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Machine Learning approaches to predict the ideal stability properties of spherical tokamak plasmas

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One of the biggest challenges to achieve the goal of producing fusion energy in tokamak devices is avoidance, or mitigation, of disruptions of the plasma current due to instabilities. In order to analyse these disruptions, the Disruption Event Characterization and Forecasting (DECAF) framework has been developed [1], integrating physics models of several causal events that can lead to a disruption. Two different machine learning approaches are proposed to improve the ideal magnetohydrodynamic (MHD) no-wall limit component of the full kinetic stability model included in DECAF.
First, a powerful and partially interpretable machine learning algorithm, the Random Forest Regressor [2], was adopted to reproduce the DCON [3] computed change in plasma potential energy without wall effects, $\delta W^{n=1}_{no-wall}$. When trained on a large database of equilibria from the National Spherical Torus Experiment (NSTX), the Random Forest can significantly improve the prediction performance as well as the classification of stable/unstable points. Furthermore, this tree-based method provides an analysis of the contribution of each input feature, showing that the plasma parameters that most affect the estimated value of $\delta W^{n=1}_{no-wall}$ are the ones expected by the underlying physics. Secondly, a multilayer perceptron neural network has been trained on sets of calculations with the DCON code, to get an improved closed form equation of the no-wall limit as a function of the relevant plasma parameters provided by the Random Forest. Although being slightly worse than the Random Forest in classification performance, this approach can directly provide an estimated value of $\beta^{n=1}_{N,no-wall}$, which is key to determine the mode growth rate inside the overall kinetic stability model [4]. The model has been incorporated into DECAF and tested against a set of experimentally stable and unstable discharges. The portability of the model is also investigated, showing initial encouraging results by testing the NSTX-trained algorithm on the Mega Ampere Spherical Tokamak (MAST).

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