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Real-time Prediction and Avoidance of Fusion Plasmas Instabilities using Feedback Control

Development of machine learning algorithms to predict the plasma evolution and how they can be used in control of the plasma to achieve combined high performance and high stability, and its application to fusion reactors is presented. Due to the nature of tokamak plasmas, operation in higher fusion gain increases the probably of instabilities which may then lead to disruptions and damage the reactor. To avoid this problem, machine learning algorithms have been successfully applied in fusion reactors to predict an imminent disruption. This allows for mitigation of the effects of the disruption. However, this approach cannot be used often or be a basis for commercial reactor operations. Thus, it is more important to be able to learn to operate at as high a performance as possible. This can be only achieved be if we can predict the evolution of the plasma and take action avoid the plasma to move into regions of instability. Unfortunately, currently available plasma physics simulations give only good qualitative predictions are not good enough to optimize or control the plasmas. An alternative approach where experimental data is used to come up with plasma evolution models using machine learning can be potential solution. The physical nature of plasma profiles is both spatially and temporally complex; therefore, any reasonably efficient machine learning model tasked with predicting the temporal evolution of tokamak plasmas requires mechanisms capable of resolving highly abstract temporal patterns. We implemented various neural network models to look at plasma evolution, with the Long Short-Term Memory (LSTM) recurrent neural network (RNN) model giving the best results thus far. LSTM is a form of memory that allows a neural network to remember information that recently passed through the system. As training input, plasma profiles (Te, Ti, ne, ni, current and rotation) and control actuators: total neutral beam injection (NBI) power and torque; gas puffing flow-rates; and total electron-cyclotron heating (ECH) power, for hundreds of DIII-D discharges were extracted from a DIII-D database. ML was then trained to predict 50-ms to 200-ms of profile temporal evolution (this is roughly the confinement time scale for DIII-D, which is the right time scale for plasma manipulation). The results of the algorithm applied to untrained data set show are good enough for development of control system. In order to use these machine learning algorithms in control, we convert the codes to real-time C/C++ to implement in Plasma Control System. We first present the initial test of the real-time control system that employs this profile predictor to achieve user given profiles. We, then, present the plasma control that was implemented on DIII-D that regulates neutral beams to keep the plasma in a stable regime; if this fails and predicted disruptivity becomes too high, the system ramps down the plasma. Application of machine learning to understand and control the fusion plasmas is a relatively new field and there is a lot of promise, we comment on the possible future direction in this area.

Member State or International Organization

United States of America

Affiliation

Princeton University

Primary authors: KOLEMEN, Egemen (Princeton University); ABBATE, J (Princeton University); CONLIN, W (Princeton University); FU, Y (Princeton University); BUTT, J (Columbia University)

Presenter: KOLEMEN, Egemen (Princeton University)

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