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

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

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

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 → force → displacement

```
Magnet + Coil → Force → Motion
```

Applications

- Loudspeakers
- Precision positioning

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
```

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4. Actuator Characteristics

4.1 Key Characteristics

- **Weight**
- **Power rating**
- **Power-to-weight ratio**
- **Torque-to-weight ratio**
- **Stiffness**
- **Compliance**

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

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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**.

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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

```
              Desired Position
                     ↓
Controller → Actuator → Motion
                     ↑
              Sensor Feedback
```

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8. Actuation in Robotic Systems

8.1 Actuation Based on Load

- Light loads → Electric motors
- Heavy loads → Hydraulic actuators

8.2 Actuators Used in Robots

- Stepper motors (precise steps)
- Servo motors (closed-loop control)
- DC motors
- Relays

8.3 Three-Switch Reversible Motor

Purpose

- Forward and reverse rotation

```
Switch A → Forward
Switch B → Reverse
Switch C → Stop
```

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9. Automation and Autonomy

9.1 Automation

Definition
Execution of **predefined tasks**.

Characteristics

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

9.2 Autonomy

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

Characteristics

- Environment-aware
- Adaptive behavior
- Uses AI / ML

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
