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MASTER'S THESIS

Model Predictive Control of Unknown Systems with Latent States using Variational Inference

Problem description:

Safe learning-based optimal control aims to optimize the behavior of (nonlinear) dynamical systems from data while accounting for model uncertainty. While many Bayesian methods assume full state observability, the setting with latent (i.e., unobserved) states remains significantly more challenging, as the resulting posterior distributions are analytically intractable.
A recent approach [1] combines Bayesian state-space models with Particle Markov Chain Monte Carlo for inference and integrates this into an optimal control framework. This enables optimal control with formal performance guarantees—but at the cost of high computational complexity, making it unsuitable for many practical scenarios.
This thesis aims to explore variational inference (VI) as a computationally more efficient alternative for inference in Gaussian process state-space models. Building on the free-form VI framework proposed in [2], the goal is to integrate VI-based inference into model predictive control (MPC) and assess its suitability for fast, uncertainty-aware control of unknown systems with latent states. The performance of the resulting algorithm shall be evaluated in numerical simulation.

Tasks:

- Review relevant literature on Gaussian process state-space models, variational inference, and model predictive control.
- Develop an MPC framework incorporating variational inference for dynamics and state inference.
- Implement the proposed approach.
- Evaluate the performance of the method in numerical simulations and compare it to existing approaches.

Bibliography:

[1] R. Lefringhausen, S. Srithasan, A. Lederer, and S. Hirche, "Learning-based optimal control with performance guarantees for unknown systems with latent states," in *2024 European Control Conference (ECC)*, pp. 90–97, IEEE, 2024.
[2] X. Fan, E. V. Bonilla, T. O'Kane, and S. A. Sisson, "Free-form variational inference for Gaussian process state-space models," in *International Conference on Machine Learning*, pp. 9603–9622, PMLR, 2023.

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Start: -
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