

Real-Time Identification of sawtooth on HL-3 using a deep learning framework

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Sawtooth instability is one of the most violent magnetohydrodynamic (MHD) instabilities that must be actively controlled in a tokamak fusion reactor. In present tokamak experiments, various auxiliary heating systems, such as neutral beam injection and ion or electron cyclotron resonance heating, are used. Electron cyclotron (EC) beams are particularly well-suited for controlling plasma instabilities due to their flexible power deposition, allowing for rapid adjustments across the plasma cross-section using mirror actuators. However, the current EC beam control system lacks real-time capabilities, making it difficult for sawtooth recognition algorithms to meet the required real-time processing speeds.

To address this challenge, a hybrid deep learning model integrating a long short-term memory (LSTM) network with a convolutional neural network (CNN) was developed. LSTM, a type of recurrent neural network specifically designed for long time-series data, effectively captures temporal dependencies in sawtooth oscillations. Meanwhile, CNN extracts spatial features from diagnostic signals, enhancing the model's ability to detect intricate waveform patterns. This combination leverages both sequential and spatial feature extraction, improving recognition accuracy and robustness. The model was trained using over 10,000 sawtooth cycles derived from soft X-ray and electron cyclotron emission diagnostic data, reliably capturing characteristic sawtooth patterns in fusion plasmas. During validation, the algorithm achieved an accuracy of **92.5%** in real-time experiments and **95.3%** on post-processed data, demonstrating strong performance in both speed and accuracy. Additionally, cross-verification confirmed that the model's statistical predictions align with the physical properties of HL-3 plasmas, making it a reliable tool for real-time sawtooth period control. This work contributes to the advancement of plasma diagnostics and control systems in fusion research.

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