

Introduction to Control Systems

Introduction to Control Systems

Designed as a quick-reference guide for students and engineers

1. What Is a Control System?

Aspect	Description
Definition	A set of devices or algorithms that manages, directs, or regulates the behavior of other devices or processes to achieve a desired performance.
Goal	Keep a system's output (or state) close to a reference value despite disturbances, uncertainties, or changes in operating conditions.
Typical Components	• Plant – the process or device to be controlled (e.g., motor, chemical reactor). • Sensor – measures the plant output (e.g., temperature, position). • Controller – compares measured output with the reference and generates a corrective action. • Actuator – implements the controller's command (e.g., valve, motor driver).
Examples	• Cruise control in a car • Temperature regulation in a HVAC system • Flight path control of an aircraft • Robotics joint positioning

2. Classification of Control Systems

Category	Open-Loop vs. Closed-Loop	Key Characteristics
Open-Loop (Non-feedback)	No feedback path; controller acts only on the reference.	Simple, cheap, but cannot compensate for disturbances or model errors.
Closed-Loop (Feedback)	Output is measured and fed back to the controller.	Robust to disturbances, can improve accuracy and stability.

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Category	Open?Loop vs. Closed?Loop	Key Characteristics
Continuous?Time vs. Discrete?Time	Signals vary continuously vs. sampled at discrete intervals.	Continuous: analog electronics, differential equations. Discrete: digital computers, difference equations.
Linear vs. Non?Linear	Linear: superposition holds; described by linear differential equations. Non?Linear: equations contain products, powers, saturations, etc.	Linear systems are easier to analyze; many real systems are approximated as linear around an operating point.
Time?Invariant vs. Time?Varying	Parameters do not change with time vs. they do.	Most textbook analysis assumes time?invariant (LTI) systems.
Single?Input Single?Output (SISO) vs. Multi?Input Multi?Output (MIMO)	One input/one output vs. multiple interacting inputs/outputs.	MIMO requires matrix?based methods (state?space, decoupling).

3. Fundamental Concepts

3.1 Signals and Systems

- **Signal** – a function of time (continuous) or index (discrete) representing a physical quantity.
- **System** – a mapping from an input signal ($u(t)$) to an output signal ($y(t)$).

3.2 Transfer Function (Laplace Domain)

[$G(s) = \frac{Y(s)}{U(s)}$ quad\text{(for zero initial conditions)}]

- Captures the input?output relationship of a linear time?invariant (LTI) system.
- Poles ? natural dynamics (stability).
Zeros ? frequency shaping.

3.3 Block Diagram Representation

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- **Blocks** = transfer functions or gains.
- **Summing junctions** = algebraic addition/subtraction of signals.
- **Takeaway:** Block diagrams simplify the visualization of signal flow and are the basis for systematic analysis (e.g., Mason's Gain Formula).

3.4 Stability

Test	Description
Pole location	All poles of $(G(s))$ must lie in the left