How are Learned Perception-Based Controllers Impacted by the Limits of Robust Control

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Motivation

Observability measures how much information about latent states can be obtained from measurements.

Robustness describes how well a system operates in the face of uncertainty (e.g. disturbances).

Poor observability reduces robustness.

Theorem: *Suppose a LTI system $P(\zeta)$ has unstable pole p, and unstable zero q. Then the norm of the complementary sensitivity T (a measure of fragility) satisfies:*

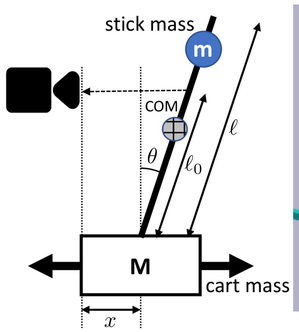
$$\|T(\zeta)\|_\infty \geq \frac{1 - p^{-1} q^{-1}}{p^{-1} - q^{-1}}$$

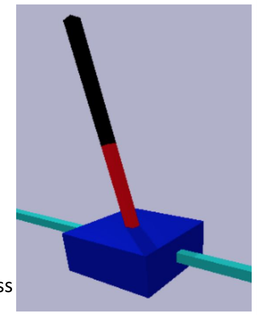
What is the impact of observability on the sample complexity and performance of learned controllers?

Testbed

We run simulations of a partially observed cartpole system.

Head-on camera observations of the top of the obscured pole





Allows us to explore the impact of

1. *Incomplete observations*: by changing fixation point (reducing observability)
2. *Noisy observations*: by changing image quality (introducing disturbances)

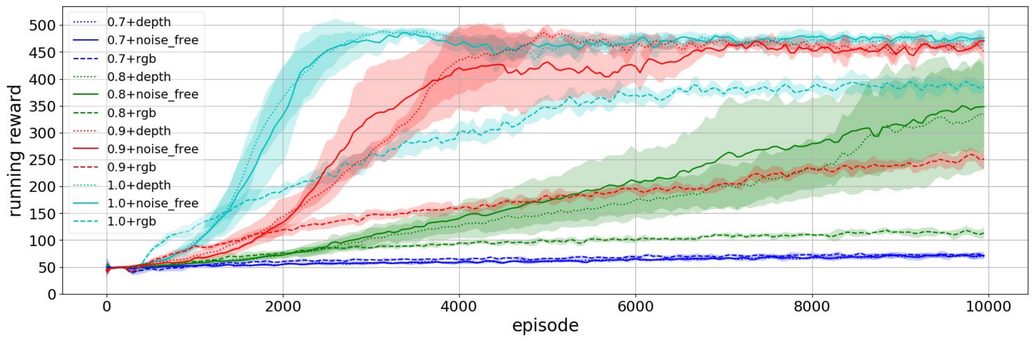
Experiments

We test the impact of observability on both RL, and H_∞ control after system ID.

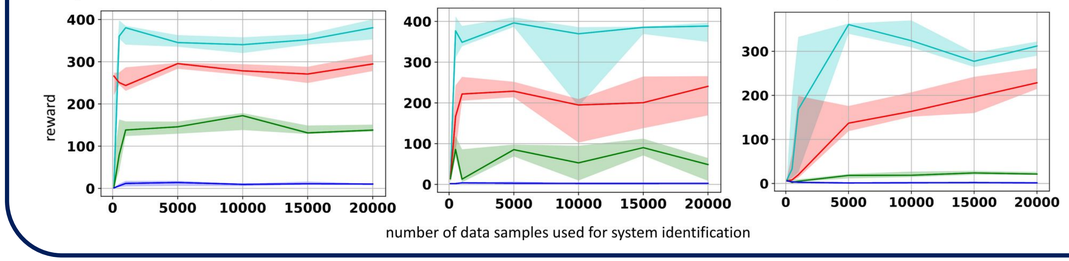
- Perception
  - Estimate the depth z of the fixation point
  - Train a CNN for each value of fixations, and each of depth / RGB images
- Reinforcement Learning: Soft Actor-Critic with a neural network approximator
- H_∞ Control: Synthesize H_∞ controller using an identified linear model

Results

Average running reward for reinforcement learning (max 500). Shaded region is standard deviation from 5 initializations.

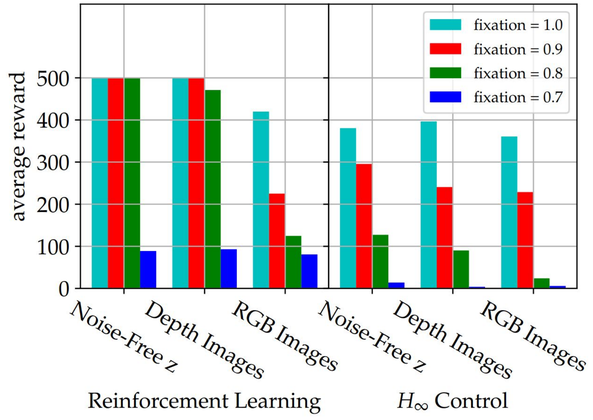


Average rewards for system identification followed by control. Shaded region is first and fourth quartile from 7 initializations.



RL agent finds it harder to stabilize the cartpole as the quality of perception deteriorates and fixation height decreases. Similar trends are seen for H_∞ control.

- Performance uniformly deteriorates as the fixation height decreases
- The impact of poorer observation quality is higher at low fixation heights, highlighting a loss of robustness with decreasing observability
- For RL (which uses a more complex approximation) sample complexity increases with decreasing observability



As observability decreases, sample complexity increases, and robustness decreases.