Module - 2

IoT Sensing and Actuation - Introduction

- Sensors
- Sensor characteristics
- Sensorial Deviations
- Sensing Types
- Sensing considerations
- Actuators
- Actuator types
- Actuator characteristics

Introduction :-

Almost all applications of IOT - be it industrial, consumer or control & monitoring, sensing is the first step and Actuation forms the last step in whole operation of IOT applicati-on deployment.

The basic science of sensing and Actuation is based on process of Transduction. Transducers are the devices which enable Transduction process of energy conversion from one from to another.

A Transducer takes energy from one form and converts it to another from like electrical, Mechanical, chemical, light, soud and others.

Ex:- A Microphone converts Sound waves into electrical signals and a loud speaker converts electrical signal back to Sound waves.

The basic terminological differences between Transducers, sensors and actuators can be outlined as shown.

Transducers	Sensors	Actuators
→ Converts Energy from one form to another	converts various forms of energy into Electrical signals	Converts electrical signals into various forms of energy
→ can be used to represent a sensor as well as an actuator	It is an input Transducers	It is an out put Transducer

can work as a sensor or an actuator but not simultaneously	used for quantifying environmental signals into electrical signals	used for converting electrical signals into mechanical & electrical o/p.
Ex:- Any sensor or Actuator	Temp, Humidity, pressure sensors.	Motors, Force leads.

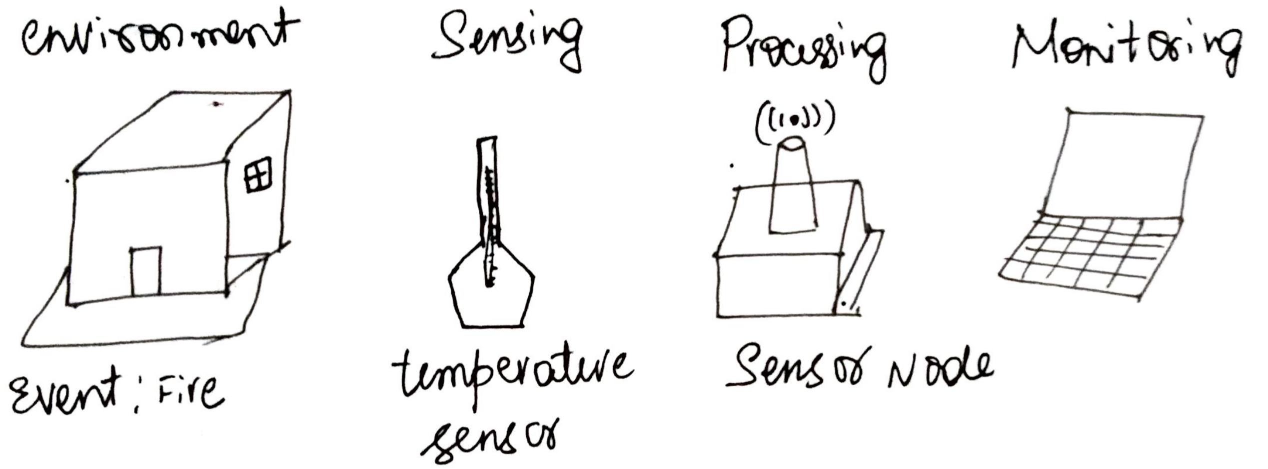
Sensors :-

Sensors are the devices that can measure, or quantify or respond to ambient changes in their environment or within zone of their deployment. They can generate responses to external stimuli through characterization of input functions and their conversion into typically electrical signals.

Ex:- Temperature sensor converts heat into electrical signals.

A sensor is only sensitive to measured property and does not influence the measured property for example a temperature sensor is sensitive to only temperature and insensitive to any other property in that environment and measuring temperature does not reduce or increase temperature.

The sensing task in IOT is as discussed below. A sensor keeps on checking changes in environment and these changes are communicated to remote monitor via processor.



Classification of sensors :- The various sensors can be classified based on 1) Power Requirements 2) Sensor output and 3) Property to be measured.

Power Requirements :- Some sensors need to be provided with separate power sources for them to function whereas some sensors do not require any power sources. Depending on power requirements sensors can be two types - Active and Passive.

Active Sensors :- These sensors do not require external power circuitary. It directly responds to external stimuli and converts it into electrical signals

Ex :- photo diode - Converts light into electrical signals

Passive Sensors :- These sensors require external mechanism to power them up. Sensed properties are modulated with sensor's inherent characteristics to generate o/p

ex :- Thermistors - change in resistance due to temperature is detected by applying voltage difference across it or passing current through it.

Sensor Output :- Sensors are broadly classified as Analog and digital sensors based on the type of output generated.

Analog sensors :- These sensors generate the output voltage or signal proportional to input quantity being measured and is continous in time and amplitude.

Ex :- Temperature, pressure, displacement, strain sensors converts these continous analog quantities into electrical signals.

To integrate these analog sensors to digital processors to IoT node additional interfacing mechanisms such as analog to digital (ADC) converters, voltage level converters are required.

Digital Sensors :- These sensors generate the O/P of discrete time digital representation of quantity being measured in the form of O/P signals or voltages.

Ex :- binary O/P signals logic 1/0 (ON/OFF) values are associated with these sensors as bits or bytes.

Almost all modern day sensors are digital and can be interfaced directly to digital processors.

Measured Property :- The property of environment being measured decides the number of sensors in IoT. Some properties to be measured do not show spatial variation and can be quantified only based on temporal variations such as temperature, pressure. Some properties to be measured show high spatial as well as temporal variations such as sound, image.

Based on properties measured sensors can be classified into Scalar and Vector.

Scalar sensors :- These sensors produces o/p proportional only to magnitude of quantity being measured.

Ex :- Temperature, pressure, strain.

factors such as changes in sensor orientation or direction do not affect the quantity being measured.

Vector sensors :- Physical quantities such as velocity, image requires additional information besides their magnitude for completely categorizing them. Sensor used to measure such vector quantities are Vector sensors and their orientation / direction affect the quantity being measured.

Ex :- Gyroscope is used in aircraft for detecting orientation of itself with respect to Earth's orientation along all three axes.

Examples of Sensors - camera, color sensor, current sensor, temperature, humidity, flame, gas sensor, Infrared sensor, Rainfall sensor, ultrasonic distance sensor.

Sensor classification

Power Requirements
1) Active
2) Passive

Output
1) Analog
2) Digital

Measured Property
1) Scalar
2) Vector

Sensor Characteristics:- Sensors can be categorised by their ability to sense phenomenon based on following 3 fundamental properties.

Resolution:- The smallest change in the measurable quantity that a sensor can detect is reffered as Resolution of a sensor. The more the resolution, the more accurate is its precision.

Ex:- If a sensor 'A' can detect up to 0.5'c changes in temperature and 'B' can detect up to 0.25'c changes in temperature then Resolution of Sensor B is higher than that of A.

Scale A   Scale B

Scale 'B' is having high resolution than Scale 'A'.

Accuracy :- It is the ability of a sensor to measure the parameter as close as to its true value.

Ex:- If a weight sensor detects weight of 100 Kg mass as 99.98 Kg, then we can say that this sensor is 99.98 % accurate with an error rate of ± 0.02 %.

Precision :- The principle of repeatability governs the precision of a sensor. Upon multi-ple repetitions if sensor is found to have the same errorrate it can be deemed as highly precise.

Ex:- If a weight sensor reports measurements of 98.28 Kg, 100.34 Kg and 101.11 Kg upon 3 repeat measurements for a mass of actual weight of 100 Kg then sensor is not precise because of significant variations in temporal measurements for same object under same condition.

Sensorial Deviations :-

Deviations in sensorial output affect the nature of undertaken tasks in IoT applications. However in critical applications of IoT such as healthcare and industrial process monitoring these deviations are not accepted and requires high quality measurement capabilities. As the quality of measurement depends on large number of factors and leads to errors. Some of such factors are discussed below.

Under real conditions sensitivity of a sensor differ from specified value and leads to sensitivity error. This deviation is attributed to sensor fabrication errors and its calibration.

$$\text{Sensitivity} = \frac{\text{change in O/P}}{\text{change in I/P}}$$

If the sensor's output differs from the actual value to be measured by a constant then the sensor is said to have an offset error or bias.

This error occurs due to uncertainties from electronics and magnetic core retentivity.

Some sensors have a non-linear behaviour either due to its Transfer function(relation between input and output) or due to exteral effects. This changes the physical quantity measured. If the output of a sensor changes slowly and independently of a measured quantity, then the behaviour is termed as drift. Physical changes in sensor or its material may result in long term drift.

Noise is a temporally varying random deviation of signals.

If the sensor's o/p deviates due to sensor's previous input values. then it is reffered as Hysterisis error, which can be observed in analog sensors, magnetic sensors.

The o/p of an digital sensor is an approximation of measured property which induces Quantization error. The difference between actual analog signal and its closest digital approximation during sampling stage of analog to digital conversion leads to this error.

Dynamic error are caused due to mis handling of sampling frequencies which give rise to aliasing errors. Aliasing leads to input signal becoming a multiple of sampling rate when sampling frequency is not correctly chosen.

Finally environment plays a crucial role in inducing sensorial deviations.

Ex:- semi conductor based sensor are influenced by temperature of their environment.

Sensing Types :-

Sensing can be broadly divided into 4 categories based on Nature of environment being sensed and physical sensors used as 1> Scalar sensing 2> Multimedia sensing 3> Hybrid sensing

3) Hybrid sensing and 4) Virtual sensing.

Scalar Sensing:-

Sensing of the features that can be quantified by measuring changes in amplitude of measured value with respect to time such as temp, current, pressure, rainfall, light, humidity, flux etc which are scalar values and do not of directional or spatial properties assigned with them is called as Scalar sensing.

Ex:- Simple scalar temperature sensing for fire detection event.

Multimedia Sensing:-

Sensing of the features that have a spatial variance property associated with temporal variance i,e measuring amplitude along with direction such as images, speed, acceleration, sound, force, mass, energy ect which are vector quantities and have both direction ~~and~~ as well as magnitude with them

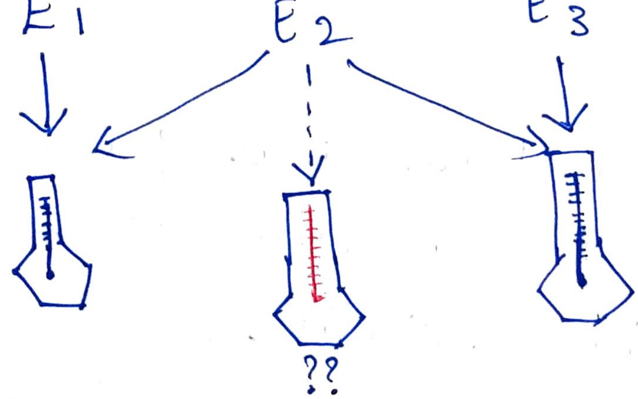
is called Multimedia sensing.
Ex:- camera based sensors for surveilla-nce.

Hybrid Sensing:- The act of using Scalar as well as multimedia sensing at same time is reffered as Hybrid sensing. Many times there is need to measure certain vector as well as scalar properties of an environment.

Ex:- In Agricultural field it is required to measure soil conditions at regular intervals of time to determine health of plant. Sensors such as soil moisture and soil temperature are deployed to estimate water retention capacity of soil at any inst-ant of time. However this determines only plants are getting water in sufficient quantity or not. But plant's health does not depend on only water, but also on other factors, to check plant's health a camera sensor can be used. Some other examples are parking system and traffic management systems.

Virtual Sensing:- In this cact of virtual sensing, actual sensors are used determine some parameters and these parameters are used for taking decisions/give advise for other environment near to this since very dense and large-scale deployment of sensor nodes over large area of monitoring is required.

Ex:- In agricultural field pameters like moisture & temp of soil does not show signifian spatial variations. Hence if sensors are deployed is farmer A's field, it is highly likely that measurements from his sensor will be able to provide almost consice measurements of his neighbor B's fields. This is true of fields which are immedi-ately surrounding A's fields. Exploiting this property if A's field is digitized using an IoT infrastructure and this is used for advising regarding watering, fertilizer and Pesticides, this advisory can be used by B for maintaing his crops. In short. A's sensors are being used for actual measurement of parameters whereas virtual data is being used for advising B. Similarly virtual sensing can be used in forest fire monitoring, environmental monitoring etc.



Sensing Considerations:-

The choice of sensors in an IOT sensor node is critical and following factors influence the choice sensors.

1) Sensing range:- Sensing range of a sensor node defines sensing fidelity of the node. Typical approaches to optimize sensing range in deployment include fixed coverage and dynamic coverage.

Fixed coverage for life long results in reduced area as it requires more number of sensor node and sensing range may overlap also.

Dynamic coverage incorporates mobile sensor nodes post detection of an event but implementation of such dynamicity is costly and may not be deployable in all operational areas.

Sensing range of a sensor may also be used to signify upper and lower bounds of a sensor's measurement range. Ex:- proximity sensor has typical sensing range of few meters whereas camera sensor has range varying from fewmeters to hundreds of meters.

As the complexity of sensor and sensing range increases the cost of sensor also increases significantly.

2) Accuracy and Precision :- These are the critical parameters that decide the usage of sensors in specific functional processes. Typically consumer sensors are low on requirements & often very cheap. However

their performance is limited to regular application domains.

Ex:- Regular temperature sensors have low temp sensing range, relatively low precision & accuracy. For industrial applications sensors with accuracy upto 3-4 decimal places is required and hence regular sensors cannot be used. Industrial sensors are typically very sophisticated and costly, however they have high accuracy and precision even under harsh operating conditions.

3) Energy:- The energy consumed by a sensing device is crucial in determining the lifetime of the deployment. If the sensor node is not energy efficient it requires replenishment of its energy sources quite frequently and cost of maintainance goes up, also deployment feasibility goes down. Some times accessing the nodes is not possible after deployment for ex forest area, top of glaciers etc., if energy requirements of sensors are

high, such deployment will not last long, and solution of deployment is highly infeasi-ble as charging and changing of energy sources are not an option.

Device Size :- Most of the IOT applications requires sensors which are so small that they do not hinder activities of the envir-onment. If the size of sensors are large, the obstruction caused by it, energy requirements and cost will go high and less is the demand for bulk devices in IOT applications. Hence wearable sensors took off strongly instead of bulky instruments, which are energy efficient, smaller in size.

Actuators

An Actuators can be considered as a machine or system's components that can affect the movement or control the said mechanism or system. The system activates the actuator through a control signal which may be digital or analog.

The commands to the system are given to sensor node through mechanical / electronic / software based system / human or any other input. The sensor node processes this information and converts it into sequential signals to control the tasks through actuators.

Ex:- Commands received are processed by processor and signals are generated to control the motor so that robotic arm connected to motor moves according to the requirement which enables the robot to do assigned task in a Automation system of a factory.

examples of Actuators - DC motor, stepper motor, Relay array, flow valve, Switch, push button switch

Actuator Types :- Broadly actuators are divided into 7 different classes as follows.

1) Hydraulic Actuators - These actuators works on the principle of compression and decompression of fluids. These actuators facilitate mechanical tasks such as lifting loads through the use of hydraulic power derived from fluids in cylinders or fluid motors. The mechanical ~~force~~ force applied to hydraulic actuator is converted to either linear, rotary or oscillatory system motion. The force exerted can be significant in such type of actuators because of incompressible property of liquids.

Ex:- Crane drives, wheel motors in military ~~vehi~~ vehicles, Hydraulic jack & brake, positioning of heavy loads.

2) Pneumatic Actuators - These actuators works on the principle of compression and decompression of gases. These actuators use

a compressed air at high pressure and convert it into either linear or rotary motion. These actuators have quick response and exerts large ~~pressure~~ force with small pressure changes.

Ex:- Pneumatic break, Pneumatic rack and pinion actuators are used for value control of water pipes.

3) Electric Actuators:-

Electric Actuators create motion of a load, or an action that requires a force like clamping by using electric motor. This class of actuators are cheap, clean and speedy compared to others.

Ex:- Solenoid valves control the flow of water in pipes in response to electrical signal.

4) Thermal or Magnetic Actuators:- These actuators use thermal or Magnetic energy. They are compact, lightweight, economical.

Ex:- Shaped Memory Materials (SMM) such

as Shaped Memory Alloy (SMA).

5) Mechanical Actuators —

Rotary motion of the actuator is converted into linear motion to execute some movement in these type of actuators. Gears, rails, pulleys, chains and other devices are used to operate these actuators. These actuators can be easily used conjunction with pneuma-tic, hydraulic, electrical actuators.

Ex:- Hydroelectric generator convert the water flow induced rotary motion of a turbine into electrical energy. Similarly mechanical switches uses mechanical motion of the switch to on or off an electric circuit.

6) Soft Actuators :- These actuators are polymer based actuators consists of elasto-meric polymers that are used as embedded fixtures in flexible materials such as cloth, paper, fiber, particles. The conversion of molecular level microscopic changes into

tangible macroscopic deformations. These actuators have high stake in modern day robotics. They are designed to handle fragile objects such as agricultural fruit harvesting or precise operations during robot assisted surgeries.

7) Shape Memory Polymers-

Shape Memory Polymers (SMP) are considered as smart materials that respond to some external stimulus by changing their shape, and then revert back to their original shape after the stimulus is removed. These polymers have features such as high strain recovery, biocompatibility, low density, biodegradability. Modern day SMPs have been designed to respond to wide range of stimuli such as PH changes, heat differentials, light intensity, frequency changes magnetic changes and others.

Ex:- Medical devices, Smart Medical implants.

Actuator Characteristics :-

Actuators perform the physically heavier tasks in an IoT deployment, tasks such as moving, changing the orientation of physical objects, changing the state of objects etc. The correct choice of actuators is necessary for long-term sustenance and continuity of operations as well as for increasing the lifetime of the actuators. The following charateristics are to be considered for selection of Actuators.

1) **Weight** - weight of actuators has to be considered while deciding its application in IoT deployment. For example heavier actuators are preferred for industrial applications with no mobility. Lightweight actuators find usage in drones, home IoT applications.

2) **Power Rating** - This helps in deciding nature of application with which an actuator

can be associated. Power rating defines the min & Max operating power an actuator can safely withstand without damage.

Ex:- Servo motors used for hobby projects have max rating of 5 V.DC, 500 mA which can be battery operated.

Servo motors in larger applications have a rating of 460 VAC, 2.5 A which requires standalone power supply systems for operation.

Torque to weight Ratio:- The ratio of torque to weight of moving part of device is referred as torque/weight ratio. This indicates sensitivity of actuator. Higher is weight lower will be the torque to weight ratio for a given power.

Stiffness and compliance:- The resistance of a material against deformation is known as Stiffness and its opposite nature is compliance. Stiff systems are more accurate than compliant systems for example hydraulic H/c are stiff & non compliant whereas pneumatic systems are compliant.

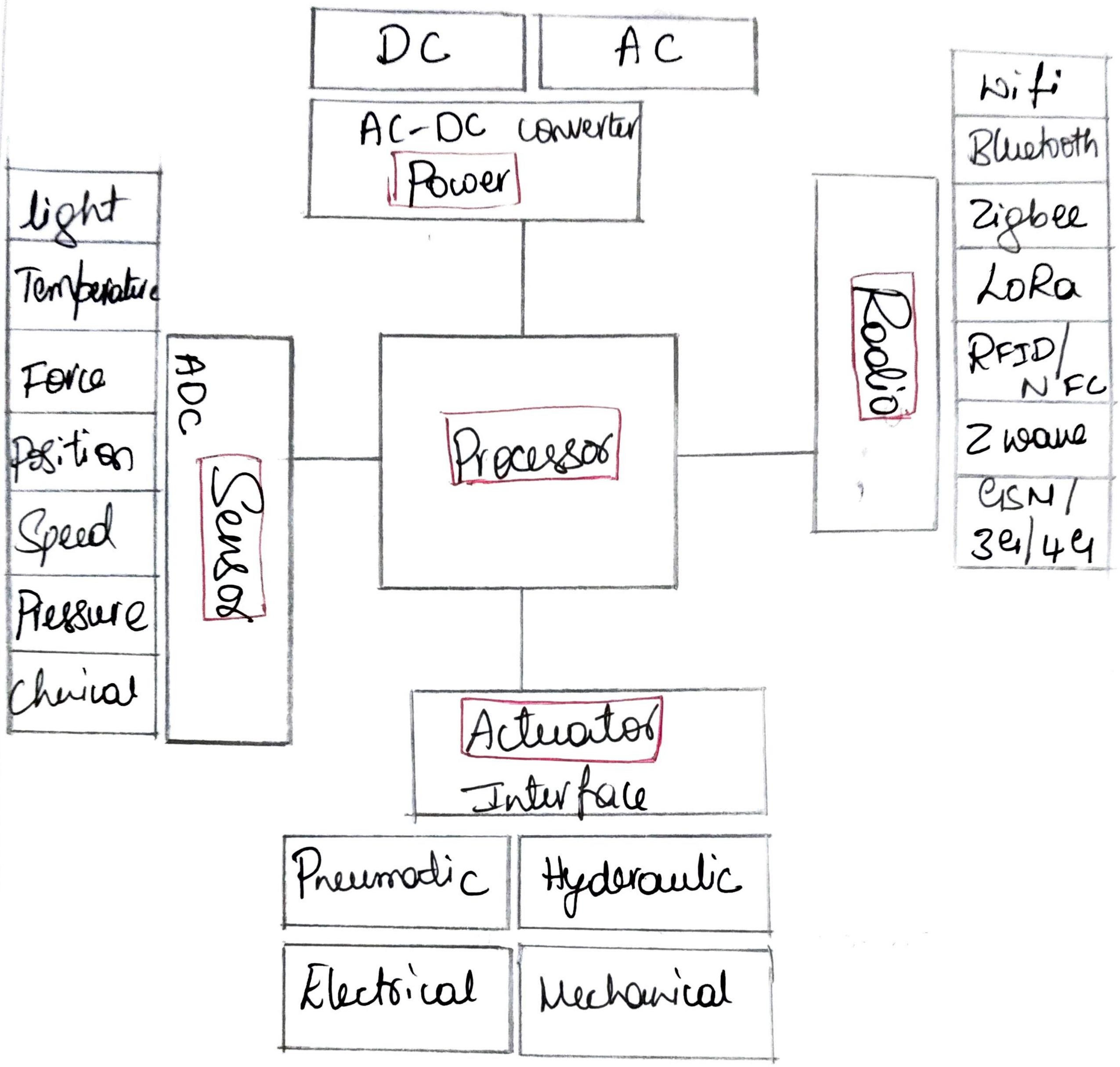
Functional blocks of Typical sensor node in IOT.

A Sensor node is madeup of a combination of sensor/ sensors, a processor unit, a radio unit and a power unit.

The nodes are capable of sensing the envirnoment they are set to measure and communicate the information to other sensor nodes or remote sensors.

Typically a sensor node should have low-power requirements so that they can be deployed in vast range of scenarios without the constant need for changing their power sources.

Sensor are also expected to be wireless so that they can be easily relocatable and deployed in large numbers without bothering about nagging wires. The functional outline of typical IOT sensor node is as shown.


DC
AC
AC-DC converter
Power
light
Temperature
Force
Position
Speed
Pressure
Chemical
ADC
Sensor
Processor
Radio
Wifi
Bluetooth
Zigbee
LoRa
RFID/NFC
Z wave
GSM/3G/4G
Actuator
Interface
Pneumatic
Hydraulic
Electrical
Mechanical