UNIT 2
Sensing and Actuation

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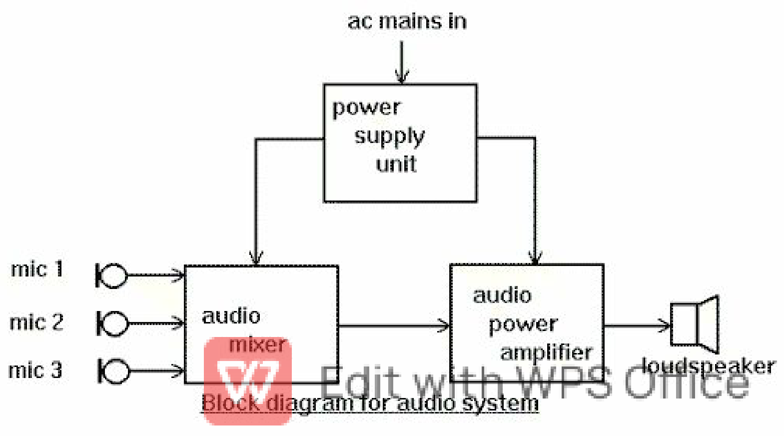
Objectives

- List the salient features of transducers
- Differentiate between sensors and actuators
- Characterize sensors and distinguish between types of sensors
- List the multi-faceted considerations associated with sensing
- Characterize actuators and distinguish between types of actuators
- List the multi-faceted considerations associated with actuation

Introduction

- Sensing forms the first step and actuation forms the final step of any IoT Application
- Sensors and actuators are transducers.
- Transducers take energy in any form (for which it is designed)electrical, mechanical, chemical, light, sound, and others—and convert it into another, which may be electrical, mechanical, chemical, light, sound, and others.
- Example : audio system



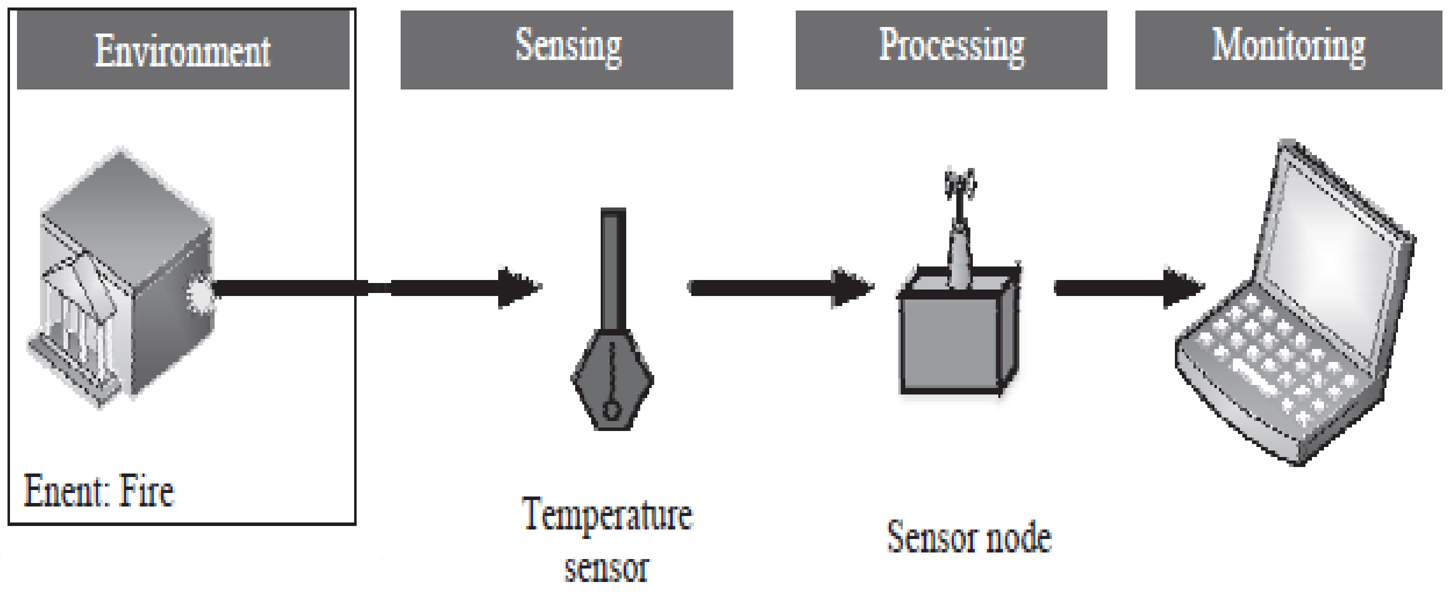
Difference between Transducer , Sensor and Actuator

Parameters	Transducers	Sensors	Actuators
Definition	Converts energy from one form to another.	Converts various forms of energy into electrical signals.	Converts electrical signals into various forms of energy, typically mechanical energy.
Domain	Can be used to represent a sensor as well as an actuator.	It is an input transducer.	It is an output transducer.
Function	Can work as a sensor or an actuator but not simultaneously.	Used for quantifying environmental stimuli into signals.	Used for converting signals into proportional mechanical or electrical outputs.
Examples	Any sensor or actuator	Humidity sensors, Temperature sensors, Anemometers (measures flow velocity), Manometers (measures fluid pressure), Accelerometers (measures the acceleration of a body), Gas sensors (measures concentration of specific gas or gases), and others	Motors (convert electrical energy to rotary motion), Force heads (which impose a force), Pumps (which convert rotary motion of shafts into either a pressure or a fluid velocity).

Sensors

- Sensors are devices that can measure, or quantify, or respond to the ambient changes in their environment or within the intended zone of their deployment.
- Sensor is only sensitive to the measured property. For each physical parameter most of the times different sensors are required. (e.g., a temperature sensor only senses the ambient temperature of a room).
- It is insensitive to any other property besides what it is designed to detect (e.g., a temperature sensor does not bother about light or pressure while sensing the temperature).
- Sensor does not influence the measured property (e.g., measuring the temperature does not reduce or increase the temperature).

Simple sensing system to monitor fire



Classification of Sensors

- Sensors can be classified based on:
  - ❉power requirements
  - ❉Sensor output
  - ❉property to be measured.
- **Classification Based on power requirement**
  - ✓**Active sensors**
    - ➤ do not require an external circuitry or mechanism to provide it with power.
    - ➤ It directly responds to the external stimuli from its ambient environment and converts it into an output signal.
    - ➤ Example- photodiode converts light into electrical impulses.
  - ✓**Passive sensors**
    - ➤ require an external mechanism to power them up.
    - ➤ The sensed properties are modulated with the sensor's inherent characteristics to generate patterns in the output of the sensor.
    - ➤ Example- thermistor's resistance can be detected by applying voltage difference across it or passing a current through it.

Classification of Sensors

Classification Based on Sensor Output

- **Analog sensors**
  - ✓generate an output signal or voltage, which is proportional (linearly or non-linearly) to the quantity being measured and is continuous in time and amplitude.
  - ✓Physical quantities such as temperature, speed, pressure, displacement, strain, and others are all continuous and categorized as analog quantities.
  - ✓Example, a thermometer or a thermocouple can be used for measuring the temperature of a liquid (e.g. , in household water heaters). These sensors continuously respond to changes in the temperature of the liquid.
  - ✓Output of sensors cannot be fed to embedded devices (IoT Nodes) directly. It has to be given through ADC
- **Digital sensors**
  - ✓generate the output of discrete time digital representation (time, or amplitude, or both) of a quantity being measured, in the form of output signals or voltages. Typically, binary output signals in the form of a logic **1** or a logic **0** for **ON** or **OFF**, respectively are associated with digital sensors.
  - ✓The generated discrete (non-continuous) values may be output as a single "bit" (serial transmission), eight of which combine to produce a single "byte" output (parallel transmission) in digital sensors
  - ✓**Example: motion sensors**
  - ✓Output of sensors can be fed to embedded devices (IoT Nodes) directly

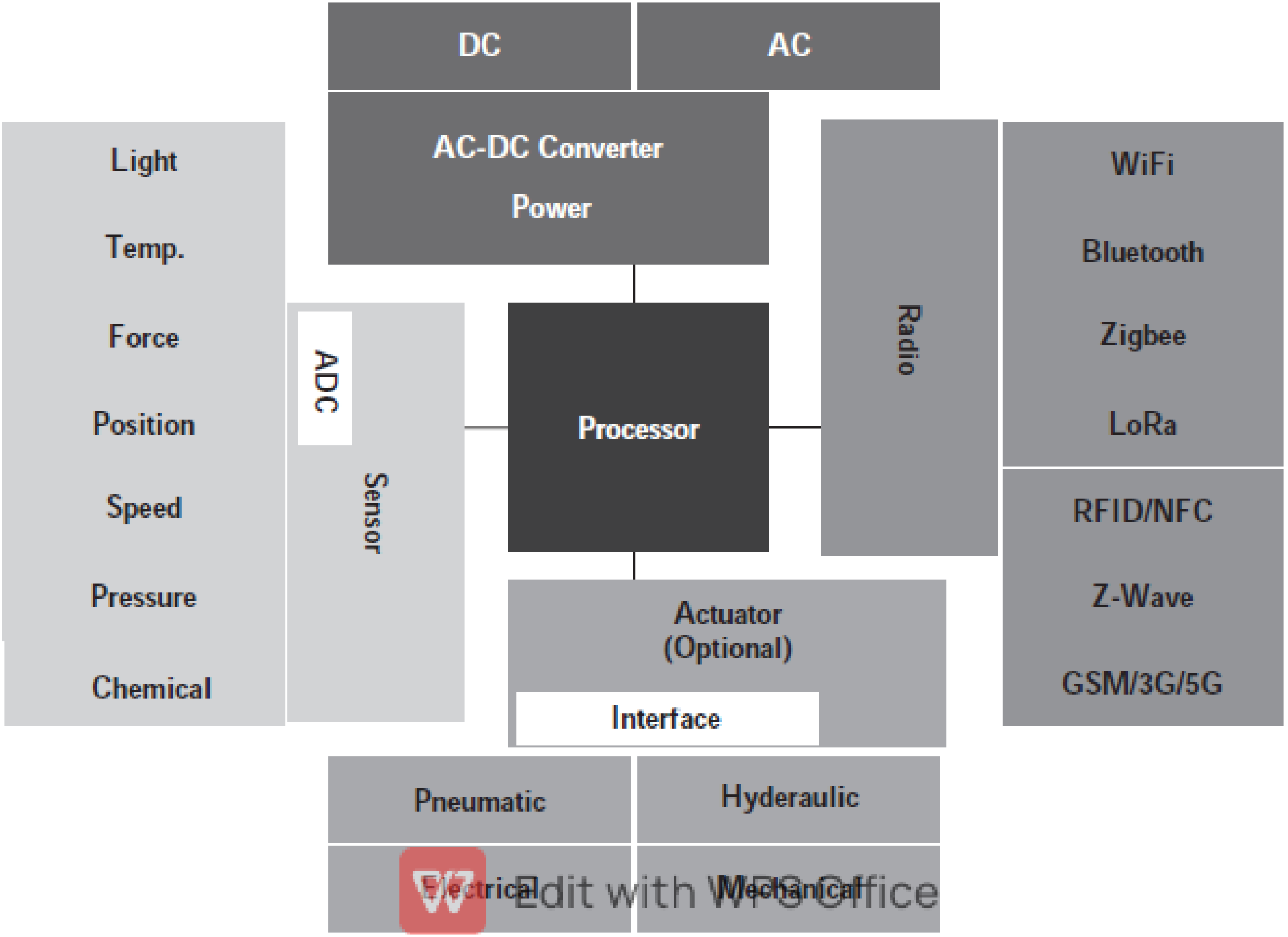
Classification of Sensors

- Classification Based on Measured Property
- **Scalar sensors**
  - ✓ Produce an output proportional to the magnitude of the quantity being measured. The output is in the form of a signal or voltage.
  - ✓ Scalar physical quantities are those where only the magnitude of the signal is sufficient for describing or characterizing the phenomenon and information generation.
  - ✓ Examples - color, pressure, temperature, strain, and others.
  - ✓ A thermometer or thermocouple is an example of a scalar sensor that has the ability to detect changes in ambient or object temperatures (depending on the sensor's configuration).
  - ✓ Factors such as changes in sensor orientation or direction do not affect these sensors (typically).

Classification of Sensors

- **Vector sensors**
  - ✓These sensors are affected by the magnitude as well as the direction and/or orientation of the property they are measuring.
  - ✓ Physical quantities such as velocity and images that require additional information besides their magnitude for completely categorizing a physical phenomenon are categorized as vector quantities.
  - ✓Example- electronic gyroscope, which is commonly found in all modern aircraft, is used for detecting the changes in orientation of the gyroscope with respect to the Earth's orientation along all three axes.

Functional Blocks of a Typical Sensor Node in IoT



Sensor Node

- A sensor node is a combination of sensor/sensors, a processor unit, a radio unit, and a power unit.
- The nodes are capable of sensing the environment they are set to measure and communicate the information to other sensor nodes or a remote server.
- Typically, a sensor node should have low-power requirements and be wireless. This enables them to be deployed in a vast range of scenarios and environments without the constant need for changing their power sources or managing wires.
- The wireless nature of sensor nodes would also allow them to be freely relocatable and deployed in large numbers without bothering about managing wires.

Common Commercially Available Sensors Used for IoT-based Sensing Applications

Sensor Characteristics

- **Sensor Resolution:**
  - ✓The smallest change in the measurable quantity that a sensor can detect is referred to as the resolution of a sensor.
  - ✓For digital sensors, the smallest change in the digital output that the sensor is capable of quantifying is its sensor resolution.
  - ✓The more the resolution of a sensor, the more accurate is the precision.
  - ✓ A sensor's accuracy does not depend upon its resolution. For example, a temperature sensor **A** can detect up to 0:5 C changes in temperature; whereas another sensor **B** can detect up to 0:25 C changes in temperature. Therefore, the resolution of sensor **B** is higher than the resolution of sensor **A**.
- **Sensor Accuracy:**
  - ✓ The accuracy of a sensor is the ability of that sensor to measure the environment of a system as close to its true measure as possible.
  - ✓Example- a weight sensor detects the weight of a 100 kg mass as 99.98 kg. We can say that this sensor is 99:98% accurate, with an error rate of 0:02%.

Sensor Characteristics

- **Sensor Precision**:
- The principle of repeatability governs the precision of a sensor.
- Only if, upon multiple repetitions, the sensor is found to have the same error rate, can it be deemed as highly precise. For example, consider if the same weight sensor described earlier reports measurements of 98.28 kg, 100.34 kg, and 101.11 kg upon three repeat measurements for a mass of actual weight of 100 kg.
- The sensor precision is not deemed high if significant variations in the temporal measurements for the same object under the same conditions
- Conclusion: The more the resolution of a sensor, the more accurate is the precision. A sensor's accuracy does not depend upon its resolution.

Sensorial Deviations

Most of the sensing in IoT is non-critical, where minor deviations in sensorial outputs seldom change the nature of the undertaken tasks. However, some critical applications of IoT, such as healthcare, industrial process monitoring, and others, do require sensors with high-quality measurement capabilities

- Sensitivity Error
  - ✓ If the sensor's output signal goes beyond its designed maximum or minimum capacity for measurement, the sensor output is truncated to its maximum or minimum value, which is known as sensor's limits
  - ✓ The measurement range between a sensor's characterized minimum and maximum values is also referred to as the full scale range of that sensor.
  - ✓ Under real conditions, the sensitivity of a sensor may differ from the value specified for that sensor leading to sensitivity error.
  - ✓ This error is due to sensor fabrication errors and its calibration.

Sensorial Deviations

- offset error or bias
  - ✓ If the output of a sensor differs from the actual value to be measured by a constant, the sensor is said to have an offset error or bias.
  - ✓ For example, while measuring an actual temperature of 0 C, a temperature sensor outputs 1.1 C every time. In this case, the sensor is said to have an offset error or bias of 1.1 C.
- Drift
  - ✓ Most sensors have linear behavior.
  - ✓ If the output signal of a sensor changes slowly and independently of the measured property, this behavior of the sensor's output is termed as drift.
  - ✓ Physical changes in the sensor or its material may result in long-term drift, which can span over months or years

Sensorial Deviations

- Hysteresis Error
  - if a sensor's output varies/deviates due to deviations in the sensor's previous input values, it is referred to as hysteresis error.
  - If the present output of the sensor depends on the past input values provided to the sensor. Hysteresis error are more likely to occur
  - Typically, the phenomenon of hysteresis can be observed in analog sensors, magnetic sensors, and during heating of metal strips.
  - One way to check for hysteresis error is to check how the sensor's output changes when we first increase, then decrease the input values to the sensor over its full range. It is generally denoted as a positive and negative percentage variation of the full-range of that sensor.

Sensorial Deviations

- Quantization Error.
  - ✓In digital sensors, if the digital output of a sensor is an approximation of the measured property, it induces quantization error.
  - ✓This error can be defined as the difference between the actual analog signal and its closest digital approximation during the sampling stage of the analog to digital conversion.
- Aliasing Error
  - ✓Dynamic errors caused due to mishandling of sampling frequencies can give rise to aliasing errors.
  - ✓Aliasing leads to different signals of varying frequencies to be represented as a single signal in case the sampling frequency is not correctly chosen, resulting in the input signal becoming a multiple of the sampling rate

Sensorial Deviations

- Environment itself plays a crucial role in inducing sensorial deviations.
- Some sensors may be prone to external influences, which may not be directly linked to the property being measured by the sensor. This sensitivity of the sensor may lead to deviations in its output values.
- For example, as most sensors are semiconductor based, they are influenced by the temperature of their environment.

Sensing Types in IoT

Four types of Sensing commonly seen in IOT are

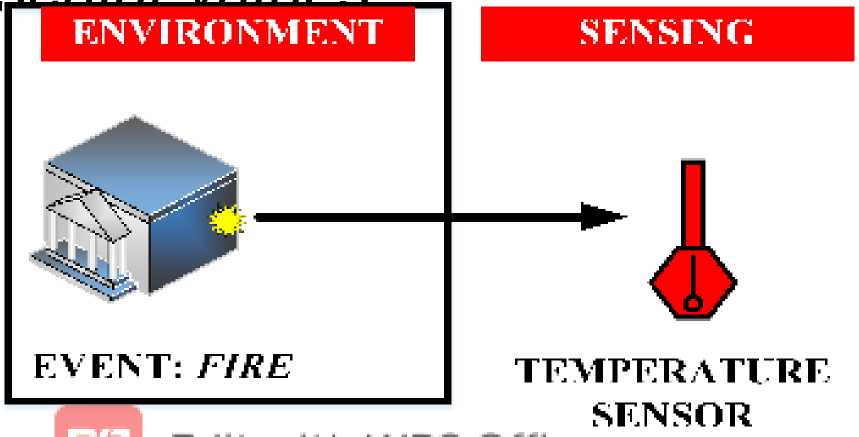
1. Scalar Sensing
2. Multimedia Sensing
3. Hybrid Sensing
4. Virtual Sensing

Sensing Types in IoT

1. Scalar *Sensing*

✓*Sensing of features that can be quantified simply by measuring changes in the amplitude of the measured values with respect to time .*

✓*Quantities such as ambient temperature, current, atmospheric pressure, rainfall, light, humidity, flux, and others are considered as scalar values*



Sensing Types in IoT

2. Multimedia sensing

- Senses features that have a spatial variance property associated with the property of temporal variance ' Multimedia sensors are used for capturing the changes in amplitude of a quantifiable property concerning space (spatial) as well as time (temporal).
- Quantities such as images, direction, flow, speed, acceleration, sound, force, mass, energy, and momentum have both directions as well as a magnitude.
- vector sensors which have different values in different directions for the same working condition at the same time.

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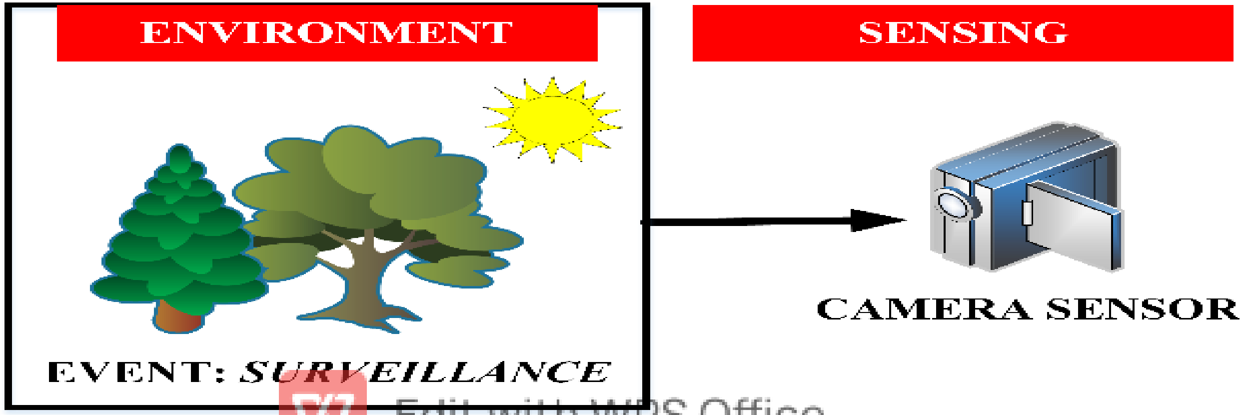
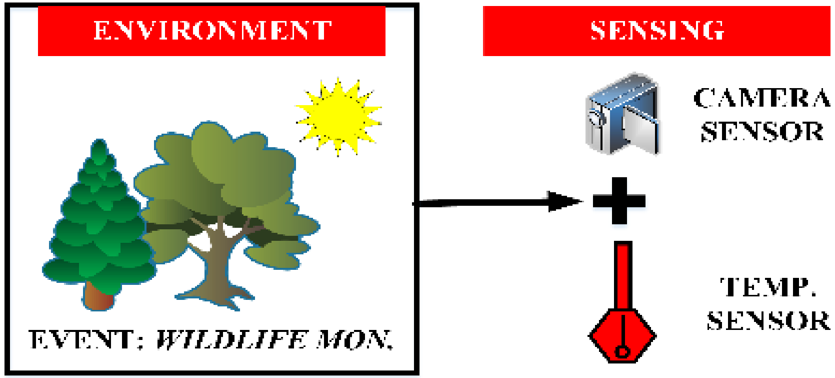


Sensing Types in IoT

3. Hybrid Sensing

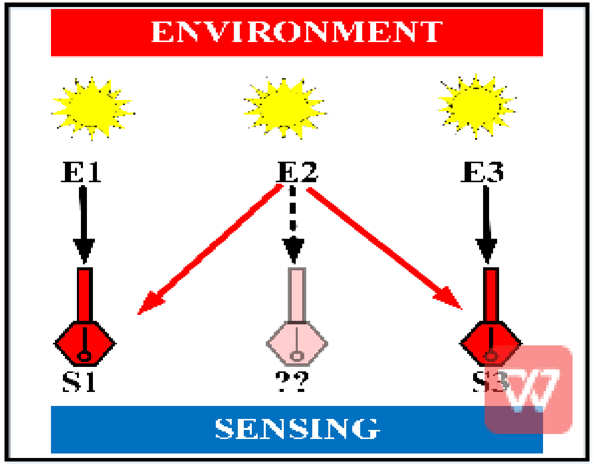
- The act of using scalar as well as multimedia sensing at the same time is referred to as hybrid sensing.
- Many a time, there is a need to measure certain vector as well as scalar properties of an environment at the same time. Under these conditions, a range of various sensors are employed (from the collection of scalar as well as multimedia sensors) to measure the various properties of that environment at any instant of time, and temporally map the collected information to generate new information.
- example, agricultural field
  - ✓ soil moisture and soil temperature are deployed underground to estimate the soil's water retention capacity and the moisture being held by the soil at any instant of time.
  - ✓ camera sensor with the plant may be able to determine the actual condition of a plant by additionally determining the color of leaves. .



Sensing Types in IoT

4. Virtual Sensing

- ✓if the data from **A**’s field is digitized using an IoT infrastructure and this system advises him regarding the appropriate watering, fertilizer, and pesticide regimen for his crops, this advisory can also be used by **B** for maintaining his crops. In short, **A** ’s sensors are being used for actual measurement of parameters; whereas virtual data (which does not have actual physical sensors but uses extrapolation-based measurements) is being used for advising **B**.



Two temperature sensors S1 and S3 monitor three nearby events E1, E2, and E3 (fires). The event E2 does not have a dedicated sensor for monitoring it; however, through the
superposition of readings from sensors S1 and S3, the presence of fire in E2 is inferred

Sensing Considerations: Sensing Range

- The sensing range of a sensor node defines the detection fidelity of that node.
- Typical approaches to optimize the sensing range in deployments include fixed k-coverage and dynamic k-coverage.
- A lifelong fixed k-coverage tends to usher-in redundancy as it requires a large number of sensor nodes, the sensing range of some of which may also overlap.
- In contrast, dynamic k-coverage incorporates mobile sensor nodes post detection of an event, which, however, is a costly solution and may not be deployable in all operational areas and terrains.
- The sensing range of a sensor may also be used to signify the upper and lower bounds of a sensor's measurement range.
- For example, a proximity sensor has a typical sensing range of a couple of meters. In contrast, a camera has a sensing range varying between tens of meters to hundreds of meters.
- **As the complexity of the sensor and its sensing range goes up, its cost significantly increases. So range must be selected based on the need in the application**

Sensing Considerations: Accuracy and Precision

- The accuracy and precision of measurements provided by a sensor are critical in deciding the operations of specific functional processes.
- Typically, off-the-shelf consumer sensors are low on requirements and often very cheap. However, their performance is limited to regular application domains.
- For example, a standard temperature sensor can be easily integrated with conventional components for hobby projects and day-to-day applications, but it is not suitable for industrial processes.
- Regular temperature sensors have a very low-temperature sensing range, as well as relatively low accuracy and precision.
- The use of these sensors in industrial applications, where the precision of up to 3-4 decimal places is required, cannot be facilitated by these sensors. Industrial sensors are typically very sophisticated, and as a result, very costly. However, these industrial sensors have very high accuracy and precision score, even under harsh operating conditions

Sensing Considerations: Energy

- The energy consumed by a sensing solution is crucial to determine the lifetime of that solution and the estimated cost of its deployment.
- If a sensor or the sensor node is so energy inefficient, that it requires replenishment of its energy sources quite frequently, the effort in maintaining the solution and its cost goes up, whereas its deployment feasibility goes down.
- Example : if sensor nodes are deployed on the top of glaciers.

Sensing Considerations: Device Size

- Modern-day IoT applications have a wide penetration in all domains of life. Most of the applications of IoT require sensing solutions, which are so small that they do not hinder any of the regular activities that were possible before the sensor node deployment was carried out.
- Larger the size of a sensor node, larger is the obstruction caused by it, higher is the cost and energy requirements, and lesser is its demand for the bulk of the IoT applications.
- Ex: human activity detector. If the detection unit is too large to be carried or too bulky to cause hindrance to regular normal movements, the demand for this solution would be feeble.
- Ex: The wearable sensors are highly energy-efficient, small in size, and almost part of the wearer's regular wardrobe.