MASTER

Bayesian optimization-based parameter tuning of model predictive controllers for shared control and autonomous motion of medical imaging robots

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Bayesian optimization-based parameter tuning of model predictive controllers for shared control and autonomous motion of medical imaging robots

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Abstract

There has been an increasing presence of large medical robots, such as those used for Image Guided Therapy (IGT), in operating rooms. The development and implementation of Model Predictive Control (MPC) allows these robots to achieve ever higher degrees of autonomy. However, the performance of these controllers is highly dependent on their parameters, the tuning of which can be time-consuming and require specialized knowledge. In light of this, a novel automated tuning algorithm using Bayesian optimization is implemented in this project to optimize the parameters of MPC controllers for IGT robots.

First, an evaluation framework consisting of various metrics is developed to quantify the motion performance of the robot. The metrics cover relevant aspects such as safety, efficiency, and smoothness. Subsequently, a Bayesian optimization-based tuning algorithm is designed to optimize a specific set of MPC parameters with a limited number of closed-loop simulations. Each iteration of the algorithm optimizes for a collection of separate point-to-point movements in parallel. The objective is calculated from a weighted sum of the metrics multiplied with several penalty functions. Constraints are implemented using a weighted expected improvement acquisition function. The elementary effects sensitivity analysis method enables the selection of the most impactful optimization variables.

The developed algorithm is validated on two distinct use cases, an MPC designed for autonomous movements and another designed for shared control. The metrics are demonstrated to be applicable to both cases, and both use cases exhibit improved performance after optimization. A user experiment using a virtual reality setup of the robot for the second use case also showed significant performance improvements with optimized parameters.