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STUDY NOTES

# ROBOTICS AND AUTOMATION

*Unit II — Sensors in Robotics*

**Topics Covered (03 Hours)**

Transducers vs. Sensors & Transduction Principles
Roles & Challenges of Sensors in Robotic Systems
Proximity Sensors (Inductive, Capacitive, Ultrasonic, IR)
Photoelectric Sensors (Thru-beam, Retro-reflective, Diffuse)
Position Sensors: Piezoelectric Sensors & Mechanical Stress
Linear Variable Differential Transformers (LVDT) & Resolvers
Encoders: Absolute vs. Incremental Optical Encoders
Magnetic, Capacitive, and Pneumatic Position Sensors
Range Finders, Time-of-Flight (ToF) & Laser Range Meters
Touch and Tactile Sensors (Resistive Arrays, Capacitive Grids)
Force and Torque Sensing Wrist Systems & Strain Gauges

*Compiled in a simple, easy-to-understand, book style format*
*for students of Computer Science and Engineering*

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## 2.1 Transducers vs. Sensors in Robotics

Robots must interact with their physical environment. To do so, they rely on sensors to gather information about their own state (internal metrics) and the world around them (external metrics). Before studying specific sensors, we must distinguish between sensors and transducers.

**Sensor vs. Transducer Definitions**

*Transducer: A physical device that converts energy from one form to another (e.g., converting physical pressure, heat, or light into an electrical voltage or resistance change).*

*Sensor: A complete system that includes a transducer, signaling filters, and amplifiers, designed to measure a physical quantity and output a readable electrical signal.*

### Role of Sensors in Robotics

Sensors act as the eyes, ears, and touch of the robot. They are split into two categories:

- **Proprioceptive (Internal) Sensors:** Measure internal parameters of the robot (e.g., joint angles, motor speeds, battery levels). Essential for closed-loop control.
- **Exterioceptive (External) Sensors:** Measure environmental parameters (e.g., distance to obstacles, ambient light, object shapes). Essential for autonomous navigation and task execution.

## 2.2 Proximity, Photoelectric, and Position Sensors

These sensors allow the robot to detect the presence of nearby objects without physical contact.

### Proximity Sensors

- **Inductive Proximity Sensors:** Generate a high-frequency electromagnetic field from an internal coil. When a metallic (ferrous) target enters this field, eddy currents are induced in the metal, which dampens the field amplitude. The sensor detects this change. Operates only on metal targets at short distances.
- **Capacitive Proximity Sensors:** Consist of two internal metal plates that act as an open capacitor. When any target (metal, plastic, liquid) enters the space, it changes the dielectric constant, altering the capacitance. Operates on non-metallic targets.
- **Ultrasonic Proximity Sensors:** Transmit a high-frequency sound wave burst and measure the time taken for the echo to bounce back. Measures distances to objects regardless of color or transparency.
- **Infrared (IR) Sensors:** Emit infrared light and measure the intensity of the reflected light, or use triangulation to determine target distance.

### Photoelectric Sensors

- **Thru-Beam:** The emitter and receiver are in separate housings aligned facing each other. The sensor triggers when the target breaks the light beam. Offers longest range but requires wiring to two separate modules.
- **Retro-Reflective:** The emitter and receiver are in the same housing. The beam is directed at a reflector across the path, which returns it. The sensor triggers when the target blocks the reflected beam.
- **Diffuse-Reflective:** The emitter and receiver are in the same housing. The beam bounces directly off the target itself to return to the receiver. Requires no reflector but range is short and depends on target reflectivity.

### Position Sensors

- **Piezoelectric Sensor:** Utilizes materials (like quartz crystals) that generate an electrical charge when subjected to mechanical stress or strain. Used to measure impact, vibration, and dynamic force.
- **LVDT (Linear Variable Differential Transformer):** Consists of a hollow cylinder containing one primary coil, two secondary coils, and a movable ferromagnetic core connected to the robot link. An AC voltage is applied to the primary coil. As the core slides, it alters the magnetic coupling, producing a differential AC voltage between the secondary coils that indicates linear displacement. Highly precise.

- **Resolvers:** A rotary transformer that measures angular position. Consists of a rotor coil and two stator coils placed at 90 degrees to each other. As the rotor turns, the output amplitudes of the stator coils vary as sine and cosine, indicating absolute angle.

# 2.3 Encoders, Range, Touch, and Force Sensors

These sensors measure joint rotation, range distance, tactile feedback, and contact forces.

## Rotary Encoders

Rotary encoders are mounted on motor shafts to measure rotation. They are classified into two main types:

- **Incremental Encoders:** Use a slotted disk that blocks/passes light to generate a series of pulses as the shaft rotates. They measure relative movement from a starting position. The quadrature style uses two channels (A and B) shifted by 90 degrees to detect the direction of rotation.
- **Absolute Encoders:** Use a disk with complex concentric track patterns representing unique binary codes (usually Gray code) for every angle. They provide the exact angular position immediately upon power-up, without requiring calibration movements.

Physical implementation options include Optical (photodiodes reading glass slots), Magnetic (Hall effect sensors reading magnetic poles), Capacitive (electrostatic variations), and Pneumatic (detecting back-pressure changes in air slots).

## Range, Touch, and Force Sensors

- **Laser Range Meters:** Use Laser diodes to measure range. Time-of-Flight (ToF) sensors measure the nanosecond delay for a light pulse to return. Phase-Shift sensors measure the phase change of modulated laser waves. Highly accurate over long ranges.
- **Touch & Tactile Sensors:** Detect physical contact. Simple touch sensors are binary microswitches. Tactile sensors use arrays of resistive or capacitive grids to map the distribution of pressure, allowing the robot to feel textures and detect slip.
- **Force & Torque Sensors:** Mounted at the robot wrist. They use strain gauges arranged in a Wheatstone Bridge circuit. As forces are applied to the end-effector, the metal link deforms microscopically, changing the resistance of the strain gauges. This allows the controller to measure forces (Fx, Fy, Fz) and torques (Tx, Ty, Tz) to guide tasks like assembly and polishing.

# Unit Summary

This unit explored the principles of sensors in robotic systems.

- Transducers convert physical energy forms, while sensors output conditioned electrical signals.
- Proximity sensors include inductive (metals), capacitive (any material), and ultrasonic (sound waves).
- Photoelectric designs use thru-beam, retro-reflective, or diffuse reflection.
- Position sensors include piezoelectric elements, LVDTs (linear), and resolvers (rotary).
- Encoders measure shaft rotation. Incremental encoders measure pulses, while absolute encoders use track codes to provide start-up angles.
- Laser range meters use ToF or phase-shift. Tactile grids sense touch, while strain gauge bridges measure force and torque.