Multimodal super-resolution diagnostics for analyzing fast transient events in fusion plasma

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We present a groundbreaking multimodal neural network model designed for diagnostics resolution enhancement, which innovatively leverages inter-diagnostic correlations within a system. Traditional approaches have primarily focused on unimodal enhancement strategies, such as pixel-based image enhancement or heuristic signal interpolation. In contrast, our model employs a novel methodology by harnessing the diagnostic relationships within the physics of fusion plasma. Initially, we utilize the correlation among diagnostics within the tokamak to substantially enhance the temporal resolution of the Thomson Scattering (TS) diagnostic. This enhancement goes beyond simple interpolation, offering a "super-resolution" TS (SRTS) that preserves the underlying physics inherent in inter-diagnostic correlation. Increasing the resolution of TS from conventional 230Hz to 500kHz could capture the structural evolution of plasma instabilities and the response to external field perturbations, which is challenging to do with conventional TS.

This physics-preserving super-resolution technique may enable the discovery of new physics that were previously undetectable due to resolution limitations and/or allow for the experimental verification of phenomena that have previously only been predicted through computationally intensive simulations. Furthermore, the proposed approach holds significant potential for disruption prediction and mitigation by enhancing the accuracy of early detection of disruptive events, enabling timely and precise control actions to prevent or mitigate these events.

Figure 1 shows the general diagram of developing the neural network model (Diag2Diag) to generate SRTS data. It also presents an example of generating synthetic SRTS at 500kHz for an ELMy H-mode DIII-D discharge 153764. The synthetic and measured TS match well whenever TS measurements are available. Additionally, synthetic TS captures nearly all the ELM events (indicated by D_α spectroscopy) that are missed by the measured TS even though it is configured in bunch-mode with higher temporal resolution.

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