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Applications of machine learning for plasma control in fusion reactors

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Machine learning techniques have been applied successfully in EAST plasma equilibrium reconstruction and disruption prediction. Regression neural network models are trained to identify the plasma center position and calculate equilibrium plasma parameters including li,β_p,κ,q_0 and a_minor with magnetic diagnostic signals as input features [1][2]. The results on test dataset show good calculation accuracy compared with the tokamak simulation code (TSC) calculated value. Mean absolute errors of the horizontal and vertical positions of current center are within 1 mm and the normalized errors of these equilibrium parameters are within 1%. Alongside that, the Bayes inference method is applied to reconstruct the plasma current density profile and boundary recognition [3]. An accurate boundary can be obtained with only magnetic diagnostic, but to get an accurate current density profile especially in core plasma area, additional diagnostic is needed. Both the neural network and Bayes model can iterate one step at around ˜1ms, which is fast enough for real-time equilibrium reconstruction and current profile control. If with appropriate accelerating such as parallel calculating, they can also be used for controller that require faster response, such as vertical displacement control.
Beside the above examples, machine learning also show great potential in area of disruption prediction. A convolutional neural network (CNN) that is trained on a database of EAST disruption discharges is used to recognize disruptive discharges and distinguish them from non-disruptive discharges. The true positive rate of the model increases up to 87.5%, while the false rate decreases to 6.1% [4]. Meanwhile, a real-time disruption predictor using a random forest (DPRF) was developed for high-density disruptions and used in the plasma control system of the EAST tokamak [5]. During the dedicated experiments, when the disruption probability signal increases up to a preset, configurable threshold for more than 10 ms, a trigger signal is sent to the MGI system and neon gas was injected into the plasma to successfully mitigate disruption damage.
With cooperation between EAST, Alcator C-Mod and DIII-D group, disruption databases of three single machine are built and managed with MySQL tablets [6]. Cross-machine disruption prediction is carried out on the database of three machines [7]. A hybrid deep-learning algorithm is trained with a dataset composed with only 20 EAST discharges and with more than a thousand discharges from DIII-D and C-Mod for disruption prediction. Then testing this disruption predictor on EAST and a predictive accuracy of AUC=0.973 is achieved. Machine learning shows great potential to act as the solution for future fusion reactor's disruption prediction.

Ref.
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[2] Chinese Physics B 28.12 (2019): 125204.
[3] Fusion Engineering and Design 172 (2021): 112722.
[4] Plasma Physics and Controlled Fusion 63.2 (2020): 025008.
[5] Nuclear Fusion 61.6 (2021): 066034.
[6] Nuclear Fusion, 2019, 59(9): 096015.
[7] Nuclear Fusion 61.2 (2020): 026007.

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