1. Introduction to IoT

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EVOLUTION OF IOT

- **ATM:** ATMs or automated teller machines are cash distribution machines, which are linked to a user's bank account. ATMs dispense cash upon verification of the identity of a user and their account through a specially coded card. The central concept behind ATMs was the availability of financial transactions even when banks were closed beyond their regular work hours. These ATMs were ubiquitous money dispensers. The first ATM became operational and connected online for the first time in 1974.
- **Web:** World Wide Web is a global information sharing and communication platform. The Web became operational for the first time in 1991. Since then, it has been massively responsible for the many revolutions in the field of computing and communication.
- **Smart Meters:** The earliest smart meter was a power meter, which became operational in early 2000. These power meters were capable of communicating remotely with the power grid. They enabled remote monitoring of subscribers' power usage and eased the process of billing and power allocation from grids.
- **Digital Locks:** Digital locks can be considered as one of the earlier attempts at connected home-automation systems. Present-day digital locks are so robust that smartphones can be used to control them. Operations such as locking and unlocking doors, changing key codes, including new members in the access lists, can be easily performed, and that too remotely using smartphones.
- **Connected Healthcare**: Here, healthcare devices connect to hospitals, doctors, and relatives to alert them of medical emergencies and take preventive measures. The devices may be simple wearable appliances, monitoring just the heart rate and pulse of the wearer, as well as regular medical devices and monitors in hospitals. The connected nature of these systems makes the availability of medical records and test results much faster, cheaper, and convenient for both patients as well as hospital authorities.

EVOLUTION OF IOT

- **Connected Vehicles**: Connected vehicles may communicate to the Internet or with other vehicles, or even with sensors and actuators contained within it. These vehicles self-diagnose themselves and alert owners about system failures.
- **Smart Cities**: This is a city-wide implementation of smart sensing, monitoring, and actuation systems. The city-wide infrastructure communicating amongst themselves enables unified and synchronized operations and information dissemination. Some of the facilities which may benefit are parking, transportation, and others.
- **Smart Dust**: These are microscopic computers. Smaller than a grain of sand each, they can be used in numerous beneficial ways, where regular computers cannot operate. For example, smart dust can be sprayed to measure chemicals in the soil or even to diagnose problems in the human body.
- **Smart Factories**: These factories can monitor plant processes, assembly lines, distribution lines, and manage factory floors all on their own. The reduction in mishaps due to human errors in judgment or unoptimized processes is drastically reduced.
- **UAVs**: UAVs or unmanned aerial vehicles have emerged as robust public domain solutions tasked with applications ranging from agriculture, surveys, surveillance, deliveries, stock maintenance, asset management, and other tasks.

IoT vs M2M

- M2M or the machine-to-machine paradigm refers to communications and interactions between various machines and devices. These interactions can be enabled through a cloud computing infrastructure, a server, or simply a local network hub.
- M2M collects data from machinery and sensors, while also enabling device management and device interaction. Telecommunication services providers introduced the term M2M, and technically emphasized on machine interactions via one or more communication networks (e.g., 3G, 4G, 5G, satellite, public networks).
- M2M is part of the IoT and is considered as one of its sub-domains.
- M2M standards occupy a core place in the IoT landscape. However, in terms of operational and functional scope, IoT is vaster than M2M and comprises a broader range of interactions such as the interactions between devices/things, things, and people, things and applications, and people with applications; M2M enables the amalgamation of workflows comprising such interactions within IoT. Internet connectivity is central to the IoT theme but is not necessarily focused on the use of telecom networks.

IoT versus CPS

- Cyber physical systems (CPS) encompasses sensing, control, actuation, and feedback as a complete package. In other words, a digital twin is attached to a CPS-based system.
- A digital twin is a virtual system–model relation, in which the system signifies a physical system or equipment or a piece of machinery, while the model represents the mathematical model or representation of the physical system's behavior or operation. Many a time, a digital twin is used parallel to a physical system, especially in CPS as it allows for the comparison of the physical system's output, performance, and health.
- Based on feedback from the digital twin, a physical system can be easily given corrective directions/commands to obtain desirable outputs. In contrast, the IoT paradigm does not compulsorily need feedback or a digital twin system. IoT is more focused on networking than controls.
- Some of the constituent sub-systems in an IoT environment (such as those formed by CPS-based instruments and networks) may include feedback and controls too.
- CPS may be considered as one of the sub-domains of IoT

IoT versus WoT

- From a developer's perspective, the Web of Things (WoT) paradigm enables access and control over IoT resources and applications.
- These resources and applications are generally built using technologies such as HTML 5.0, JavaScript, Ajax, PHP, and others. REST (representational state transfer) is one of the key enablers ofWoT.
- The use of RESTful principles and RESTful APIs (application program interface) enables both developers and deployers to benefit from the recognition, acceptance, and maturity of existing web technologies without having to redesign and redeploy solutions from scratch.
- Still, designing and building the WoT paradigm has various adaptability and security challenges, especially when trying to build a globally uniform WoT.
- As IoT is focused on creating networks comprising objects, things, people, systems, and applications, which often do not consider the unification aspect and the limitations of the Internet, the need for WoT, which aims to integrate the various focus areas of IoT into the existing Web is really invaluable.
- Technically, WoT can be thought of as an application layer-based hat added over the network layer. However, the scope of IoT applications is much broader; IoT also which includes non-IP-based systems that are not accessible through the web.

Enabling IoT and the Complex Interdependence of Technologies

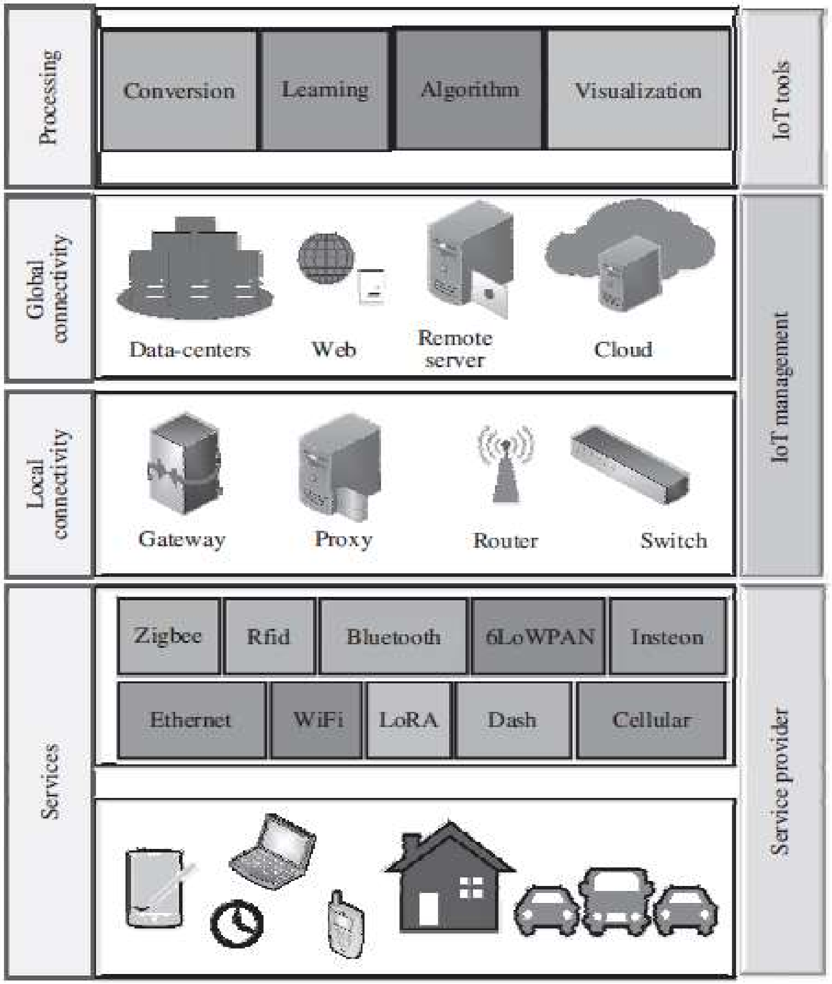
- IoT is a paradigm built upon complex interdependencies of technologies (both legacy and modern), which occur at various planes of this paradigm.
- We can divide the IoT paradigm into four planes: services, local connectivity, global connectivity, and processing. If we consider a bottom-up view, the services offered fall under the control and purview of service providers. The service plane is composed of two parts:

  1.Things or devices 2) low-power connectivity .

- Typically, the services offered in this layer are a combination of things and low power connectivity. For example, any IoT application requires the basic setup of sensing, followed by rudimentary processing (often), and a low-power, low-range network, which is mainly built upon the IEEE 802.15.4 protocol.
- The things may be wearables, computers, smartphones, household appliances, smart glasses, factory machinery, vending machines, vehicles, UAVs, robots, and other such contraptions (which may even be just a sensor). The immediate low-power connectivity, which is responsible for connecting the things in local implementation, may be legacy protocols such as WiFi, Ethernet, or cellular. In contrast, modern-day technologies are mainly wireless and often programmable such as Zigbee, RFID, Bluetooth, 6LoWPAN, LoRA, DASH, Insteon, and others. The range of these connectivity technologies is severely restricted; they are responsible for the connectivity between the things of the IoT and the nearest hub or gateway to access the Internet.
- The local connectivity is responsible for distributing Internet access to multiple local IoT deployments. This distribution may be on the basis of the physical placement of the things, on the basis of the application domains, or even on the basis of providers of services.

Eabling IoT and the Complex Interdependence of Technologies

- Services such as address management, device management, security, sleep scheduling, and others fall within the scope of this plane. For example, in a smart home environment, the first floor and the ground floor may have local IoT implementations, which have various things connected to the network via low-power, low-range connectivity technologies. The traffic from these two floors merges into a single router or a gateway.
- The total traffic intended for the Internet from a smart home leaves through a single gateway or router, which may be assigned a single global IP address (for the whole house). This helps in the significant conservation of already limited global IP addresses. The local connectivity plane falls under the purview of IoT management as it directly deals with strategies to use/reuse addresses based on things and applications. The modern-day “edge computing” paradigm is deployed in conjunction with these first two planes: services and local connectivity.
- In continuation, the penultimate plane of global connectivity plays a significant role in enabling IoT in the real sense by allowing for worldwide implementations and connectivity between things, users, controllers, and applications. This plane also falls under the purview of IoT management as it decides how and when to store data, when to process it, when to forward it, and in which form to forward it.



Enabling IoT and the Complex Interdependence of Technologies

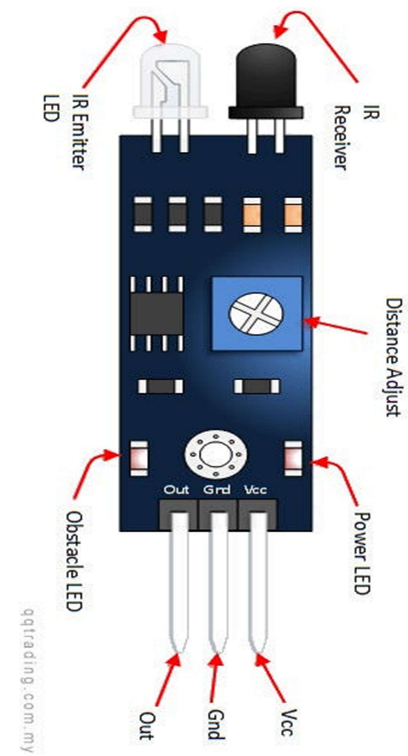
- The Web, data-centers, remote servers, Cloud, and others make up this plane. The paradigm of "fog computing" lies between the planes of local connectivity and global connectivity. It often serves to manage the load of global connectivity infrastructure by offloading the computation nearer to the source of the data itself, which reduces the traffic load on the global Internet.
- The final plane of processing can be considered as a top-up of the basic IoT networking framework. The continuous rise in the usefulness and penetration of IoT in various application areas such as industries, transportation, healthcare, and others is the result of this plane.
- The members in this plane may be termed as IoT tools, simply because they wring-out useful and human-readable information from all the raw data that flows from various IoT devices and deployments.
- The various sub-domains of this plane include intelligence, conversion (data and format conversion, and data cleaning), learning (making sense of temporal and spatial data patterns), cognition (recognizing patterns and mapping it to already known patterns),algorithms (various control and monitoring algorithms), visualization (rendering numbers and strings in the form of collective trends, graphs, charts, and projections),and analysis (estimating the usefulness of the generated information, making sense of the information with respect to the application and place of data generation, and estimating future trends based on past and present patterns of information obtained). Various computing paradigms such as "big data", "machine Learning", and others, fall within the scope of this domain.

Sensors

1. Infrared Sensor(IR Sensor)
2. Temperature & Thermocouple Sensors
3. Proximity Sensor
4. Ultrasonic sensor
5. Accelerometers Sensor
6. Gyroscope Sensor
7. Pressure Sensor
8. Hall Effect Sensor
9. Load cell
10. Light Sensor & Color Sensor
11. Touch Sensor
12. Tilt Sensor
13. PIR Motion Detector
14. Vibration Sensor
15. Metal detector Sensor
16. Water Flow Sensor
17. Heartbeat Sensor
18. Flow and Level Sensor
19. Smoke, Fog, Gas, Ethanol & Alcohol Sensor
20. Humidity Sensor
21. Soil Moisture Sensor
22. Rain Sensor

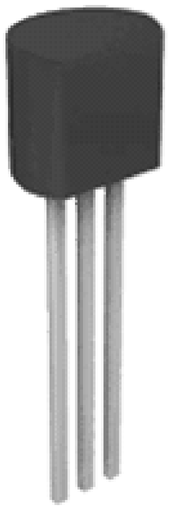
Infrared Sensor(IR Sensor)

- An infrared sensor is an electronic instrument which is used to sense certain characteristics of its surrounding by either emitting and/or detecting motion.
- Infrared sensors are also capable of measuring the heat being emitted by an object and detecting motion.
- Infrared waves are not visible to human eye. In the electromagnetic spectrum, infrared radiations can be found between the visible and microwave regions.
- The Infrared waves typically have wavelengths range from 780nm to 1mm
- IR LED keeps transmitting infrared rays up to some range.
- When some objects comes in the IR range the IR wave hits the object and comes back at some angle
- The photodiode next to IR led detects the IR rays which got reflected from the object.



Temperature Sensors

- It is a type of temperature sensor, which is made by joining two dissimilar metals at one end. The joined end is referred to as the HOT JUNCTION. The other end of these dissimilar metals is referred to as the COLD JUNCTION.
- The cold junction is formed at the last point of thermocouple material. If there is a difference in temperature between the hot junction and cold junction, a small voltage is created. This voltage is referred to as an EMF (electro-motive force) and can be measured and in turn used to indicate temperature.
- CPU temperature
- Battery temperature
- Ambient temperature



Proximity Sensor

- A proximity sensor is a sensor able to detect the presence of nearby objects without any physical contact.
- A proximity sensor often emits an electromagnetic field or a beam of electromagnetic radiation (infrared), and looks for changes in the field.
- There is no contact between the sensors and sensed object and lack of mechanical parts, these sensors have long functional life and high reliability.
- Proximity sensors are commonly used on smartphones to detect (and skip) accidental touchscreen taps when held to the ear during a call.
- They are also used in machine vibration monitoring to measure the variation in distance between a shaft and its support bearing. This is common in large steam turbines, compressors, and motors that use sleeve-type bearings.

Smoke, Fog, Gas Sensors

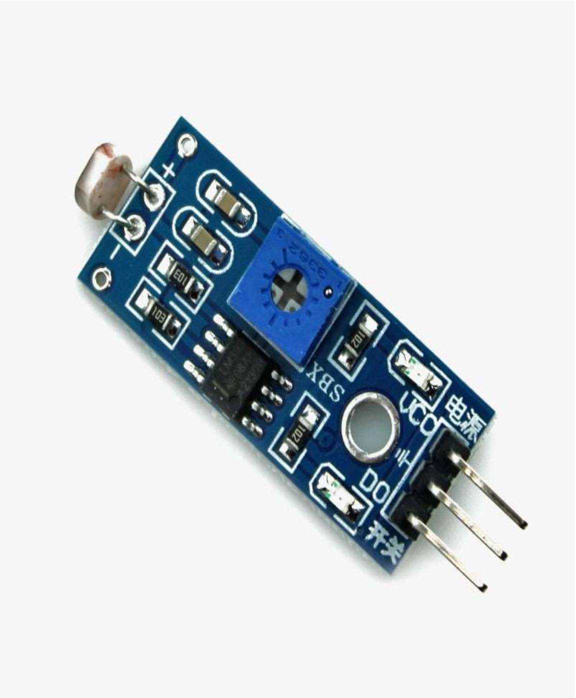
- This sensor is also used for Air quality monitoring, Gas leak alarm and for maintaining environmental standards in hospitals. In industries, these are used to detect the leakage of harmful gases.
- This sensor contains a sensing element, mainly aluminum-oxide based ceramic, coated with Tin dioxide, enclosed in a stainless steel mesh. Oxygen gets adsorbed on the surface of sensing material when it is heated in air at high temperature. Then donor electrons present in tin oxide are attracted towards this oxygen, thus preventing the current flow.
- When reducing gases are present, these oxygen atoms react with the reducing gases thereby decreasing the surface density of the adsorbed oxygen. Now current can flow through the sensor, which generated analog voltage values.
- These voltage values are measured to know the concentration of gas. Voltage values are higher when the concentration of gas is high.

Soil Moisture Sensor

- The fork-shaped probe with two exposed conductors acts as a variable resistor (similar to a potentiometer) whose resistance varies with the soil's moisture content.
- This resistance varies inversely with soil moisture:
- The more water in the soil, the better the conductivity and the lower the resistance.
- The less water in the soil, the lower the conductivity and thus the higher the resistance.
- The sensor produces an output voltage according to the resistance, which by measuring we can determine the soil moisture level.

Light Sensor & Color Sensor

- Light sensors are a type of photodetector (also called photosensors) that detect light. Different types of light sensors can be used to measure illuminance, respond to changes in the amount of light received, or convert light to electricity.
- Light sensors work by the photoelectric effect. Light can behave as a particle, referred to as a photon.
- When a photon hits the metal surface of the light sensor, the energy of the light is absorbed by the electrons, increasing their kinetic energy and allowing them to be emitted from the material.
- This movement of electrons, and therefore charge, is electrical current.



Ultra Sonic Sensor

- An Ultrasonic sensor is a device that can measure the distance to an object by using sound waves.
- It measures distance by sending out a sound wave at a specific frequency and listening for that sound wave to bounce back.
- By recording the elapsed time between the sound wave being generated and the sound wave bouncing back, it is possible to calculate the distance between the sonar sensor and the object.
- Since it is known that sound travels through air at about 344 m/s, you can take the time for the sound wave to return and multiply it by 344meters to find the total round-trip distance of the sound wave.
- Round-trip means that the sound wave traveled 2 times the distance to the object before it was detected by the sensor; it includes the 'trip' from the sonar sensor to the object AND the 'trip' from the object to the Ultrasonic sensor (after the soundwave bounced off the object).

PIR Motion Detector

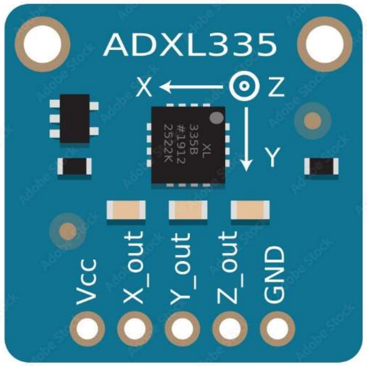
- PIR sensors allow you to sense motion, almost always used to detect whether a human has moved in or out of the sensors range.
- They are small, inexpensive, low-power, easy to use and don't wear out.
- For that reason they are commonly found in appliances and gadgets used in homes or businesses.
- They are often referred to as PIR, "Passive Infrared“ "Pyroelectric", or "IR motion" sensors.
- PIRs are basically made of a pyroelectric sensor (the round metal can with a rectangular crystal in the center), which can detect levels of infrared radiation.
- Everything emits some low level radiation, and the hotter something is, the more radiation is emitted.

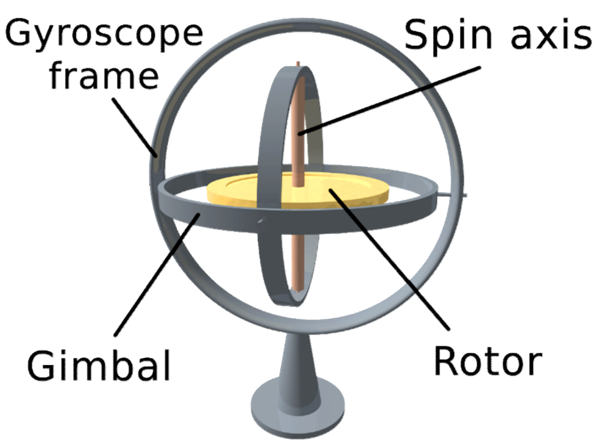
Metal detector Sensor

- Metal detector is a device that can detect metal, the basics can make a sound when it is near some metal.
- Metal detectors work on the principle of transmitting a magnetic field and analyzing a return signal from the target and environment.
- when some metals are coming close to the coil the amplitude of the reflective pulse is getting little lower and a duration of the pulse a little longer.
- The need for detection is very clear to protect our self from any kind of danger.
- Metal detectors contain one or more inductor coils. When metal is placed in a close proximity to a varying magnetic field (generated by the coil or coils), currents are induced in the metallic part.
- These fields act in such a direction as to oppose that generated by the coils. The resultant field and using a specially designed electronic circuit can indicate the type of material being magnetized.

Gyroscope Sensor

- Gyroscopes sensors is a micro-electromechanical device which is small, with inexpensive sensors which are used to measure angular velocity or rotational motion or displacement.
- The unit of angular velocity is measured in revolutions per second (RPS) or degrees per second. It simply measures the speed of rotation.
- Mechanically, Gyroscopes is a spinning wheel or disc mounted on an axle and the axle is free to assume directions.
- They rely on the same principle that is vibrating objects undergoing rotation.





Sensor Characteristics

All sensors can be defined by their ability to measure or capture a certain phenomenon and report them as output signals to various other systems. However, even within the same sensor type and class, sensors can be characterized by their ability to sense the phenomenon based on the following three fundamental properties.

- **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. For 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 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. Here, the sensor precision is not deemed high because of significant variations in the temporal measurements for the same object under the same conditions.

Sensorial Deviations

- Sensor's output signal going beyond its designed maximum and minimum capacity for measurement, the sensor output is truncated to its maximum or minimum value, which is also the 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. In Real time the sensitivity of a sensor may differ from the value specified for that sensor leading to sensitivity error. This deviation is mostly attributed to sensor fabrication errors and its calibration.
- 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
- some sensors have a non-linear behavior. If a sensor's transfer function (TF) deviates from a straight line transfer function, it is referred to as its **non-linearity.**
- 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.
- 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 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.
- Dynamic errors caused due to mishandling of sampling frequencies can give rise to **aliasing errors**

Sensing Types

Sensing can be broadly divided into four different categories based on the nature of the environment being sensed and the physical sensors being used to do so

(1) scalar sensing,

(2) multimedia sensing,

(3) hybrid sensing, and

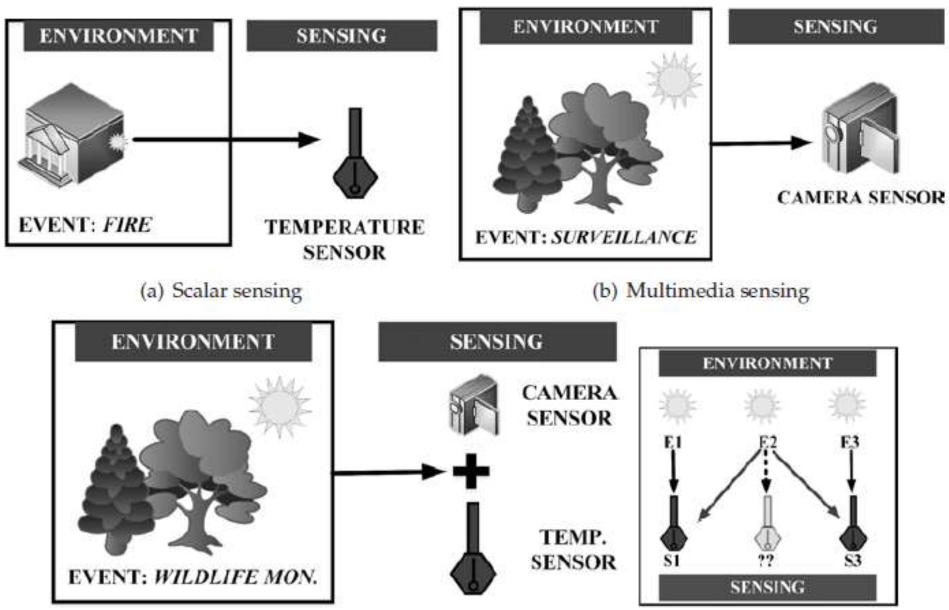
(4) Virtual sensing

- **Scalar sensing** : Scalar sensing encompasses the 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 as they normally do not have a directional or spatial property assigned with them. Simply measuring the changes in their values with passing time provides enough information about these quantities.
- **Multimedia sensing :** Unlike scalar sensors, 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. Additionally, these quantities follow the vector law of addition and hence are designated as vector quantities. They might have different values in different directions for the same working condition at the same time. The sensors used for measuring these quantities are known as vector sensors.

Sensing Types

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.

Virtual sensing : there is a need for very dense and large-scale deployment of sensor nodes spread over a large area for monitoring of parameters. One such domain is agriculture. Here, often, the parameters being measured, such as soil moisture, soil temperature, and water level, do not show significant spatial variations

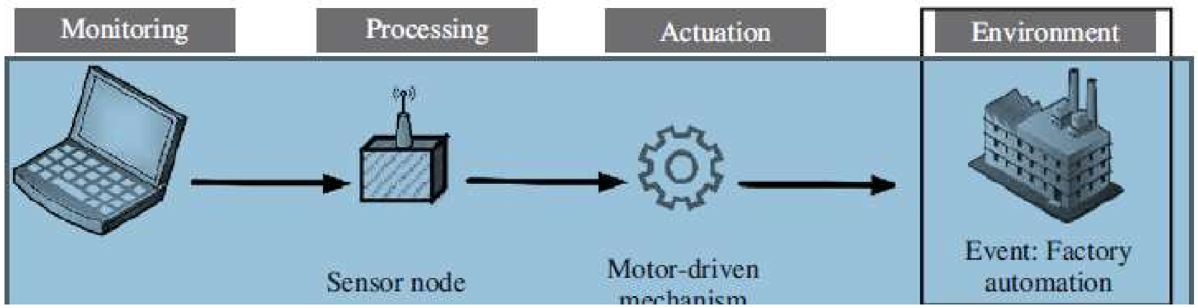


(a) Scalar sensing (b) Multimedia sensing

(c) Hybrid sensing (d) Virtual sensing

Actuators

- An actuator can be considered as a machine or system's component that can affect the movement or control the said mechanism or the system. Control systems affect changes to the environment or property they are controlling through actuators. The system activates the actuator through a control signal, which may be digital or analog. It elicits a response from the actuator, which is in the form of some form of mechanical motion. The control system of an actuator can be a mechanical or electronic system, a software-based system (e.g., an autonomous car control system), a human, or any other input.



Types of Actuators

Hydraulic actuators: A hydraulic actuator 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 motion applied to a hydraulic actuator is converted to either linear, rotary, or oscillatory motion. The almost incompressible property of liquids is used in hydraulic actuators for exerting significant force. These hydraulic actuators are also considered as stiff systems. The actuator's limited acceleration restricts its usage.

Pneumatic actuators: A pneumatic actuator works on the principle of compression and decompression of gases. These actuators use a vacuum or compressed air at high pressure and convert it into either linear or rotary motion. Pneumatic rack and pinion actuators are commonly used for valve controls of water pipes. Pneumatic actuators are considered as compliant systems. The actuators using pneumatic energy for their operation are typically characterized by the quick response to starting and stopping signals. Small pressure changes can be used for generating large forces through these actuators. Pneumatic brakes are an example of this type of actuator which is so responsive that they can convert small pressure changes applied by drives to generate the massive force required to stop or slow down a moving vehicle. Pneumatic actuators are responsible for converting pressure into force. The power source in the pneumatic actuator does not need to be stored in reserve for its operation.

Types of Actuators

Electric actuators : Typically, electric motors are used to power an electric actuator by generating mechanical torque. This generated torque is translated into the motion of a motor’s shaft or for switching (as in relays). For example, actuating equipment's such as solenoid valves control the flow of water in pipes in response to electrical signals. This class of actuators is considered one of the cheapest, cleanest and speedy actuator types available.

Thermal or magnetic actuators : The use of thermal or magnetic energy is used for powering this class of actuators. These actuators have a very high power density and are typically compact, lightweight, and economical. One classic example of thermal actuators is shape memory materials (SMMs) such as shape memory alloys (SMAs). These actuators do not require electricity for actuation. They are not affected by vibration and can work with liquid or gases. Magnetic shape memory alloys (MSMAs) are a type of magnetic actuators.

Actuator Characteristics

- **Weight**: The physical weight of actuators limits its application scope. For example, the use of heavier actuators is generally preferred for industrial applications and applications requiring no mobility of the IoT deployment. In contrast, lightweight actuators typically find common usage in portable systems in vehicles, drones, and home IoT applications. It is to be noted that this is not always true. Heavier actuators also have selective usage in mobile systems, for example, landing gears and engine motors in aircraft.
- **Power Rating**: This helps in deciding the nature of the application with which an actuator can be associated. The power rating defines the minimum and maximum operating power an actuator can safely withstand without damage to itself. Generally, it is indicated as the power-to-weight ratio for actuators. For example, smaller servo motors used in hobby projects typically have a maximum rating of 5V DC, 500 mA, which is suitable for an operations-driven battery-based power source. Exceeding this limit might be detrimental to the performance of the actuator and may cause burnout of the motor. In contrast to this, servo motors in larger applications have a rating of 460 VAC, 2.5 A, which requires standalone power supply systems for operations. It is to be noted that actuators with still higher ratings are available and vary according to application requirements.
- **Torque to Weight Ratio**: The ratio of torque to the weight of the moving part of an instrument/device is referred to as its torque/weight ratio. This indicates the sensitivity of the actuator. Higher is the weight of the moving part; lower will be its torque to weight ratio for a given power.
- **Stiffness and Compliance**: The resistance of a material against deformation is known as its stiffness, whereas compliance of a material is the opposite of stiffness. Stiffness can be directly related to the modulus of elasticity of that material. Stiff systems are considered more accurate than compliant systems as they have a faster response to the change in load applied to it. For example, hydraulic systems are considered as stiff and non-compliant, whereas pneumatic systems are considered as compliant.