

Advanced Control Strategies

Advanced Control Strategies – Study Notes

1. Overview

Aspect	Description
Goal	Achieve desired system performance (stability, speed, accuracy, robustness) in the presence of uncertainties, non-linearities, and external disturbances.
Why “advanced”?	Classical PID control works for many linear, time-invariant plants. Advanced strategies extend capability to: • Multivariable (MIMO) systems • Non-linear dynamics • Time-varying or uncertain parameters • Constraints on inputs/outputs
Typical application domains	Aerospace & flight control, robotics, process industry, automotive (ADAS, electric-vehicle drive), power systems, renewable energy, biomedical devices.

2. Classification of Advanced Strategies

Category	Core Idea	Typical Algorithms	Key Advantages
Model-Based Predictive	Use a plant model to predict future behavior and compute optimal control moves.	• Model Predictive Control (MPC) • Receding Horizon Control • Economic MPC	Handles multivariable constraints, optimality over a horizon, easy integration of soft constraints.
Robust Control	Guarantee performance despite bounded model uncertainties.	• H^∞ (H-infinity) Control • μ-Synthesis • Loop-Shaping Design	Provides formal robustness margins; suitable for high-risk aerospace/defense systems.

Advanced Control Strategies

Category	Core Idea	Typical Algorithms	Key Advantages
Adaptive Control	Online adjustment of controller parameters to track changing plant dynamics.	• Model Reference Adaptive Control (MRAC) • Self-tuning Regulators (STR) • Gain Scheduling (parameter varying) • Feedback Linearization	Maintains performance when plant parameters drift or operating point changes.
Nonlinear Control	Directly address nonlinear dynamics without linearization.	• Sliding Mode Control (SMC) • Backstepping • Lyapunov-based designs • Neural Network Controllers • Fuzzy Logic	Strong performance for highly nonlinear systems; SMC offers inherent robustness.
Intelligent / Data-Driven	Exploit machine learning, fuzzy logic, or neural networks for control law synthesis.	• Reinforcement Learning (RL) / Actor-Critic • Gaussian Process-Based MPC • Adaptive MPC • Robust Adaptive Control	Capable of handling complex, poorly modeled dynamics; adaptivity through learning.
Hybrid / Hierarchical	Combine two or more strategies to leverage complementary strengths.	• Hierarchical MPC + Low-level SMC • Supervisory RL for gain scheduling	Balances optimality, robustness, and adaptability.

Advanced Control Strategies

3. Model Predictive Control (MPC)

3.1 Principle

1. **Prediction Model** – Usually a discrete-time state-space model (linear or nonlinear).
2. **Cost Function** – Quadratic (e.g., tracking error + control effort) or economic (profit, energy).
3. **Constraints** – Input limits, rate limits, state/output bounds.
4. **Optimization** – Solve a finite-horizon constrained quadratic program (QP) at each sampling instant.
5. **Receding Horizon** – Apply only the first control move; repeat at next sample.

3.2 Variants

Variant	When to Use	Notable Feature
Linear MPC	Near-linear operation, fast sampling	