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Deep Learning and Machine Learning algorithms for disruption prediction and heat-load monitoring in fusion devices

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Developing reliable control systems for long pulse operation in fusion devices is crucial and challenging for the development of ITER and DEMO. In this context, two of the most critical issues are plasma-facing components (PFCs) protection from high heat loads and disruption prevention. This talk deals with Machine Learning (ML) tools developed for machine protection from these two issues, focusing on state-of-the-art techniques. ML models for heat load monitoring and protection from overloads and for real-time monitoring disruption risk during plasma evolution will be described.
Real-time monitoring of the heat flux (HF) on PFCs is a key objective for high-performance fusion operation. At W7–X, infrared cameras monitor the PFCs by measuring the surface temperature. Typically, the HF is localized on specific regions of the divertor called strike-lines. Since high HF can damage the PFCs, a lot of effort is devoted to the estimation of HF on the divertor tiles and to strike-line control. THEODOR (Thermal Energy Onto DivertOR) code computes the HF by numerically solving the heat equation, but the computation time does not allow the real-time application. A new approach based on Physics Informed Neural Networks (PINNs) is proposed for solving the heat equation. PINN are NNs that learn Partial Differential Equations (PDEs) by minimizing the PDE loss in a mesh-free domain. Integrating PI laws into state-of-the-art NN architecture allows PINNs to real-time estimate the HF on the divertor tiles.
Moreover, a Deep CNN was trained to learn an inverse model, to determine the control coils currents (actuators) necessary to achieve a desired HF distribution (desired state) at W7-X. Control coils were installed for an active control of thermal power distribution on the divertor. The HF images were obtained by the analysis of thermographic data. Understanding and modelling the relationship between the HF distribution in the strike-lines and the actuators influencing them important step toward strike-line control.
Disruptions are an unforeseen loss of plasma confinement inducing thermal loads on PFC and electromagnetic forces on surrounding structures. Even if present devices are not extremely affected by disruptions, the consequences of disruption events for future tokamaks and reactors could be ruinous, due to the higher amounts of stored thermal and magnetic energies. Disruption causes are not always understood, and first principle models are able to exhaustively explain only some disruption dynamics. Their prediction, mitigation and avoidance are critical needs for the success of next-step fusion devices. Different ML models will be presented, including supervised techniques, such as CNNs, and unsupervised techniques, such as Self Organising Map (SOM) or ISOmetric MApping (ISOMAP), applied both to disruption prediction in tokamak. Each technique brings its own specific advantages: CNNs allow one to efficiently manage the spatiotemporal information from the plasma profiles (temperature, density and radiation), together with other commoly used diagnostic signals. In SOMs and ISOMAP no human intervention is needed during training: in particular, labelling of the samples of disruptive discharges, necessary to supply the model with the information about the presence of disruption precursors in each time instant, is not required.

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