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Real-Time Instability Tracking with Deep Learning on FPGAs in Magnetic Confinement Fusion Devices

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Active feedback control in magnetic confinement fusion devices is desirable to mitigate plasma instabilities and enable robust operation. Optical high-speed cameras provide a powerful, non-invasive diagnostic and can be suitable for these applications. In this study, we process fast camera data, at rates exceeding 100kfps, on in situ Field Programmable Gate Array (FPGA) hardware to track magnetohydrodynamic (MHD) mode evolution and generate control signals in real-time. Our system utilizes a convolutional neural network (CNN) model which predicts the n=1 MHD mode amplitude and phase using camera images with better accuracy than other tested non-deep-learning-based methods. Open source tools such as hls4ml are used to optimize, translate, and synthesize the CNN to a register transfer level description for FPGA deployment. By implementing this model directly within the standard FPGA readout hardware of the high-speed camera frame grabber, our mode tracking system achieves a total trigger-to-output latency of 17.6us and a throughput of up to 120kfps. This study at the High Beta Tokamak-Extended Pulse (HBT-EP) experiment demonstrates an FPGA-based high-speed camera data acquisition and processing system, enabling application in real-time machine-learning-based tokamak diagnostic and control as well as potential high-speed applications in other scientific domains.

Minioral

No

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No

Are you a student?

Yes

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