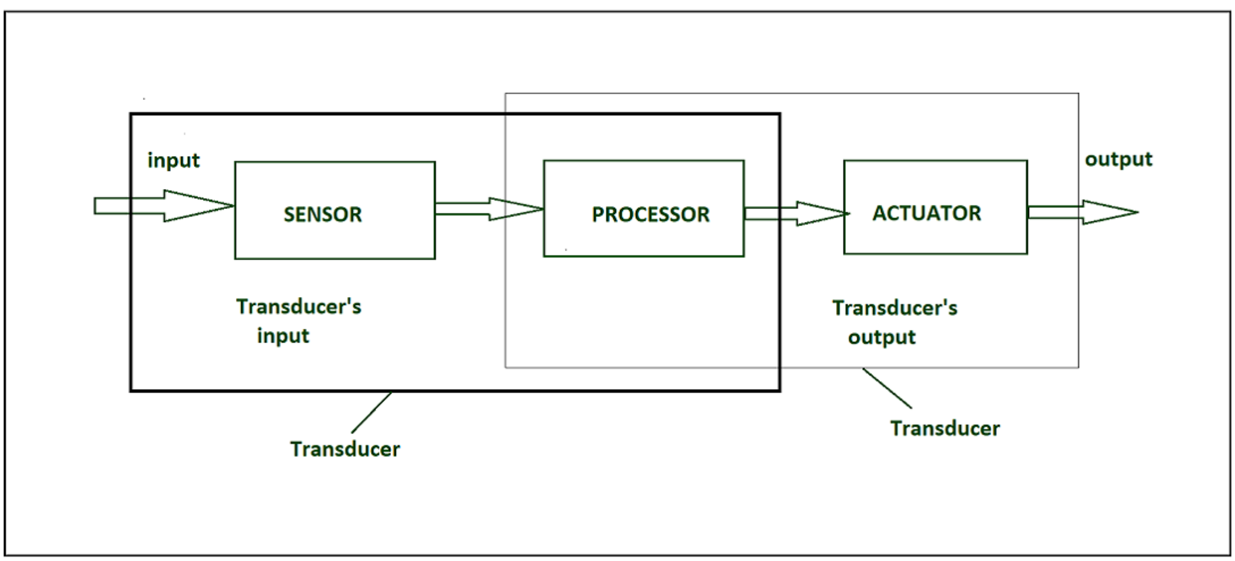
Unit 3. Sensors and Actuators in IoT

3.1 Definition of Sensors

Generally, sensors are used in the architecture of IOT devices. **Sensors** are used for sensing things and devices etc.

A device that provides a usable output in response to a specified measurement. The sensor attains a physical parameter and converts it into a signal suitable for processing (e.g. electrical, mechanical, optical) the characteristics of any device or material to detect the presence of a particular physical quantity.

The output of the sensor is a signal which is converted to a human-readable form like changes in characteristics, changes in resistance, capacitance, impedance etc.



Transducer:

- A transducer converts a signal from one physical structure to another.

- It converts one type of energy into another type.
- It might be used as actuators in various systems.

Sensors characteristics:

1. Static
2. Dynamic

3.2 Types of sensors and its usage (Temperature, Humidity, Gas Detector, Ultrasonic, Fire detector, Light, Sound, IR, Water Level)

Sensors are designed to respond to specific types of conditions in the physical world, and then generate a signal (usually electrical) that can represent the magnitude of the condition being monitored. Those conditions may be light, heat, sound, distance, pressure, or some other more specific situation, such as the presence or absence of a gas or liquid. The common IoT sensors that will be employed include:

- Temperature sensors
- Pressure sensors
- Motion sensors
- Level sensors
- Image sensors
- Proximity sensors
- Water quality sensors
- Chemical sensors
- Gas sensors
- Smoke sensors
- Infrared (IR) sensors
- Acceleration sensors
- Gyroscopic sensors
- Humidity sensors
- Optical sensors

A description of each of these sensors is provided below.

Temperature sensors:

Temperature sensors detect the temperature of the air or a physical object and concert that temperature level into an electrical signal that can be calibrated accurately reflect the measured temperature. These sensors could monitor the temperature of the soil to help with agricultural output or the temperature of a bearing operating in a critical piece of equipment to sense when it might be overheating or nearing the point of failure.

Pressure sensors:

Pressure sensors measure the pressure or force per unit area applied to the sensor and can detect things such as atmospheric pressure, the pressure of a stored gas or liquid in a sealed system such as tank or pressure vessel, or the weight of an object.

Motion sensors:

Motion sensors or detectors can sense the movement of a physical object by using any one of several technologies, including passive infrared (PIR), microwave detection, or ultrasonic, which uses sound to detect objects. These sensors can be used in security and intrusion detection systems, but can also be used to automate the control of doors, sinks, air conditioning and heating, or other systems.

Level sensors:

Level sensors translate the level of a liquid relative to a benchmark normal value into a signal. Fuel gauges display the level of fuel in a vehicle's tank, as an example, which provides a continuous level reading. There are also point level sensors, which are a go-no/go or digital representation of the level of the liquid. Some automobiles have a light that illuminates when the fuel level tank is very close to empty, acting as an alarm that warns the driver that fuel is about to run out completely.

Image sensors:

Image sensors function to capture images to be digitally stored for processing. License plate readers are an example, as well as facial recognition systems. Automated production lines can use image sensors to detect issues with quality such as how well a surface is painted after leaving the spray booth.

Proximity sensors:

Proximity sensors can detect the presence or absence of objects that approach the sensor through a variety of different technology designs. These approaches include:

- Inductive technologies which are useful for the detection of metal objects
- Capacitive technologies, which function on the basis of objects having a different dielectric constant than that of air
- Photoelectric technologies, which rely on a beam of light to illuminate and reflect back from an object, or
- Ultrasonic technologies, which use a sound signal to detect an object nearing the sensor

Water quality sensors:

The importance of water to human beings on earth not only for drinking but as a key ingredient needed in many production processes dictates the need to be able to sense and measure parameters around water quality. Some examples of what is sensed and monitored include:

- chemical presence (such as chlorine levels or fluoride levels)
- oxygen levels (which may impact the growth of algae and bacteria)
- electrical conductivity (which can indicate the level of ions present in water)
- pH level (a reflection of the relative acidity or alkalinity of the water)
- turbidity levels (a measurement of the amount of suspended solids in water)

Chemical sensors:

Chemical sensors are designed to detect the presence of specific chemical substances which may have inadvertently leaked from their containers into spaces that are occupied by personnel and are useful in controlling industrial process conditions.

Gas sensors:

Related to chemical sensors, gas sensors are tuned to detect the presence of combustible, toxic, or flammable gas in the vicinity of the sensor. Examples of specific gases that can be detected include:

- Bromine (Br_2)
- Carbon Monoxide (CO)
- Chlorine (Cl_2)
- Chlorine Dioxide (ClO_2)
- Ethylene (C_2H_4)
- Ethylene Oxide (C_2H_4O)
- Formaldehyde (HCHO)
- Hydrazine(s):
- (H_2NNH_2, CH_3NHNH_2, $[CH_3]_2NNH_2$)
- Hydrogen (H_2)
- Hydrogen Bromide (HBr)
- Hydrogen Chloride HCl)
- Hydrogen Cyanide (HCN)
- Hydrogen Peroxide (H_2O_2)
- Hydrogen Sulfide (H_2S)
- Nitric Oxide (NO)
- Nitrogen Dioxide (NO_2)
- Ozone (O_3)
- Peracetic Acid ($C_2H_4O_3$)
- Propylene Oxide (C_3H_6O)
- Sulfur Dioxide (SO_2)

Smoke sensors:

Smoke sensors or detectors pick up the presence of smoke conditions which could be an indication of a fire typically using optical sensors (photoelectric detection) or ionization detection.

Infrared (IR) sensors:

Infrared sensor technologies detect infrared radiation that is emitted by objects. Non-contact thermometers make use of these types of sensors as a way of measuring the temperature of an object without having to directly place a probe or sensor on that object. They find use in analyzing the heat signature of electronics and detecting blood flow or blood pressure in patients.

Acceleration sensors:

While motion sensors detect movement of an object, acceleration sensors, or accelerometers as they are also known, detect the rate of change of velocity of an object. This change may be due to a free-fall condition, a sudden vibration that is causing movement with speed changes, or rotational motion (a directional change). One of several technologies that are employed in acceleration sensors include:

- Hall-effect sensors (which rely on measuring changes in magnetic fields)
- Capacitive sensors (which depend on measuring changes in voltage from two surfaces)
- Piezoelectric sensors (which generate a voltage that changes based on pressure from distortion of the sensor)

Gyroscopic sensors:

Gyroscopes or gyroscopic sensors are used to measure the rotation of an object and determine the rate of its movement called the angular velocity, using a 3-axis system. These sensors enable the determination of the object’s orientation without having to visibly observe it.

Humidity sensors:

Humidity sensors can detect the relative humidity of the air or other gas, which is a measure of the amount of water vapor contained in that gas. Controlling environmental conditions is critical in the production processes of materials and humidity sensors enable readings to be taken and changes made to mitigate increasing or decreasing levels. A common application is in HVAC systems to maintain desired comfort levels.

Optical sensors:

Optical sensors respond to light that is reflected off of an object and generate a corresponding electrical signal for use in detecting or measuring a condition. These sensors work by either sensing the interruption of a beam of light or its reflection caused by the presence of the object. The types of optical sensors include:

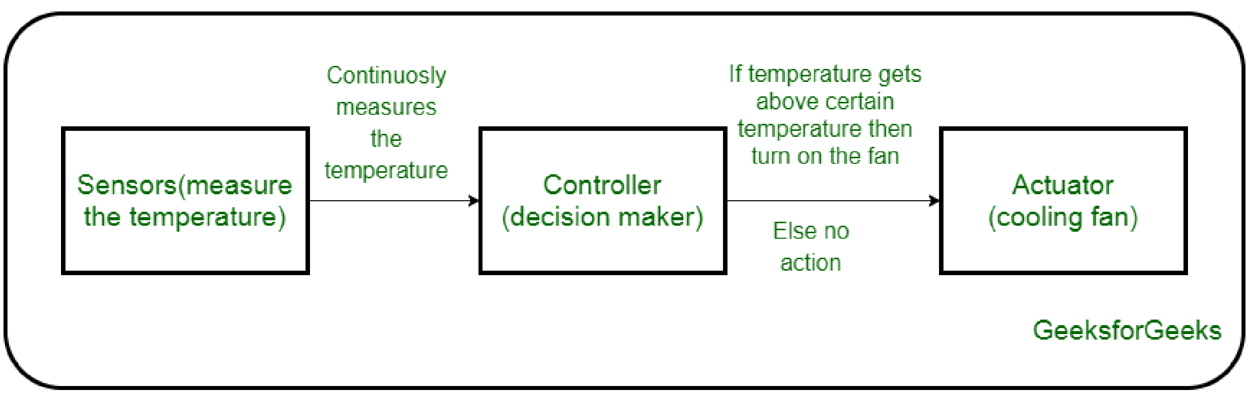
- Through-beam sensors (which detect objects by the interruption of a light beam as the object crosses the path between a transmitter and remote receiver)
- Retro-reflective sensors (which combine transmitter and receiver into a single unit and use a separate reflective surface to bounce the light back to the device)
- Diffuse reflection sensors (which operate similarly to retro-reflective sensors except that the object being detected serves as the reflective surface)

3.3 Introduction to Actuators

An IoT device is made up of a Physical object ("thing") + Controller ("brain") + Sensors + Actuators + Networks (Internet). An actuator is a machine component or system that moves or controls the mechanism of the system. Sensors in the device sense the environment, then control signals are generated for the actuators according to the actions needed to perform.

A servo motor is an example of an actuator. They are linear or rotatory actuators, can move to a given specified angular or linear position. We can use servo motors for IoT applications and make the motor rotate to 90 degrees, 180 degrees, etc., as per our need.

The following diagram shows what actuators do, the controller directs the actuator based on the sensor data to do the work.



The control system acts upon an environment through the actuator. It requires a source of energy and a control signal. When it receives a control signal, it converts the source of energy to a mechanical operation. On this basis, on which form of energy it uses, it has different types given below.

3.4 Types of Actuators

Types of Actuators :

1. Hydraulic Actuators –

A hydraulic actuator uses hydraulic power to perform a mechanical operation. They are actuated by a cylinder or fluid motor. The mechanical motion is converted to rotary, linear, or oscillatory motion, according to the need of the IoT device. Ex- construction equipment uses hydraulic actuators because hydraulic actuators can generate a large amount of force.

Advantages :

- Hydraulic actuators can produce a large magnitude of force and high speed.
- Used in welding, clamping, etc.
- Used for lowering or raising the vehicles in car transport carriers.

Disadvantages :

- Hydraulic fluid leaks can cause efficiency loss and issues of cleaning.
- It is expensive.
- It requires noise reduction equipment, heat exchangers, and high maintenance systems.

2. Pneumatic Actuators –

A pneumatic actuator uses energy formed by vacuum or compressed air at high pressure to convert into either linear or rotary motion. Example- Used in robotics, use sensors that work like human fingers by using compressed air.

Advantages :

- They are a low-cost option and are used at extreme temperatures where using air is a safer option than chemicals.
- They need low maintenance, are durable, and have a long operational life.
- It is very quick in starting and stopping the motion.

Disadvantages :

- Loss of pressure can make it less efficient.
- The air compressor should be running continuously.
- Air can be polluted, and it needs maintenance.

3. Electrical Actuators –

An electric actuator uses electrical energy, is usually actuated by a motor that converts electrical energy into mechanical torque. An example of an electric actuator is a solenoid based electric bell.

Advantages :

- It has many applications in various industries as it can automate industrial valves.
- It produces less noise and is safe to use since there are no fluid leakages.
- It can be re-programmed and it provides the highest control precision positioning.

Disadvantages :

- It is expensive.

- It depends a lot on environmental conditions.

Other actuators are –

- **Thermal/Magnetic Actuators–**

  These are actuated by thermal or mechanical energy. Shape Memory Alloys (SMAs) or Magnetic Shape-Memory Alloys (MSMAs) are used by these actuators. An example of a thermal/magnetic actuator can be a piezo motor using SMA.

- **Mechanical Actuators –**

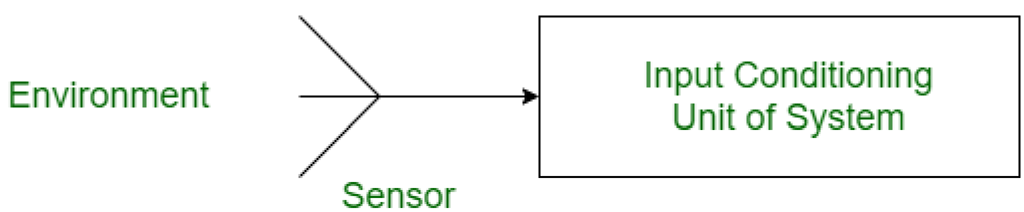
A mechanical actuator executes movement by converting rotary motion into linear motion. It involves pulleys, chains, gears, rails, and other devices to operate. Example – A crankshaft.

- Soft Actuators
- Shape Memory Polymers
- Light Activated Polymers
- With the expanding world of IoT, sensors and actuators will find more usage in commercial and domestic applications along with the pre-existing use in industry.

3.5 Difference between Sensors & Actuators

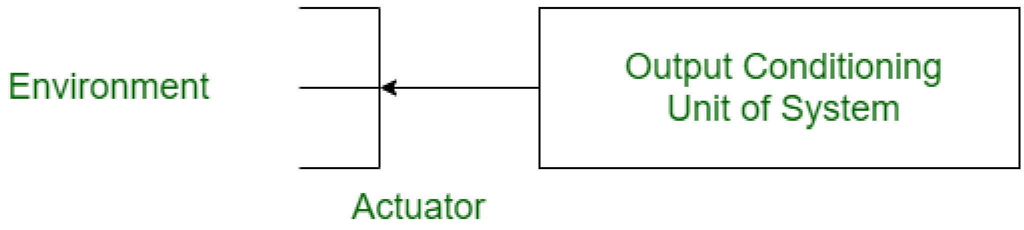
1. **Sensor:**

   Sensor is a device used for the conversion of physical events or characteristics into the electrical signals. This is a hardware device that takes the input from environment and gives to the system by converting it. For example, a thermometer takes the temperature as physical characteristic and then converts it into electrical signals for the system.



2. **Actuator:**

Actuator is a device that converts the electrical signals into the physical events or characteristics. It takes the input from the system and gives output to the environment.
For example, motors and heaters are some of the commonly used actuators.



Difference between Sensor and Actuator :

SENSOR	ACTUATOR
It converts physical characteristics into electrical signals.	It converts electrical signals into physical characteristics.
It takes input from environment.	It takes input from output conditioning unit of system.
It gives output to input conditioning unit of system.	It gives output to environment.
Sensor generated electrical signals.	Actuator generates heat or motion.
It is placed at input port of the system.	It is placed at output port of the system.
It is used to measure the physical quantity.	It is used to measure the continuous and discrete process parameters.
It gives information to the system about environment.	It accepts command to perform a function.
Example: Photo-voltaic cell which converts light energy into electrical energy.	Example: Stepper motor where electrical energy drives the motor.