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Physics-Informed Neural Networks for Multi-Diagnostic Equilibrium Reconstruction in Tokamaks

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Equilibrium reconstruction is a fundamental task in tokamaks, as it provides the distribution of the fields and currents inside the plasma. In recent years, the magnetic configurations and plasma scenarios have become increasingly complex. Their accurate identification is therefore particulalrly important to achieve the required performances. Accurate knowledge of the magnetic fields is also often a prerequisite for the interpretation of various diagnostic measurements. Unfortunately the equilibrium reconstruction is a severely ill-posed problem. It is therefore essential to constrain the algorithms with multiple diagnostics to achieve accurate results. The subject of the present work is a Physics-Informed Neural Network (PINN) algorithm for reconstructing plasma equilibrium using a multi-diagnostic approach, which includes magnetics, kinetic pressure, and interferometer-polarimeter data. Among these, the interferometer-polarimetric measurements are among the most valuable, as they provide line-integrated information about the internal magnetic fields. However, the polarisation evolution of an electromagnetic wave traversing a magnetised plasma exhibits non-linear effects, which render quite challenging the integration of this information into the reconstruction process. In the past this difficulty was circumvented by making recourse to various approximations. Unfortunately, these linearisations and approximations significantly limit the accuracy of the reconstructions in many plasma scenarios, particularly at high fields and currents. The developed PINN algorithm implements a comprehensive model (defined as the hot plasma model) that accounts for these nonlinearities and also thermal effects, both relativistic and non-relativistic. Parametric analyses conducted on synthetic cases demonstrate that the hot plasma model consistently yields results much more accurate than those obtained with the cold-plasma approximation or linearization of the polarimetric measurements. The PINN model has been also extensively tested with JET data of various high current campaigns, confirming the quality of the obtained reconstructions in all the investigated experimental conditions.

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