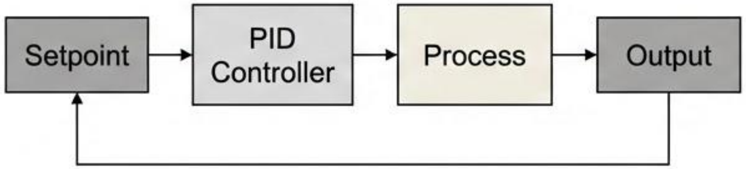
Smart Throttle Control

Intro to Advanced and Nonlinear Control
(5)

The Need Beyond PID

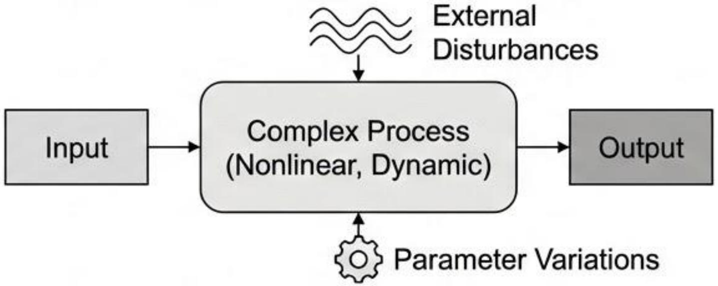
Classic PID Control (Simple Transfer Function)



$$G(s) = Kp + Ki/s + Kd*s$$

Assumes linearity, time-invariance, and minimal external disturbance. Effective for simple, stable systems.

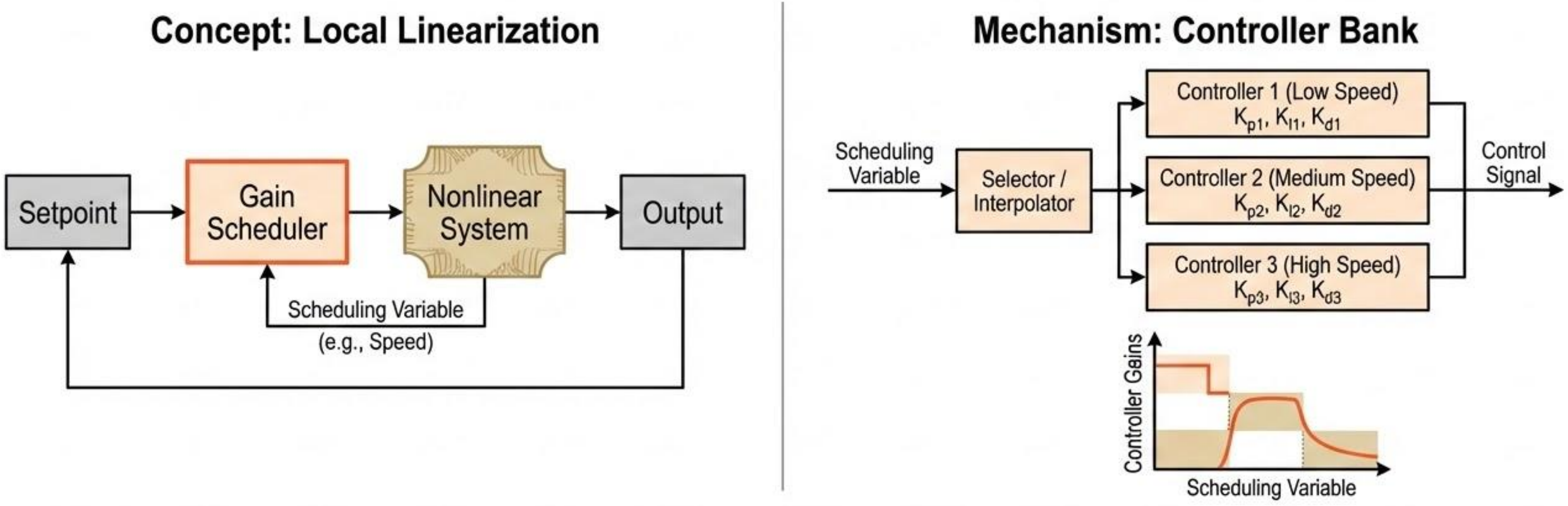
Modern Systems (Why PID Fails)



- **Nonlinearity**: PID assumes linear behavior, fails in highly nonlinear regimes.
- **Time-Variance**: System parameters change over time (e.g., wear, load), PID requires constant retuning.
- **Constraints**: PID doesn't handle actuator or process constraints (e.g., saturation, safety limits).
- **Disturbances**: Poor rejection of complex, unmeasured disturbances.

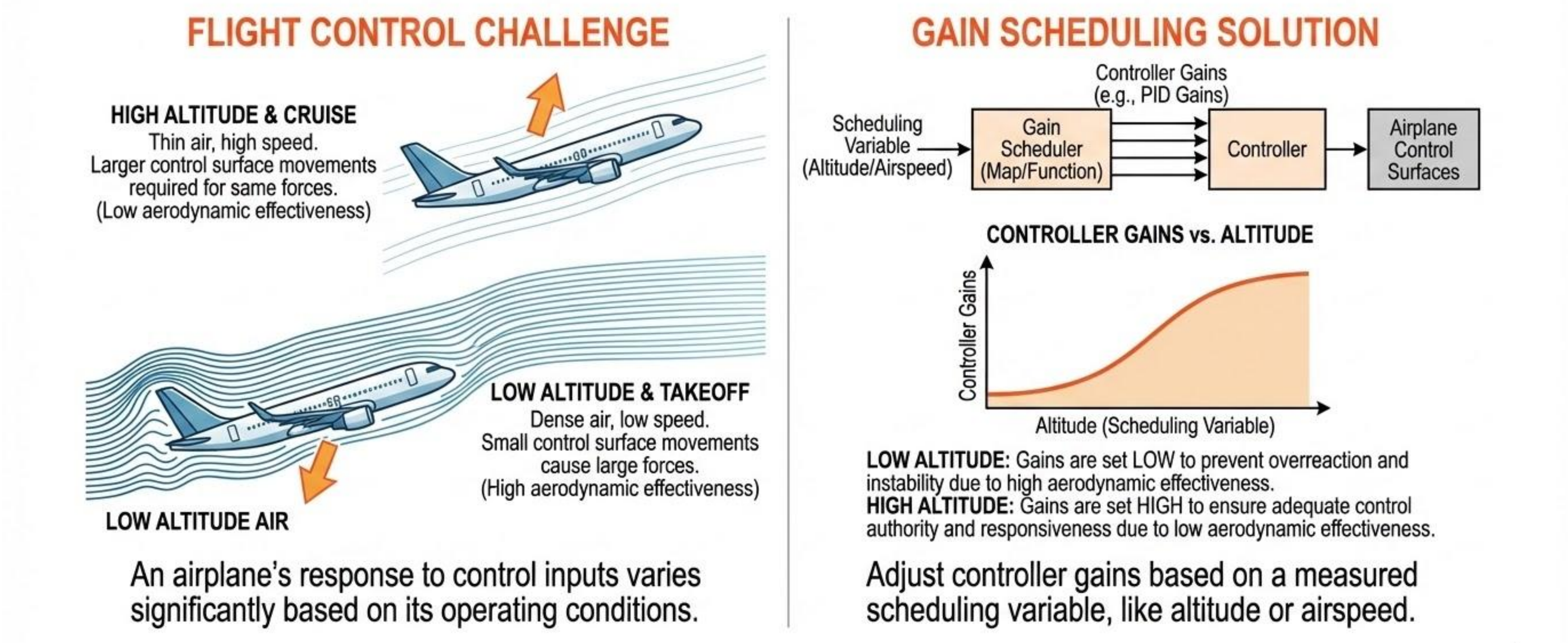
Gain Scheduling

Linearizing Control for Nonlinear Systems



- **Handles Nonlinear Dynamics:** Adapts control strategy as the system's behavior changes.
- **Uses Simple Linear Controllers:** Leverages established techniques (e.g., PID) within limited operating regions.
- **Based on Operating Point:** Switching is triggered by a measurable 'scheduling variable'.
- **Smooth Transitions:** Can use interpolation for seamless switching between controllers.

Example



FLIGHT CONTROL CHALLENGE
HIGH ALTITUDE & CRUISE
Thin air, high speed.
Larger control surface movements required for same forces.
(Low aerodynamic effectiveness)
LOW ALTITUDE & TAKEOFF
Dense air, low speed.
Small control surface movements cause large forces.
(High aerodynamic effectiveness)
LOW ALTITUDE AIR
An airplane's response to control inputs varies significantly based on its operating conditions.
GAIN SCHEDULING SOLUTION
Controller Gains (e.g., PID Gains)
Scheduling Variable (Altitude/Airspeed)
Gain Scheduler (Map/Function)
Controller
Airplane Control Surfaces
CONTROLLER GAINS vs. ALTITUDE
Controller Gains
Altitude (Scheduling Variable)
LOW ALTITUDE: Gains are set LOW to prevent overreaction and instability due to high aerodynamic effectiveness.
HIGH ALTITUDE: Gains are set HIGH to ensure adequate control authority and responsiveness due to low aerodynamic effectiveness.
Adjust controller gains based on a measured scheduling variable, like altitude or airspeed.

Linear-Quadratic Regulator

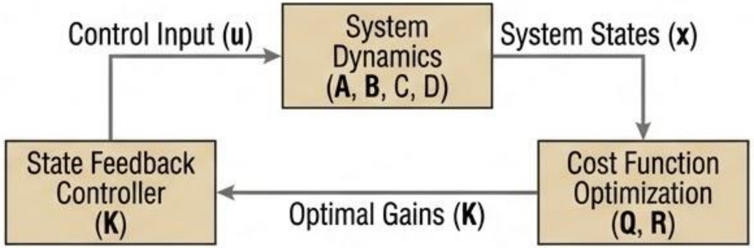
OVERVIEW & CONCEPT

LQR is an optimal control strategy that calculates a feedback controller for a linear system to minimize a quadratic cost function. The cost function balances system performance (state deviation) and control effort (input energy).

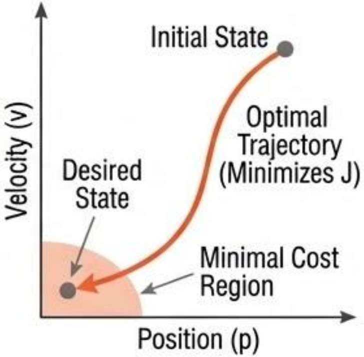
KEY COMPONENTS & FUNCTION

COMPONENT	FUNCTION
Linear System Model (**A**, **B**)	Describes the system's dynamics and response to inputs.
Quadratic Cost Function (**J**)	Mathematical expression representing performance (Q) and control effort (R) goals.
Q: State Weighting Matrix	Penalizes deviations of system states from target.
R: Control Weighting Matrix	Penalizes excessive control input (energy consumption).
Feedback Gain Matrix (**K**)	Optimal gains calculated to minimize J. Control Law: **u** = **-Kx**.

CONCEPTUAL VISUALIZATION



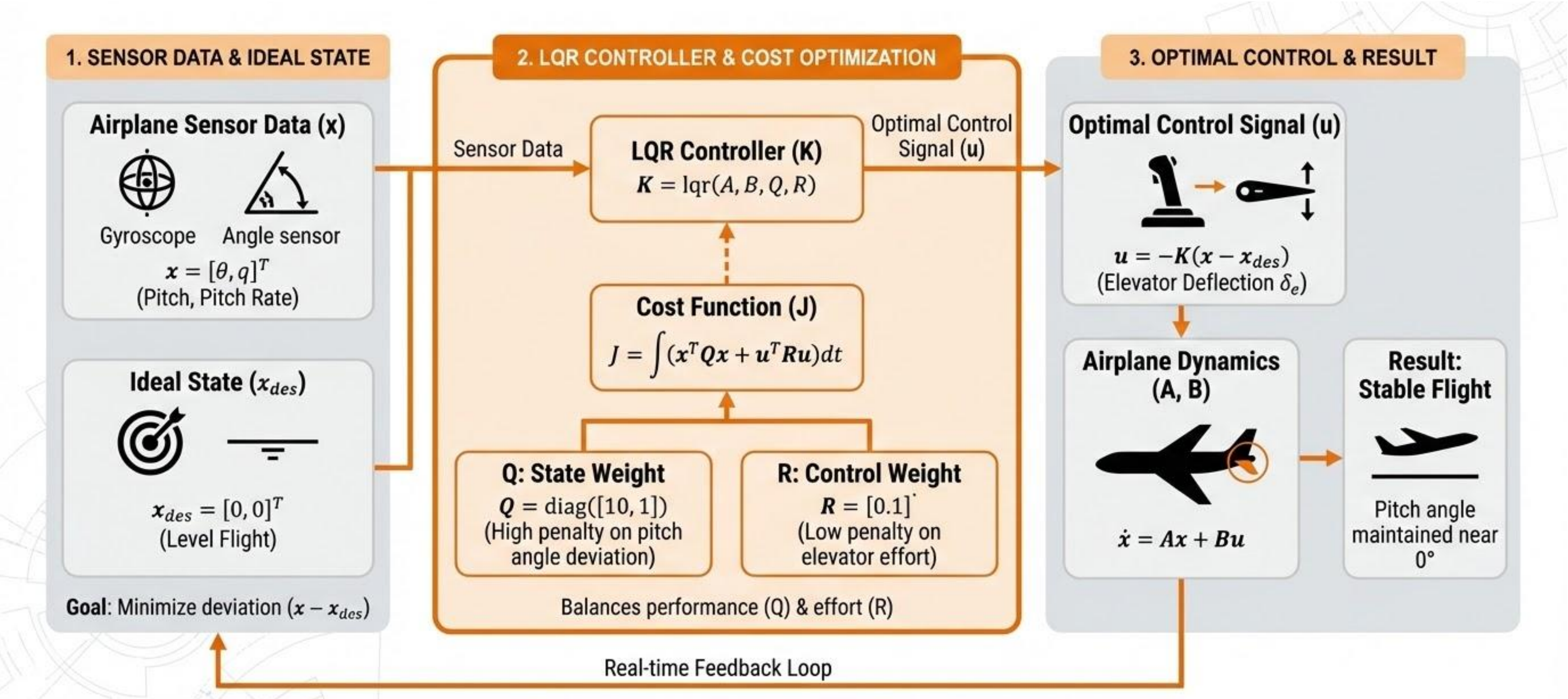
STATE-SPACE TRAJECTORY



PROS & CONS

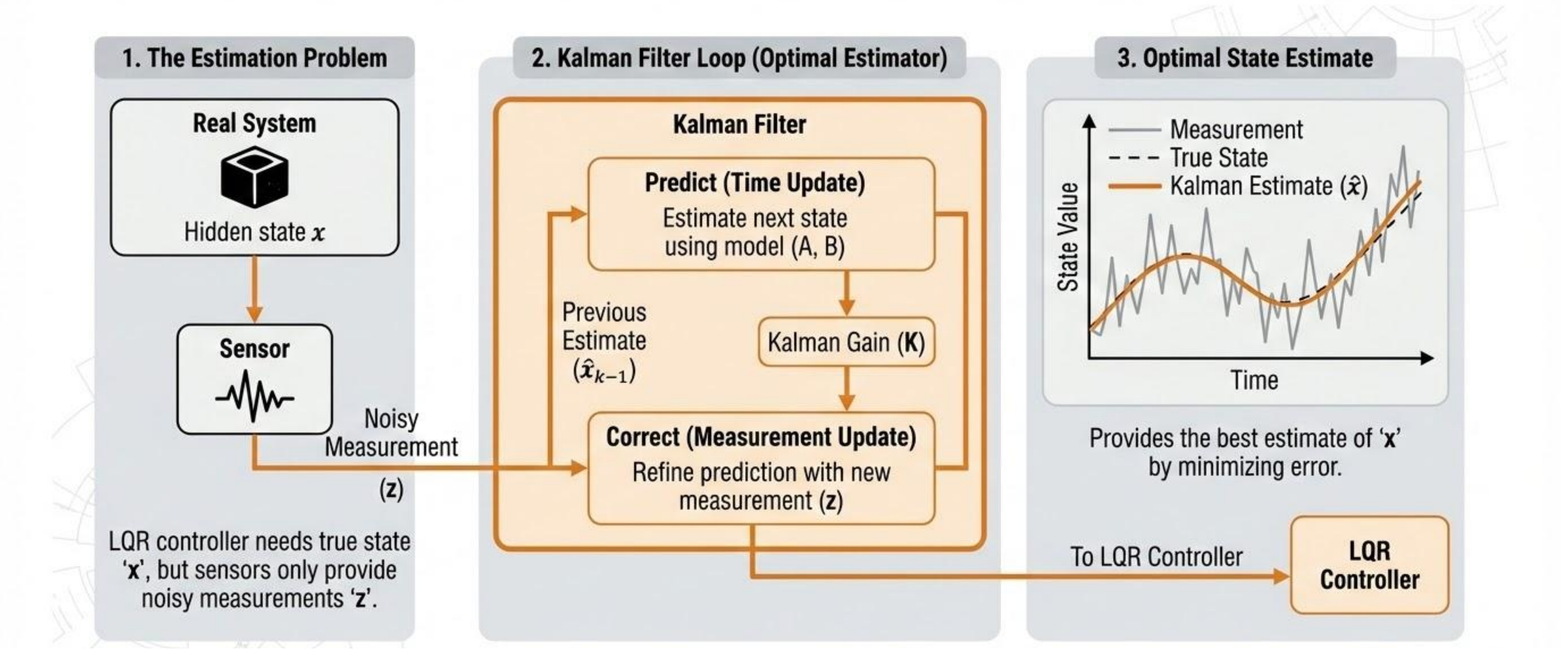
- **PROS**: Guarantees stability and optimality for linear systems. Provides systematic balance of performance and effort. Well-established, widely used.
- **CONS**: Requires accurate linear model. Performance degrades with nonlinearities. Tuning Q and R can be iterative/non-intuitive.

Example



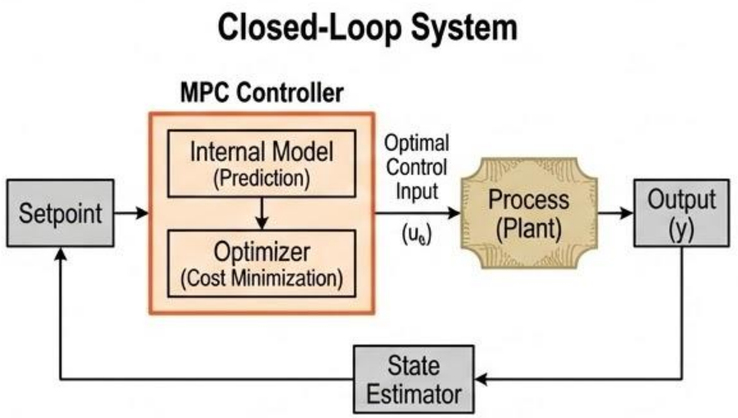
1. SENSOR DATA & IDEAL STATE
Airplane Sensor Data (x)
Gyroscope
Angle sensor
$x = [\theta, q]^T$
(Pitch, Pitch Rate)
Ideal State (x_{des})
$x_{des} = [0, 0]^T$
(Level Flight)
Goal: Minimize deviation ($x - x_{des}$)
2. LQR CONTROLLER & COST OPTIMIZATION
Sensor Data
LQR Controller (K)
$K = \mathrm{lqr}(A, B, Q, R)$
Optimal Control Signal (u)
Cost Function (J)
$J = \int (x^T Q x + u^T R u) dt$
Q: State Weight
$Q = \mathrm{diag}([10, 1])$
(High penalty on pitch angle deviation)
R: Control Weight
$R = [0.1]$
(Low penalty on elevator effort)
Balances performance (Q) & effort (R)
3. OPTIMAL CONTROL & RESULT
Optimal Control Signal (u)
$u = -K(x - x_{des})$
(Elevator Deflection δ_e)
Airplane Dynamics (A, B)
$\dot{x} = Ax + Bu$
Result: Stable Flight
Pitch angle maintained near 0°
Real-time Feedback Loop

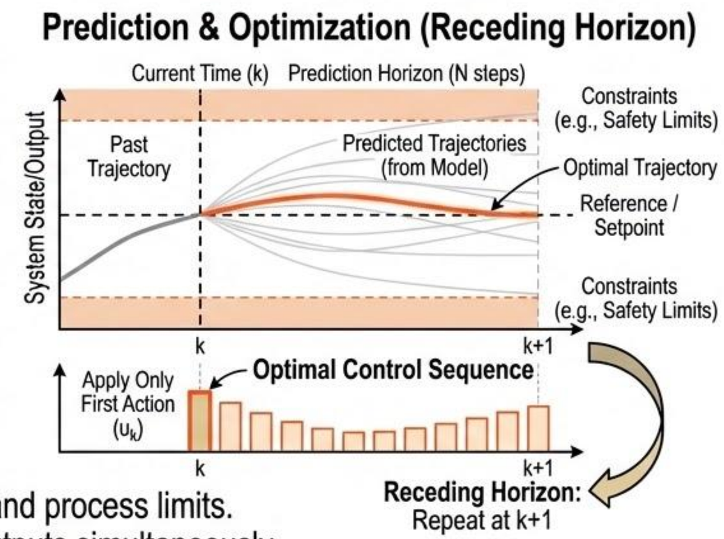
Kalman Filter



Model Predictive Control

Optimizing Future Performance with a Receding Horizon





- **Key Features**
- **Handles Constraints**: Explicitly accounts for actuator and process limits.
- **Multivariable Control**: Manages multiple inputs and outputs simultaneously.
- **Predictive**: Anticipates future behavior to take preemptive actions.
- **Optimization-Based**: Systematically finds the best control strategy.

Some More....


Sliding Mode Controller
Fuzzy Logic Controller
Lyapunov-Based Control
NN and RL based controllers
ZERO ERROR GOAL
If error exists -> MAKE IT ZERO
Terms may differ and even sound overwhelming but deep down all controllers have one function

Thank You !!!