Multimodal Super-Resolution Diagnostics for Physics Discovery with Application to Fusion

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This work introduces Diag2Diag, a multimodal neural network model for resolution enhancement in fusion devices, leveraging inter-diagnostic correlations. Traditional uni-modal approaches, like pixel-based image enhancement, are limited. In contrast, Diag2Diag employs diagnostic relationships within fusion plasma physics, enhancing the temporal resolution of the Thomson Scattering (TS) diagnostic from 200Hz to 500kHz, capturing structural plasma instabilities and responses to external field perturbations.

Experimental fusion reactors like DIII-D use various diagnostics, each with strengths and limitations. For instance, Electron Cyclotron Emission (ECE) and Interferometer track fast dynamics but have low spatial resolution, while TS has high spatial but low temporal resolution. Diag2Diag reconstructs a diagnostic's amplitude from others, preserving intrinsic physics, and improves temporal resolution more intelligently than conventional methods. Input diagnostics include Interferometer, ECE, Magnetic probes, Charge Exchange Recombination, and MSE.

We investigated whether synthetic super-resolution TS can verify hypotheses in fusion plasma physics. Two phenomena are studied: ELM cycle analysis [1] and plasma response to external field perturbations [2]. For ELM cycles, the SRTS follows the measured TS when available and indicates ELM cycles often missed by the measured TS, even when TS is configured at "bunch mode" [3]. For external field perturbations, the SRTS reveals the experimental island effect induced by Resonant Magnetic Perturbation (RMP), providing the first diagnostic evidence of profile flattening at magnetic islands.

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