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Machine-learning control of coherent combining of fiber lasers for plasma accelerators

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One of the most promising technical paths to high-average-power, high-peak-power, ultrafast lasers is coherent combination of fiber lasers, which could produce Joule/kHz laser pulses to drive next-generation laser-plasma accelerators (LPA), e.g. kBELLA (kilohertz Berkeley Lab Laser Accelerator). Advanced controls are essential for many-beam, many-pulse coherent combination, and to optimize the overall laser system by sensing, diagnosing, and controlling at high speed (as compared with perturbations). Advanced machine learning (ML) has proved to be advantageous over more commonly used algorithms for complex systems where errors are irretrievable from measured data (e.g. phase error from amplitude data), or the system has too many unknown, time-varying parameters and is highly nonlinear, preventing deterministic error prediction. We have created innovative solutions to address some of the key challenges in ML control, to enable ML to learn on an unstable system with noise and drift. We have, for the first time, demonstrated stabilizing laser power with ten times faster convergence speed than random dither-and-search algorithms and experimentally demonstrated 0.4% stability with high combining efficiency when coherently combining 8 beams. Key features of our novel ML-based active feedback controls include scaling to many outputs while retaining high speed, and ability to actively re-learn while in operation. We are also implementing ML on Field-Programmable Gate Arrays (FPGA) to reduce the control latency to microseconds, to enable fast control over >10 kHz repetition rate and allow precision controls to reach optimal error reduction and stability. This approach will provide a robust technical path to active control of coherently-combined multi-kHz, high-power ultrafast lasers, achieving the power stability and combining efficiency needed for laser-based accelerators.

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