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Multi-Objective Bayesian Optimization of Beam Emittances and Energy Spread in Linear Accelerators

This study explores a multi-objective optimization and modeling approach for enhancing the performance of a linear accelerator (linac) used in Fourth Generation Synchrotron Radiation (4GSR) facilities, focusing on the minimization of horizontal and vertical emittances as well as energy spread at the linac end. Efficient control of these parameters is critical to achieving high beam quality, essential for advanced synchrotron applications. Traditional optimization methods often face challenges in balancing these competing objectives. Therefore, we employ a Bayesian optimization technique that combines probabilistic modeling with sequential sampling to efficiently navigate the high-dimensional parameter space of the linac configuration. Bayesian optimization allows for the systematic trade-off between exploration and exploitation, leveraging prior knowledge and continuously updating with new observations to optimize performance with fewer evaluations. The approach models the complex, nonlinear relationships between operational parameters and beam quality, providing an adaptive framework that adjusts for uncertainties inherent in linac operations. Our results demonstrate that Bayesian optimization not only reduces horizontal and vertical emittances and energy spread effectively but also achieves this in a computationally efficient manner. The findings suggest that this framework could serve as a robust optimization tool for other accelerator systems, offering a generalizable methodology for improving performance in multi-objective settings.

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