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PFNN：Less data and better performance on disruption prediction via physics-informed deep learning

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Disruption prediction and mitigation is a crucial topic, especially for future large-scale tokamaks, due to disruption's concomitant harmful effects on the devices. Recent progresses have proved that deep neural network can accurately predict the coming disruptions by learning from history experimental data, which becomes a potential solution for the disruption prediction in future devices [1, 2]. This technique routine has also been proved in HL-2A by offline testing and online experiment [3, 4]. However, a key issue is whether deep learning models can be developed on future devices, which can only tolerate a few disruptions and therefore can't provide much training data [5]. In this research, a predict-first neural network (PFNN) is developed. Two predict-first tasks are designed to embed physical knowledge into the neural network. Ablation experiments show that the embedded physical information significantly improves the algorithms'performance, especially when the amount of training data is limited.

The first predict-first task is to let the neural network predict the evolution of electronic temperature (Te), electronic density (Ne) and horizontal displacement (Dh) according to the control actuators and the plasma state. A preparatory neural network based on encoder-decoder framework [6] is trained on this task and three empirical equations are hidden in the design of its structure. After the training, the neural network learns the three equations and can accurately predict the evolution of paramters. Then this preparatory network can be used as a feature extractor in the disruption prediction algorithm and use the three equations to promote the performance of disruption prediction.

The second predict-first task is to mask part of the experimental data and let the neural network restore them. Another preparatory neural network based on masked auto-encoder framework [7] is trained. It can realistically reconstruct the masked parts according to the unmasked parts and the correlation between different input signals. This preparatory neural network can also be used as a feature extractor in the disruption prediction algorithm and use the correlation between different input signals to promote the performance of disruption prediction.

Ablation experiments show that the embedded physical information significantly improves the algorithms'performance. When the amount of training shots is limited to 1283 shots, the AUC (area under receiver-operator characteristic curve) of PFNN is 5% higher than the ordinary one. In general, PFNN, which is pretrained by predict-first tasks to learn physical information and then trained for disruption prediction in the second step, performs much better on disruption prediction when the amount of training data is limited. It can be a potential solution for future tokamaks'disruption prediction problem.

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