Adaptive feedback and machine learning for time-varying particle accelerator systems

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Abstract

Particle accelerators are large complicated time-varying systems with thousands of coupled components whose performance drifts over time. For example, the resonance frequencies of RF accelerating cavities are disturbed by vibrations and drift due to temperature changes, which also introduce arbitrary offsets in the phases of RF signals. Magnet power supplies also experience disturbances in the form of high frequency ripples. The accelerated charged particle bunches are also complex and time varying objects composed of billions of interacting particles whose dynamics are governed by nonlinear collective effects such as space charge forces and whose initial conditions at the entrance of the accelerator change over time due to effects such as plasma source fluctuations and changing quantum efficiency of photocathodes. Finally, on top of all of this uncertainty, accelerators have few non-invasive diagnostics that can provide a detailed view of their beam's 6D (x,y,z,p_x,p_y,p_z) phase space in real time. Typical accelerator diagnostics provide 2D slices of the 6D phase space, usually through time consuming measurements that disrupt operations, such as physically passing wires through the beams or passing the beams through various thin slits. Some of the most advanced diagnostics are provided by transverse deflecting RF cavity systems, destructive measurements that can provide 2D (z,p_z) measurements. The non-invasive diagnostics that are most commonly available are beam position monitors (BPM) which provide center of mass measurements or scaler measurements such as current and loss monitors. The complexity, uncertainty, and limited diagnostics of accelerators make quick and precise adjustments of their beams' phase space challenging. In this seminar we give an overview of some of the machine learning (ML) tools that are being applied to accelerators and discuss some recent efforts at Los Alamos National Laboratory to develop adaptive model independent feedback algorithms for virtual beam diagnostics [1], online multi-objective optimization [2], online reinforcement learning for optimal control of unknown and time-varying systems [3], and adaptive ML approaches for automatic phase space controls of time-varying beams [4].

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