UNIT - I:

Introduction and definition of IoT, Evolution of IoT, IoT growth, Application areas of IoT, Characteristics of IoT, IoT stack, Enabling technologies, IoT levels, IoT sensing and actuation, Sensing types, Actuator types.

What is Internet

In simple term " Internet" – is a network of networks or Interconnected LANs.

What is Network

A network consists of two or more computers linked together to share resources (such as printers and CD's), exchange files or data.

The computers on the network are linked through cables, telephone lines, radio waves , satellites or infrared light beams.

There are two common types of networks

- ❑ Local area networks (LAN)
- ❑ Wide area network (WAN)

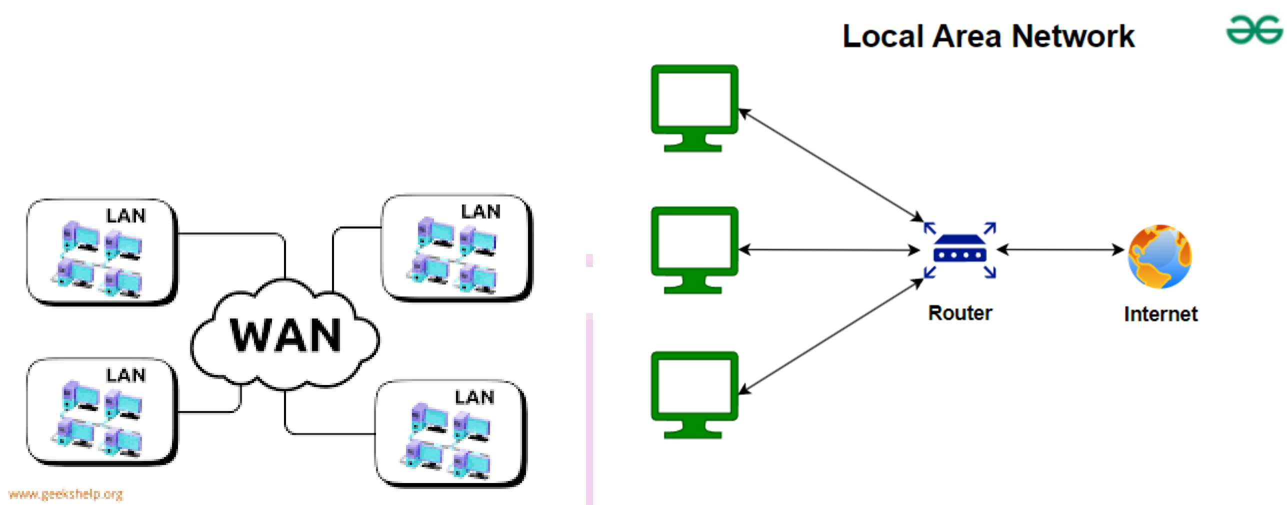


Figure1.1 : LAN,WAN

What is Thing in IoT?

- The thing or device in IoT could be any device embedded with electronics , software and sensors like a smart refrigerator , a smart air conditioner, lights in house hold , connected security systems or even a person with a heart monitor or an automobile.

  OR

- A thing in the context of IoT, is an entity or physical object that has a unique identifier, an embedded systems and the ability to transfer data over a network.
- Every device has its unique id which makes the communication possible among them.
- During 2008, the number of things connected to the internet exceeded the number of people on the earth.

These things are not just smart phones and tablets.

- By 2020 there will be 50 billion things are connected to internet.
- Is it possible to assign addresses (unique id's) to all the devices in the world?
  "yes", IPV6 has a huge address space of 2^{128}
- Tons of data are collected from devices all over the world where could we store this huge sum of data?
  "clouds"
- The objects or things can sense , communicate and share information , all interconnected over public or private internet protocol (IP) networks.
- These interconnected objects have regularly collected, analyzed and used to initiate action, providing a wealth of intelligence for planning, management and decision making. This is the world of internet of things.

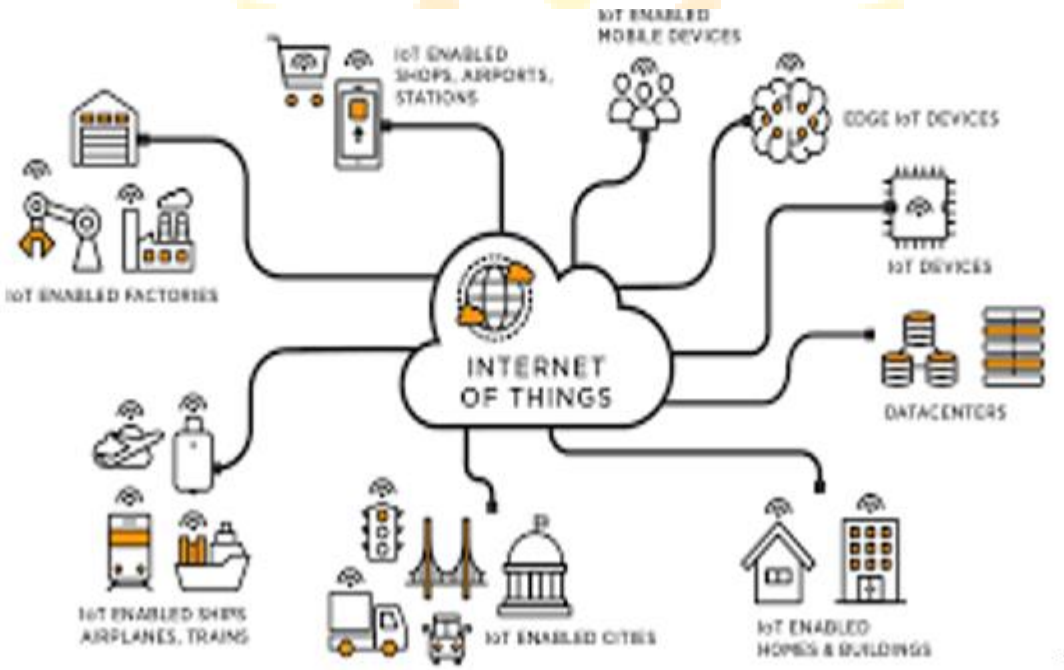


Figure 1.2 : Internet of Things Applications

- **Difference between internet and Web:**

The internet is a global networks while the web also referred to formally as world wide Web (WWW) is a collection of information that is accessed via the internet.

or

The internet is infrastructure while the web is served on top of that infrastructure.

Internet , Intranet , Extranet:

1. **Internet :** Public network accessible to anyone.
2. **Intranet-** private networks accessible only to authorized users with in an organization.
3. **Extranet :** Private networks that allow external parties to acces certain parts of an organizations intranet.

Infrastructure:

- The basic facilities and system serving a country, region or community.
- The basic physical and organizational structures and facilities (eg buildings, roads, power supplies) needed for the operation of a society or enterprise.

Ex: Telecommunication networks.

General definition of IoT:

- IoT is an emerging , popular term.
- There are multiple ways to define IoT
- The IoT is a scenario in which “uniquely identifiable objects or things communicate or transfer data over a network with out/ with minimal intervention of human –to-human or human to computer interaction.

or

- The IoT is the network of physical objects/ things embedded with electronics , software, sensors and network connectivity which enables these objects to collect and exchange data.

or

- IoT is network of interconnected computing devices, which are embedded in every objects, enabling them to send and receive data.

or

- IoT connects physical to digital.
- IoT is not just limited to the connected or networked devices but also the IoT devices exchange meaningful information from one device to another to get desired result.
- IoT is not a single technology. It’s a combination of technologies and domain knowledge.
- As a result, engineers from different domains have to work together for building a complete IoT product.
- Life – to be governed entirely by Internet and IoT in the near future.

Goal of IoT:

- The main goal of IoT is to configure , control, and network the devices or things, to internet , which are traditionally not associated with the internet i.e thermostats, utility meters, a Bluetooth connected head set, irrigation pumps and sensors or control circuits for electric car’s engine that makes energy, logistics, industrial control, retail, agriculture and many other domain smarter
- The scope of IoT is not just limited to connected things to the internet.
- IoT allows these things to communicate and exchange data . It executes the applications to achieve a user or machine goal.

What is Data?

- It does not have a meaning by itself.
- It has to be contextualized and processed into useful information.

- Ex: Series of raw sensor measurements generated by a weather monitoring station.
- ((72,45);(84,56))

Information:

- Applications on IoT networks use the lower level data – filters, process, categorize , condense and contextualize that to extract and create information.
- Ex: in the above example ((72,45);(84,56)) – meaning is given to the data by adding the context.
- Each tuple in the data represents the temperature and humidity – measured every minute.
- By adding the context, we know the meaning called information.

Knowledge:

- The information obtained is then organized and structure to infer knowledge about the system – its users , its environment, its operations.
- It then progresses towards objectives- which results in a smater performance.
- **Ex:** once the information is obtained by categorizing, condensing or processing the data- i.e the average temperature and humidity readings for last five mins- is obtained by averaging the last five data tuples.
- The next step is – organize the information and understand the relation ships between the pieces of information to gain knowledge and put that into action.
- **Ex:** If the average temperature in the last 5 mins exceeds 120F, an alert is raised based on the users geographical position.

Inferring Information and Knowledge from Data :

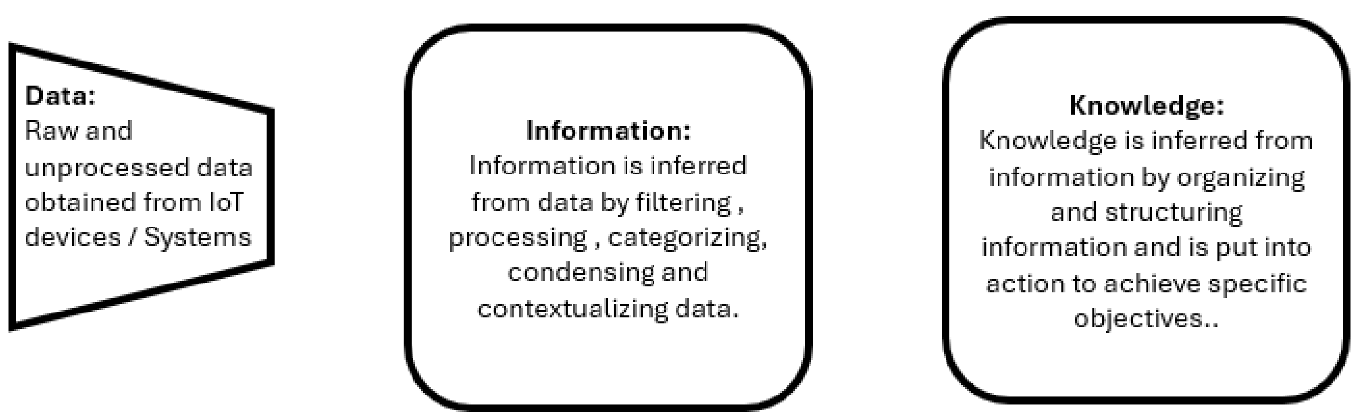
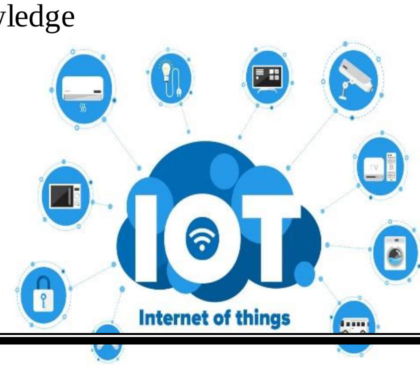


Figure 1.3: Data Vs Information Vs Knowledge

Why IoT:



- To automate everything
- To control everything remotely
- To see data in real time.
- Dynamic control of industry and daily life.

- Improve the resource utilization ratio.
- Integrating human society and physical systems.
- Acts as technologies integrator.
- Flexible configuration.

Why it came:

- Idea of physical objects communicating and interacting with each other online.
- Extends internet connectivity beyond traditional devices like desktop, laptop computers, smartphones and tablets to a diverse range of devices and every day things that utilize embedded technology to communicate and interact with the external environment, all via the internet.

Figure 1.4: In Real world Applications

Evolution / History of IoT:

- The Internet of Things (IoT) emerged around 2008-2009 when the number of internet-connected devices surpassed the world's population. Kevin Ashton, while working for Procter & Gamble in1999, coined the term "Internet of Things" to describe the idea of linking the company's supply chain to the internet. IoT involves giving computers the ability to sense and collect data independently. The evolution of the internet can be divided into four phases: Connectivity, Networked Economy, Immersive Experiences, and IoT. Each phase builds on the previous one, providing increasing value to businesses and society.

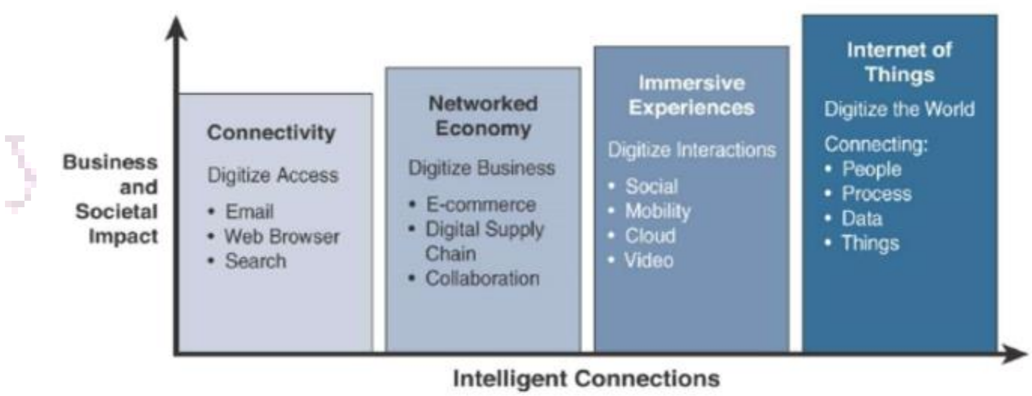


Figure 1.5: Evolutionary Phases of Internet

- **Connectivity (Mid-1990s):** The initial phase focused on establishing internet connectivity, which was initially limited to universities and corporations. The challenge was to connect people efficiently, marking the beginning of online accessibility for the average person.
- **Networked Economy:** The second phase, marked by the late 1990s and early 2000s, shifted the focus to leveraging connectivity for efficiency and profit. E-commerce and digitally connected supply chains became prominent, causing major disruptions in traditional retail.
- **Immersive Experiences:** This phase, characterized by the emergence of social media and widespread mobility on various devices, transformed person-to-person interactions into digitized experiences. Connectivity became pervasive, enabling communication and collaboration across multiple platforms.
- **Internet of Things:** The current phase involves connecting machines and objects, along with humans. Despite being in the early stages, IoT is generating significant increases in data and knowledge. This connectivity is leading to new insights, increased automation, and improved process efficiencies. While IoT has the potential to revolutionize various aspects of business and society, a significant portion of "things" is still unconnected, indicating the vast potential for growth and impact in the future.

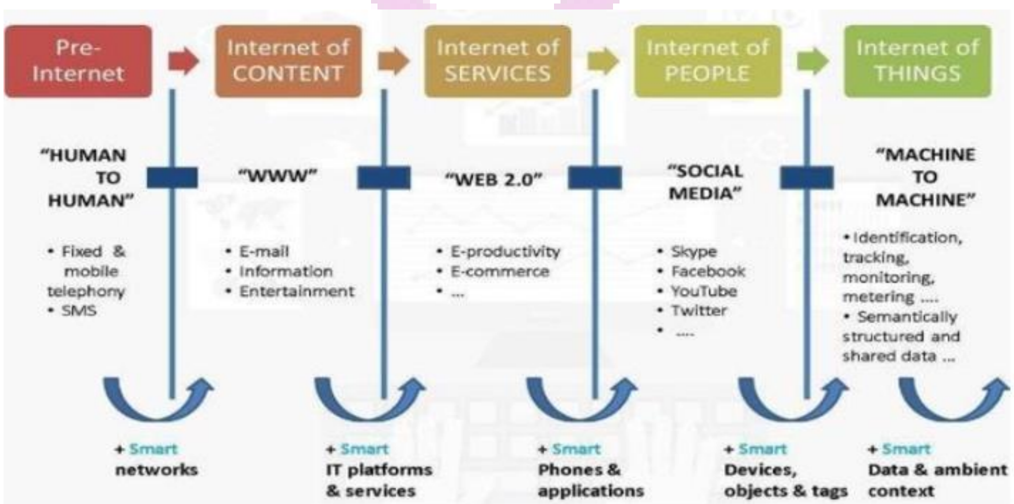


Figure 1.6 : Evaluation of Internet of Things

IoT growth:

- Impact on Various Industries:

Healthcare:

- IoT enables remote monitoring of patients, leading to improved care and early detection of health issues.
- Wearables and smart devices track vital signs, while connected medical devices allow for more personalized treatment.

Smart Cities:

- IoT contributes to the development of smart cities by optimizing energy usage, improving traffic management, enhancing public safety, and reducing environmental impact through smart grids, connected streetlights, and waste management systems.

Agriculture:

- IoT in agriculture, often termed "smart farming," involves using sensors for soil moisture, temperature, and crop monitoring. It leads to more efficient water usage, better crop management, and increased productivity.
- **Role of IoT in Digital Transformation:**
- **Data-Driven Decisions:**
- o IoT generates massive amounts of data from connected devices. This data, when analyzed, provides valuable insights that drive smarter business decisions and strategies.
- **Automation and Efficiency:**
- o IoT automates routine tasks, optimizes resource usage, and enhances efficiency across various processes, leading to cost savings and increased productivity.
- **Enhanced Customer Experience:**
- o In retail, IoT enables personalized shopping experiences through connected devices that track customer preferences and behaviors. In other sectors, IoT ensures better service delivery through real-time monitoring and proactive maintenance.
- **Innovation and New Business Models:**
- IoT fosters innovation by enabling new business models, such as subscription-based services for smart products and pay-per-use models in industrial equipment. It also opens up new revenue streams through data monetization.
- IoT is not just a technological trend but a fundamental shift in how we interact with the world around us. Its impact is widespread, driving digital transformation across industries and shaping the future of technology and business.

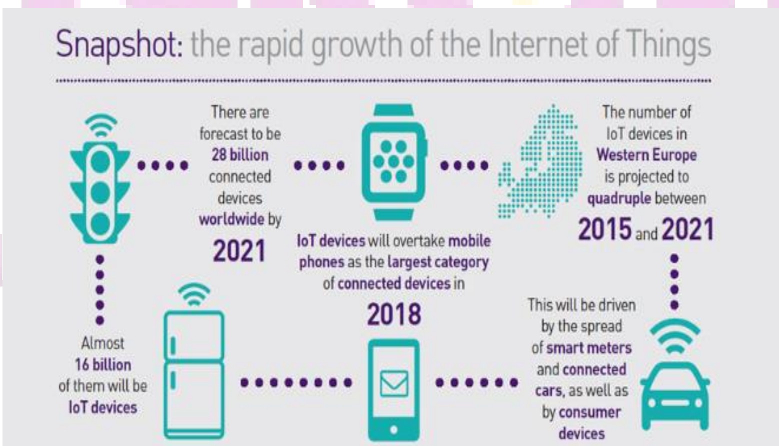


Figure 1.7 : The rapid growth of the Internet of Things

Application areas of IoT :

- **Smart Home:**
  The smart home is one of the most popular applications of IoT. The cost of owning a house is the biggest expense in a homeowner's life. Smart homes are promised to save the time, money and energy.
- **Smart cities:**
  The smart city is another powerful application of IoT. It includes smart surveillance, environment monitoring, automated transformation, urban security, smart traffic management, water distribution, smart healthcare etc.
- **Wearables:**
  Wearables are devices that have sensors and software installed which can collect data about the user which can be later used to get the insights about the user. They must be energy efficient and small sized.
- **Connected cars:**
  A connected car is able to optimize its own operation, maintenance as well as passenger's comfort using sensors and internet connectivity.
- **Smart retail:** Retailers can enhance the in-store experience of the customers using IoT. The shopkeeper can also know which items are frequently bought together using IoT devices.
- **Smart healthcare:** People can wear the IoT devices which will collect data about user's health. This will help users to analyze themselves and follow tailor-made techniques to combat illness. The doctor also doesn't have to visit the patients in order to treat them.

Figure 1.8 : Applications of IoT

Characteristics of IoT :

i) Connectivity

Connectivity is an important requirement of the IoT infrastructure. Things of IoT should be connected to the IoT infrastructure. Anyone, anywhere, anytime can connect, this should be guaranteed at all times. For example, the connection between people through Internet devices like mobile phones, and other gadgets, also a connection between Internet devices such as routers, gateways, sensors, etc.

ii) Intelligence and Identity

The extraction of knowledge from the generated data is very important. For example, a sensor generates data, but that data will only be useful if it is interpreted properly. Each IoT device has a unique identity. This identification is helpful in tracking the equipment and at times for querying its status.

iii) Scalability

The number of elements connected to the IoT zone is increasing day by day. Hence, an IoT setup should be capable of handling the massive expansion. The data generated as an outcome is enormous, and it should be handled appropriately.

iv) Dynamic and Self-Adapting (Complexity)

IoT devices should dynamically adapt themselves to changing contexts and scenarios. Assume a camera meant for surveillance. It should be adaptable to work in different conditions and different light situations (morning, afternoon, and night).

v) Architecture

IoT Architecture cannot be homogeneous in nature. It should be hybrid, supporting different manufacturers ' products to function in the IoT network. IoT is not owned by anyone engineering branch. IoT is a reality when multiple domains come together.

vi) Safety

There is a danger of the sensitive personal details of the users getting compromised when all his/her devices are connected to the internet. This can cause a loss to the user. Hence, data security is the major challenge. Besides, the equipment involved is huge. IoT networks may also be at risk. Therefore, equipment safety is also critical.

iv) Self Configuring

This is one of the most important characteristics of IoT. IoT devices are able to upgrade their software in accordance with requirements with a minimum of user participation. Additionally, they can set up the network, allowing for the addition of new devices to an already-existing network.

v) Interoperability

IoT devices use standardized protocols and technologies to ensure they can communicate with each other and other systems. It refers to the ability of different IoT devices and systems to communicate and exchange data with each other, regardless of the underlying technology or manufacturer.

Interoperability is critical for the success of IoT, as it enables different devices and systems to work together seamlessly and provides a seamless user experience. Without interoperability, IoT systems would be limited to individual silos of data and devices, making it difficult to share information and create new services and applications.

To achieve interoperability, IoT devices, and systems use standardized communication protocols and data formats. These standards allow different devices to understand and process data in a consistent and reliable manner, enabling data to be exchanged between devices and systems regardless of the technology used.

IoT stack :

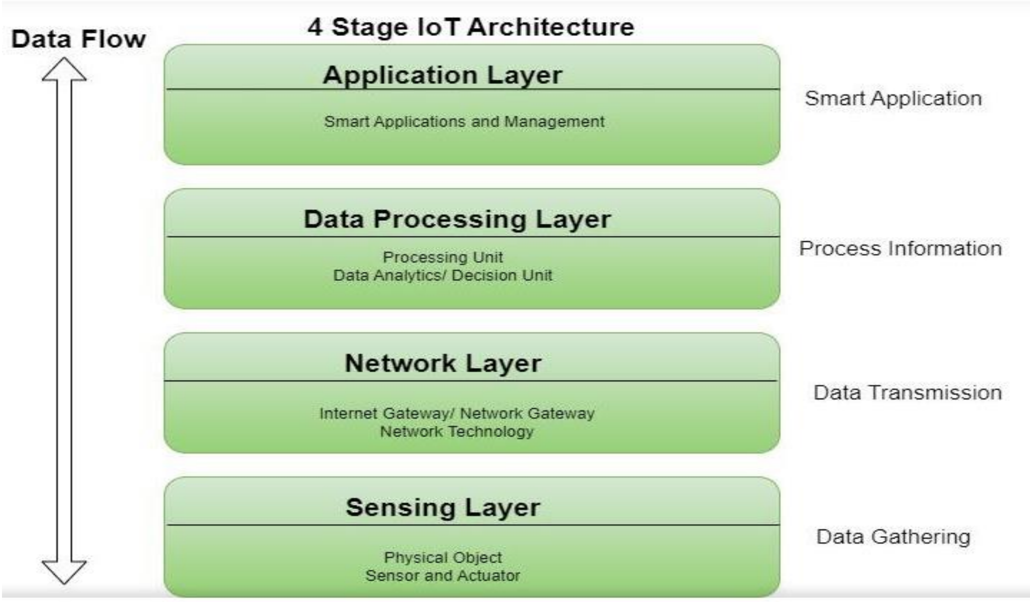


Figure 1.9: 4 Stage IoT Architecture

Sensing layer:

This is the physical layer that **collects data from the real world**.

Components:

- Sensors (temperature, humidity, motion, light, etc.)
- Actuators (motors, valves)
- Embedded devices (Raspberry Pi, Arduino, ESP32)
- RFID, QR code readers, cameras, etc.

Purpose:

- Detect changes in environment
- Perform initial signal conditioning

Network Layer (Connectivity & Communication)Responsible for transmitting data from devices to cloud or edge servers.

Technologies:

- **Short-range:** Wi-Fi, Zigbee, Bluetooth,
- **Z-Wave Long-range:** LoRaWAN, NB-IoT, Sigfox
- **Cellular:** 4G, LTE-M, 5G
- **Wired:** Ethernet, Modbus, CAN bus

Functions:

- Data transmission
- Protocol translation (e.g., MQTT, CoAP, HTTP)

Data Processing Layer (Cloud Platforms & Middleware)

- The data processing layer of IoT architecture refers to the software and hardware components that are responsible for collecting, analyzing, and interpreting data from IoT devices.
- This layer is responsible for receiving raw data from the devices, processing it, and making it available for further analysis or action.

Popular Platforms:

- AWS IoT Core, Azure IoT Hub, Google Cloud IoT
- IBM Watson IoT, ThingSpeak, Kaa, Particle

Functions:

- Data ingestion and storage (e.g., NoSQL, time-series databases)
- Stream processing
- Rule engines and automation
- Integration with AI/ML services

Application Layer (End-User Services)

- The application layer of IoT architecture is the topmost layer that interacts directly with the end-user.
- It is responsible for providing user-friendly interfaces and functionalities that enable users to access and control IoT devices.

Examples:

- Dashboards, mobile apps, analytics tools
- Home automation interfaces
- Industrial control panels (SCADA systems)
- Predictive maintenance apps

Features:

- Visualization (graphs, alerts, heatmaps)
- Control commands
- Reporting & forecasting

Enabling technologies :

Wireless Sensor Networks :

- A WSN comprises distributed devices with sensors which are used to monitor the environmental and physical conditions.
- It is a network formed by large number of sensors nodes to detect light, heat, pressure etc…
- A WSN consists of end nodes, routers & coordinators.
- Each node having several sensors attached to it.
- End node act as a router.

- Coordinator collects data from all nodes.
- It acts like a gateway (WSN-Internet).
- **Weather Monitoring System:** in which nodes collect temp, humidity and other data, which is aggregated and analyzed.

• **Indoor air quality monitoring systems:** to collect data on the indoor air quality and concentration of various gases.

• **Soil Moisture Monitoring Systems:** to monitor soil moisture at various locations.

• **Surveillance Systems:** use WSNs for collecting surveillance data(motion data detection).

• **Smart Grids :** use WSNs for monitoring grids at various points.

• **Structural Health Monitoring Systems:** Use WSNs to monitor the health of structures(building, bridges) by collecting vibrations from sensor nodes deployed at various points in the structure.

Cloud Computing

- Cloud computing is a way of making use of virtual computer world wide using the same personalized experience.
- Cloud means something which is present in remote locations.
- By using cloud computing we can access data from any where.
- **Infrastructure-as-a-service(IaaS):** Infrastructure as a service provides online services such as physical machines, virtual machines, servers, networking, storage and data center space on a pay per use basis. Major IaaS providers are Google Compute Engine, Amazon Web Services and Microsoft Azure etc.
- Ex : Web Hosting, Virtual Machine etc.
- **Platform-as-a-Service(PaaS):** a cloud computing model that provides a platform allowing developers to build, run, and manage applications without the complexity of managing the underlying infrastructure
- Ex : App Cloud, Google app engine
- **Software-as-a-Service(SaaS):** it is a way of delivering applications over the internet as a service. Instead of installing and maintaining software, you simply access it via the internet, freeing yourself from complex software and hardware management.
- SaaS Applications are sometimes called web-based software on demand software or hosted software.
- SaaS applications run on a SaaS provider's service and they manage security availability and performance.
- Ex : Google Docs, Gmail, office etc.

Big data Analysis

- Big data is defined as collections of data sets whose volume , velocity or variety is so large that it is difficult to store, manage, process and analyze the data using traditional databases and data processing tools.
- Some examples of big data generated by IoT are Sensor data generated by IoT systems. • Machine

sensor data collected from sensors established in industrial and energy systems.

• Health and fitness data generated IoT devices.

• Data generated by IoT systems for location and tracking vehicles.

• Data generated by retail inventory monitoring systems.

Volume: There is no fixed threshold for the volume of data for big data. Big data is used for massive scale data.

Velocity: Velocity is another important characteristics of Big Data and the primary reason for exponential growth of data.

Variety: Variety refers to the form of data. Big data comes in different forms such as structured or unstructured data including test data, image , audio, video and sensor data .

- **Communication Protocols:** Communication Protocols form the back-bone of IoT systems and enable network connectivity and coupling to applications.
- Allow devices to exchange data over network.
- Define the exchange formats, data encoding addressing schemes for device and routing of packets from source to destination.
- It includes sequence control, flow control and retransmission of lost packets.

Embedded Systems:

- Embedded Systems is a computer system that has computer hardware and software embedded to perform specific tasks.
- Key components of embedded system include microprocessor or micro controller, memory (RAM, ROM, Cache), networking units (Ethernet Wi-Fi Adaptor), input/output units (Display, Keyboard, etc..,) and storage (Flash memory).
- Embedded System range from low cost miniaturized devices such as digital watches to devices such as digital cameras, POS terminals, vending machines, appliances etc.,

IoT components :

- **Devices-** physical objects embedded with sensors, software, and other technologies that enable them to connect and exchange data over the internet or other networks.
- **Resource** – any component in the IoT system that has limited availability and is used to perform operations or provide services.
- **Controller service** – acts as the brain of the system, making decisions based on data collected from sensors and then directing actuators to perform specific actions.
- **Data base-**a specialized database system designed to handle the unique demands of data generated by Internet of Things (IoT) devices.
- **Web service** – act as a crucial bridge, enabling communication and data exchange between connected

devices and applications.

- **Analysis component** – crucial for transforming raw data from connected devices into actionable insights..
- **Application :** it's provide an interface that the user can use to control and monitor.

IoT Level-1 : Level-1 IoT systems has a single node that performs sensing and/or actuation, stores data, performs analysis and host the application. Suitable for modeling low cost and low complexity solutions where the data involved is not big and analysis requirement are not computationally intensive. An e.g., of IoT Level1 is **Home automation**. The system consist of a single node that allows controlling the lights and appliances in a home the device used in this system interfaces with the lights and appliances using electronic rely switches. The status information of each light or appliances is maintained in a local database. REST services deployed locally allow retrieving and updating the state of each lighter appliance in the status database. The controller service continuously monitors the state of each light or appliance by retrieving the light from the database.

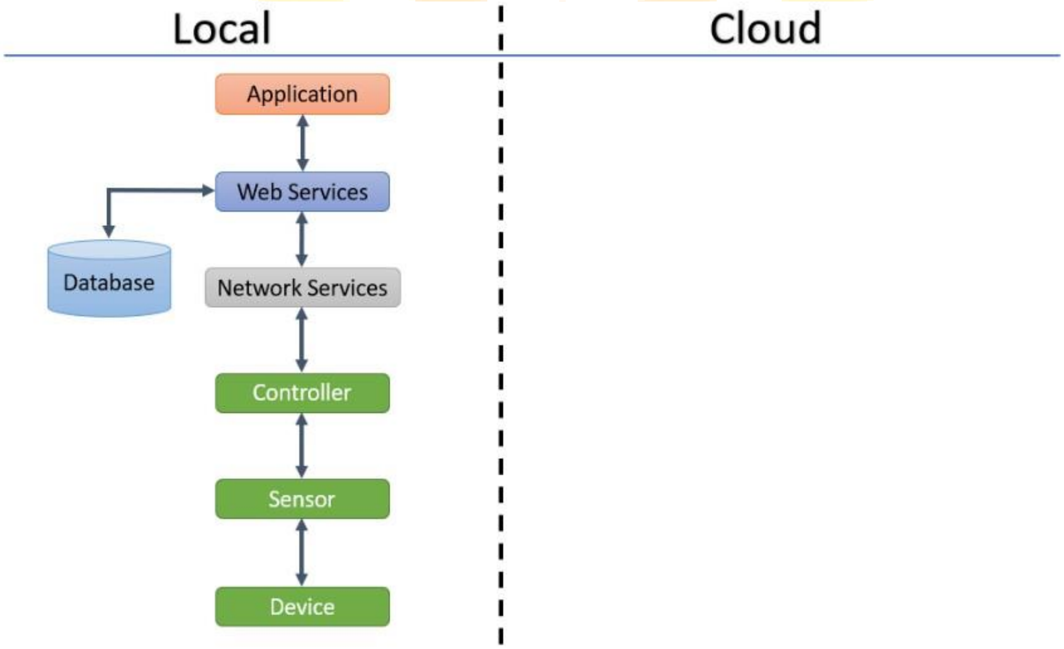


Figure 1.10 : IoT Level 1

IoT Level 2 : IoT Level2 has a single node that performs sensing and/or actuating and local analysis as shown in fig. Data is stored in cloud and application is usually cloud based. Level2 IoT systems are suitable for solutions where data are involved is big, however, the primary analysis requirement is not computationally intensive and can be done locally itself. An e,g., of Level2 IoT system for **Smart Irrigation.** The system consists of a single node that monitors the soil moisture level and controls the irrigation system. The device used system collects soil moisture data from sensors. The controller service continuously monitors the moisture level. A cloud based REST web service is used for storing and retrieving moisture data which is stored in a cloud database. A cloud based application is used for visualizing the moisture level over a period of time which can help in making decision about irrigation schedule.

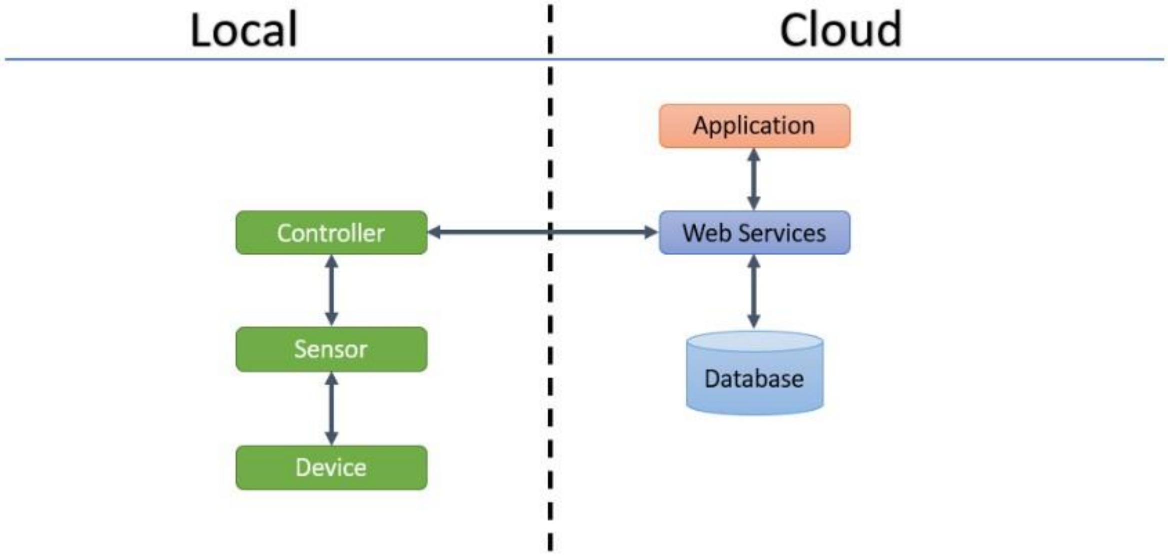


Figure 1.11 : IoT Level 2

IoT Level 3 : This System has a single node. Data is stored and analyzed in the cloud application is cloud based as shown in fig. Level3 IoT systems are suitable for solutions where the data involved is big and analysis requirements are computationally intensive. The system consists of a single node that monitors the vibration levels for the **package being shipped** . The device in this system uses **accelerometer and gyroscope sensor** for monitoring vibration levels. The controller serves in the sensor data to the cloud in a real time using a web socket service. The data is stored in the cloud and also visualizing the cloud based applications . The analysis components in the **cloud can trigger alerts if the vibration level becomes greater than the threshold.**

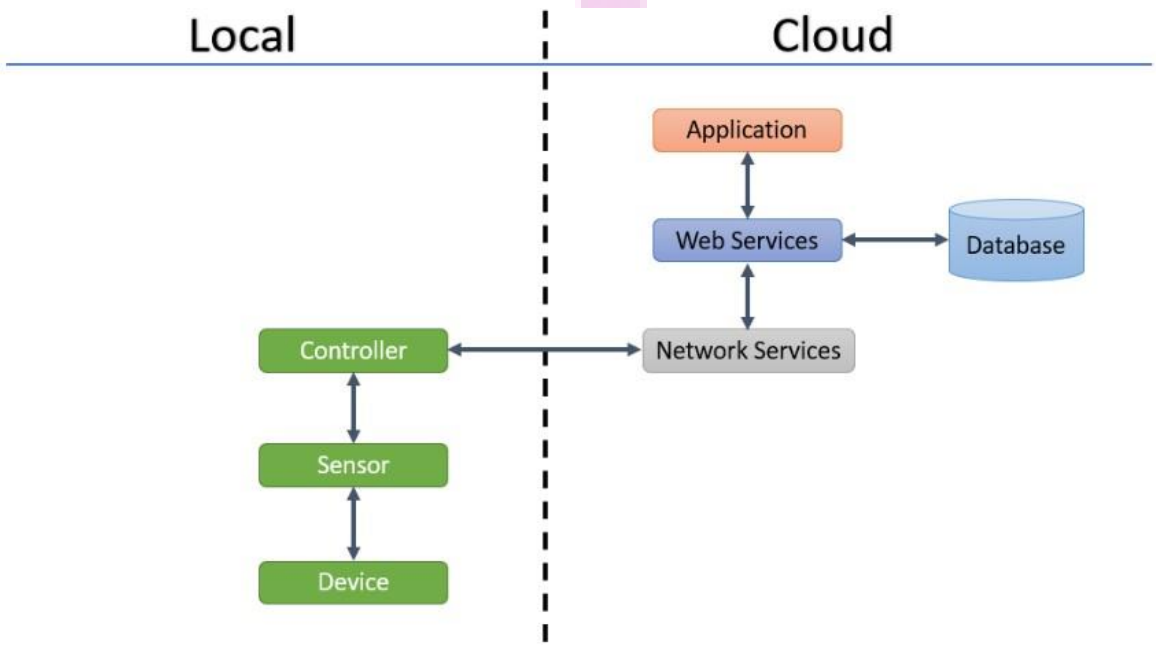


Figure 1.12: IoT Level 3

- **IoT Level 4**

This System has multiple nodes that perform local analysis. Data is stored in the cloud and application is cloud based as shown in fig. Level4 contains local and cloud based observer nodes which can subscribe to and receive information collected in the cloud from IoT devices. Level 4 IoT systems are suitable for solutions where multiple nodes are required, the data involved in big and the analysis requirements are computationally intensive. Example : IoT System for **Noise Monitoring**. The system consists of multiple nodes placed in different locations for monitoring noise levels in an area. The nodes in this example are equipped with sound sensors. **Nodes are independent** of each other. Each nodes runs its owner controller service that sends the data to the cloud . The data is stored in cloud database. The analysis of data c1ollected from a number of nodes is done in the cloud. A cloud based application is used for visualizing the aggregated data.

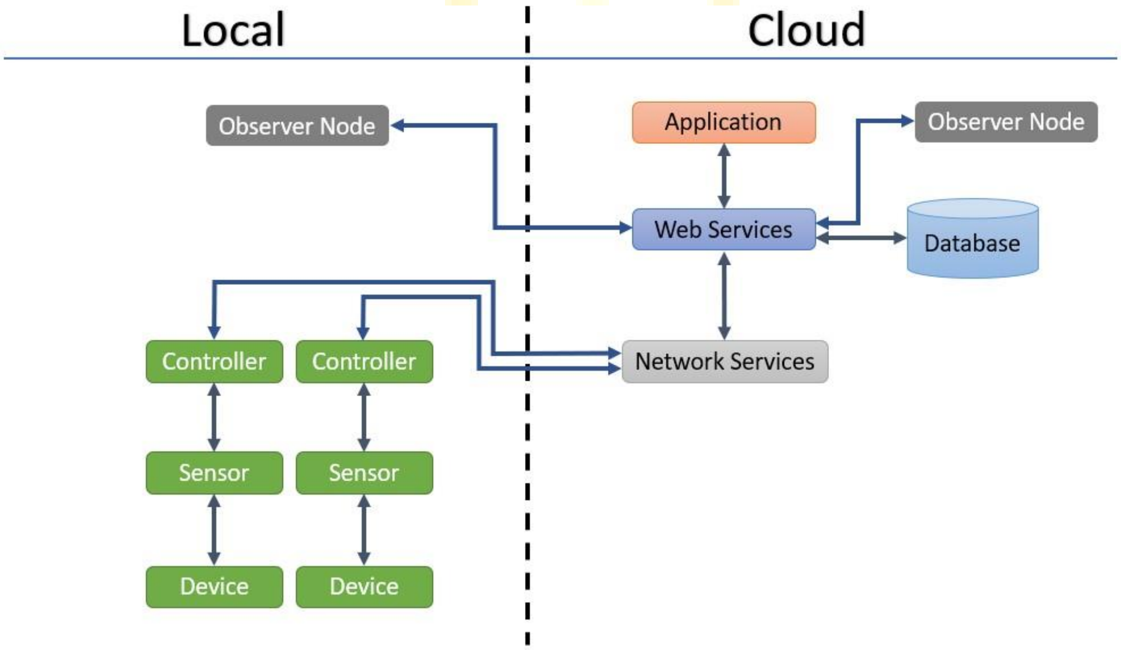


Figure 1.13: IoT Level 4

IoT Level 5

System has multiple end nodes and one coordinator node as shown in fig. The end nodes that perform sensing and/or actuation. Coordinator node collects data from the end nodes and sends to the cloud. Data is stored and analyzed in the cloud and application is cloud based. Level5 IoT systems are suitable for solution based on wireless sensor network, in which data are high intensive.

Example : IoT system for **Forest Fire Detection.** The system consists of multiple nodes placed in different locations for monitoring **temperature, humidity and CO2 level**s in a forest. The end nodes in this example are equipped with various sensors such as temperature, humidity and CO2. The coordinator node collects the data from the end nodes and act as a gateway that provides internet connectivity to the IoT system. The controller service on the coordinator device sends the collected data to the cloud. The data is stores in a cloud database. The analysis of data is done in the computing cloud to aggregate the data and make predictions. A cloud based applications is used for visualizing the data .

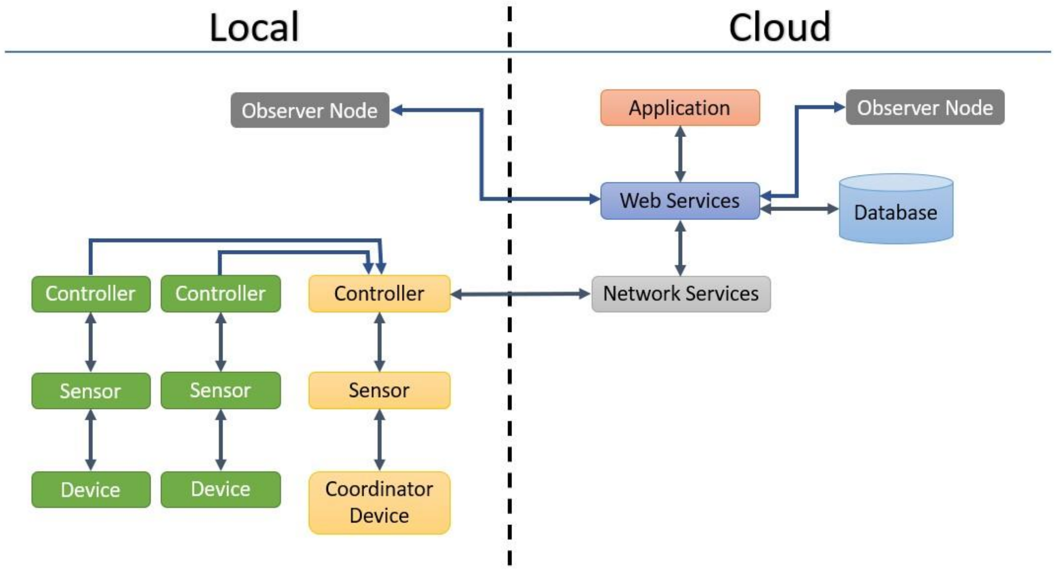


Figure 1.14 : IoT Level 5

IoT Level 6 : System has multiple independent end nodes that perform sensing and/or actuation and sensed data to the cloud. Data is stored in the cloud and application is cloud based as shown in fig. The analytics component analyses the data and stores the result in the cloud data base. The results are visualized with the cloud based applications. The centralized controller is aware of the status of all end nodes and sends control commands to the nodes.

Example weather monitoring system.

The system consists of multiple nodes placed in different locations for **monitoring temperatures, humidity and pressure in an area**. The end nodes are equipped with various sensors(such as temperature, humidity and pressure).the end nodes send the data to the cloud real-time using a web socket service. the data is stored in a cloud database. The analysis of data is done in a cloud to aggregate a data and make predictions. a cloud based application is used for visualizing the data.

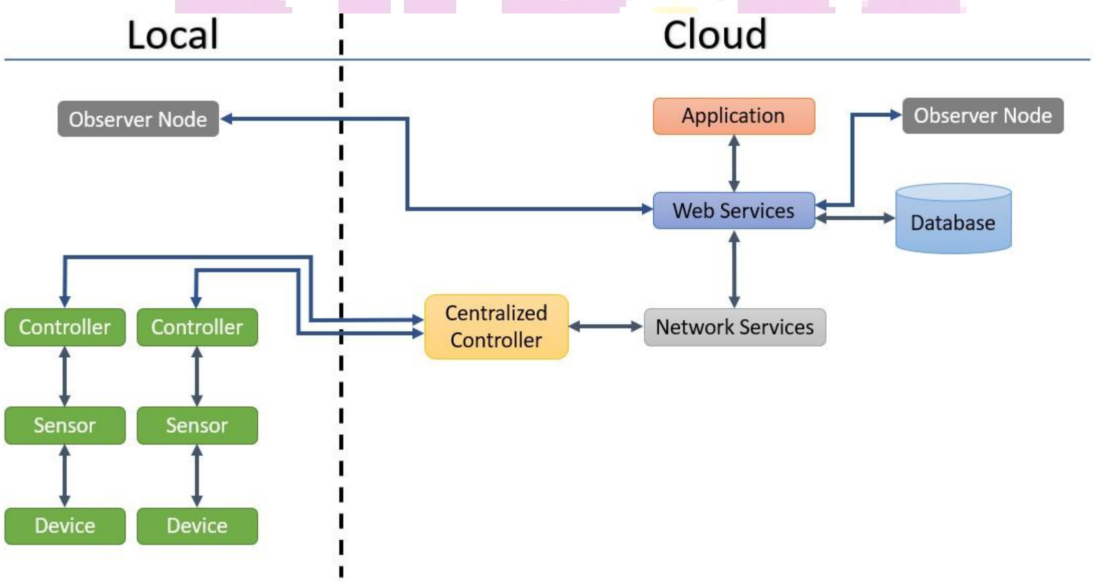


Figure1.15 : IoT Level 6

IoT sensing and actuation :

The basic science of sensing and actuation is based on the process of transduction. Transduction is the process of energy conversion from one form to another. A transducer is a physical means of enabling transduction. 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.

Table 1.1 : Functional Comparison of Transducers, Sensors, and Actuators

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 (measure flow velocity), Manometers (measure fluid pressure), Accelerometers (measure acceleration of a body), Gas sensors.	Motors (convert electrical energy to rotary motion), Force heads (impose a force), Pumps (convert electrical energy into fluid motion).

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.

For example, heat is converted to electrical signals in a temperature sensor, or atmospheric pressure is converted to electrical signals in a barometer. Here, a temperature sensor keeps on checking an environment for changes. In the event of a fire, the temperature of the environment goes up. The temperature sensor notices this change in the temperature of the room and promptly communicates this information to a remote monitor via the processor.

The various sensors can be classified based on:

1) power requirements

2) sensor output

3) property to be measured

Power Requirements: The way sensors operate decides the power requirements that must be provided for an

IoT implementation. 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 the requirements of power, sensors can be of two types.

1. **Active:** Active sensors **do not** require an **external circuitry** or mechanism to provide it with power. It **directly** responds to the external **environment** and converts it into an output signal. For example, a photodiode converts light into electrical impulses.
2. **Passive:** 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. For example, a thermistor's resistance can be detected by applying voltage difference across it or passing a current through it.

Sensor Output: The output of a sensor helps in deciding the additional components to be integrated with an IoT node or system. Typically, almost all modern-day processors are digital; digital sensors can be directly integrated to the processors.

The integration of analog sensors to these digital processors or IoT nodes requires additional interfacing mechanisms such as analog to digital converters (ADC), voltage level converters, and others. Sensors are broadly divided into two types based on the type of output.

(i) **Analog:** 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: 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.

(ii) **Digital:** These 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.

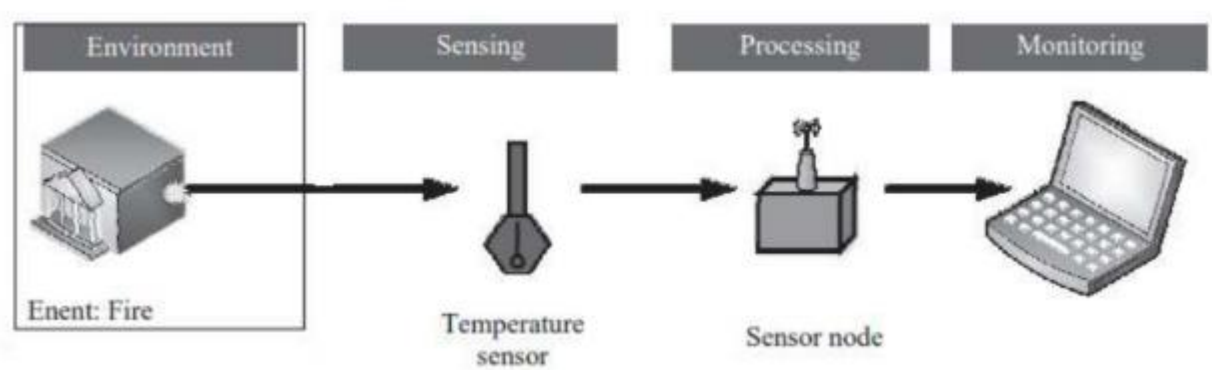


Figure 1.16 : The simple outline of a sensing task.

Measured Property: The property of the environment being measured by the sensors can be crucial in deciding the number of sensors in an IoT implementation.

Some properties to be measured do not show high spatial variations and can be quantified only based on temporal variations in the measured property, such as ambient temperature, atmospheric pressure, and others. Whereas some properties to be measured show high spatial as well as temporal variations such as sound, image, and others.

Depending on the properties to be measured, sensors can be of two types.

(i) Scalar: 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.

Examples of such measurable physical quantities include color, pressure, temperature, strain, and others.

(ii) Vector: Vector sensors are affected by the magnitude as well as the direction and/or orientation of the property they are measuring.

For example, an 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.

Fig shows the some commercially available sensor devices.

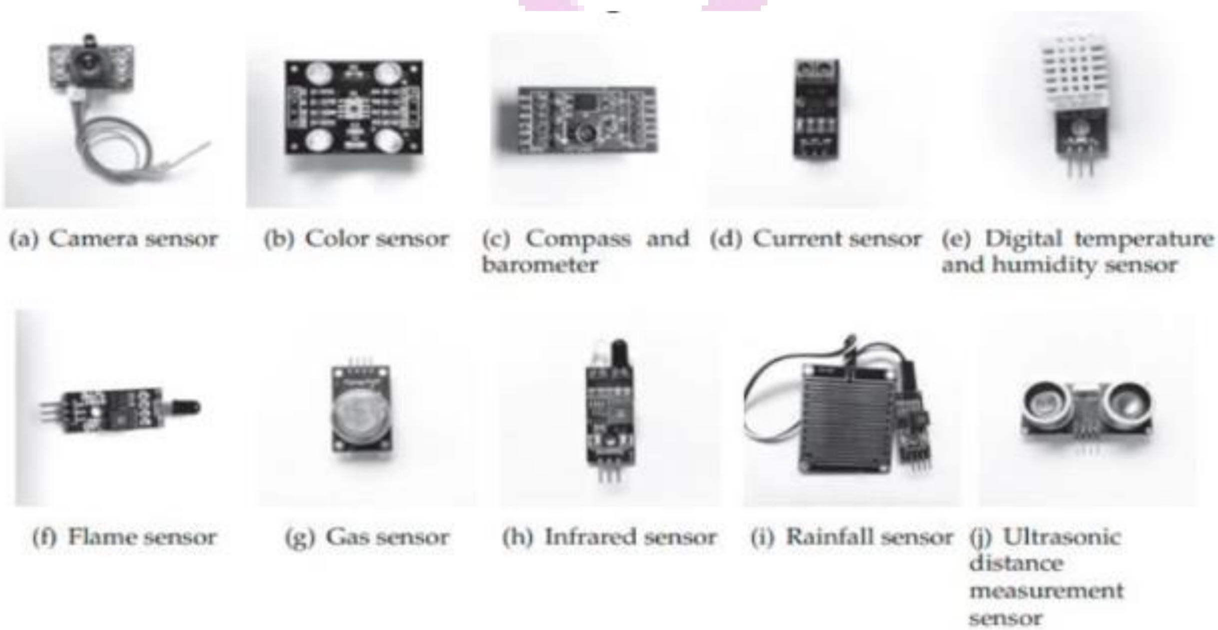


Figure 1.17 :The some commercially available sensor devices.

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 4) virtual sensing

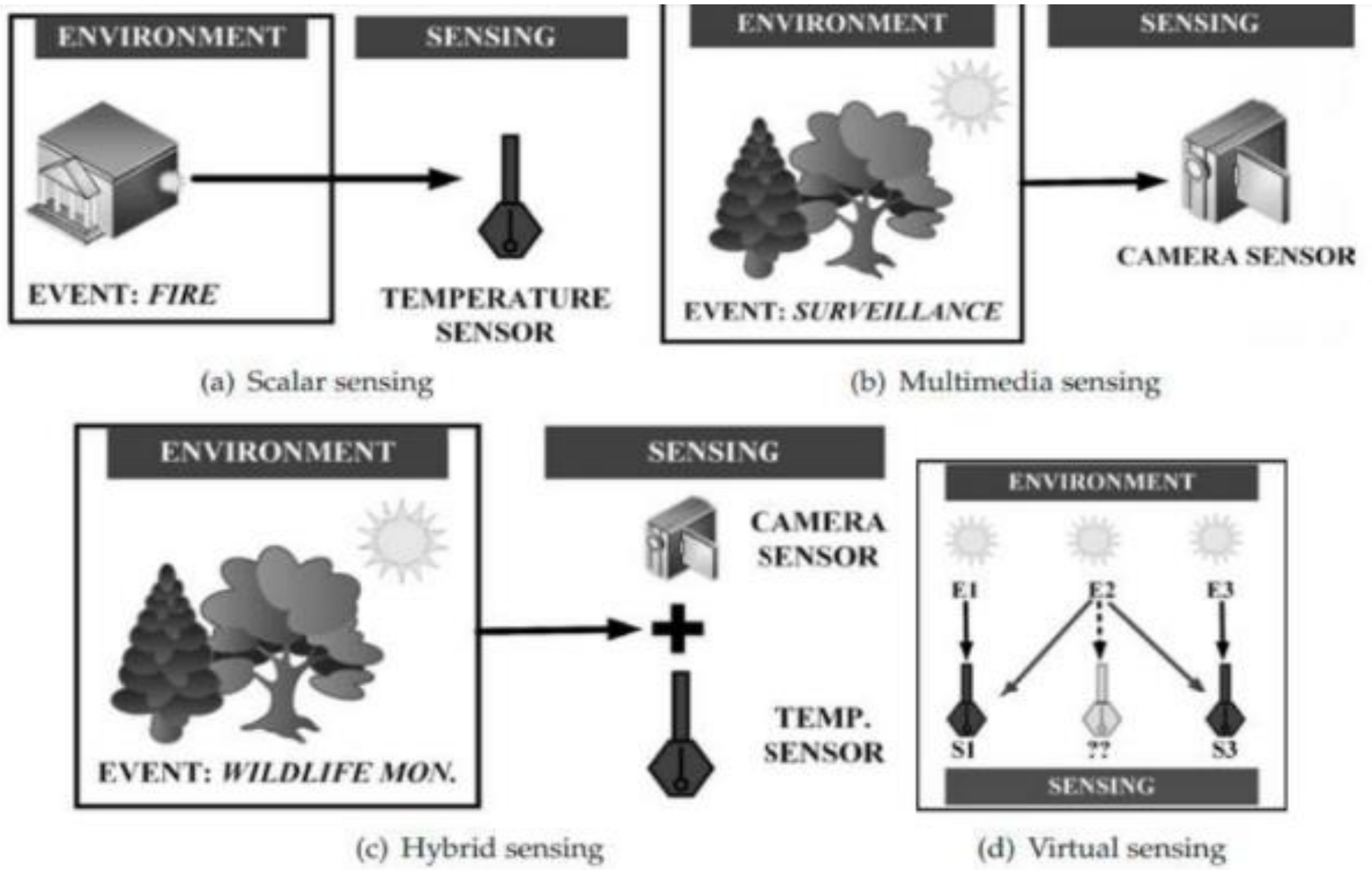


Figure 1.18 : Sensing Types

1) **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. Example ambient temperature, current, atmospheric pressure, rainfall, light, humidity, flux The sensors used for measuring these scalar quantities are referred to as scalar sensors, and the act is known as scalar sensing. Refer Figure for example of scalar sensors. A simple scalar temperature sensing of a fire detection event is shown in Figure .
2) **Multimedia Sensing:** Multimedia sensing encompasses the sensing of features that have a spatial variance property associated with the property of temporal variance. They are used for capturing the changes in amplitude of a quantifiable property concerning space (spatial) as well as time (temporal). Example images, direction, flow, speed, acceleration, sound, force, mass, energy, and momentum have both directions as well as a magnitude. 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. Figures and are vector sensors. A simple camera-based multimedia sensing using surveillance as an example is shown in Figure.
3) **Hybrid Sensing:** The act of using scalar as well as multimedia sensing at the same time is referred to as hybrid sensing. In sensors it is necessary to measure vector as well as scalar properties of an environment at the same time. For example, in an agricultural field, it is required to measure the soil

conditions at regular intervals of time to determine plant health. Sensors such as 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. However, this setup only determines whether the plant is getting enough water or not. There may be a host of other factors besides water availability, which may affect a plant's health. The additional inclusion of a camera sensor with the plant may be able to determine the actual condition of a plant by additionally determining the color of leaves. The aggregate information from soil moisture, soil temperature, and the camera sensor will be able to collectively determine a plant's health at any instant of time. Other examples are smart parking systems, traffic management systems. Figure shows an example of hybrid sensing, where a camera and a temperature sensor are collectively used to detect and confirm forest fires during wildlife monitoring.

4) **Virtual Sensing:** in agriculture domain, there is a need for very dense and large-scale deployment of sensor nodes spread over a large area for monitoring of parameters like measuring the soil moisture, soil temperature, and water level. For example, 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. This is the virtual sensing paradigm. Figure shows an example of virtual sensing.

Actuator type :

An actuator can be considered as a machine or system's component that can affect the movement or control of 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.

The 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. Figure shows the outline of a simple actuation system. A remote user sends commands to a processor. The processor instructs a motor controlled robotic arm to perform the commanded tasks accordingly. The processor is primarily responsible for converting the human commands into sequential machine-language command sequences, which enables the robot to move. The robotic arm finally moves the designated boxes, which was its assigned task.

Actuator type :

The actuators can be divided into seven classes: 1) Hydraulic 2) pneumatic 3) electrical 4) thermal/magnetic 5) mechanical 6) soft 7) shape memory polymers

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.

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.

Electric actuators: They 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. 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.

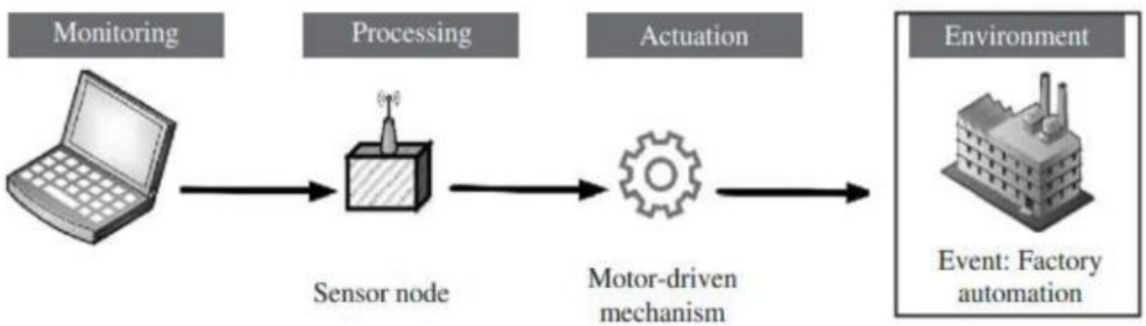


Figure 1.19 : Actuator Types

Figure 1.20 : Different types of Actuators

The actuators can be divided into seven classes: 1) Hydraulic 2) pneumatic 3) electrical 4) thermal/magnetic 5) mechanical 6) soft 7) shape memory polymers

Characteristics of Actuator :

- **Weight:**
- physical weight directly influence its application
  - Industrial application – heavier actuators
  - Drones- light weight and compact actuators.
- **Power rating:**
  - electrical power it can safely handle minimum and maximum power.
  - High power rating- can handle more demanding applications
  - Small actuators – servo motors-500mA- projects
  - Large actuators – servo motor- 25A-factories
  - - electrical vehicles.
- **Torque to weight ratio :**
  - How much torque/ force an actuator can generate relative to its weight.
  - This ratio indicates that the actuators that an actuators can expert more force without being too heavy.
  - High ratio- brusheless DC motors- Drones
  - Low ratio:- heavy duty industrial hydrolic actuators- construction equipment.