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Scalable Real-time Framework Enabling Machine Learning Based Plasma Control

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The Princeton Plasma Physics Lab (PPPL) has demonstrated the effectiveness of a scalable real-time framework that enables plasma control system (PCS) algorithms to utilize heterogeneous inputs at both millisecond and microsecond speeds. Current developments target real-time plasma control algorithm challenges by combining new hardware technologies and proven software techniques with new methods of machine learning inference. The deployed framework integrates various hardware components, including remote I/O, wire-speed latency between computers, high speed analog digitizers, an nVidia A100 and V100 GPU, an FPGA, and a camera. Primary input consists of 160 analog signals acquired at 1MHz in buffers of 32 microseconds. Alongside providing that data directly to the PCS, the FPGA also consumes data for future processing through machine learning inference engines tunable at runtime. Timing analysis shows 1 millisecond end to end inference times and the potential for 50 microsecond control loops on the raw data. Even without the FPGA, 3 machine learning models have been implemented and are capable of running in 560 microsecond cycle times. Key findings indicate the feasibility of real-time plasma control using a hardware-accelerated approach, demonstrating significant improvements in processing speed and efficiency compared to strictly software-based methods. This research provides new tools to enable increasingly complex plasma control systems, paving the way for enhanced stability and performance.

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