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Reinforcement Learning for Control of Polarized Cryogenic Targets at Jefferson Lab

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The operation of solid, cryogenic polarized targets in nuclear physics experiments relies on continuous tuning of the microwave frequency to compensate for radiation damage and evolving material properties, a task that is traditionally performed through manual trial-and-error by expert operators. This work presents a data driven control framework that combines surrogate modeling with reinforcement learning to optimize the target polarization. Using operational data from the APOLLO cryogenic target system, we train and evaluate multilayer perceptron and Gaussian process regression models to predict polarization as a function of microwave frequency, beam current, and accumulated radiation dose. We show that Gaussian process-based models provide well calibrated uncertainty estimates and reliably identify regions outside the training distribution, while MLPs exhibit limited sensitivity to distributional shift. To enable learning and control across multiple target samples, we introduce a Gaussian process approximation and embed the surrogate model within a standardized simulation environment. A reinforcement learning agent is trained using a lower confidence-bound reward formulation that balances performance maximization against uncertainty.

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