
UNIT–5 : Actuators and Robotic Applications

1. Actuators

1.1 Definition of Actuator

An **actuator** is a device that **converts energy into physical motion or force**.

Role of Actuators

- Execute control commands
- Produce motion (linear / rotary)
- Interface between **control system and physical world**

Control Signal → Actuator → Mechanical Motion

Actuators in CPS / IoT

- Final stage of control loop
- Work with sensors + controllers
- Essential for automation and robotics

2. Types of Actuators

2.1 Classification of Actuators

2.1.1 Hydraulic Actuators

Working Principle

Uses **pressurized liquid** (oil) to generate force.

Pump → Pressurized Fluid → Cylinder → Motion

Characteristics

- Very high force output
- High stiffness
- Bulky and heavy

Applications

- Heavy machinery
 - Industrial robots
 - Aircraft control systems
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2.1.2 Pneumatic Actuators

Working Principle

Uses **compressed air**.

Compressor → Air → Piston → Motion

Characteristics

- Fast response
- Lower force than hydraulic
- Compliant behavior

Applications

- Valves
 - Assembly lines
 - Pick-and-place robots
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2.1.3 Electric Actuators

Types

- DC motors
- Stepper motors
- Servo motors
- Solenoids

Characteristics

- Easy control
- High efficiency
- Clean and compact

Applications

- Robotics
- CNC machines
- Consumer electronics

2.1.4 Thermal / Magnetic Actuators

Examples

- Shape Memory Alloys (SMA)
- Magnetic Shape Memory Alloys (MSMA)

Characteristics

- Motion caused by temperature or magnetic field
- Compact
- Slow response

Applications

- Micro-actuators
- Medical devices

2.1.5 Mechanical Actuators

Mechanisms

- Gears
- Rack and pinion
- Levers
- Pulleys

Purpose

- Convert rotary ↔ linear motion

Motor → Gear → Linear Motion

2.1.6 Soft Actuators

Definition

Actuators made of **flexible, elastic materials**.

Characteristics

- High compliance
- Safe for human interaction

Applications

- Soft robotics
 - Biomedical devices
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2.1.7 Shape Memory Polymers (SMP)

Definition

Polymers that change shape when stimulated (heat/light).

Applications

- Biomedical implants
 - Adaptive robotic structures
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3. Electromagnetic Actuators

3.1 Moving Coil Actuator

Principle

- Coil placed in magnetic field
- Current \rightarrow force \rightarrow displacement

Magnet + Coil \rightarrow Force \rightarrow Motion

Applications

- Loudspeakers
 - Precision positioning
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3.2 d'Arsonval Mechanism

Principle

- Used in DC ammeters
- Coil rotates in magnetic field

Components

- Coil
- Permanent magnet
- Springs

- Pointer

Current → Coil Rotation → Pointer Deflection

3.3 DC Motor

Principle

- Interaction of magnetic field and current-carrying conductor

Main Parts

- Armature
- Field magnet
- Commutator
- Brushes

Electrical Energy → Rotational Motion

4. Actuator Characteristics

4.1 Key Characteristics

- Weight
 - Power rating
 - Power-to-weight ratio
 - Torque-to-weight ratio
 - Stiffness
 - Compliance
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4.2 Stiff vs Compliant Systems

Feature	Stiff System	Compliant System
Force output	High	Moderate
Safety	Low	High
Accuracy	High	Moderate
Examples	Hydraulic	Pneumatic, soft actuators

5. Robotic Applications

5.1 Introduction to Robotics

A **robot** is a **programmable electromechanical system** capable of sensing, decision-making, and actuation.

Sensors → Controller → Actuators

Robots are **real-time embedded systems**.

6. Robotic Arm

6.1 Structure of a Robotic Arm

Main Parts

- Base
- Shoulder
- Elbow
- Wrist
- End Effector (gripper)

Base → Shoulder → Elbow → Wrist → Gripper

6.2 Degrees of Freedom (DOF)

- DOF = number of independent movements
- Common arms: **5-axis / 6-axis**

Higher DOF → greater flexibility.

6.3 Coordinate System

- Cartesian (X, Y, Z)
 - Joint coordinates
 - Elbow rotation defines reachability
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7. Sensing in Robotic Arms

7.1 Position and Motion Sensing

Sensors Used

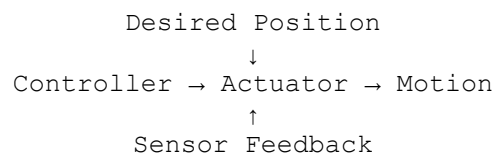
- Optical encoders
- Electrical encoders
- Limit switches

Joint → Encoder → Position Feedback

7.2 Feedback Control

Purpose

- Improve accuracy
- Correct errors



8. Actuation in Robotic Systems

8.1 Actuation Based on Load

- Light loads → Electric motors
 - Heavy loads → Hydraulic actuators
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8.2 Actuators Used in Robots

- Stepper motors (precise steps)
 - Servo motors (closed-loop control)
 - DC motors
 - Relays
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8.3 Three-Switch Reversible Motor

Purpose

- Forward and reverse rotation

Switch A → Forward

Switch B → Reverse

Switch C → Stop

9. Automation and Autonomy

9.1 Automation

Definition

Execution of **predefined tasks**.

Characteristics

- Rule-based
 - No decision-making
 - Fixed behavior
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9.2 Autonomy

Definition

Ability to **sense, decide, and adapt**.

Characteristics

- Environment-aware
 - Adaptive behavior
 - Uses AI / ML
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9.3 Automation vs Autonomy

Aspect	Automation	Autonomy
Decision making	No	Yes
Adaptability	Low	High
Intelligence	Fixed	Learning-based
CPS relevance	Limited	High

EXAM-ORIENTED FINAL SUMMARY

- Actuators convert energy into motion
 - Hydraulic and pneumatic actuators handle high force
 - Electric actuators dominate robotics
 - Smart actuator selection depends on load and precision
 - Robotic arms consist of joints and links
 - Sensors provide feedback for accuracy
 - Automation executes rules, autonomy makes decisions
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