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Industrial IoT for Digitization of Electronis Assets

Model Predictive Control via Imitation Learning

Agenda

Overview of MPC

- Model Predictive Control (MPC) is an advanced method of process control that predicts the future behavior of a system.
- MPC uses a mathematical model to make predictions and optimize control actions.
- It handles multi-variable control problems with constraints effectively.

System Model

- The system is typically represented by a state-space model:

$$x_{k+1} = Ax_k + Bu_k + w_k$$

$$y_k = Cx_k + v_k$$

- x_k: state vector, u_k: control input, y_k: output.
- A, B, C: system matrices, w_k, v_k: process and measurement noise.

Objective Function

- Objective function to be minimized over a prediction horizon N:

$$\min_{U} \sum_{k=0}^{N-1} \left(\|y_{k|t} - r_k\|_Q^2 + \|u_{k|t}\|_R^2 \right)$$

- $y_{k|t}$: predicted output, r_k: reference output, $u_{k|t}$: predicted control input.
- Q, R: weighting matrices for tracking error and control effort.

Constraints and Optimization

- MPC can handle various constraints like input, state, and output constraints.
- Optimization problem solved at each step to find the best control sequence.
- Receding horizon principle: Only the first control action is implemented and then the horizon is updated.

Formulation Agreement

- The objective function provided is a standard MPC formulation:

$$\min_{u,x,y} \sum_{k=1}^{T_{future}} \|y_k - r_k\|_Q^2 + \|u_k\|_R^2$$

- It aims to minimize the tracking error and control effort.

Conclusion

- MPC is a powerful control strategy for systems with predictive models.
- Its ability to anticipate and optimize future behavior makes it applicable in various fields.
- The mathematical formulation is key to its effectiveness.

Challenges in MPC Deployment

- Solving optimization problems online is computationally demanding.
- High-dimensional systems pose a challenge due to the complexity and required computational resources.
- Strict latency requirements and limited computational or energy resources can impede the deployment of MPC.

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[1] Ahn, Kwangjun, et al. "Model Predictive Control via On-Policy Imitation Learning." Learning for Dynamics and Control Conference. PMLR, 2023.

Interactive Data Collection Scheme

- A scheme is proposed to interactively collect data from a system in feedback with an MPC controller.
- The goal is to learn an explicit controller that directly maps states to inputs.
- This methodology aligns with imitation learning approaches in the reinforcement learning domain.

[1] Ahn, Kwangjun, et al. "Model Predictive Control via On-Policy Imitation Learning." Learning for Dynamics and Control Conference. PMLR, 2023.

Imitation Learning and MPC

- Imitation learning involves learning an explicit controller that maps states to inputs.
- It is suitable for MPC as it can query the MPC for the next input at any state by solving the optimization problem.
- This process aligns with explicit MPC, which pre-computes solutions to optimization problems for runtime efficiency.

[1] Ahn, Kwangjun, et al. "Model Predictive Control via On-Policy Imitation Learning." Learning for Dynamics and Control Conference. PMLR, 2023.

Learning Controllers with High Fidelity to MPC

- The goal is to learn a map from states to inputs that encapsulates the strategy of an MPC controller.
- Unlike methods that collect data pre-learning, our approach interacts with the system dynamics to avoid distribution shift.
- This interaction prevents sub-optimal performance and error compounding, which are common in non-interactive imitation learning.
- Our approach aims for a learned controller that matches MPC performance with high probability.

[1] Ahn, Kwangjun, et al. "Model Predictive Control via On-Policy Imitation Learning." Learning for Dynamics and Control Conference. PMLR, 2023.

'Imitation Learning from an Expert

Imitation learning aims to learn from dimostrations a controller $\hat{\pi}$

[1] Ahn, Kwangjun, et al. "Model Predictive Control via On-Policy Imitation Learning." Learning for Dynamics and Control Conference. PMLR, 2023.