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Physics-informed Bayesian Optimization for Closed Orbit Correction in Synchrotrons

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For the stable operation of synchrotrons, a controlled closed orbit is essential. The closed orbit correction methods are designed to keep the particle beam on the desired orbit. Information regarding the position of the beam is only accessible via the beam position monitors (BPM). It is feasible to attain zero deviation at the BPM with the conventional correction methods (e.g. SVD-based correction). However, given the remaining multitude of residual closed orbits errors, the objective is to achieve a minimal discrepancy between the closed orbit and the target orbit throughout the entire ring. Therefore, a Bayesian Optimization (BO) based correction method, which introduces a probabilistic modeling perspective, should be combined with beam dynamics in order to infer pattern between the BPMs, where no information are available through direct measurement. The Bayesian Optimization method is a global optimization technique for black-box functions, where a probability distribution (Gaussian Process, GP) acts as a surrogate model. A GP is fully defined by two key components: the mean function and the kernel, or covariance function.

The concept of physics-informed BO for closed orbit correction is to include beam dynamics in the GP model by estimating the kernel (and mean function) by evaluating simulated realizations. These simulations are performed with a MAD-X simulation software model of the synchrotron SIS18. Perturbations, erroneous input data, non-linearities, and noise are incorporated into the model. From these, the GP should be able to infer some information about the behavior in between the BPMs. The objective is to develop a machine model with uncertainty quantification and noise handling. This would allow for the implementation of a closed-orbit correction not only at the BPMs but also in between BPMs. Furthermore, the lattice functions could be extracted and utilized, for instance, for dispersion correction.

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