in our case) Grad-Shafranov solutions to derive the kinetic states n_e and $T_{e.}$ and subsequently simulates forward model of synthetic laser-assisted diagnostics. The data-driven surrogate aims to map two-dimensional fields of kinetic states n_e and T_e from laser-based diagnostics, namely interferometer and Thomson scattering (TS), across the poloidal cross-section of the plasma, together with magnetic equilibrium, ψ information. The reconstruction fidelity has been validated on physical diagnostics through regression metric, R^2 and relative error across multiple dynamic phases of various offline TCV discharges, included in data generation phase and as extrapolated cases. Statistical distribution analysis across five offline discharges reveal prediction error of surrogate reconstructions of n_e and T_e remains centered around Mean Relative Squared Error MSE_r, 0.05 with respect to physical TS diagnostic. Whereas there is wide coverage of error distribution in case of interferometers. The associated uncertainty in the interferometric density reconstruction when compared with RAPDENS synthetic interferometer's relative uncertainty to reconstruct the experimental diagnostic revealed the overall comparative performance of our surrogate model to be least bound to uncertainties, except Low Field Side (LFS) chords. Presented data-generation methodology and surrogate modelling, trained on free-boundary GS solutions may enable post-discharge diagnostic data analysis to isolate the forward modelling errors from physical diagnostics anomalies in context of a fast machine learning observers to constrain the kinetic states of the future born tokamak, DTT, in free boundary scenarios and also given that once the specific target discharge boundaries are known.