Advanced Control Strategies for Modern Systems

MathWorks, represented by Systematics, presented @ IAAC 2025

Challenges of Modern Control Systems

Today's control systems are becoming increasingly complex, and they are often characterized by:

- Coupled highly nonlinear dynamics
- Multiple inputs and outputs (MIMO)
- High-performance demands.

Classical control methods, such as PID controllers, are often inadequate to address these complexities. This is mainly due to their dependence on simplified models, methods, and their limited ability to handle uncertainties and constraints. To address these issues, several advanced control techniques have been developed which can provide robust performance, operating under a variety of conditions, while optimizing system behavior in real time.

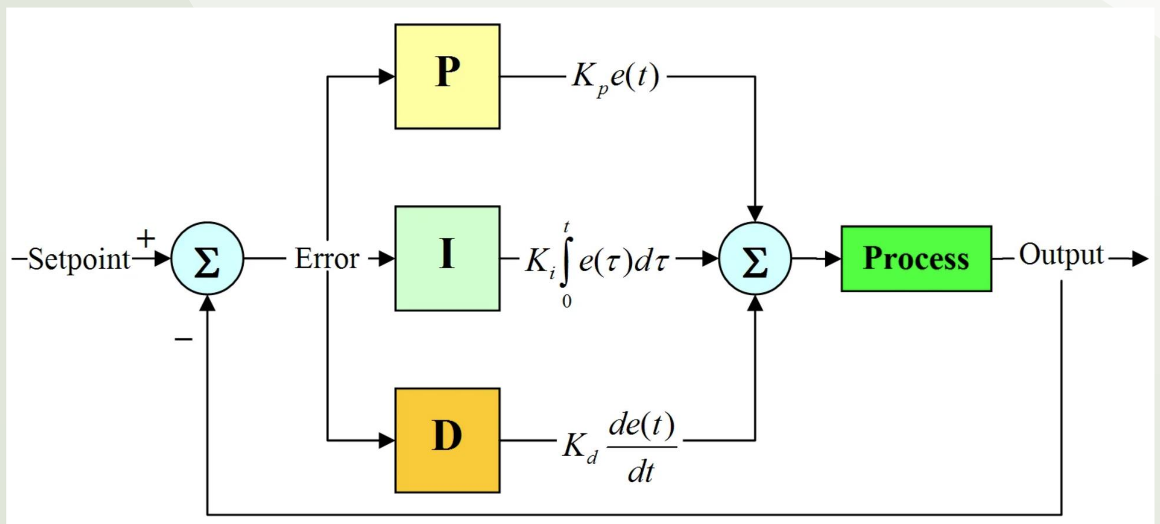


Figure 1: Existing PID Controllers

Emerging Data-Driven and AI Control Systems

To meet these challenges, we explore the design of some of the more sophisticated controllers, focusing on state-of-the-art controllers: Active Disturbance Rejection Control (ADRC), Reinforcement Learning (RL) and Data-Driven Model Predictive Control (MPC).

These modern controllers account for

- Compensation of unknown dynamics and disturbances
- Excel at handling MIMO systems with constraints
- Adapt and are suitable for complex systems with non-linear dynamics, such as Autonomous Systems

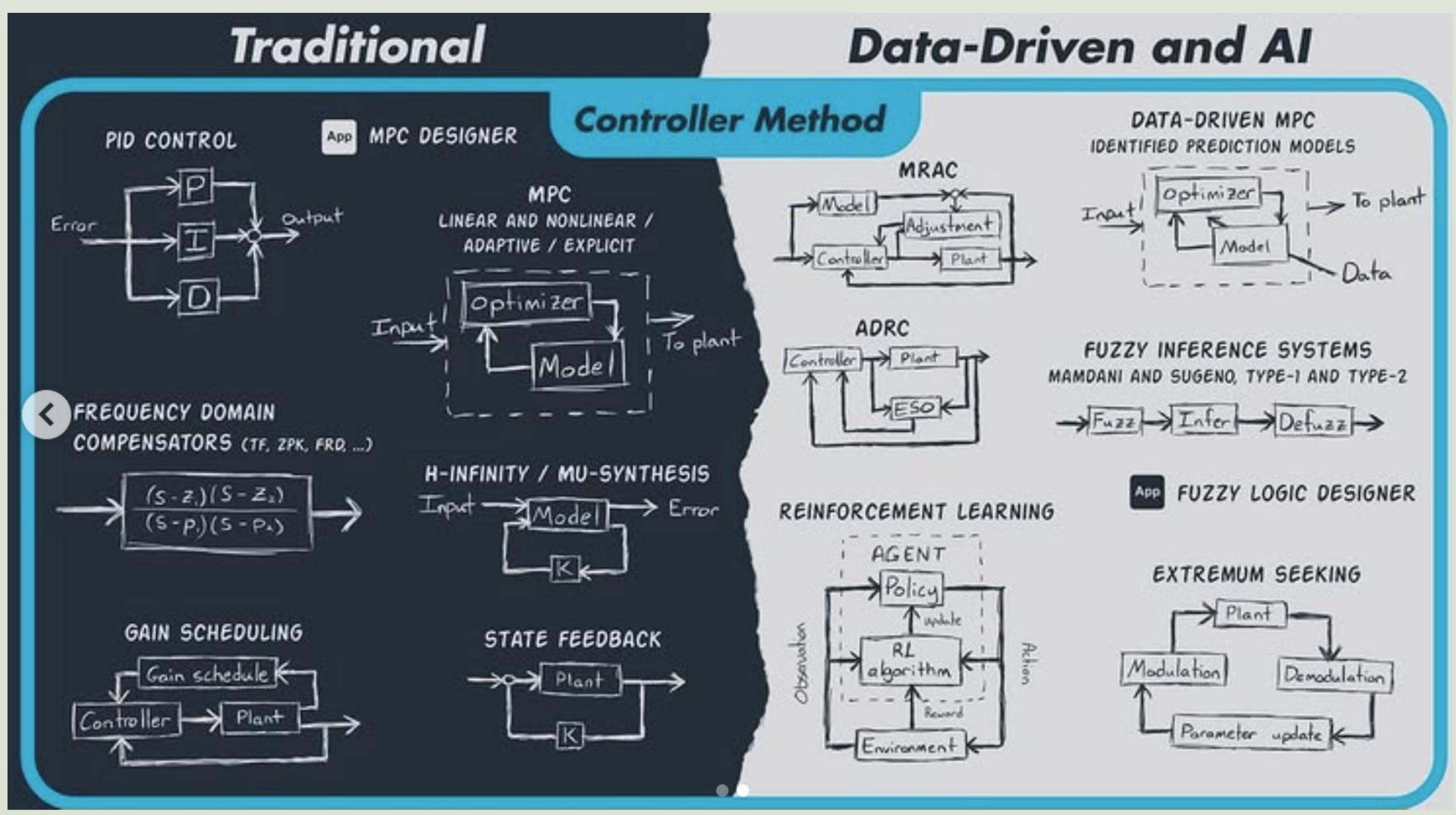


Figure 2: Emerging Control Systems

Active Disturbance Rejection Control

ADRC is a control method that extends conventional PID control by incorporating an extended state observer to estimate and compensate for unknown dynamics and disturbances, offering robust performance across a wide range of operating conditions. This technique has been shown to be particularly effective in motor control applications, where it enhances precision and stability without the need for high-fidelity system models.

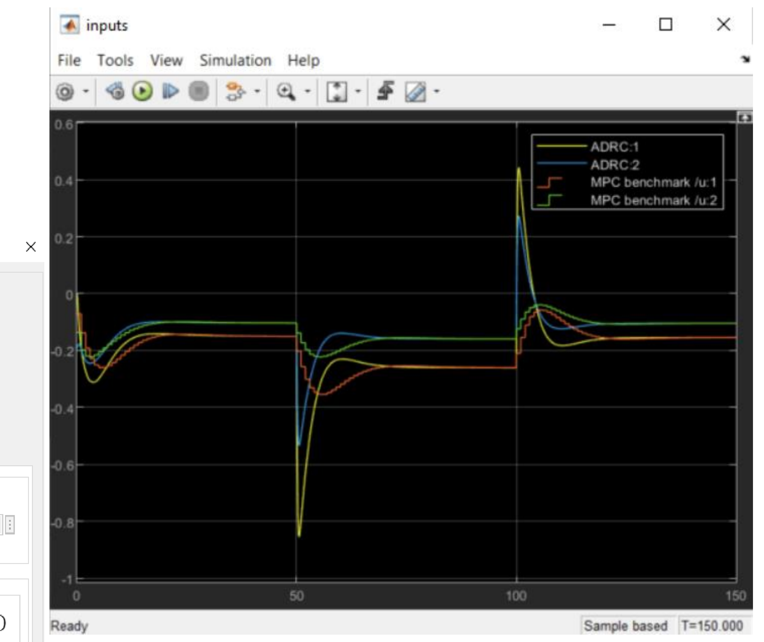


Figure 3-3: Results and compare to MPC

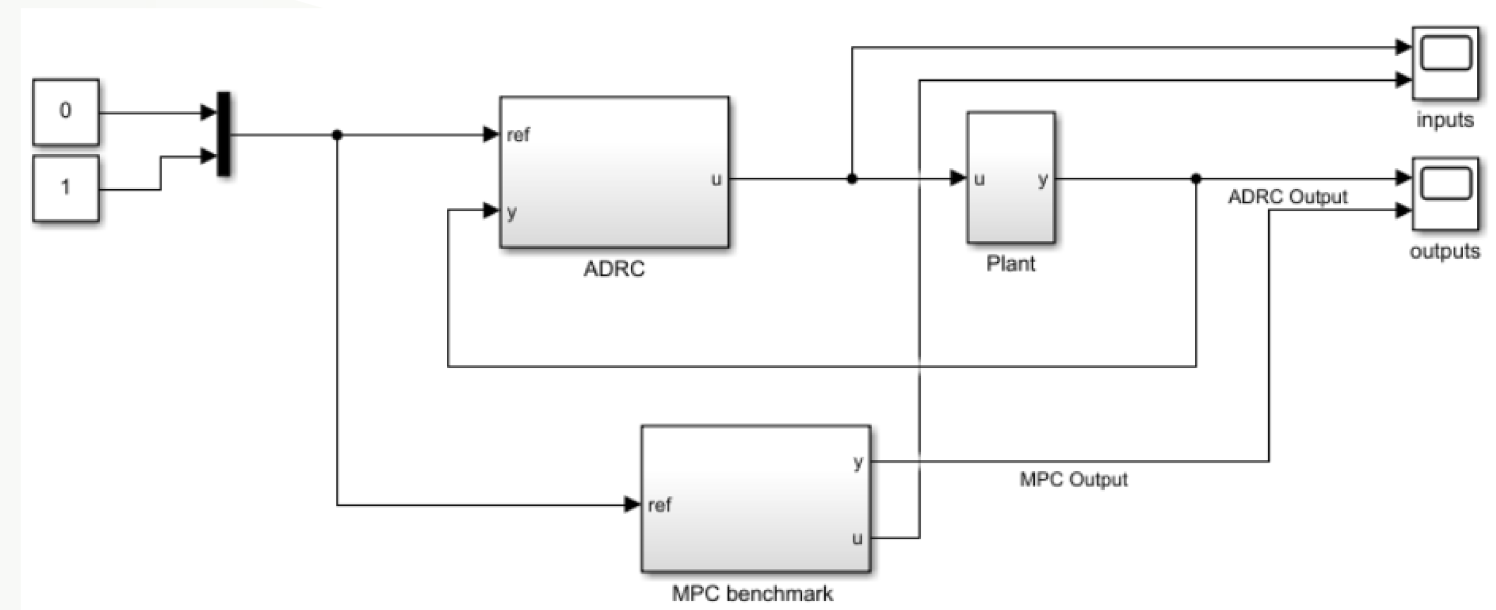


Figure 3-1: Block Diagram for ADRC

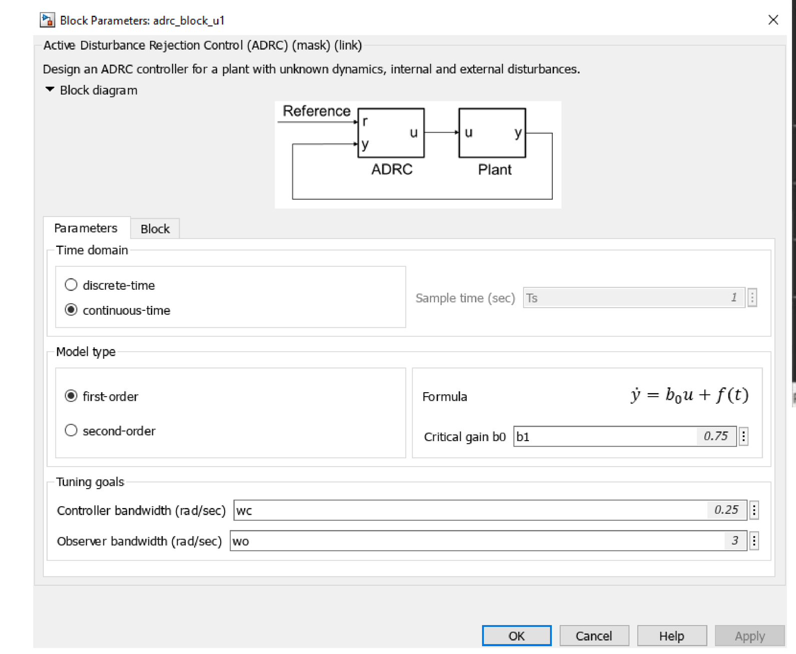
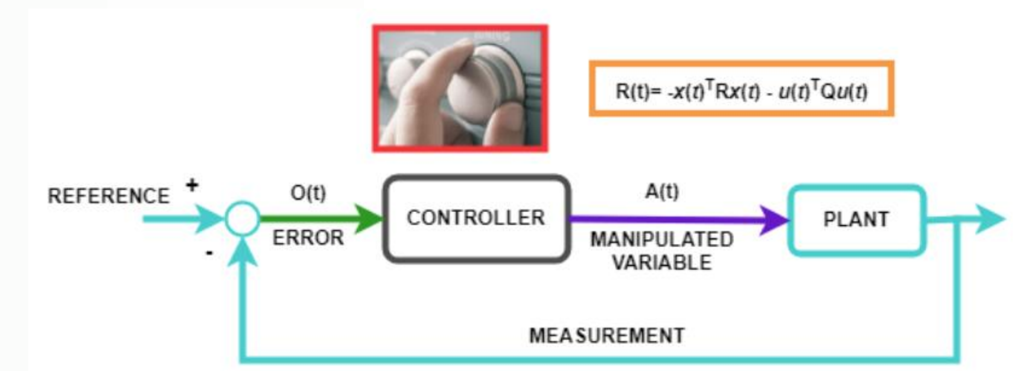
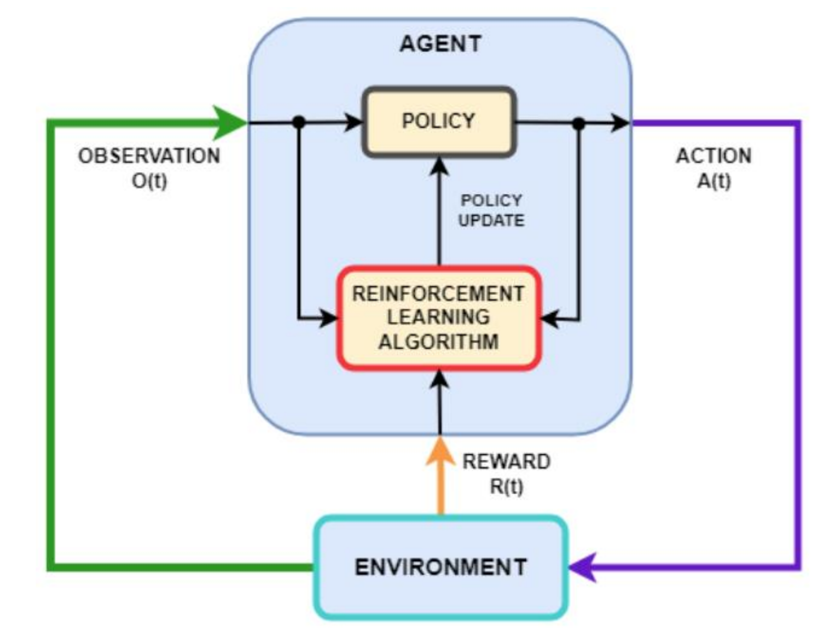


Figure 3-2: Automatic Block tuning

Reinforcement Learning

Reinforcement learning control, a machine learning technique, can be described as advanced adaptive control that learns optimal policies through interaction with the environment. This approach is particularly suitable for systems that have complex, non-linear dynamics, uncertain operating conditions, and are traditionally designed with multiple control loops, such as autonomous vehicles and robotics.





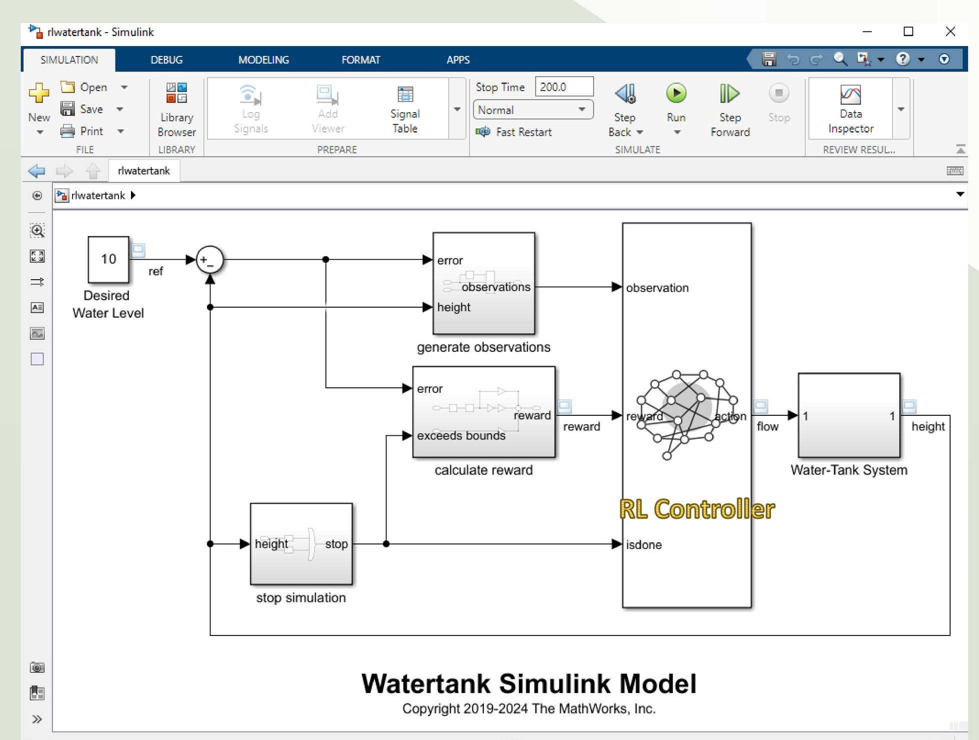


Figure 4-1: Block Diagram for RL design

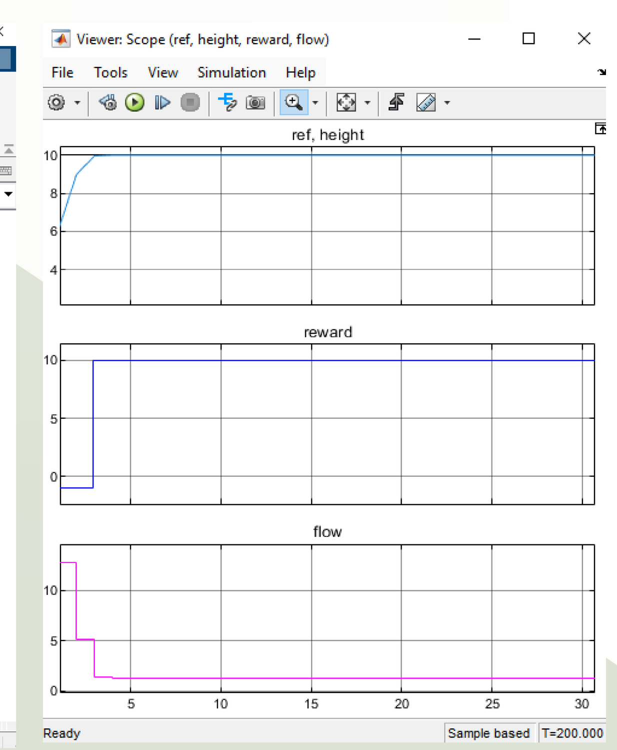


Figure 4-2: Results for Water tank system

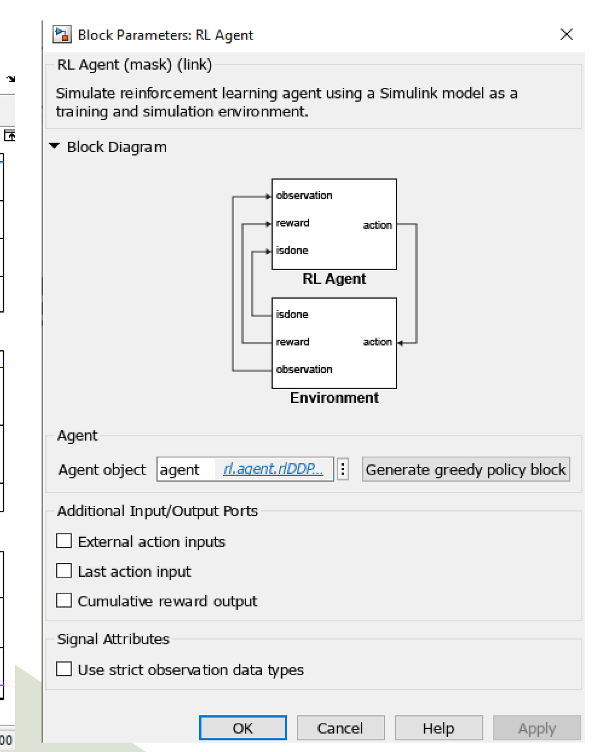
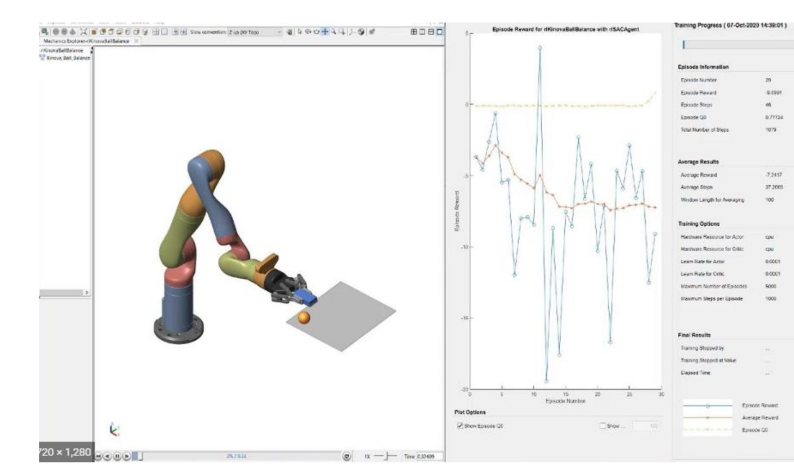
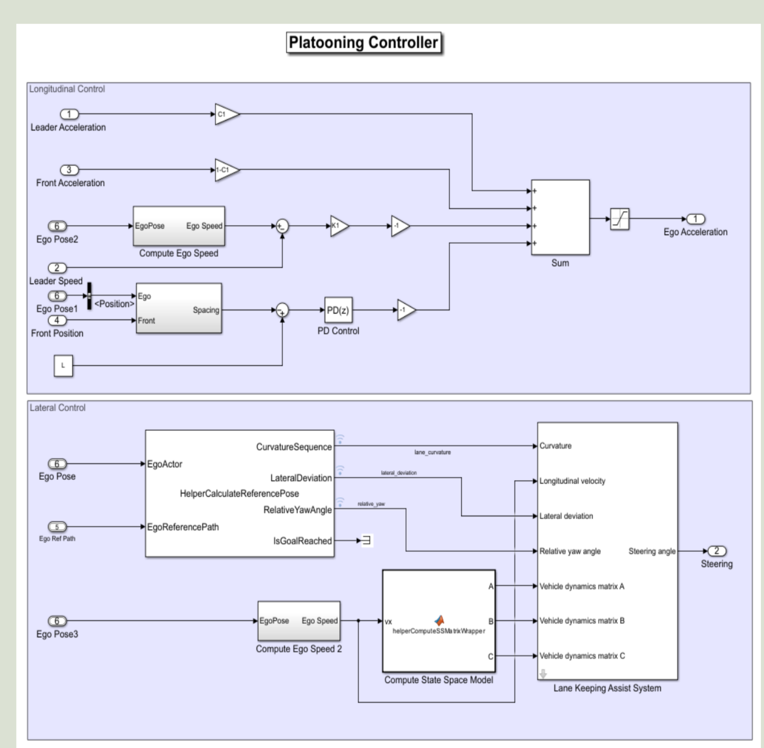


Figure 4-3: Include Agent models designed in MATLAB or external source



Leverage the MathWorks Physical Modeling platform (Simscape) to model the non-linear dynamics of the plant, to get a more-realistic control design.

Model-Predictive Control (MPC)



MPC, an optimization-based control method, excels at handling MIMO systems with constraints. By predicting future system states and optimizing control actions, MPC ensures optimal performance while adhering to physical and operational limits. This approach is invaluable in applications such as electric vehicle traction control and industrial automation, where safety and efficiency are paramount.

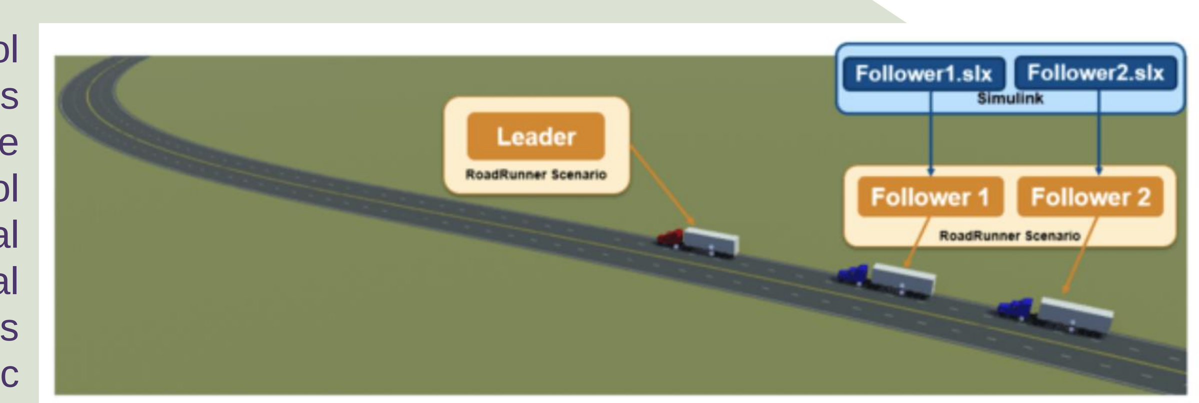


Figure 5-1: Vehicle Platooning using MPC

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