Lecture
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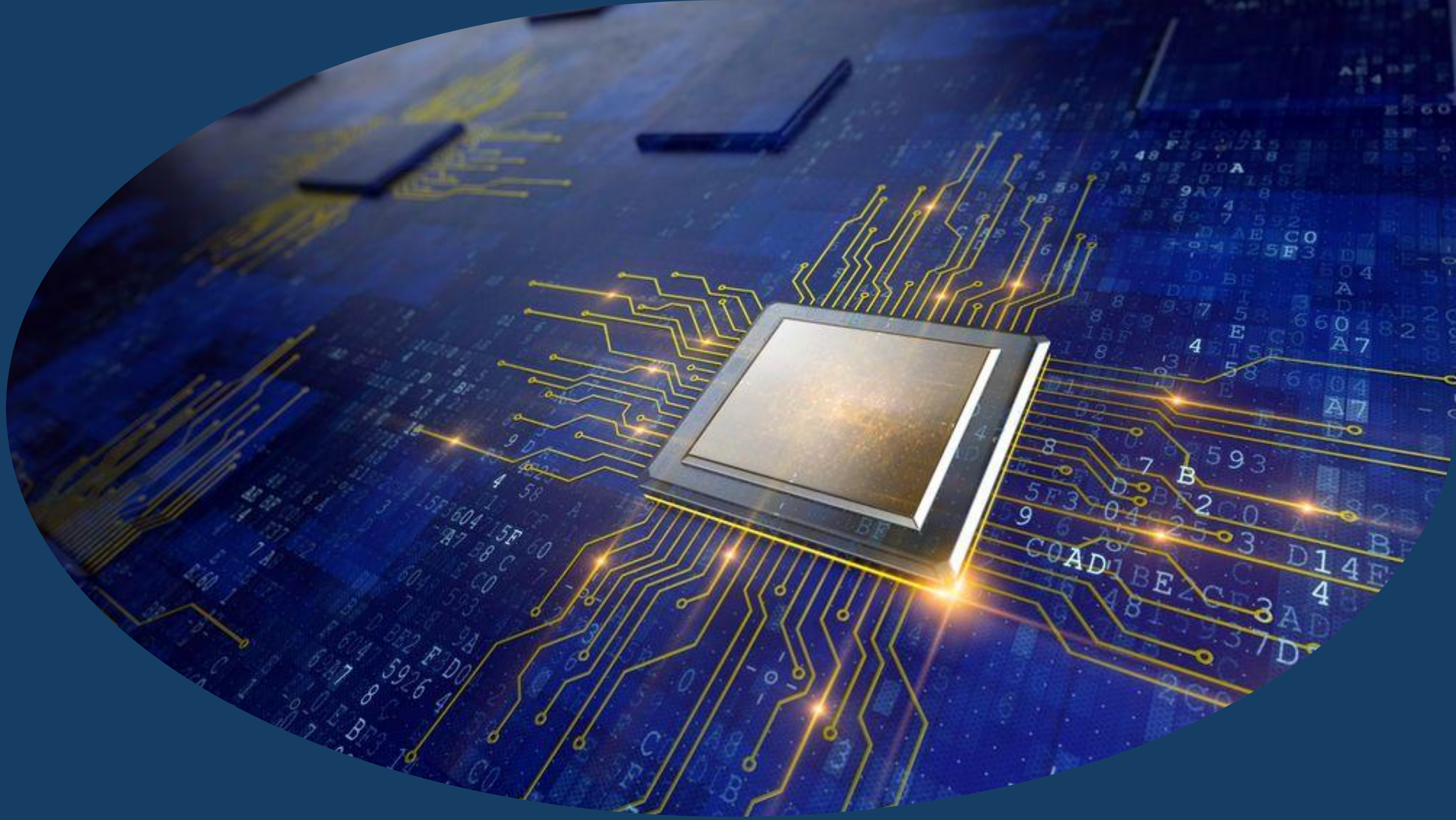


Embedded Systems

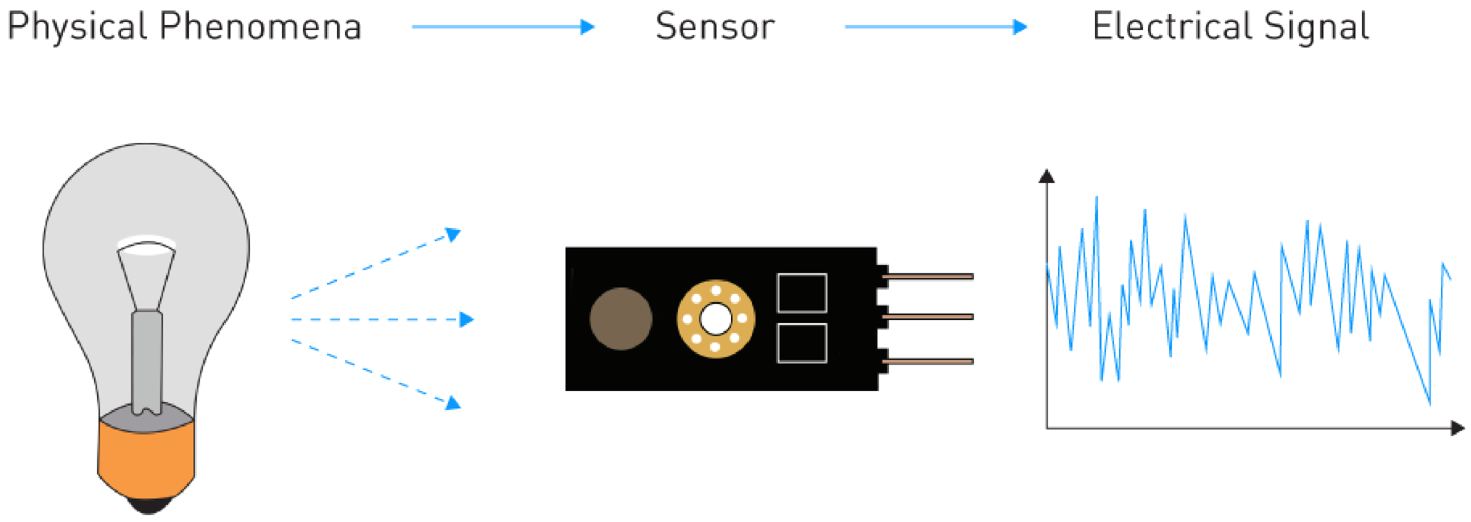
Associated Prof. Wafaa Shalash

Lecture topics

1. Introduction to IoT Sensors
2. Types of IoT Sensors & Their Ap
3. Sensor Communication & Prot
   Bluetooth, etc.)
4. Sensor Data Processing & Anal
5. Security & Challenges in IoT Se
6. Hands-on Demonstration / Case

What Are Sensors?

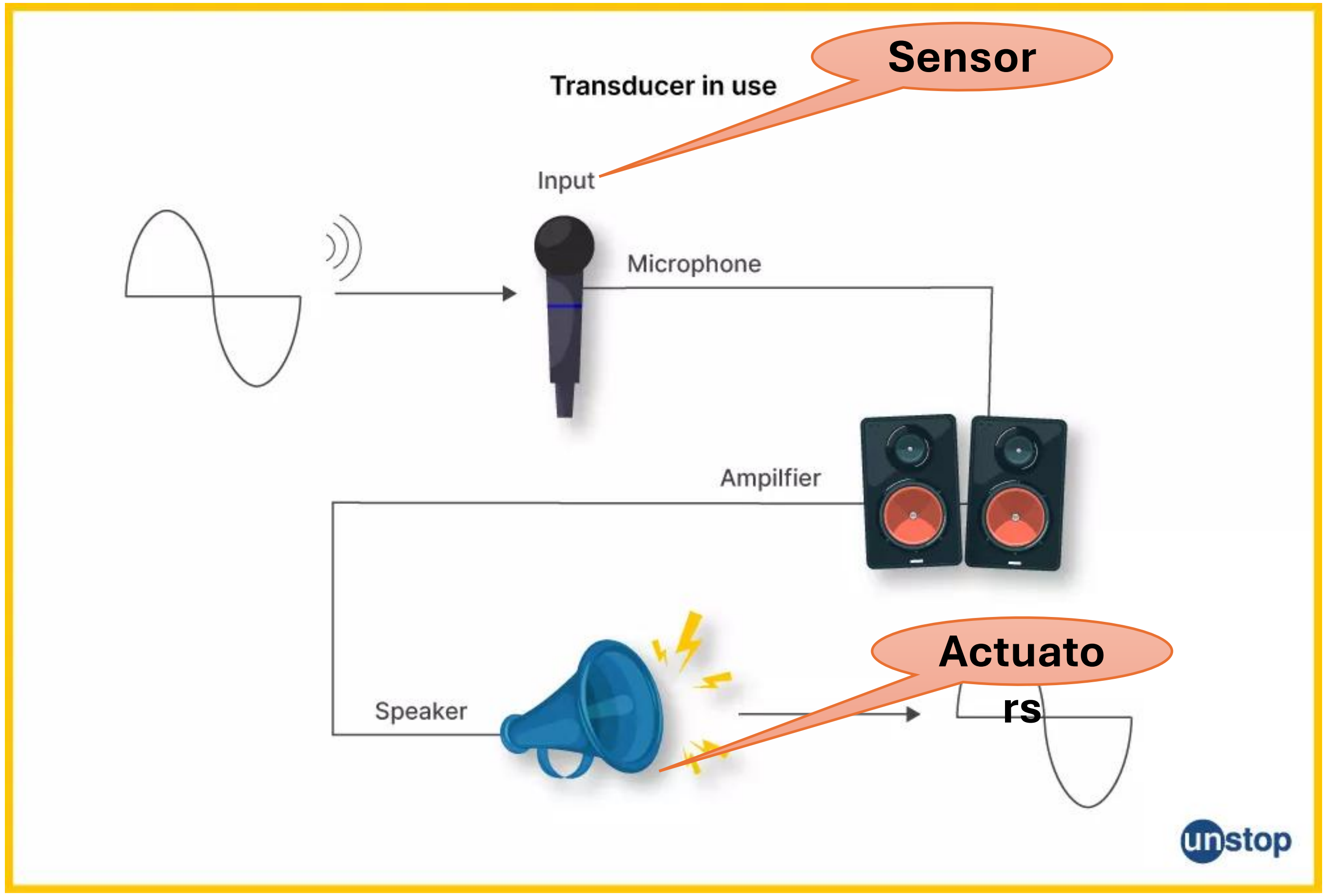
- Sensors are the bridge for interactions between the digital and physical domains.
- A **sensor** is a device that detects and responds to changes in the environment by converting physical, chemical, or biological properties into electrical signals. These signals are then processed by an IoT system to take actions or make decisions.



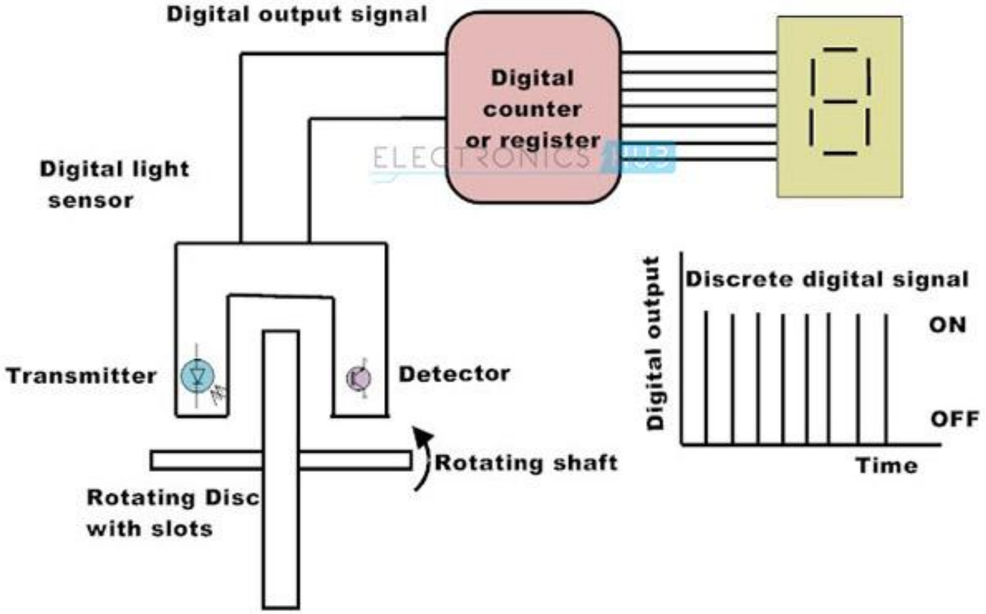
Differences between a Sensor and a Transducer

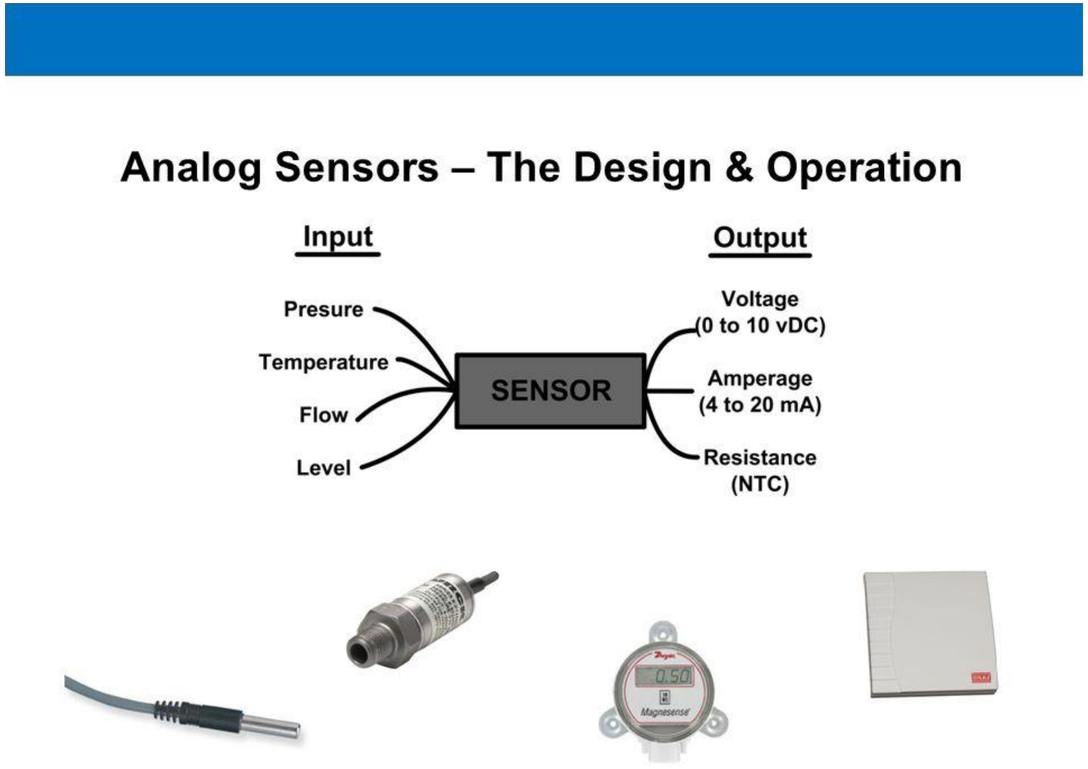
- Despite their frequent interchangeability, the terms "transducer" and "sensor" have some minor distinctions.
- In a wider term, any device that transforms energy from one form to another is referred to as a transducer. Any kind of energy, including thermal, electrical, mechanical, and so on, may be converted in this way. As an example of a transducer, consider a loudspeaker that transforms electrical energy into sound energy.
- A sensor, on the other hand, is a particular kind of transducer that is made to react to a certain stimulus and transform it into an optical or electrical output. An observer or gadget can then read this signal. Not all transducers are sensors, even if all sensors are transducers. For instance, the previously described loudspeaker is only a transducer, but a microphone—which transforms sound energy into electrical energy—is also a sensor.
- In conclusion, a sensor is a specialized device created to detect and produce a signal in response to a certain stimuli. A transducer, on the other hand, is a general term for any apparatus that has the ability to change one type of energy into another.

Differences between a Sensor and a Transducer



Analog Vs Digital Sensors





Sensors and Actuators

- Sensors and actuators are collectively stated as transducers, which serve the function of transforming signals or power from one energy domain to another .
- A sensor is an apparatus that recognizes occurrences or modifications in its surroundings and then generates a corresponding signal. Usually, this output is presented as an optical or electrical signal.
- A wide range of transduction instruments are to convert physical signals into electrical signals (i.e., sensors).
- Sensors convert variations into a particular form that can be utilized to mark or control measured variables , whereas actuators are utilized to produce mechanical motion and force/torque.
- Actuators **perform actions** based on received signals.

- **Sensors** gather real-world data, while **actuators** take action based on that data.
- **Sensors** work as input devices, while **actuators** function as output devices.
- Both are essential in **automation, robotics, and IoT applications**.

Sensors and Actuators

Feature	Sensors	Actuators
Function	Detects and measures physical properties	Converts electrical signals into physical actions
Purpose	Collects data from the environment	Performs actions based on received signals
Type of Output	Analog or digital signals	Mechanical movement, sound, light, heat, etc.
Examples	Temperature sensor, Motion sensor, Light sensor	Motor, Relay, Solenoid, LED, Buzzer
Input Type	Physical properties like temperature, pressure	Electrical signals from a controller
Power Consumption	Usually low	Can be high depending on the action performed
Use Cases	Weather monitoring, Health tracking, Industrial sensing	Robotics, Automation, Smart home devices
Data Flow	Information flows from the environment to the system	Signals flow from the system to the environment

Types of Sensors in IoT

- IoT systems use different types of sensors to collect real-time data from the environment. These sensors can be classified based on the type of data they measure.
- **Temperature Sensors** 🌡️
- **Function:** Measures temperature changes.
  Examples: DHT11, DHT22, LM35, Thermocouples.
  Applications:
  Smart thermostats (HVAC systems)
  Weather monitoring
  Industrial temperature control
- **Light Sensors** 💡

Function: Measures light intensity.
Examples: LDR (Light Dependent Resistor), Photodiodes.
Applications:
Smart street lighting
Auto-brightness in mobile screens
Solar tracking systems

Types of Sensors in IoT

- **Humidity Sensors** 💧
- **Function:** Measures moisture levels in the air.
  Examples: DHT11, DHT22, HIH-4000.
  Applications:
  Smart agriculture (soil moisture monitoring)
  Climate control in homes/offices
  Industrial drying processes
- **Motion Sensors** 🚶
- **Function:** Detects movement of objects or people.
  Examples: PIR (Passive Infrared), Ultrasonic, Microwave Sensors.
  Applications:
  Security systems (burglar alarms, CCTV automation)
  Automatic lighting systems
  Smart appliances (e.g., touchless faucets)

Types of Sensors in IoT

- **Pressure Sensors** ⚙️
- **Function:** Measures pressure changes in air, water, or gases.
  Examples: BMP180, MPX5010.
  Applications:
  Tire pressure monitoring (automobiles)
  Industrial fluid control
  Weather forecasting
- **Gas Sensors** 🏭
- **Function:** Detects harmful gases in the environment.
  Examples: MQ-2, MQ-7, CO2 Sensors.
  Applications:
  Air quality monitoring
- Gas leakage detection (LPG, CO)
  Industrial safety

Types of Sensors in IoT

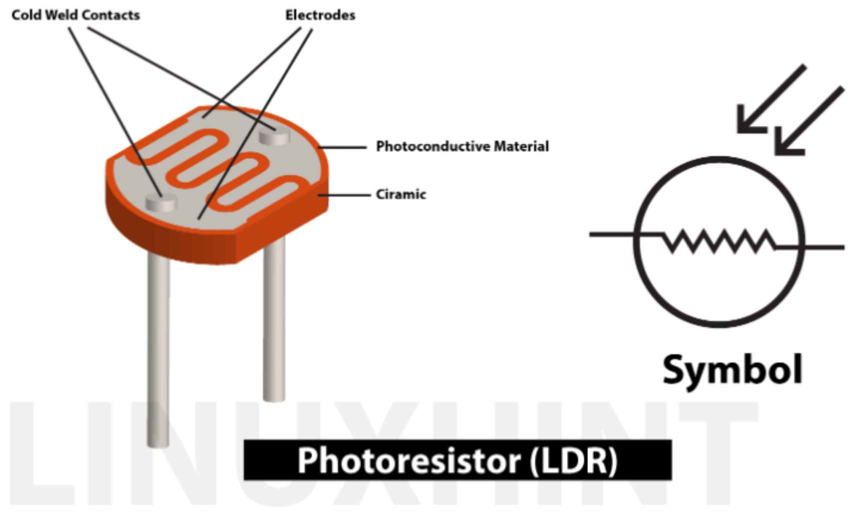
- **Sound Sensors** 🎤
- **Function:** Detects sound waves and converts them into electrical signals.
  Examples: MEMS Microphones, Sound Level Sensors.
  Applications:
  - Voice recognition in smart assistants (Alexa, Google Home)
  - Noise pollution monitoring
  - Smart security systems (sound-based alarms)
- **pH Sensors** ⚗️
- **Function:** Measures acidity or alkalinity in liquids.
  Examples: pH Meter, Analog pH Sensor.
  Applications:
  Water quality monitoring
  Soil analysis in smart farming
  Food and beverage industry
- **Accelerometers & Gyroscopes** 🔄
- **Function:** Measures motion, tilt, and orientation.
  Examples: MPU6050, ADXL345.
  Applications:
  Fitness trackers (step counting)
  Smartphone screen rotation

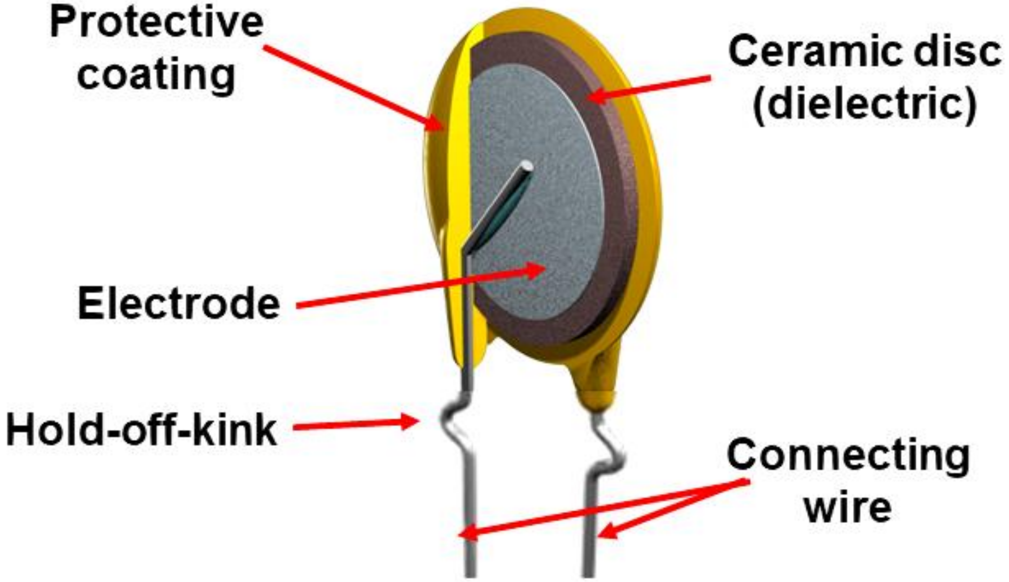
How does a sensor work?

- All sensors operate on the basic principle of taking an input and producing a related output. The steps involved are:
- **Receptors**: The receptor section senses the input phenomena such as temperature, light, or motion.
- **Transduction:** The input is converted into another form of energy via transduction. For e.g, thermal energy is converted into electrical energy.
- **Signal Conditioning:** The transduced signal is amplified and processed via filtering and digital conversion circuits.
- **Output:** The conditioned signal is converted into a human-readable output format like voltage, current, frequency, digital code, etc.
- **Feedback:** Some sensors also incorporate feedback loops to improve accuracy and compensate for environmental changes.
- In essence, a sensor detects an input phenomenon, transduces it, and generates an output signal quantifying the input amount or change.

Sensor Parts:

- Sensors consist of three parts;
- sensing element to detect the physical and chemical quantity,
- transducer to convert the detected parameter to an electrical signal,
- readout device such as a computer that is used to read and interpret the converted signal.





Thermal sensor

Sensor's performance characteristic

Sensitivity: determines the minimum value of the target substance concentration.

- **Sensitivity (S) = Output Signal / Input Signal**

  For example,

- In thermocouples **S = ΔV/°C**

Resolution: refers to a ratio between the maximum magnitudes measured to the smallest part that can be determined.

- **Resolution (R)** = Minimum Detectable Signal / Full Scale Signal

  = 1 / (2^n - 1) [For digital sensors with n-bit resolution]

- Accuracy: is defined as the amount of uncertainty in measurement with respect to an absolute standard, and it can directly influence the qualitative analysis of the sensor.

Linearity (L) = Maximum Deviation from Best Fit Line / Full Scale

Sensor's performance characteristic

limit of detection (LOD): is the lowest quantity of a substance that can be distinguished by the sensor.

The capability of a sensor: to identify a particular substance.

The response time is the particular time period when the concentration reaches a certain limit when the sensor produces a warning signal.

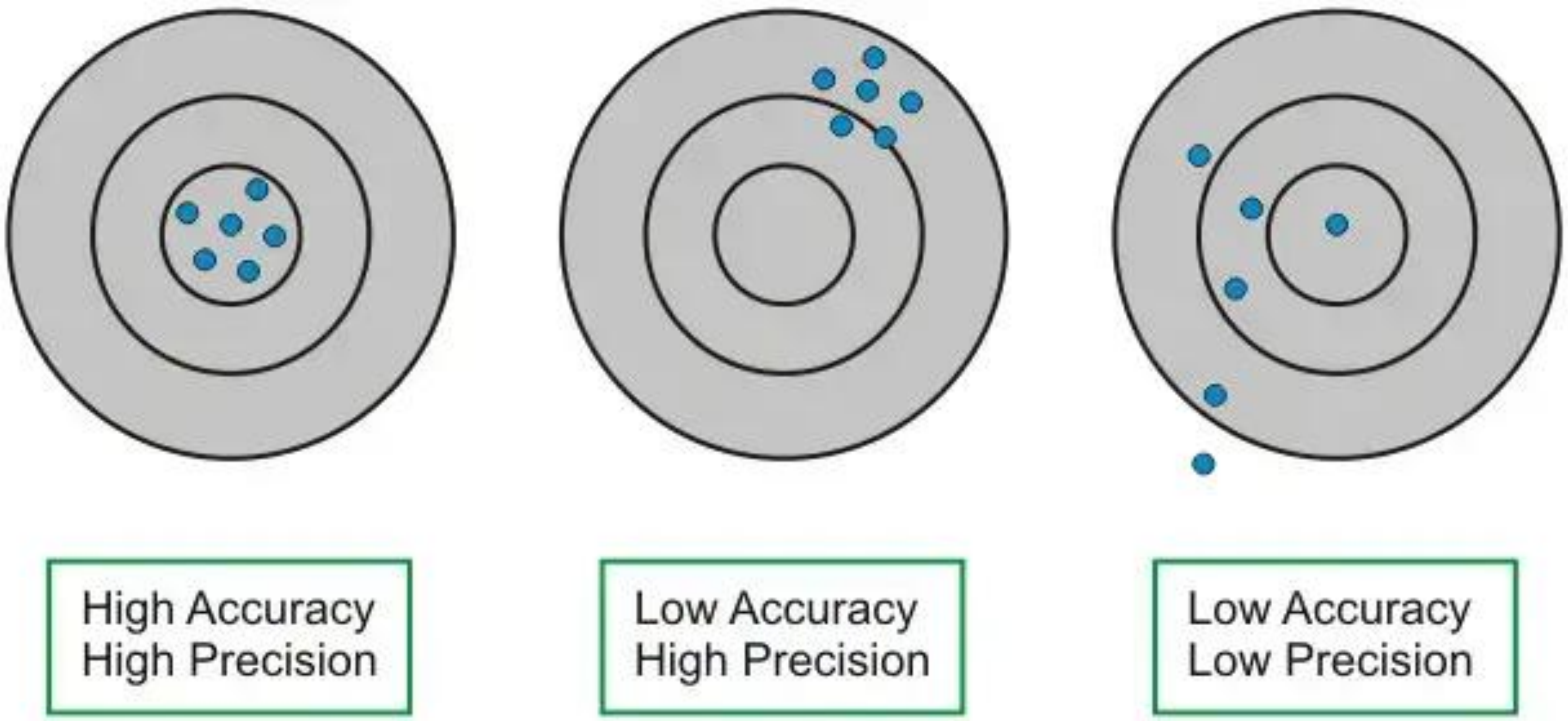
- **Response Time (Tr)** = Time to reach 63.2% of the final value
  = Time Constant (τ) for 1st order system

Repeatability (Pr) = Maximum Deviation between Repeated Output Measurements at Constant Input

The recovery time: is the period after the detection process for the sensing material that takes to recover and restore its baseline status.

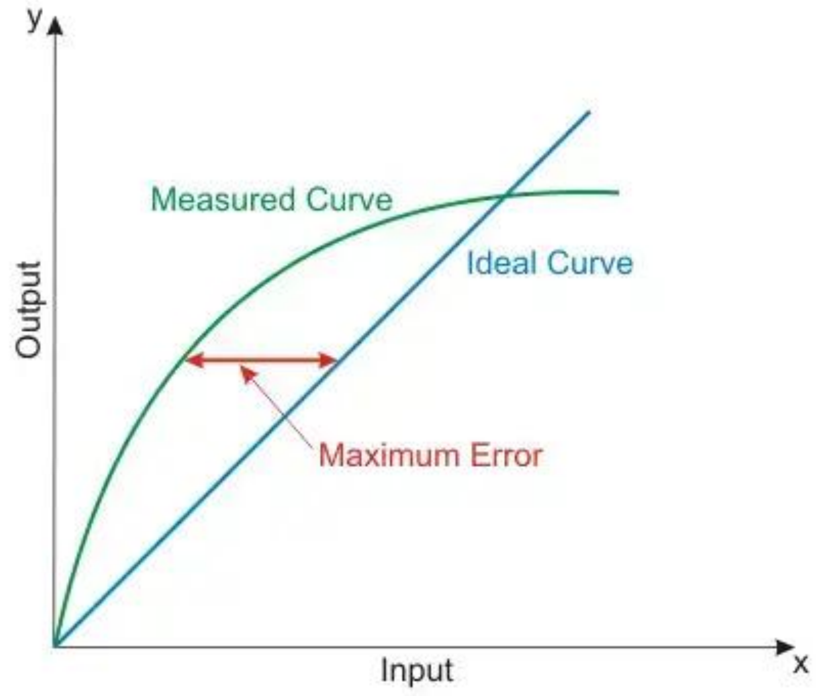
Sensor's performance characteristic

- **Accuracy vs. Precision**: Accuracy is the closeness to the true value, while precision is how close repeated measurements are to each other.

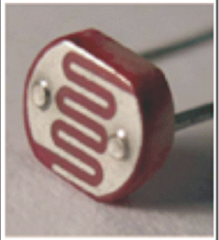
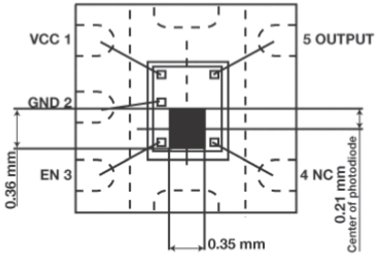
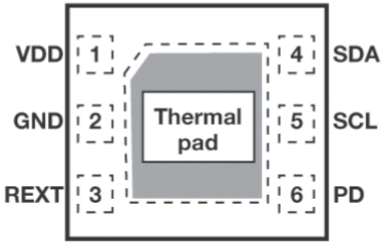


Sensor's performance characteristic

- **Linearity:** Linearity is the maximum deviation between the sensor’s measured values and the ideal response curve



Example Light sensor C/cs:

Device	Photo resistor	Photo diode	Photo transistor	Photo diode and current amplifier	Photo diode, current amp, ADC and filter
Referenced part #	PDV-P500X	Everlight DTD-15	Everlight DPT-092	EL7900	ISL29001
					
Accuracy	Not guaranteed	Not guaranteed	± 75%	± 33%	15-bit resolution
Current (1000 lux)	Varies	3 μA	2.6 mA (70 klux)	0.9 mA	0.3 mA
Range	1 to 100 lux	7 to 50 klux	1 k to 100 klux	1 to 100 klux	0.3 to 10 klux
Response time	55 ms	6 ns	15 μs	0.5 ms	100 ms
Enable function	No	No	No	Yes	Yes

https://www.eetimes.com/making-sense-of-light-sensors/

How a Light Sensor Works in IoT

- A **light sensor** detects the intensity of light in the environment and converts it into an electrical signal. This signal is processed to perform automated tasks like adjusting screen brightness, turning on streetlights, or activating alarms.
- **Working Principle of a Light Sensor**

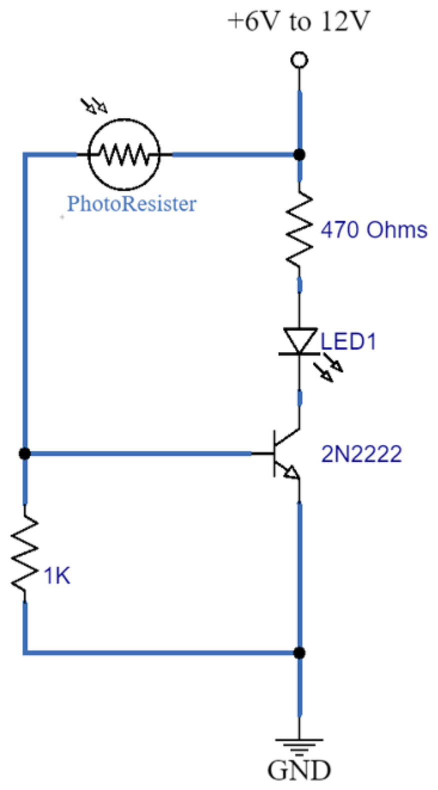
1. **Detection:** The sensor detects ambient light using **photoresistors (LDR), photodiodes, or phototransistors**.
2. **Conversion:** The light intensity is converted into an **electrical signal (voltage or current)**.
3. **Processing:** The signal is sent to a **microcontroller (ESP32, Arduino, etc.)** for analysis.
4. **Action:** Based on the data, the system can:
    1. Increase/decrease **screen brightness** on devices.
    2. Automatically **turn lights on/off** in smart homes or street lighting systems.
    3. Adjust **camera exposure** in mobile photography.

How a Light Sensor Works in IoT

- **Types of Light Sensors**
  - **LDR (Light Dependent Resistor):** Resistance changes based on light intensity.
  - **Photodiodes:** Converts light into an electrical current, used in precise applications.
  - **Phototransistors:** More sensitive than photodiodes, used in automation systems.
- **IoT Applications of Light Sensors**
- **Smart lighting systems** (streetlights, home automation)
- **Automatic brightness adjustment** (smartphones, laptops)
  Solar tracking systems (adjusting solar panels for maximum efficiency)
- **Security systems** (motion-activated lights)

Example :**Simple Light Sensor Circuit**

Light Sensor Circuit



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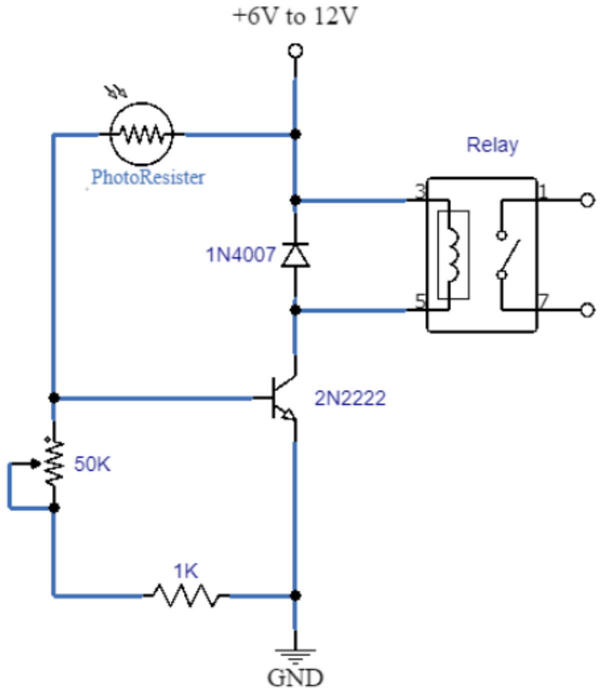
Light Sensor Relay Circuit



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Case Study : **Introduction:**

- With the increasing demand for precision farming, smart agricultural systems rely on IoT-based sensors to monitor environmental conditions and optimize crop growth. This case study examines the process of selecting appropriate sensors for a **smart irrigation system** that enhances water efficiency and crop yield.
- **2. Problem Statement**
- Traditional irrigation systems often lead to **overwatering or underwatering**, causing reduced crop productivity and excessive water usage. A smart irrigation system requires **real-time monitoring of soil and environmental parameters** to deliver water precisely when and where needed.

Case Study:**3. Sensor Selection Criteria**

- To design an efficient smart irrigation system, the following criteria were considered for sensor selection:

Criteria	**Description**
Accuracy	The sensor must provide precise measurements of soil moisture and weather conditions.
Power Consumption	Low-power sensors are preferred for long-term deployment in the field.
Connectivity	Sensors should support wireless communication (LoRa, Zigbee, or Wi-Fi) for remote monitoring.
Durability	The sensors must withstand harsh weather conditions, including heat, rain, and humidity.
Cost	The solution should be cost-effective without compromising performance.

Case Study:**4. Selected Sensors**

- Based on the criteria, the following sensors were chosen:

Sensor Type	**Model/Technology**	**Function**
Soil Moisture Sensor	Capacitive Soil Moisture Sensor	Measures soil water content.
Temperature & Humidity Sensor	DHT22	Monitors environmental conditions.
Light Sensor	BH1750	Detects sunlight intensity for plant growth monitoring.
Rain Sensor	FC-37	Determines if irrigation is needed based on rainfall.
pH Sensor	Analog pH Sensor	Checks soil acidity for optimal crop health.

Case Study:**5. Implementation & Integration**

- **Data Collection**: Sensors are deployed in different areas of the field to collect localized data.
- **Wireless Communication**: The sensors transmit data via **LoRaWAN** to a central monitoring system.
- **Automated Decision-Making**: Based on real-time data, the system controls irrigation valves, ensuring optimal water usage.
- **User Dashboard**: Farmers access real-time insights through a mobile or web application.

Case Study 2: **Selecting Sensors for a Healthcare Monitoring System**

- **Introduction:**
- With the rising demand for remote patient monitoring and healthcare automation, selecting the right sensors is crucial for building an efficient **healthcare monitoring system**. This case study explores the selection process for sensors in a system designed to track **vital signs** and enhance patient care.
- **Problem Statement:**
- Hospitals and healthcare providers need real-time patient monitoring to detect early symptoms of critical conditions. Manual monitoring is prone to **human error, delays, and inefficiency**. A smart healthcare system requires **continuous, non-invasive monitoring** to improve patient outcomes and reduce hospital workload.

Case Study 2: **Selecting Sensors for a Healthcare Monitoring System**

3. Sensor Selection Criteria

To design an effective healthcare monitoring system, the following criteria were considered for selecting sensors:

Criteria	Description
Accuracy	The sensor must provide precise and real-time vital sign measurements.
Power Efficiency	Low-energy consumption for long-term wearable use.
Connectivity	Sensors should support **Bluetooth, Wi-Fi, or cellular** for real-time data transfer.
Comfort & Safety	Must be non-invasive and comfortable for continuous use.
Cost & Scalability	The solution should be cost-effective and scalable for hospitals and home use.

Case Study 2: **Selecting Sensors for a Healthcare Monitoring System**

4. Selected Sensors

Based on the criteria, the following sensors were chosen:

Sensor Type	**Model/Technology**	**Function**
Heart Rate Sensor	Photoplethysmography (PPG)	Measures heart rate by detecting blood flow changes.
Blood Pressure Sensor	Optical or Cuff-Based BP Sensor	Monitors blood pressure levels.
SpO2 Sensor	Pulse Oximeter (MAX30100)	Measures blood oxygen saturation.
Temperature Sensor	Infrared Thermometer Sensor	Tracks body temperature without contact.
ECG Sensor	AD8232 ECG Module	Captures electrical heart activity for cardiac monitoring.
Motion Sensor	Accelerometer & Gyroscope	Detects patient movement and fall detection.