Chapter 1: General Information On Control Systems

In the Context of Control Systems

In control engineering, a **system** is defined as **an arrangement of physical components connected or related in such a manner as to command, direct, or regulate itself or another system.**

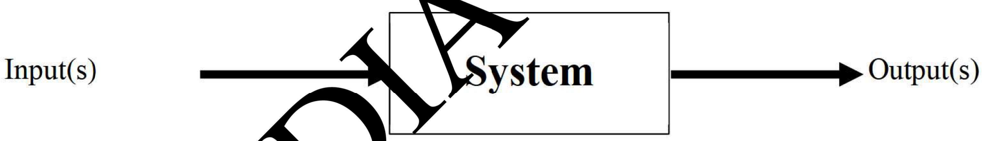
In simpler terms, it's **an object** (or a **process**) **upon which we want to exert a specific control.**

Key Characteristics of a Control System:

1. **It has an Input and an Output:**
    - **Input (or Excitation):** The stimulus applied to the system from an external source to produce a specific output.
    - **Output (or Response):** The actual result obtained from the system due to the applied input.
2. **Its behavior can be modeled mathematically.** Engineers use equations (differential equations, transfer functions) to predict how the system will respond to different inputs.

The Core Concept:

This is the most fundamental model, often called a "Black Box" model. We may not know the internal details, but we can observe how it reacts.



- **Example 1 (Electric Fan):**
    - **System:** The fan's motor and blades.
    - **Input:** The position of the knob (which sets the voltage).
    - **Output:** The rotational speed of the blades.
- **Example 2 (Cruise Control in a Car):**
    - **System:** The car's engine, drivetrain, and wheels.
    - **Input:** The desired speed set by the driver.
    - **Output:** The actual measured speed of the car.

Types of Systems in Control Theory

Systems are categorized based on their characteristics:

Category	Definition	Simple Example
Static vs. Dynamic	**Static:** Output depends only on the present input. (No memory). **Dynamic:** Output depends on both present and past inputs. (Has memory, involves energy storage).	**Static:** A simple resistor (V=IR). **Dynamic:** A car suspension (it oscillates based on past bumps).
Linear vs. Non-linear	**Linear:** Obeys the principles of superposition (scaling and additivity). Easier to analyze. **Non-linear:** Does not obey superposition. More common in real life.	**Linear:** A spring (mostly). **Non-linear:** A human operator (gets tired, reacts differently).
Time-Invariant vs. Time-Variant	**Time-Invariant:** System parameters do not change with time. **Time-Variant:** System parameters change with time.	**Time-Invariant:** An electrical circuit with fixed components. **Time-Variant:** A rocket (mass changes as fuel burns).
Causal vs. Non-Causal	**Causal:** Output depends only on present and past inputs. (All physical systems are causal). **Non-Causal:** Output depends on future inputs. (Theoretical, used for signal processing).	**Causal:** Any real-world system. **Non-Causal:** An ideal filter that needs to "see the future."
Open-Loop vs. Closed-Loop	**Open-Loop:** No feedback. The input is applied without checking the output. **Closed-Loop:** Uses feedback to compare the output with the desired result and corrects any error.	**Open-Loop:** A cheap toaster. **Closed-Loop:** Cruise control in a car.

Terminology of control systems

- **Control System:** An interconnection of components forming a system configuration that will provide a desired system response. The basis for analyzing a control system is to **produce a desired output based on a known input**.
- **Plant (or Process):** The physical object or system to be controlled (e.g., a motor, a chemical process, an aircraft, a heating furnace).
- **Controller:** The device that generates the command signal to the plant. It uses the difference between the input and the feedback to decide the corrective action.
- **Actuator:** The component that directly manipulates the plant (e.g., a valve, a servo motor, a heater). It converts the control signal from the controller into a physical action.
- **Sensor (or Transducer):** The component that measures the output of the plant and converts it into a usable signal for the controller (e.g., a thermocouple, an encoder, a pressure sensor).

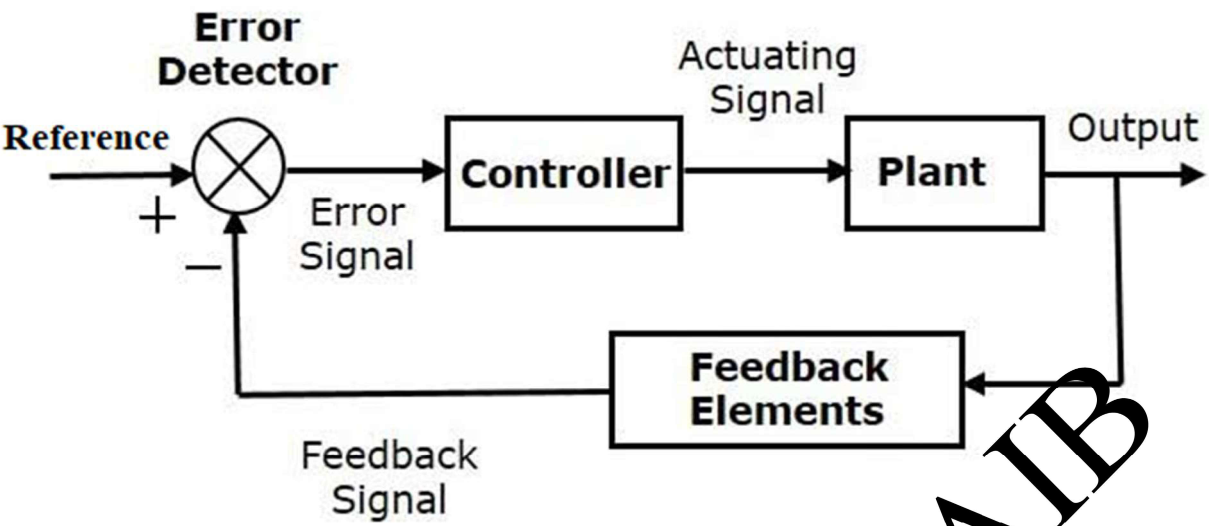


Figure 1. Block Diagram for Process Control System

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1. System Configurations & Structure

- **Open-Loop Control System:**
  - A system where the output has no effect on the control action. The controller does not use feedback to determine if the desired output was achieved.
  - **Analogy:** A toaster with a timer. You set a time, but it doesn't check if the bread is actually browned.

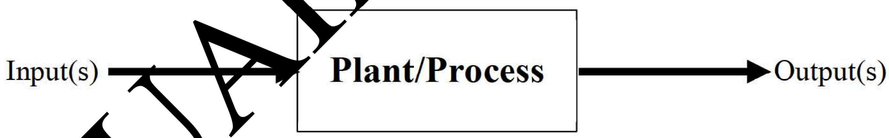

Figure 2. Block Diagram for Open Loop System

- **Closed-Loop Control System (Feedback Control System):**
  - A system that uses a measurement of the output and compares it to the desired input to take corrective action. This forms a "closed loop" of information.
  - **Analogy:** Cruise control in a car. It measures the car's speed and adjusts the throttle continuously to maintain the set speed, even on hills.

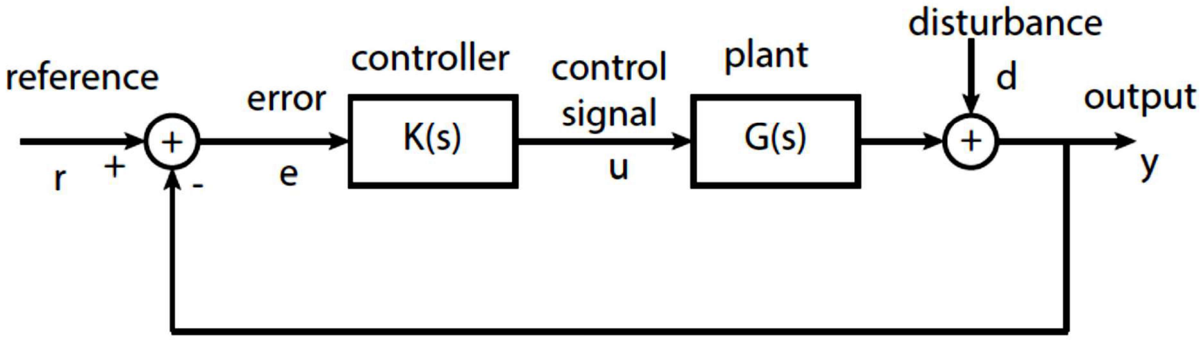

Figure 3. Closed Loop System

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2. Signals & Variables

- **Reference Input (Setpoint, R):** The desired value for the system output.
- **Controlled Output (C):** The actual, measured variable of the plant that we want to control.
- **Actuating Signal (or Control Signal, U):** The signal produced by the controller and sent to the actuator.
- **Feedback Signal (B):** The signal from the sensor that is fed back to the summing junction.
- **Error Signal (E):** The difference between the reference input and the feedback signal
  ($E = R - B$). The controller acts to minimize this error.
- **Disturbance (D):** An unwanted external input that affects the system's output (e.g., a gust of wind on a drone, a change in room temperature for a furnace).

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3. System Response & Performance Metrics

- **Stability:** The most critical property. A system is stable if its output remains bounded for any bounded input. An unstable system's output will oscillate uncontrollably or diverge to infinity.
- **Transient Response:** The system's behavior in the short term, as it moves from its initial state to its final state following a change in input.
  - **Rise Time:** Time for the output to go from 10% to 90% of its final value.
  - **Settling Time:** Time for the output to reach and stay within a certain tolerance band (e.g., ±2%) of its final value.
  - **Overshoot:** The amount the output exceeds its final value, expressed as a percentage.
  - **Peak Time:** Time at which the overshoot peak occurs.

- **Steady-State Response:** The system's behavior as time approaches infinity, after all transients have died out.
  - **Steady-State Error:** The final, persistent error between the desired output and the actual output when the system has settled.

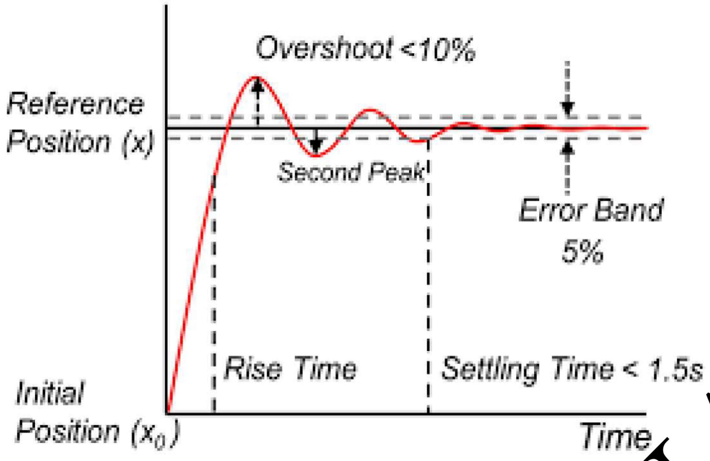

Figure 4. System Response & Performance Metrics

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4. Control Actions & Algorithms

- **ON/OFF Control:**
  - The simplest form of control. The actuator is either fully on or fully off (e.g., a home thermostat).
- **PID Control (Proportional-Integral-Derivative):**
  - The workhorse of the control industry. The controller output is a weighted sum of three terms:
    - **Proportional (P):** Reacts to the *present* error. Higher gain = faster response, but can cause overshoot and instability.
    - **Integral (I):** Reacts to the accumulation of *past* errors. Eliminates steady-state error but can cause a slower response and overshoot.
    - **Derivative (D):** Predicts *future* error based on its rate of change. Dampens the system and reduces overshoot, but is sensitive to measurement noise.
- **State-Space Representation:**
  - A modern mathematical framework for modeling and analyzing systems (especially MIMO) using a set of first-order differential equations and matrices. It uses internal *state variables* to describe the system.

- **Adaptive Control:**
    - A control strategy where the controller parameters are automatically adjusted to accommodate changes in the plant dynamics or disturbances.
- **Robust Control:**
    - A control design methodology that aims to achieve performance and stability despite model uncertainties and disturbances.
- **Optimal Control:**
    - A design method that seeks to maximize or minimize a *performance index* (e.g., minimize energy consumption or time to complete a task).

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5. Analysis & Design Tools

- **Transfer Function:** A mathematical model (in the Laplace domain for continuous systems) that represents the relationship between the input and output of a linear, time-invariant (LTI) system.
- **Block Diagram:** A pictorial representation of the system's structure, showing the components and the flow of signals.
- **Bode Plot:** A graph of the system's frequency response, showing magnitude (gain) and phase shift as a function of frequency. Used for stability and performance analysis.
- **Root Locus:** A graphical technique that shows how the poles of the closed-loop system move in the complex plane as a controller gain is varied. Used for stability analysis and design.
- **Nyquist Plot:** Another frequency-domain technique used to assess the stability of a closed-loop system.