College of Electrical Engineering and Computing

Department of Electrical Power and Control Engineering

Introduction to Control System (EPCE3204)

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CHAPTER ONE
INTRODUCTION TO CONTROL SYSTEM

Learning Outcomes

After completing this chapter, you will be able to:

- Clearly define systems and control systems
- Identify and explain components of control systems
- Classify control systems based on structure and behavior
- Distinguish between open-loop and closed-loop systems
- Relate control systems to real-world engineering applications

1. Basic Definitions and Importance of Control System

- **System:** is an interconnection of physical components that act together to achieve a common objective.

  Examples,

  - Electrical power system
  - Mechanical suspension system
  - Thermal heating system
  - Robotic systems

Fig. 1. Block diagram for system

- **System elements:** Input → Process (plant) → Output

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- **Control System:** is a system, designed to manage, command, direct, or regulate the behavior of other systems using control system elements such as, Sensors, Controllers, and Actuators
- Forces the output of a plant to follow a desired reference input.
- Aim to reduce the difference between desired output and actual output.

Control objective:

- Regulation (maintain constant output)
- Tracking (follow changing reference)
- Disturbance rejection
- Stability and robustness

Importance of Control System

- **Automation and Labor optimization**: Control systems enable automation of repetitive tasks, freeing up human workforce for more complex responsibilities.
- **Precision and Consistency**: By utilizing feedback loops, control systems can precisely maintain desired outputs, leading to consistent quality and performance in manufacturing or other processes.
- **Efficiency and Cost Reduction**: By optimizing system operations, control systems can minimize energy consumption, reduce waste, and prevent unnecessary downtime, resulting in cost savings.

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- **Safety Enhancement**: In hazardous environments, control systems can monitor critical parameters and initiate safety measures to prevent accidents.
- **Adaptability to Changes**: Feedback mechanisms allow control systems to react to changing conditions and adjust accordingly, ensuring optimal performance even when external factors fluctuate.

In general, we build control system for four primary reasons:

- Power amplification
- Remote control
- Convenience of input form
- Compensation of disturbance

2. Components of Control System

- **Plant:** It is defined as the portion of a system which is to be controlled or regulated, it is also called process.
- **Controller:** It is an element within the system itself, or external to the system and which controls the plant or the process. Decision making unit that processes input signals and generate control actions.
- **Actuator:** Converts control signal from the controller into mechanical motion.

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- **Reference input:** The desired output (setpoint) or command signal defining the desired output.
- **Output (Controlled variable):** The actual response obtained from the control system.
- **Disturbance or noise**: is a signal which enters the system at a point other than the reference input and has the effect of undermining the normal system operation.

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- If such a disturbance is generated with in the system itself, it is called an **internal disturbance**.
- The disturbance generated outside the system acting as an extra input to the system in addition to its normal input, affecting the output adversely is called an **external disturbance**.

- Every control system has (at least) a controller and an actuator (also called a final control element (FCE)).

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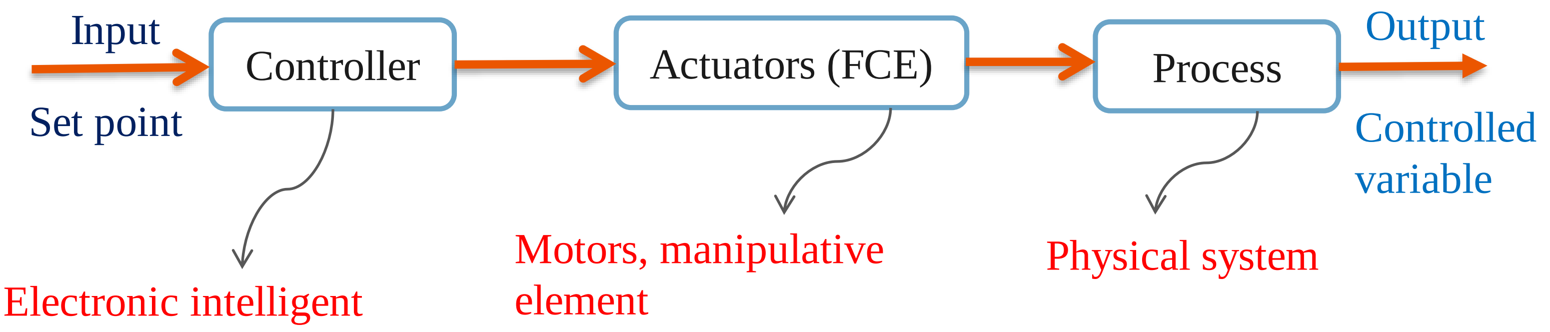


Fig. 2. Block diagram for a control system

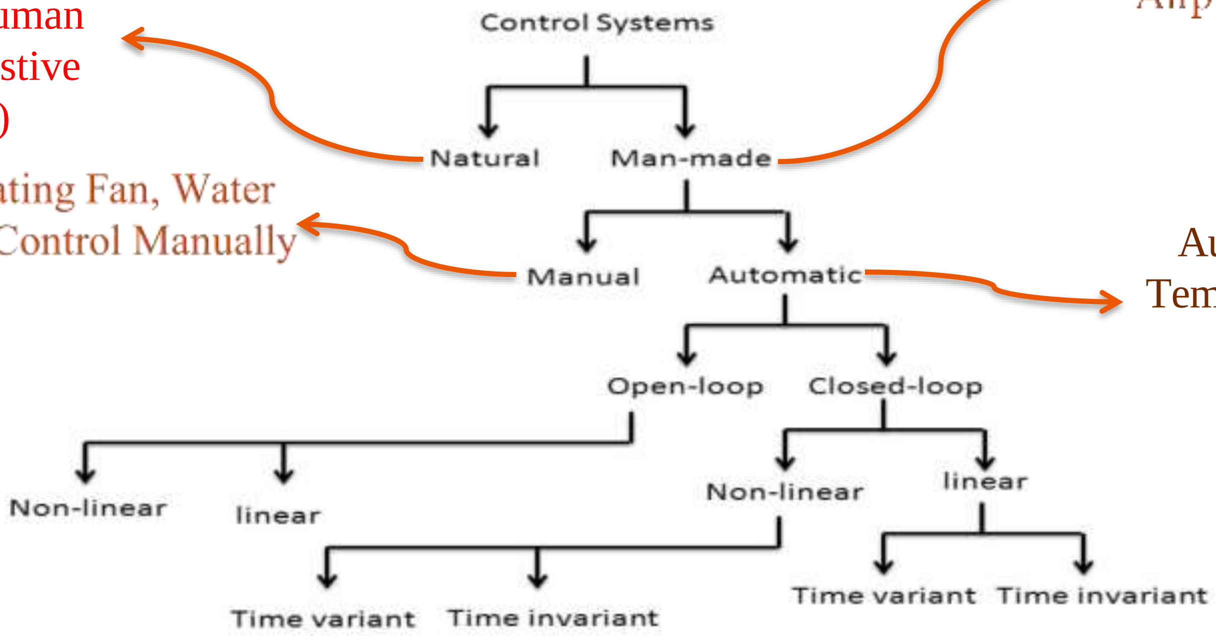
3. Classification of Control Systems

Universe (Solar System), Human Body (Digestive System)

Vehicles
Airplanes

Operating Fan, Water Level Control Manually

Automatic Room Temperature Control



4. Types of Control System

- There are two major configuration of control systems (based on the internal architecture of the control system)
    - Open loop control system (system without a feedback)
    - Closed loop control system (system with feedback)

A. Open loop control system

- Is a control system in which **control action doesn't depend on output it's only depends on the input signal**.
- A control system where the output is not fed back into the controller for correction.
- The input to the system is predetermined based on a set of predetermined rules or instructions.

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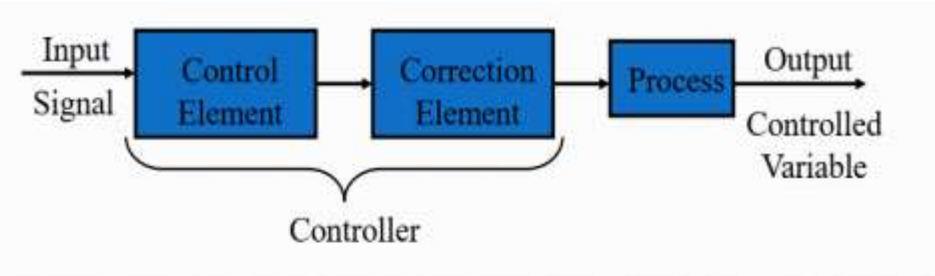

Fig. 3. Block diagram for an open-loop control system

Examples

- An **Electric Kettle** with a selection switch
- Systems which operate by preset timing mechanisms like :-**Traffic Lights**, **Washing Machine, Microwave Oven.**

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Advantages

- Simple design and easy to construct
- Low cost with generally good reliability
- Highly stable operation
- Easy maintenance

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Disadvantages

- Less accurate due to absence of feedback (error correction mechanism)
- More sensitive to changes in component characteristics
- More sensitive to disturbances
- Limitation on applications (used in systems where accuracy is not critical)

B. Closed loop control system

- A control system where output is fed back to the controller to correct any deviations from the desired output/ set point/ reference signal.
- Control actions of the system are **dependent on both the output or change in output and input**.
- The measure of the output is called the **feedback signal**.
- A feedback signal to the input from the output will be sent and used to modify the input to the controller, so that the output is maintained constant regardless of any changes in conditions (disturbances).

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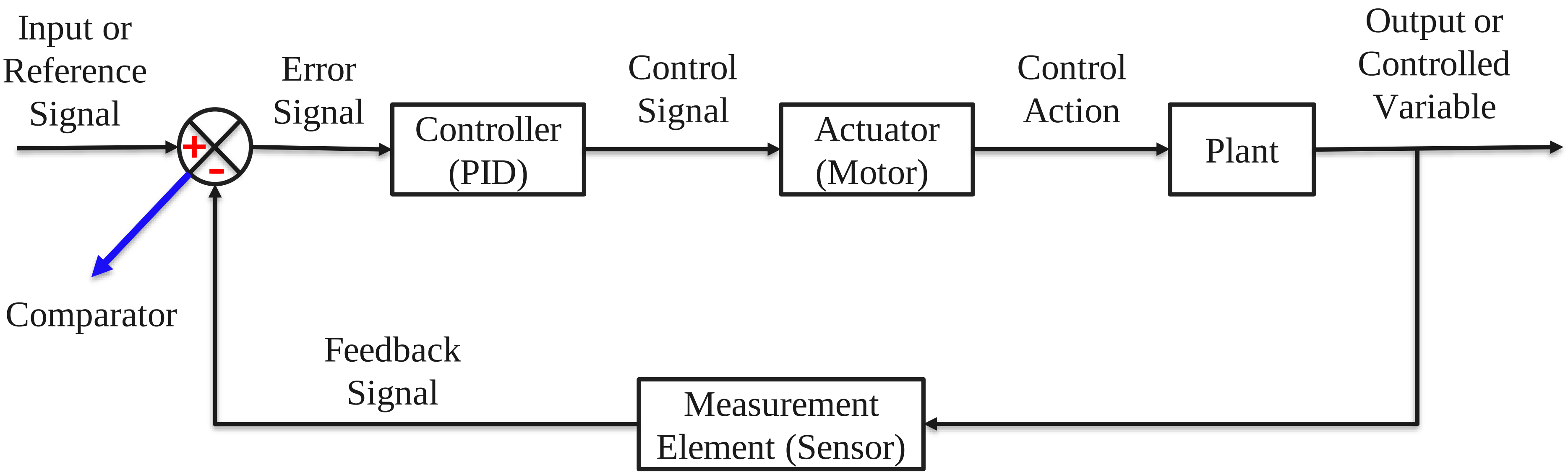

Fig. 4. Block diagram for a closed-loop control system

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Basic Components of Closed Loop Control System

The basic elements are:

- ✓ **Comparison Element:** Compares the reference value of the variable being controlled with the measured value of the actual output and produces an error signal.
- ✓ **Control Element:** Decides what action to be taken after it gets an error signal.

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- **Correction Element (actuator):** Used to produce a change in the process in order to avoid the error.
- ***Process Element (Plant):*** is the system of which a variable is being controlled
- **Measurement Element (Sensor):** Produces a Signal related to the actual output and provides a feedback signal to the comparison element.

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Advantages

- More accurate since there is continuous error correction
- Less sensitive to variation in the system parameters and other characteristics
- Increased speed of response and hence increased band width
- Reduce the effect of non linearity
- Ability to reject external disturbance and measurement noise

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Disadvantages

- These systems are complicated to design and more expensive
- These system may become unstable, because of time delays when transferring corrective action

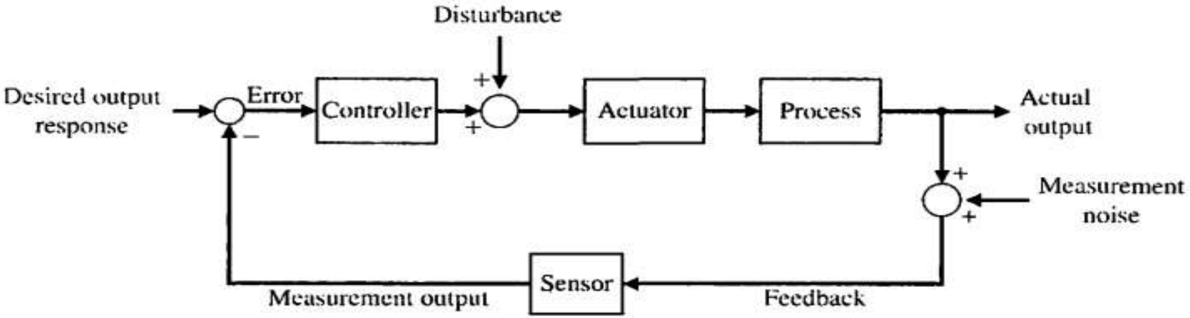

Fig. 5. Closed-loop control system with external disturbances and measurement noise

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The most important tasks of control Engineers

- Determine the controlled variable
- Checking whether automatic control offers significant advantages
- Determining the measurement site
- Selecting the manipulator
- Selecting disturbance
- Selecting a suitable controller
- Installation of the controller in accordance with applicable regulation
- Starting up adjusting parameters, optimizing an unsatisfactory control loop

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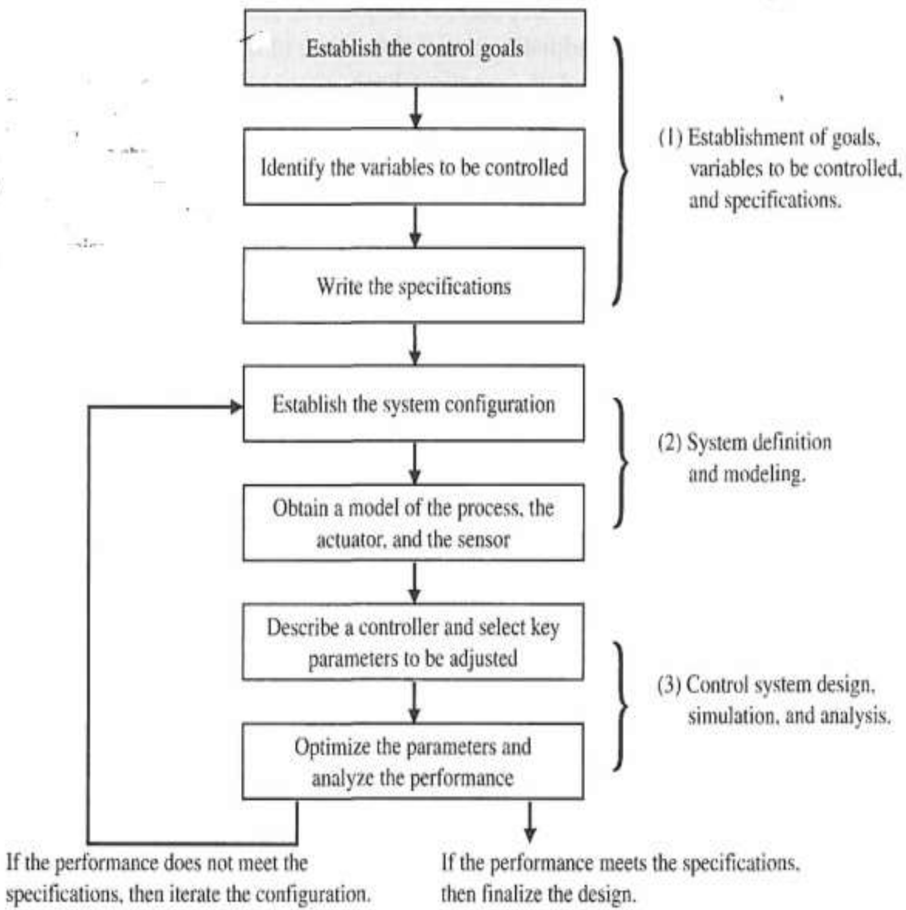
Fig. 6. Control system design process



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Examples

1. A manual control system for regulating the level of fluid in a tank by adjusting the output valve. The operator views the level of fluid through a port in the side of the tank.

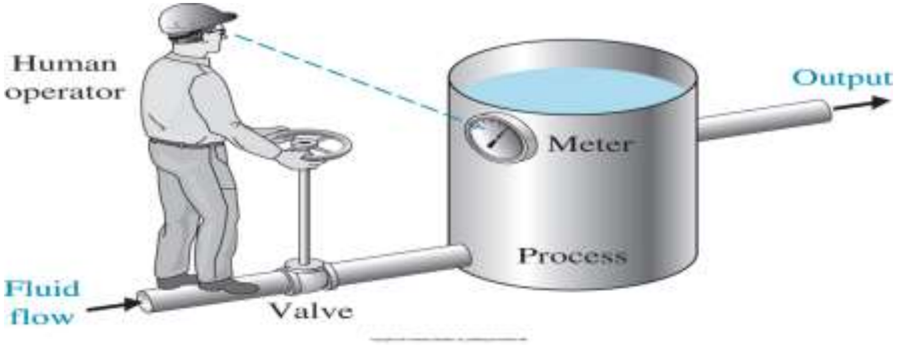

Fig. 7. Manual water level control system

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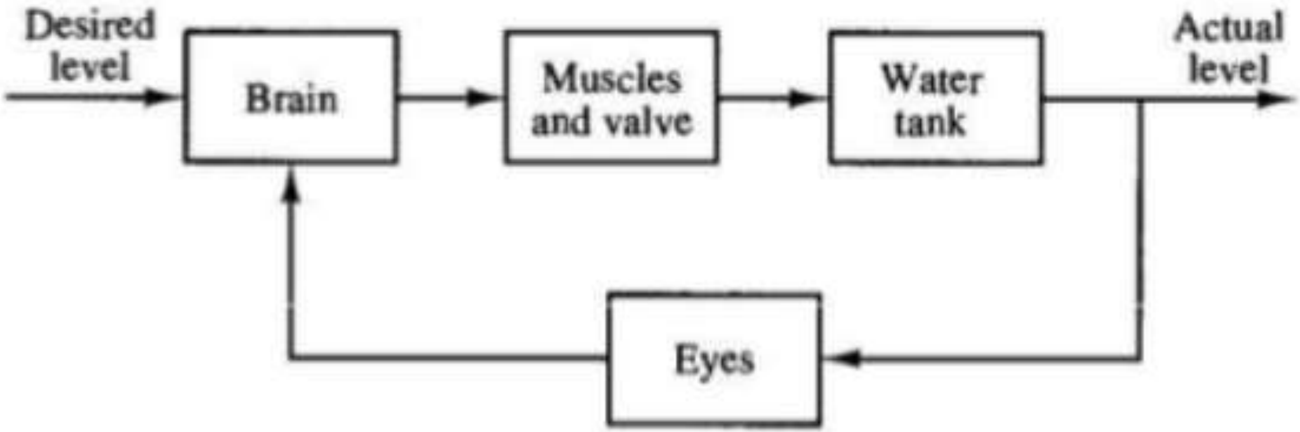

Fig. 8. **Block diagram of manual water level control system**

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2. The driver uses the difference between the actual and the desired direction of travel to generate a controlled adjustment of the steering wheel.

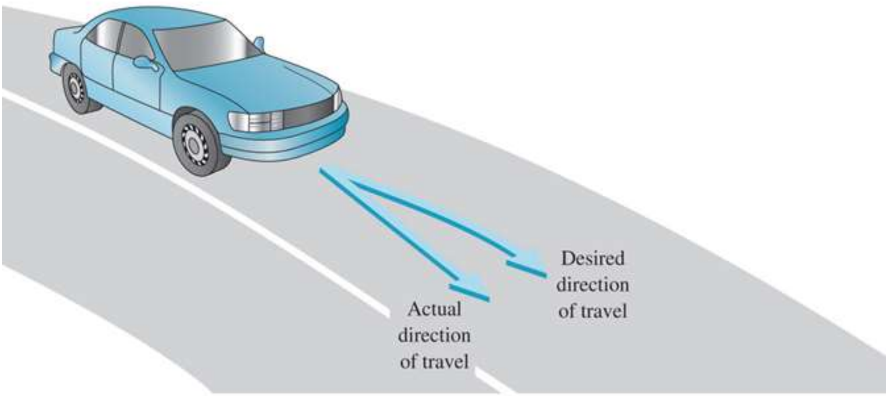

Fig. 9. Manual cruise control system

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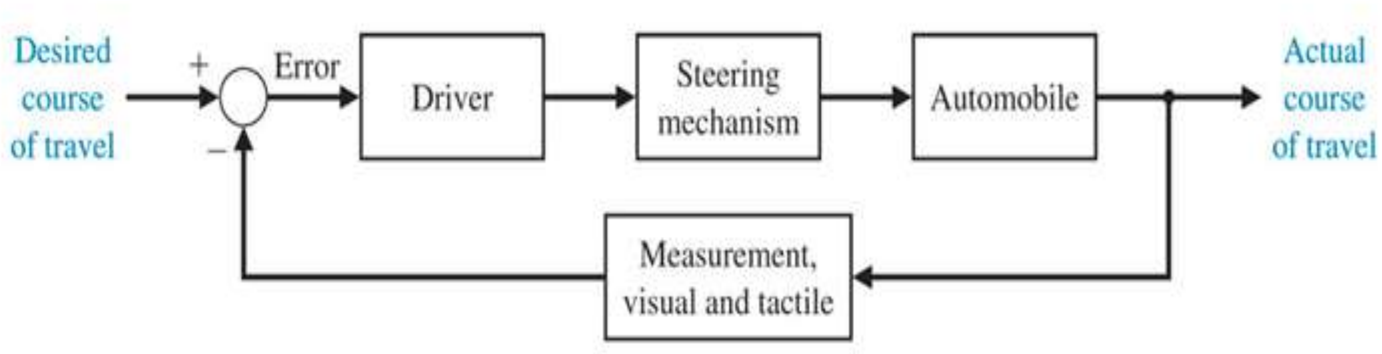

Fig. 10. **Block diagram of manual cruise control system**

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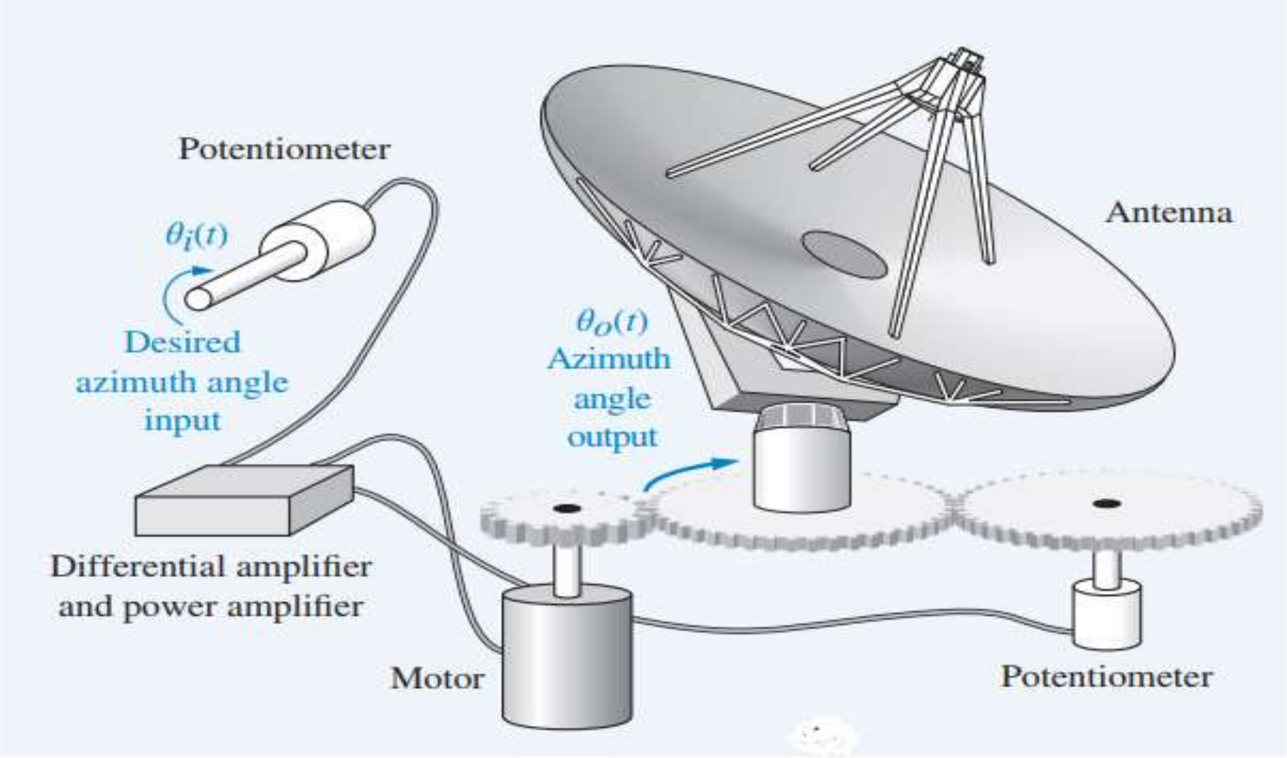

3. Antenna azimuth position control system

Fig. 11. Antenna azimuth position control system

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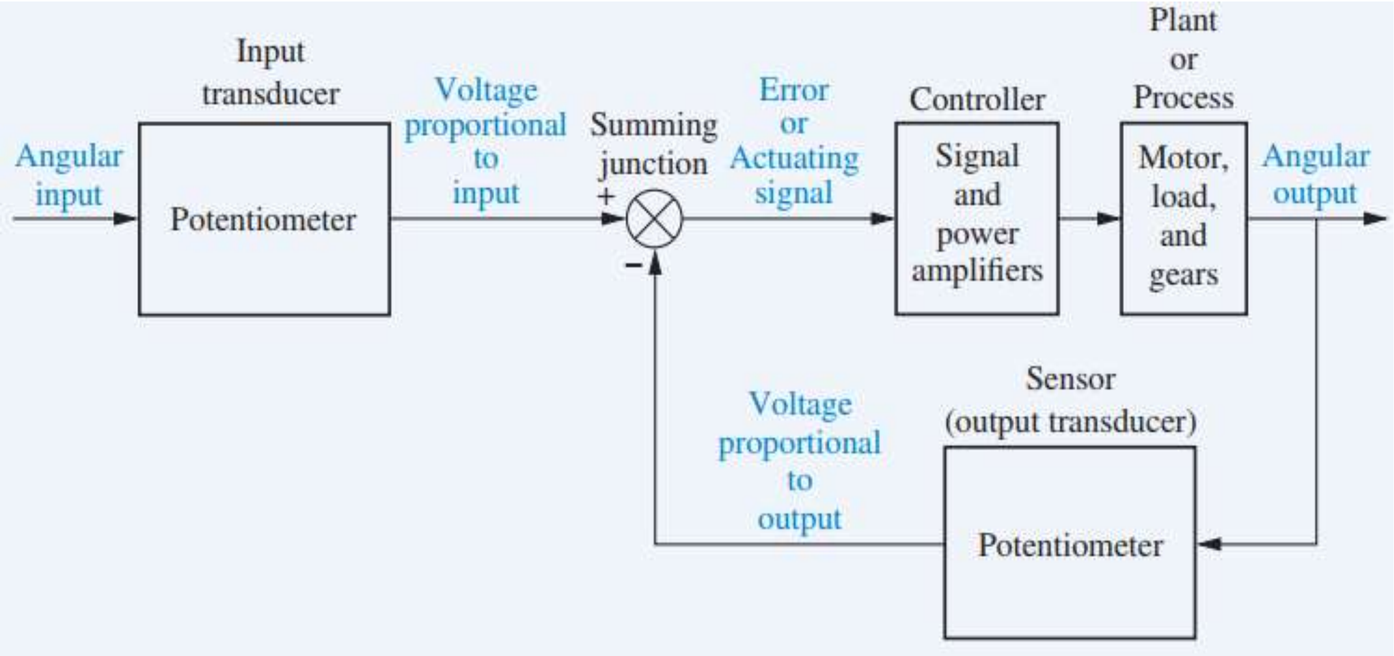

Fig. 12. **Block diagram of Antenna azimuth position control system**

5. Control Strategies (Methods)

- **Linear Control:** deals with linear systems or systems that can be linearized at a point.
  - PID (Proportional Integral Derivative)
  - Lead-lag and Loop shaping
  - Full state feedback
- **Non-linear Control:** deals with systems having non-linear dynamics.
  - Bang-bang and Feedback linearization
  - Backstepping and Sliding mode
  - Gain scheduling and dynamic inversion

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- **Robust Control:** designed to maintain the desired performance under uncertainties and disturbances.
  - ✓ H-infinity and mu Synthesis
  - ✓ Active Disturbance Rejection Control
- **Optimal Control:** Seeks to optimize a performance criterion, such as minimum energy use or fast response.
  - ✓ LQR (Linear Quadratic Regulator)
- **Adaptive Control:** Adjusts its parameters in real-time to manage changing system dynamics.
  - ✓ Model Reference Adaptive Control (MRAC)

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- **Predictive Control:** Uses models to predict future outputs and make control decisions.
  - ✓ Model Predictive Control (MPC)
- **Intelligent Control:** Utilizes AI techniques like **fuzzy logic**, **neural networks**, and **reinforcement learning.**
- **Multi-agent Control:** Involves multiple agents working cooperatively to achieve control objectives.
  - ✓ Swarm

6. Applications of Control System

❖ Industrial and Manufacturing

In factories, control systems optimize production by reducing waste and ensuring consistent quality.

- ✓ **Process Control:** Maintaining precise temperature, pressure, and flow rates in chemical and food processing plants.
- ✓ **Automation:** Programmable Logic Controllers (PLCs) manage assembly lines and industrial robotics for tasks like welding and painting.
- ✓ **SCADA Systems:** Supervisory Control and Data Acquisition (SCADA) provides real-time monitoring of large-scale industrial operation.

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❖ **Transportation and Automotive**

Control systems are critical for safety and efficiency on roads, rails, and in the air.

- ✓ **Automotive:** Manages engine performance via Electronic Control Units (ECUs), as well as safety features like Anti-lock Braking Systems (ABS) and cruise control.
- ✓ **Aerospace:** Autopilot systems maintain stability and navigation, while missile guidance systems ensure precise trajectories.
- ✓ **Traffic Management:** Automated traffic light systems regulate flow based on time or real-time sensor data.

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❖ Energy and Power Systems

Reliable power delivery depends on stabilizing the electrical grid.

- ✓ **Grid Management:** Systems monitor and balance load demand with power generation in real-time.
- ✓ **Renewable Energy:** Optimizes the orientation of solar panels and the pitch of wind turbine blades to maximize energy capture.
- ✓ **Voltage Regulation:** Automatic Voltage Regulators (AVRs) prevent surges that could damage electrical infrastructure.

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❖ **Healthcare Medical Devices**

Medical technology uses control loops for life-critical functions where human error must be eliminated.

- ✓ **Life Support:** Ventilators and dialysis machines use feedback loops to regulate oxygen levels and fluid filtration.
- ✓ **Precision Delivery:** Infusion pumps deliver exact medication dosages based on real-time patient data.
- ✓ **Imaging:** MRI and CT scanners use high-precision motor controls to position hardware accurately for clear results.

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❖ Building and Home Automation

Smart environments rely on control systems for comfort and energy conservation.

- ✓ **HVAC:** Thermostats act as closed loop controllers, adjusting heating or cooling based on environmental temperature.
- ✓ **Security:** Access control systems manage cameras, motion detectors, and automated door locks.
- ✓ **Appliances:** Washing machines and microwaves use preset open-loop controls to perform tasks for specific durations.

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❖ **Agriculture**

"Smart farming" techniques use control systems to increase crop yields.

- ✓ **Precision Irrigation:** Sensors monitor soil moisture and trigger automated watering systems only when needed.
- ✓ **Automated Harvesting:** Control-based robotics can identify and harvest ripe crops with minimal damage.

THANK YOU