Implementation of “Safe and Robust Learning Control with Gaussian Processes” in safe-control-gym

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### 1. Motivation

Gaussian processes are widely used to learn unknown dynamics because of their properties and their ability to consider uncertainties in the data. Robust control provides performance and stability guarantees for uncertain systems. The work presented in [1] demonstrates a Robust Controller that is able to learn and improve online by using Gaussian Processes.

# 2. Methodology

The approach considers non-linear systems with unknown dynamics, and measurement and process noise. It is implemented on stabilization tasks about an equilibrium point.

First, input and measurement data are obtained. Second, the Gaussian Process kernel hyperparameters are learned and the GP is trained on the data. A new operating point is obtained by solving a small optimization problem using the GP learned mean. The dynamics are linearized about this new operating point by leveraging the GP derivatives, and finally a Robust Control problem is formulated and solved by finding an H2 state feedback controller.

# 3. Outline of Experiments and Comparisons

* Since the proposed algorithm considers a stabilization task, we will first test the algorithm on 1-D quadrotor stabilization and, if successful, proceed with 2-D quadrotor stabilization.
* We intend to compare the algorithm against GP-MPC, which is a very similar approach, and MPC, which is a non-learning-based approach. Unfortunately, we aren’t aware of a robust control implementation in the safe-control-gym environment. We are also open to feedback for algorithms to compare to generate fair comparisons.
* We would like to test on measurement noise uncertainties and input disturbances.
* Performance vs amount of data learned, and computation.

# 4. Expected Outcome

We expect the controller to perform better in both performance and computation than regular MPC when uncertainties are present, as MPC does not take model uncertainties into consideration. However, the online learning controller performance could be worse than MPC with nominal dynamics as Robust Control greatly reduces performance by expecting some sort of uncertainty in the model. For GP Robust Control vs GP MPC, we expect GP MPC to perform better, but to take more computation time to learn a controller due to the time horizon involved in MPC.

[1] F. Berkenkamp and A. P. Schoellig, "Safe and robust learning control with Gaussian processes," 2015 European Control Conference (ECC), 2015, pp. 2496-2501, doi: 10.1109/ECC.2015.7330913.