CHAPTER 3

Sensors, Actuators and Microcontrollers

3.1 INTRODUCTION

Measurement is an important subsystem in any major system, whether it may be a mechanical system or an electronic system. A measurement system consists of *sensors, actuators, transducers* and *signal processing devices*. The use of these elements and devices is not limited to measuring systems. These are also used in the systems which perform specific tasks, to communicate with the real world. The communication can be anything like reading the status of a signal from a switch or to trigger a particular output to light up an LED.

Sensors and actuators are two critical components of every closed loop control system. Such a system is also called a *mechatronics system*. A typical mechatronics system consists of a sensing unit, a controller, and an actuating unit. A sensing unit can be as simple as a single sensor or can consist of additional components such as filters, amplifiers, modulators, and other signal conditioners. The controller accepts the information from the sensing unit, makes decisions based on the control algorithm, and outputs commands to the actuating unit. The actuating unit consists of an actuator and optionally a power supply and a coupling mechanism. (See Figure 3.1).

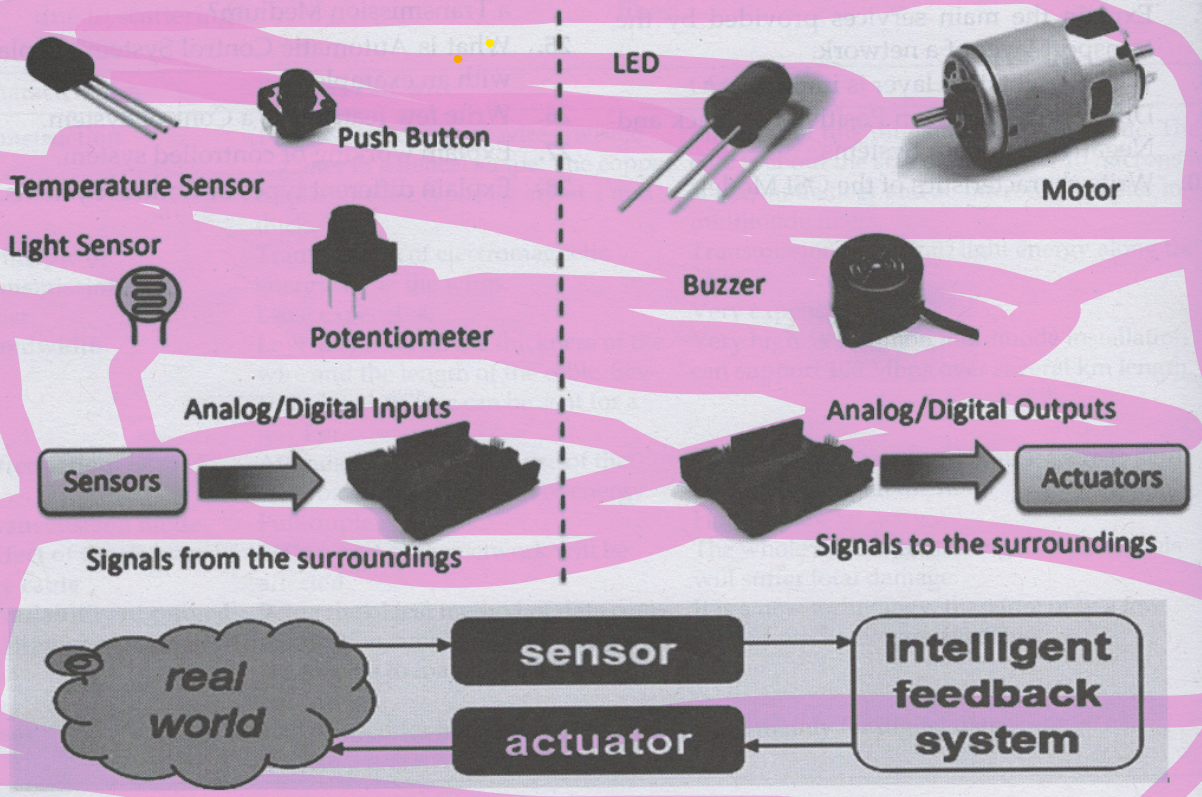

Figure 3.1 Sensor and Actuators

☞ *Linear and rotational position sensors are two of the most fundamental of all measurements used in a typical mechatronics system.*

Any device which has a sensor attached to it and has the capability to transfer data from one device to another through the Internet is known as an *IoT device*. IoT devices consist of softwares, wireless sensors, actuators and computer devices. They are connected to a particular device that operates with the help of Internet, enabling the data to transfer among the devices or people. For instance, IoT systems in your car detect the heavy flow of traffic and send a message automatically to the person waiting for you.

3.2 SENSOR

Sensors are devices that perform input function in a system as they sense the changes in a quantity. The best example of a sensor is mercury thermometer. Here, the quantity that is being measured is heat or temperature. The measured temperature is converted to a readable value on the calibrated glass tube, based on the expansion and contraction of liquid mercury. So, Sensor when exposed to a physical phenomenon (temperature, displacement, force, etc.) produces a proportional output signal (electrical, mechanical, magnetic, etc.). Sensor measures, evaluates and gathers data. The Internet of Things really comes together with the connection of sensors and machines. Due to physical objects getting connected and controlled digitally and centrally with wireless infrastructure, there is a large amount of automation and control in the workings. Without human intervention, the machines are able to communicate with each other leading to faster and timely output. Thus, provide better, more cost effective service through real-time higher solution visibility/capture and analysis of real-time product performance information. This is useful for efficient decision making. For example, doctors supervising patients can monitor their medicine intake as well as measure blood pressure, sugar levels and alert them when something goes wrong to their patients online.

In the aspect of energy conservation, household appliances can suggest optimal setting based on the user's energy consumption like turning the ideal temperature just before the owner arrives home as well as turning on and off the lights whenever the owner is out on vacation just to create the impression that somebody is still left inside the house to prevent burglars from attempting to enter. Smart refrigerators, on the other hand, can suggest food supplies that are low on inventory and needs immediate supply.

☞ *A sensor is a device which can quantitatively measure a certain physical quantity and converts a physical quantity into an electrical signal.*

The term *transducer* is often used synonymously with sensors. However, ideally, a sensor is a device that responds to a change in the physical phenomenon. On the other hand, a transducer is a device that converts one form of energy into another form of energy i.e., it converts a signal from one physical form to a corresponding signal having a different physical form. Therefore, it is an energy converter. Sensors are transducers when they sense one form of energy input and output in a different form of energy. For example, a thermocouple responds to a temperature change (thermal energy) and outputs a proportional change in electromotive force (electrical energy). Therefore, a thermocouple can be called a sensor and or transducer.

Transducers are classified as Active Transducers and Passive Transducers based on the source of energy.

In *Active Transducers*, the energy from the input is used as a control signal in the process of transferring energy from power supply to proportional output. For example, a strain gauge is an active transducer, in which the strain is converted into resistance.

In *Passive Transducers*, the energy from the input is directly converted into the output. For example, a thermocouple is a passive transducer, where the heat energy, which is absorbed from input, is converted into electrical signals (voltage).

☞ *A transducer is a device which converts one physical quantity to another from of physical quantity.*

3.3 CLASSIFICATION OF SENSORS

All the sensors can be classified into two types based on the power or signal requirement. They are active sensors and passive sensors.

Active sensors are the type of sensors that produces output signal with help of external excitation supply. In order to operate active sensors, require power signal from an external source. This signal is called an excitation signal, and based on this excitation signal the sensor produces output. Strain gauge is an example of active sensor.

☞ *Active sensors is also called as Self Generating Sensors.*

Passive sensors are the type of sensors that produces output signal without the help of external excitation supply. They do not need any extra stimulus or voltage. All the power required by a passive sensor is obtained from the measurand. A thermocouple is a passive sensor which generates a voltage value corresponding to the heat, applied. It does not require any external power supply.

Furthermore, sensors are classified as analog or digital based on the type of output signal. *Analog sensors* produce an analog output i.e. a continuous output signal with respect to the quantity being measured and typically require analog-to-digital conversion before feeding to the digital controller. The quantity that is being measured like speed, temperature, pressure, displacement, strain, etc. are all continuous in nature and hence they are analog quantities. For example, accelerometers, speed sensors, pressure sensors, light sensors, temperature sensors etc.

☞ *The sensor that produces continuous signal with respect to time with analog output is called as Analog sensors.*

Digital sensors on the other hand work with discrete or digital data that can be directly interfaced with the digital controller. The output of a digital sensor has only two states, namely 'ON' and 'OFF'. ON is logic 1 and OFF is logic 0. A push button switch is the best example of a digital sensor. In general, the accuracy of a digital sensor is high when compared to an analog sensor.

☞ *Digital sensors produce digital outputs that can be directly interfaced with the digital controller.*

Often, the digital outputs are produced by adding an analog-to-digital converter to the sensing unit. If many sensors are required, it is more economical to choose simple analog sensors and interface them to the digital controller equipped with a multi-channel analog-to-digital converter.

There are some sensors which are capable of sensing a physical quantity to convert it to other form and also sense the output signal form to get back the quantity in original form known as *Inverse sensors*. For example a piezoelectric crystal when subjected to vibration generates voltage. At the same time when a piezo crystal is subjected to varying voltage they begin to vibrate. This property make them suitable to use in microphone and speakers.

The other type of classification is based on the means of detection used in the sensor. Some of the means of detection are Electric, Biological, Chemical, Radioactive etc.

There are different types of sensors used to measure the physical properties like heartbeat & pules, Speed, Heat transfer, temperature etc. Some of the most commonly used sensors and transducers for different stimuli (the quantity to be measured) are:

a. For sensing presence of an object, are proximity sensor implemented using different techniques like Optical (like Infrared or Laser), Ultrasonic, Hall Effect, Capacitive, etc. Proximity Sensors are used in Mobile Phones, Cars (Parking Sensors), industries (object alignment), Ground Proximity in Aircrafts, etc.
b. For sensing light, the input devices or sensors are photo diode, photo transistor, light dependent resistor and solar cells. The output devices or actuators are LEDs, displays, lamps and fiber optics. Infrared Sensor are light based sensor that are used in various applications like Proximity and Object Detection. IR Sensors are used as proximity sensors in almost all mobile phones, Robots, Industrial assembly, automobiles etc. IR Sensors are used to turn on street lights.

c. For sensing temperature, the sensors are thermistor, thermocouple, resistance temperature detectors (RTDs) and thermostat. Based on the requirement, different types of sensors are used for measuring temperature in different applications. The actuators are heaters. A temperature sensor, senses the temperature i.e., it measures the changes in the temperature. Temperature sensors are used everywhere like computers, mobile phones, automobiles, air conditioning systems, industries etc.
d. For sensing position, the input devices are potentiometer, proximity sensor, and differential transformer. The output devices are motor and panel meter. Accelerometer is a type of sensor that is used to detect changes in position, velocity, and vibration by sensing motion. It can be either analog or digital type. Gyroscope sensor to sense and determine the orientation with the help of Earth's gravity i.e. it measures the angular velocity.
e. For sensing pressure, the sensors are strain gauge and load cell. The actuators are lifts and jacks and electromagnetic vibrations. Pressure sensor works on the application of input voltage and pressure value. It produces an analog output voltage.
f. For sensing sound, the input devices are microphones and output devices are loudspeakers and buzzers.
g. For sensing speed, the sensors used are tachogenerator and Doppler Effect sensors. The actuators are motors and brakes. An Ultrasonic Sensor can be used to measure distance as well as velocity of an object. An Ultrasonic Sensor works based on the properties of the sound waves with frequency greater than that of the human audible range.

3.4 TYPES OF SENSORS

3.4.1 Position

A position sensor measures the position of an object; the position measurement can be either in absolute terms (absolute position sensor) or in relative terms (displacement sensor). Position sensors can be linear, angular, or multi-axis. (See Figure 3.2).

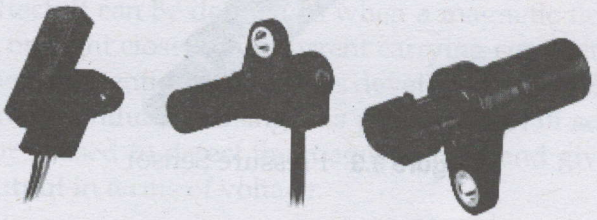

Figure 3.2 Position and Speed Sensor

3.4.2 Occupancy and motion

Occupancy sensors detect the presence of people and animals in a surveillance area, while motion sensors detect movement of people and objects. The difference between the two is that occupancy sensors will generate a signal even when a person is stationary, while a motion sensor will not. For example, Electric eye, Radar.

3.4.3 Velocity and Acceleration

Velocity (speed of motion) sensors may be linear or angular, indicating how fast an object moves along a straight line or how fast it rotates.

3.4.4 Force

Force sensors detect whether a physical force is applied and whether the magnitude of force is beyond a threshold. For example, force gauge, viscometer, tactile sensor (touch sensor).

3.4.5 Pressure

Pressure sensors are related to force sensors and measure the force applied by liquids or gases. Pressure is measured in terms of force per unit area. These sensors make it possible to create IoT systems that monitor systems and devices that are pressure propelled. With any deviation from standard pressure range, the device notifies the system administrator about any problems that should be fixed. (See Figure 3.3). For example, Barometer, Bourdon gauge, Piezometer.

Figure 3.3 Pressure Sensor

3.4.6 Flow

Flow sensors detect the rate of fluid flow. They measure the volume (mass flow) or rate (flow velocity) of fluid that has passed through a system in a given period of time. For example, Anemometer, Mass flow sensor, Water meter etc.

3.4.7 Acoustic

Acoustic sensors measure sound levels and convert that information into digital or analog data signals. (See Figure 3.4). For example, Microphone, Geophone, Hydrophone.

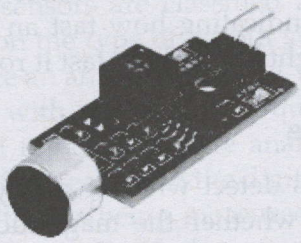

Figure 3.4 Microphone and Sound Sensor

3.4.8 Humidity

Humidity is defined as the amount of water present in the surrounding air. Humidity sensors detect humidity (amount of water vapor) in the air or a mass. (See Figure 3.5). Humidity Sensor is one of the most important devices that has been widely in consumer, industrial, biomedical, and environmental applications for measuring and monitoring Humidity. For example, Hygrometer, Humistor, Soil moisture sensor. (See Figure 3.6).

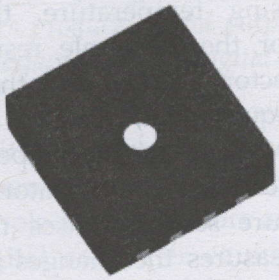

Figure 3.5 Humidity Sensor

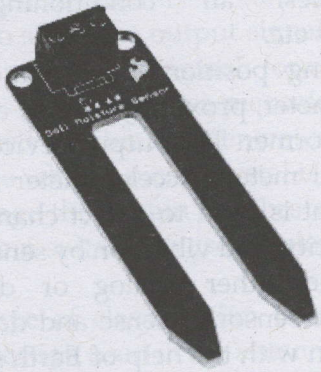

Figure 3.6 Soil and Moisture Sensor

3.4.9 Light

Light sensors detect the presence of light (visible or invisible). For example, Infrared sensor, Photodetector, Flame detector.

3.4.10 Radiation

Radiation sensors detect radiations in the environment. Radiation can be sensed by scintillating or ionization detection. For example, Scintillator, Neutron detector.

3.4.11 Temperature

Temperature sensors measure the amount of heat or cold that is present in a system. They can be broadly of two types: *contact* and *non-contact*. Contact temperature sensors need to be in physical contact with the object being sensed. Non-contact sensors do not need physical contact, as they measure temperature through convection and radiation. For example, Thermometer, Calorimeter, Temperature gauge.

3.4.12 Chemical

Chemical sensors measure the concentration of chemicals in a system. Chemical sensors are applied in a number of different industries. Their goal is to indicate changes in liquid or to find out air chemical changes. They play an important role in bigger cities, where it is necessary to track changes and protect the population. For example, Breathalyser, Smoke detector etc.

3.4.13 Image

Image sensors are instruments which are used to convert optical images into electronic signals for displaying or storing files electronically. The major use of image sensor is found in digital camera & modules, medical imaging and night vision equipment, thermal imaging devices, radar, sonar, media house, biometric etc.

3.4.14 Optical

Optical sensors measures the physical quantity of light rays and convert it into electrical signal which can be easily readable by user or an electronic instrument/device is called optical sensor. For example, Photodetector, Fiber Optics, Pyrometer etc.

3.4.15 Gas

Gas sensor plays a major role in detecting the gas leakage. These gas sensors are classified into various types based on the type of gas that to be detected. They are used in numerous industries such as manufacturing, agriculture and health and used for air quality monitoring, detection of toxic or combustible gas, hazardous gas monitoring in coal mines, oil & gas industries, chemical laboratory research.

3.4.16 Ultrasonic

Ultrasonic means the range of the frequencies. Its range is greater than audible range (>20 kHz) so even it is switched on, you can't sense these sound signals. Only specific speakers and receivers can sense those ultrasonic waves. It is used to detect the presence or to measure the distance of targets similar to radar or sonar.

3.4.17 Hall

Hall Sensor is the sensor which works on the Hall Effect. It can be defined as when a magnetic field is brought close to the current carrying conductor then a potential difference is developed across the given conductor. Using this property a Hall sensor is used to detect the magnetic field and gives output in terms of voltage.

3.4.18 Infrared sensors (IR)

An infrared sensor is a sensor which is used to sense certain characteristics of its surroundings by either emitting or detecting infrared radiation. It is also capable of measuring the heat being emitted by the objects. They are now used in a variety of IoT projects, especially in Healthcare as they make monitoring of blood flow and blood pressure simple. They are even used in a wide array of regular smart devices such as smartwatches and smartphones as well.

3.4.19 Biosensors

A Biosensor is an analytical device that detects changes in Biological processes and converts them into an electrical signal. Biosensors detect various biological elements such as organisms, tissues, cells, enzymes, antibodies, and nucleic acids. The main area of interest of Biosensor is the Medicine, Clinical and Diagnostics applications. Electrochemical based Biosensors are commonly used in biochemical labs and clinics to monitor and measure glucose levels as well as lactic acid. Glucometers are a type of Biosensors, which measure the concentration of glucose in blood. Apart from the desired medicine and health based applications, Biosensors have also found critical applications in several other fields like industrial processing, agriculture, food processing, pollution control etc. (See Figure 3.7).

Figure 3.7 A Biosensor

3.4.20 Micro and Nanosensors

Microsensors (sometimes also called MEMS) are the miniaturized version of the conventional macrosensors with improved performance and reduced cost. Silicon micromachining technology has helped the development of many microsensors and continues to be one of the most active research and development topics in this area.

Vision microsensors have found applications in medical technology. A fiberscope of approximately 0.2 mm in diameter has been developed to inspect flaws inside tubes. Another example is a microtactile sensor, which uses laser light to detect the contact between a catheter and the inner wall of blood vessels during insertion that has sensitivity in the range of 1 mN. Similarly, the progress made in the area of nanotechnology has inspired the development of nanosensors. These are relatively new sensors that take one step further in the direction of miniaturization and are expected to open new ways for sensing applications.

All the above discussed sensors are included in a variety of devices and solutions. The trend is moving towards multi-sensor platforms that incorporate several sensing elements. For example, the standard for the next-generation of personalized self-tracking products appears to be some mix of an accelerometer, GSR sensor, temperature sensor, and heart rate sensor (from which heart rate variability may be calculated).

Let us see the various types of sensors that are available in the market and discuss their functionality, working, applications etc. You need to select the desired sensor based on your project or application.

IR LED

It is also called as IR Transmitter. It is used to emit Infrared rays. The range of these frequencies are greater than the microwave frequencies. The rays generated by an infrared LED can be sensed by Photodiode. The pair of IR LED and photodiode is called IR Sensor.

Photo Diode (Light Sensor)

It is a semiconductor device which is used to detect the light rays and mostly used as IR Receiver. Using a photodiode you can build a basic automatic street lamp which glows when the sunlight intensity decreases.

LDR (Light Dependent Resistor)

It is the resistor that depends upon the light intensity. It works on the principle of photoconductivity which means the conduction due to the light. When light falls on the LDR, its resistance decreases and acts similar to a conductor.

Thermistor (Temperature Sensor)

It is a temperature sensitive resistor that changes its physical resistance with the change in temperature. When the temperature increases the resistance decreases. So, the thermistor's resistance can be varied with the rise in temperature which causes more current flow through it. This change in current flow can be used to determine the amount of change in temperature.

Thermocouple (Temperature Sensor)

These are voltage devices that indicate temperature measuring with a change in voltage. As temperature goes up, the output voltage of the thermocouple rises.

Strain Gauge (Pressure/Force Sensor)

A strain gauge is used to detect pressure when a load is applied. It works on the principle of resistance, as the resistance is directly proportional to the length of the wire and is inversely

proportional to its cross-sectional area. The same principle is applied here to measure the load. On a flexible board, a wire is arranged in a zig-zag manner so, when the pressure is applied to that particular board, it bends in a direction causing the change in overall length and cross-sectional area of the wire. This leads to change in resistance of the wire. The resistance thus obtained is very minute (few ohms) which can be determined with the help of the wheatstone bridge. The strain gauge is placed in one of the four arms in a bridge with the remaining values unchanged. Therefore, when the pressure is applied to it as the resistance changes the current passing through the bridge varies and pressure can be calculated. Strain gauges are majorly used to calculate the amount of pressure that an airplane wing can withstand and it is also used to measure the number of vehicles allowable on a particular road etc.

Load Cell (Weight Sensor)

Load cells are similar to strain gauges which measure the physical quantity like force and give the output in form of electrical signals. When some tension is applied on the load cell it structure varies causing the change in resistance.

Potentiometer

A potentiometer is used to detect the position. It generally has various ranges of resistors connected to different poles of the switch. A potentiometer can be either rotary or linear type.

Encoder

To detect the change in the position an encoder can also be used. It has a circular rotatable disk-like structure with specific openings in between such that when the IR rays or light rays pass through it only a few light rays get detected.

Accelerometer (Tilt Sensor)

An accelerometer sensor can sense the tilt or movement of it in a particular direction. It works based on the acceleration force caused due to the earth's gravity.

Microphone (Sound Sensor)

Microphone can be seen on all the smartphones or mobiles. It can detect the audio signal and convert them into small voltage (mV) electrical signals. A microphone can be of many types like condenser microphone, crystal microphone, carbon microphone etc., each type of microphone work on the properties like capacitance, piezoelectric effect, resistance respectively.

Proximity sensor

A device that detects the presence or absence of a nearby object, or properties of that object, and converts it into signal which can be easily read by user or a simple electronic instrument without getting in contact with them.

Photoelectric Sensors

Photoelectric sensor is made up of light-sensitive parts and uses a beam of light to detect the presence or absence of an object. It is an ideal alternative of inductive sensors. And used for long distance sensing or to sense non-metal object.

3.5 CRITERIA TO CHOOSE A SENSOR

A number of static and dynamic factors must be considered in selecting a suitable sensor to measure the desired physical parameter. Following is a list of typical factors:

a. **Range:** Difference between the maximum and minimum value of the sensed parameter. It indicates the limits of the input in which it can vary.
b. **Resolution:** The smallest change the sensor can differentiate.
c. **Accuracy:** The accuracy of the sensor is a key factor in selecting a sensor. It is the difference between the measured value and the true value.
d. **Precision:** Ability to reproduce repeatedly with a given accuracy.
e. **Sensitivity:** Sensitivity is a relationship between input physical signal and output electrical signal. It is the ratio of change in output of the sensor to unit change in input value that causes change in output.

f. **Ruggedness:** It is a measure of the durability when the sensor is used under extreme operating conditions.
g. **Linearity:** Percentage of deviation from the best-fit linear calibration curve. It is specified in terms of percentage of non-linearity which indicates deviation of curve of actual measurement from the curve of ideal measurement.
h. **Hysteresis:** The hysteresis is defined as the maximum difference in output at any measurable value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter.
i. **Response time:** The time lag between the input and output.
j. **Bandwidth:** Frequency at which the output magnitude drops.
k. **Resonance:** The frequency at which the output magnitude peak occurs.
l. **Operating temperature:** The range in which the sensor performs as specified.
m. **Signal-to-noise ratio:** Ratio between the magnitudes of the signal and the noise at the output.
n. **Type of Sensing:** The parameter that is being sensed like temperature or pressure.
o. **Power Consumption:** The power consumed by the sensor will play an important role in defining the total power of the system.
p. **Cost:** Depending on the cost of application, a low cost sensor or high cost sensor can be used.
q. **Repeatability:** It is the ability of the sensor to produce same output for different applications with same input value.
r. **Stability:** It is the ability of the sensor to produce the same output for constant input over a period of time.

3.6 ACTUATORS

Actuators convert information or energy from sensors into action by transmitting it to another power mechanism or system, such as heating or cooling a room (See Figure 3.8). No human intervention need be involved in the decision-making process. Actuators are basically the muscle behind a mechatronics system that accepts a control command (mostly in the form of an electrical signal) and produces a change in the physical system by generating force, motion, heat, flow, etc. Normally, the actuators are used in conjunction with the power supply and a coupling mechanism. The power unit provides either AC or DC power at the rated voltage and current. The coupling mechanism acts as the interface between the actuator and the physical system (See Figure 3.9). Typical mechanisms include rack and pinion, gear drive, belt drive, lead screw and nut, piston, and linkages.

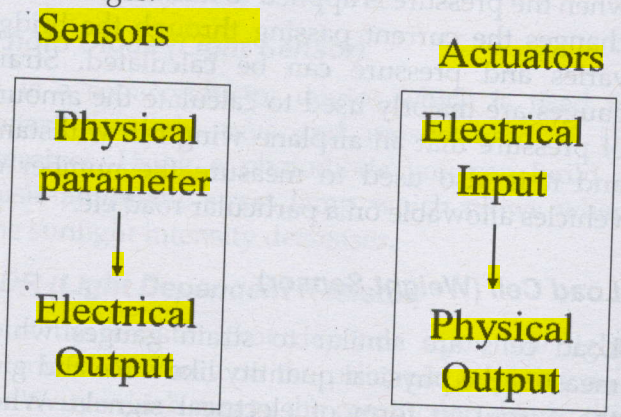

Figure 3.8 Sensor and Actuators

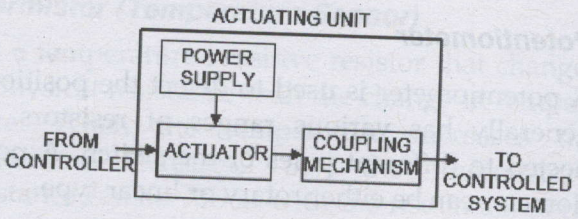

Figure 3.9 A Typical Actuating Unit

☞ *An actuator is a device that coverts an input energy into motion or mechanical energy.*

3.7 CLASSIFICATION OF ACTUATORS

An actuator is a type of motor for moving or controlling a mechanism or system. (See Figure 3.10) It is operated by a source of energy, typically electric current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into motion. An actuator is the mechanism by

which a control system acts upon an environment. Actuators can be classified based on the type of energy. They are essentially of *Electrical, Electromechanical, Electromagnetic, Hydraulic,* or *Pneumatic type*. The new generations of actuators include *Smart Material Actuators, Micro-actuators,* and *Nanoactuators*.

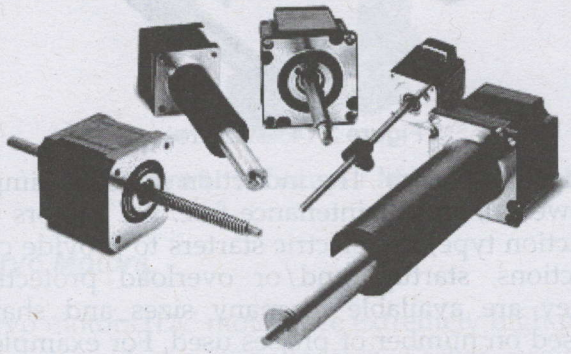

Figure 3.10 Different types of Actuator

Actuators can also be classified as binary and continuous based on the number of stable-state outputs. A relay with two stable states is a good example of a binary actuator. Similarly, a stepper motor is a good example of continuous actuator. When used for a position control, the stepper motor can provide stable outputs with very small incremental motion.

An actuator is something that converts energy into motion. Two basic motions are linear and rotary. Linear actuators convert energy into straight line motions, typically for positioning applications, and usually have a push and pull function. Some linear actuators are unpowered and manually operated by use of a rotating knob or handwheel. Rotary actuators convert energy to provide rotary motion.

An actuator requires a control signal and source of energy. An actuator typically is a mechanical device that takes energy usually energy that is created by air, electricity or liquid and converts it into some kind of motion. When the control signal is received, the actuator responds by converting the energy into mechanical motion. That motion can be in virtually any form, such as blocking, clamping or ejecting. Actuators typically are used in manufacturing or industrial applications and might be used in devices such as motors, pumps, switches and valves for *on* and *off* control, to control pressure, and to regulate flow.

3.7.1 Electrical Actuators

Electrical Actuator is an electromechanical device that converts electrical energy into mechanical energy. Most electric actuators operate through the interaction of magnetic fields and current-carrying conductors to generate force. Electrical switches are the choice of actuators for most of the on-off type control action. There are many designs of electric actuators and this depends on their function in the engine that they are installed in. Since no oil is involved, electrical actuators are considered to be one of the cleanest and readily available forms of actuators. Electric actuators are found in applications as diverse as industrial fans, blowers and pumps, machine tools, household appliances, power tools, and disk drives. (See Figure 3.11).

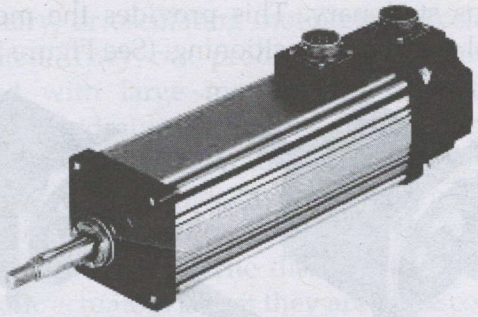

Figure 3.11 Electrical Actuator

3.7.2 Electromechanical Actuators

The most common electromechanical actuator is a motor that converts electrical energy to mechanical motion. (See Figure 3.12). Motors are the principal means of converting electrical energy into mechanical energy in industry. Broadly they can be classified as *DC Motors, AC Motors, Stepper Motors,* and *Servo Moter*:

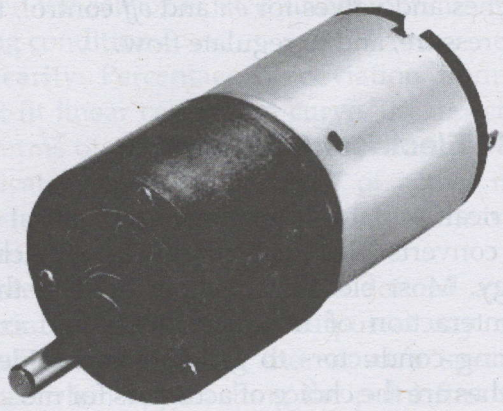

Figure 3.12 A Motor

DC Motors

DC motors, move at variable speeds. In DC motors, the coil of wire (rotor) assembly rotates in an attempt to align itself with the stator assembly but is prevented by a part known as the commutator. At the precise moment, the commutator switches the rotor field while the stator assembly remains stationary. This provides the means to control speed and positioning. (See Figure 3.13).

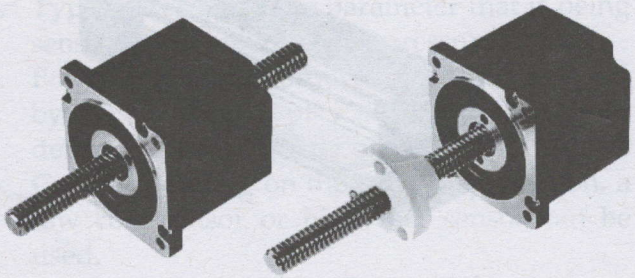

Figure 3.13 DC Motor

AC Motors

AC motors, which commonly move at a constant speed. AC motors are the most popular since they use standard AC power, do not require brushes and commutator, and are therefore less expensive. The speed of an AC motor is determined by the frequency of voltage applied by the number of magnetic poles. AC motors can be further classified as the *Induction Motors*, *Synchronous Motors*, and *Universal Motors* according to their physical construction. (See Figure 3.14).

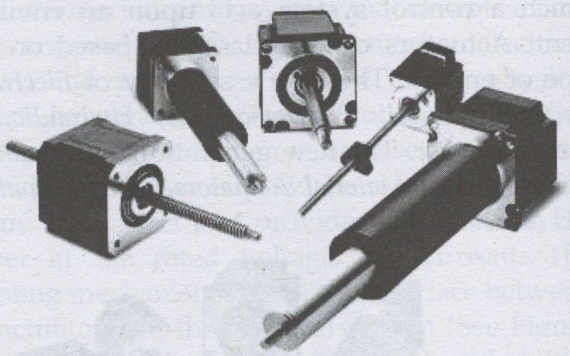

Figure 3.14 AC Motor

Induction Motors The induction motor is simple, powerful, and maintenance free. AC Motors (induction type) use electric starters to provide connections, startup, and/or overload protection. They are available in many sizes and shapes based on number of phases used. For example, a three-phase induction motor is used in large-horsepower applications, such as pump drives, steel mill drives, hoist drives, and vehicle drives. The two-phase servomotor is used extensively in position control systems. Single-phase induction motors are widely used in many household appliances.

Synchronous Motors The synchronous motor is one of the most efficient electrical motors in industry, so it is used in industry to reduce the cost of electrical power. In addition, synchronous motors rotate at synchronous speed, so they are also used in applications that require synchronous operations.

☞ *Within the AC motor are the stator assembly and the rotor assembly. If the AC motor is an induction motor, the rotor rotates slower than the stator's field. If it is a synchronous motor, the rotor and the stator move in synchronization.*

Universal Motors The universal motors operate with either AC or DC power supply. They are normally used in fractional horsepower application. The DC universal motor has the highest horsepower-per-pound ratio, but has a relatively short operating life.

Stepper Motors

Stepper motors (DC motor) are electromechanical, converting a digital pulse into rotational movement or displacement. With the rapid progress in low cost and high frequency solid-state drives,

they are finding increased applications. The stepper motors are used widely in industrial control applications and horsepower applications. Stepper motors are not good for varying loads and are typically not energy efficient, they are great for constant loads and positional accuracy. (See Figure 3.15).

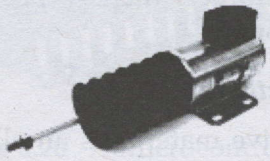

Figure 3.15 Stepper Motor

Servo Motors

Servo motors (DC motor) are extremely high performing with few weaknesses. Servos provide speed control and position accuracy due to its feedback device, are small, and priced relatively low. (See Figure 3.16).

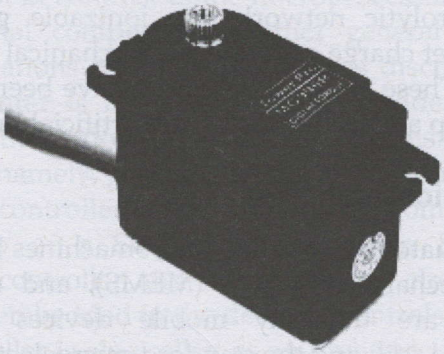

Figure 3.16 Servo Motor

3.7.3 Electromagnetic Actuators

The solenoid is the most common electromagnetic actuator. A DC solenoid actuator consists of a soft iron core enclosed within a current carrying coil. When the coil is energized, a magnetic field is established that provides the force to push or pull the iron core. AC solenoid devices are also encountered, such as AC excitation relay. (See Figure 3.17).

Another important type is the electromagnet. The electromagnets are used extensively in applications that require large forces.

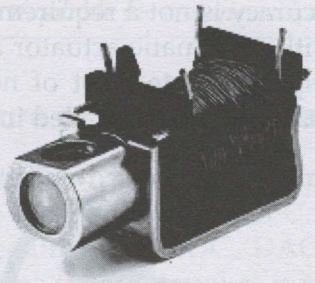

Figure 3.17 Electromagnetic Actuators

3.7.4 Hydraulic Actuators

Hydraulic and Pneumatic actuators are normally either rotary motors or linear piston/cylinder or control valves. They are ideally suited for generating very large forces coupled with large motion. (See Figure 3.18).

Hydraulic actuators consist of a cylinder or fluid motor that utilizes hydraulic power to facilitate mechanical process. Hydraulic motors output linear, rotary, or oscillating motion but acceleration is limited. They can produce very large forces coupled with large motion in a cost-effective manner. Hydraulic actuators can be operated manually, such as a hydraulic car jack, or they can be operated through a hydraulic pump, which can be seen in construction equipment such as cranes or excavators. The disadvantage with the hydraulic actuators is that they are more complex, typically inefficient, and require more than usual maintenance.

Figure 3.18 Hydraulic Actuator

3.7.5 Pneumatic Actuators

Pneumatic actuators work on the same concept as hydraulic actuators except compressed gas is used instead of liquid. Energy, in the form of

compressed gas, is converted into linear or rotary motion. These are used in applications in which positional accuracy is not a requirement. The disadvantage with pneumatic actuator are they take up a lot of space, create a lot of noise and are difficult to transport once installed in a place. (See Figure 3.19).

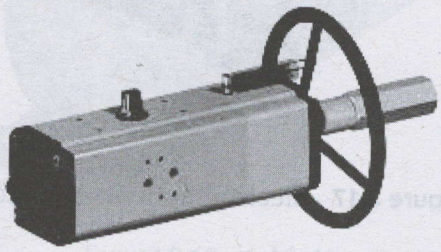

Figure 3.19 Pneumatic Actuator

3.7.6 Smart Material Actuators

Unlike the conventional actuators, the smart material actuators typically become part of the load bearing structures. This is achieved by embedding the actuators in a distributed manner and integrating into the load bearing structure that could be used to suppress vibration, cancel the noise, and change shape. Of the many smart material actuators, Shape Memory Alloys, Piezoelectric (PZT), Magnetostrictive, Electrorheological Fluids, and Ion Exchange Polymers are most common.

Shape Memory Alloys

Shape Memory Alloys (SMA) are alloys of nickel and titanium that undergo phase transformation when subjected to a thermal field. When cooled below a critical temperature, their crystal structure enters martensitic phase. In this state the alloy is plastic and can easily be manipulated. When the alloy is heated above the critical temperature the phase changes to austenitic phase. Here, the alloy resumes the shape that it formally had at the higher temperature. For example, a straight wire at room temperature can be made to regain its programmed semicircle shape when heated that has found applications in orthodontics and other tensioning devices.

Piezoelectric

The PZT actuators are essentially piezocrystals with top and bottom conducting films. When an electric voltage is applied across the two conducting films, the crystal expands in the transverse direction. When the voltage polarity is reversed, the crystal contracts thereby providing bidirectional actuation.

Magnetostrictive

Magnetostrictive material is an alloy of terbium, dysprosium, and iron that generates mechanical strains up to 2000 microstrain in response to applied magnetic fields. They are available in the form of rods, plates, washers, and powder.

Ion exchange polymers

Ion exchange polymers exploit the electro-osmosis phenomenon of the natural ionic polymers for purposes of actuation. When a voltage potential is applied across the cross-linked polyelectrolytic network, the ionizable groups attain a net charge generating a mechanical deformation. These types of actuators have been used to develop artificial muscles and artificial limbs.

3.7.7 Microactuators

Microactuators, also called Micromachines Microelectromechanical System (MEMS), and microsystems are the tiny mobile devices being developed utilizing the standard microelectronics processes with the integration of semiconductors and machined micromechanical elements.

3.8 MICROCONTROLLER

A Microcontroller is a small computer on a single integrated circuit containing electronic computing unit and logic unit (combinedly known as CPU), Memory (Program Memory and Data Memory), I/O Ports (Input / Output Ports) and few other components integrated on a single chip. The CPU (Central Processing Unit) in a microcontroller performs the arithmetic, logic, math and data-oriented function. (See Figure 3.20).

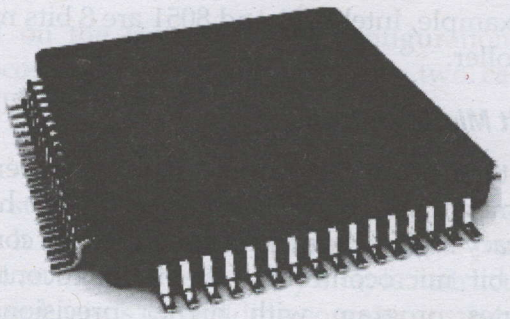

Figure 3.20 A Microcontroller

☞ *Microcontroller is like a mini computer with a CPU along with RAM, ROM, serial ports, timers, and IO peripherals all embedded on a single chip.*

Microprocessors and microcontrollers are widely used in embedded system products. Microcontrollers are designed for embedded applications for specific tasks that require a certain degree of control in contrast to the microprocessors used in personal computers or other general purpose applications consisting of various discrete chips. A printer is an example of embedded system since the processor inside it performs only one task ; namely, getting the data and printing it.

Microcontroller is also called as a Computer-on-a-Chip or a Single-Chip-Computer. Since the Microcontroller and its supporting circuitry are often embedded in the device it controls, a Microcontroller is also called as an Embedded Controller.

Most modern Microcontrollers might contain even more peripherals like SPI (Serial Peripheral Interface), I2C (Inter Integrated Circuit), ADC (Analog to Digital Converter), DAC (Digital to Analog Converter), CAN (Controlled Area Network), USB (Universal Serial Bus), and many more.

There is a wide range of microcontrollers available in the market. Various companies like Atmel, ARM, Microchip, Motorola, Philips, Texas Instruments, Renesas, Freescale, NXP Semiconductors, etc. manufacture different kinds of microcontrollers with different kinds of features.

☞ *The first microcontroller was developed in 1971 by Texas Instruments and is called TMS 1000. It was made available for commercial use in 1974.*

3.8.1 Feature of Microcontrollers

a. Microcontroller has all the required peripherals on the same chip as the CPU. The integration of features like ADC, DAC etc. on the same chip as the CPU makes it more efficient and cheaper than to use a separate ADC Chip.
b. Developing a computer controlled system involves design of the hardware and also writing an efficient software program. Since a Microcontroller has all the hardware, that are required to make a computer controlled system on a single chip, using a Microcontroller will drastically reduce the efforts and time spent on hardware design and wiring.
c. Microcontrollers may be dedicated to one task and run one specific program. The program is stored in ROM and generally does not change. Also, microcontroller is a low-power device. A battery-operated microcontroller might consume as little as 50 mill watts.

☞ *Microcontrollers may be embedded inside some other device so that they can control the features or actions of the product therefore microcontroller is also know as embedded controller.*

3.8.2 Advantages of Microcontroller

a. A microcontroller is meant to be more self-contained and independent, and functions as a tiny, dedicated computer.
b. No need for any external interfacing of basic components like Memory, I/O Ports, etc.
c. Microcontrollers doesn't require complex operating systems as all the instructions must be written and stored in the memory.
d. All the Input/Output ports are programmable.
e. Integration of all the essential components reduces the cost, design time and area of the product (or application).

(WMAN), was developed with IEEE 802.16. This technology known as WiMAX (Worldwide Interoperability for Microwave Access) makes it possible to set up WiFi hotspots. These are several WiFi access points working together in different locations.

- **Wide Area Network (WAN):** The term Wide Area Network (WAN) usually refers to a network which covers a large geographical area. Some WANs are very extensive, spanning the globe using satellite communications.
- **Virtual Private Network (VPN):** A Virtual Private Network (VPN) is a virtual communication network that uses the infrastructure of a physical network to logically connect computer systems. It allows restrict access to your network while allowing authorized users the ability to access the network from remote locations by encrypting the connection process.
- **Campus Area Network (CAN):** The computers are within a limited geographic area, such as a campus or military base.
- **Global Area Networks (GAN):** A Global Area Network (GAN) refers to a network composed of different interconnected networks that cover an unlimited geographical area. It is a network used for supporting mobile across an arbitrary number of wireless LANs, satellite coverage areas, etc.

1.11 IoT TECHNOLOGIES AND PROTOCOLS

The primary idea behind the Internet of Technology is to exchange information between real-world objects around us, with the help of leading technologies. In IoT, no one technology is involved but it consists of multiple technologies. An IoT device may consist of several interfaces for connections to other devices, both wired (such as coaxial cables, copper wires, fiber optic cables) and wireless. With respect to sending and receiving data, wired and wireless communication technologies have also improved such that nearly every type of electronic equipment can provide data connectivity.

Networking technologies, such as fixed, mobile, wired and wireless networks, allowing the highly available bi-directional communication on different levels. The communication between IoT devices is mainly wireless because they are generally installed at geographically dispersed locations. The typical wireless technologies used widely are Zigbee, Zwave, RFID, NFC etc. The most common communication technologies for short range low power communication protocols are RFID (Radio Frequency Identification) and NFC (Near Field Communication). For the medium range, they are Bluetooth, Zigbee, and WiFi. These technologies support the specific networking functionality needed in an IoT system in contrast to a standard uniform network of common systems.

Like we human communicate with each other, same way IoT devices can communicate with each other through protocols which are known as IoT protocols. The protocol is defined as a set of rules and regulation guidelines having how to react for commands from another device. There are several IoT communication protocols available, and they have different capabilities, data rates, communication range, power, and memory. Communication protocols selected depends on the number of devices to be connected to this network.

IoT has power to make the complete system automatic. There are various IOT communication protocols which are used in communication between devices in the IoT network. The wireless communication protocol is a standard set of rules with reference to which various electronic devices communicate with each other wirelessly. In Communication protocols, we will discuss popular wireless Protocols.

1.12 TECHNOLOGIES USED IN IoT

The protocols for allowing IoT sensors to relay data include wireless technologies such as RFID, NFC, Wi-Fi, Bluetooth, Bluetooth Low Energy(BLE), XBee, ZigBee, Wireless MBus and NuelNET, as well as satellite connections and mobile networks using GSM, GPRS, 3G, LTE, or WiMAX

(See Figure 1.7). Wired protocols, usable by stationary smart objects, include Ethernet, HomePlug, HomePNA and LonWorks as well as conventional telephone lines.

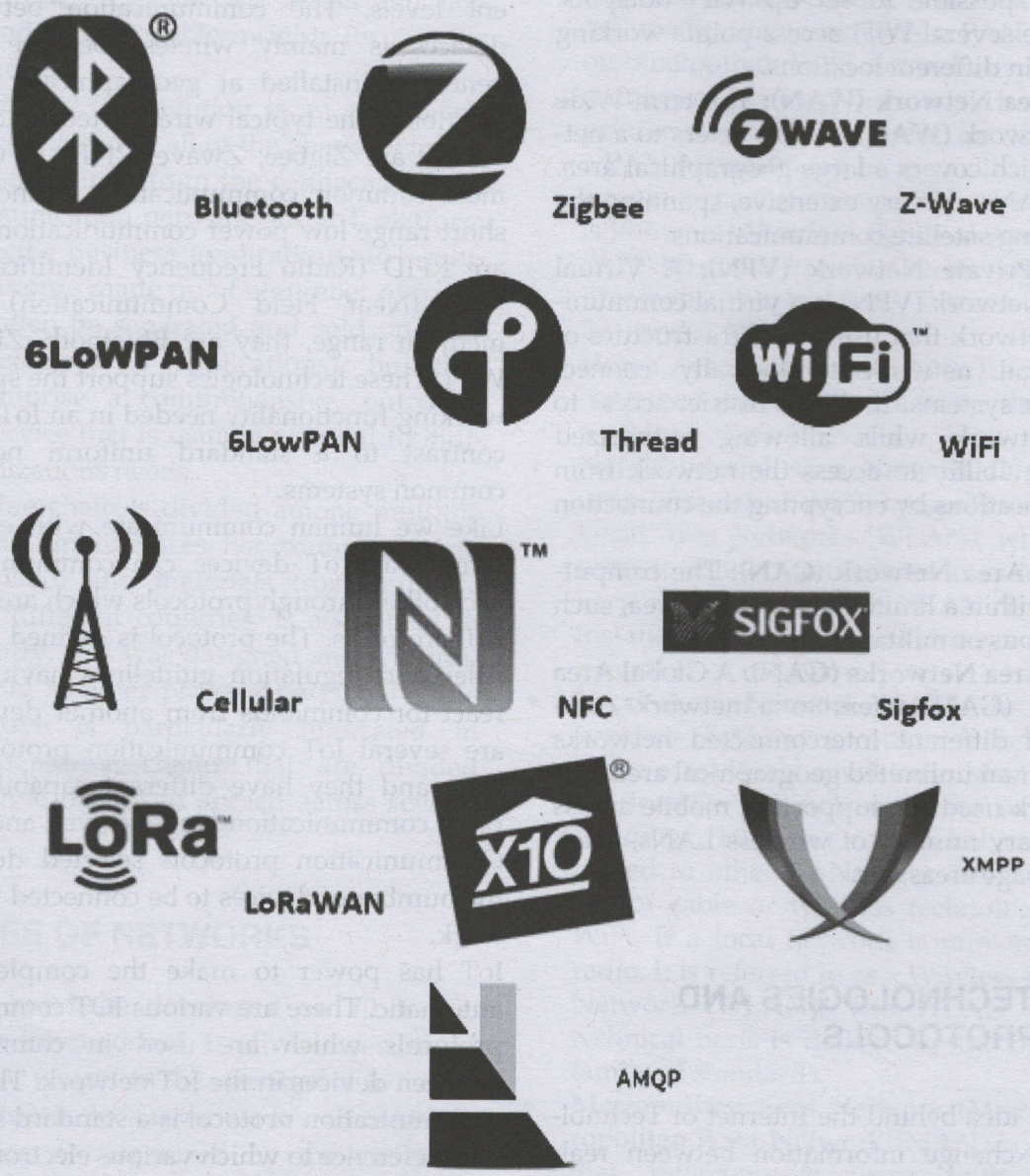

Figure 1.7 Technologies used in IoT

Some of the most common technologies used in IoT implementation are discussed below:

1.12.1 Bluetooth

Bluetooth is a Wireless Personal Area Network (WPAN) protocol designed by the Bluetooth Special Interest Group (SIG). It is an open standard for short-range transmission of digital voice and data. Some bluetooth applications have been used in cellphones, providing a wireless connection to a headset and to an automobile's audio system for hands-free operation (See Figure 1.8). It operates in the frequency band of 2.45 GHz. Data transfer rate of bluetooth is 2.1 Mbps. Some of the features of bluetooth are:

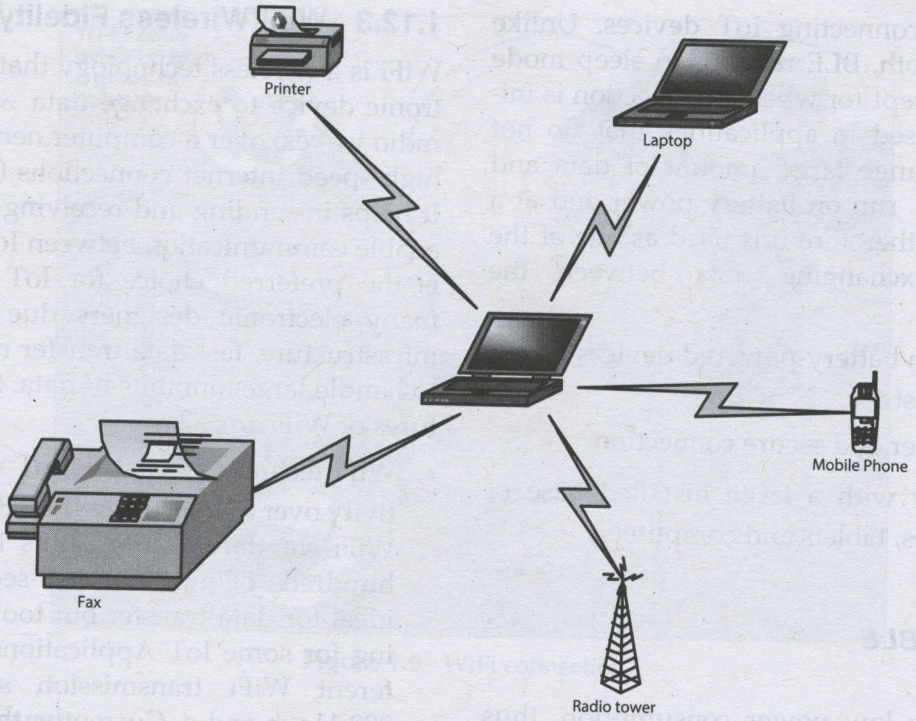

Figure 1.8 Bluetooth

- Bluetooth is one of the most widely used protocols for short-range communication.
- It supports point-to-point and multi-point applications.
- Replaces cables connecting many types of devices. It is a standard IoT protocol for wireless data transmission.
- This communication protocol is secure and perfect for short-range, low-power, low-cost, and wireless transmission between electronic devices.

Advantages of Bluetooth

- It has low power consumption.
- It has range better than Infrared communication.
- It creates adhoc connection immediately without any wires.
- Bluetooth devices are available at very cheap cost.

Disadvantages of Bluetooth

- The bandwidth is lower compare to WiFi.
- Battery usage is more compare to the condition when bluetooth is powered OFF.

1.12.2 Bluetooth Low Energy (BLE)

The Bluetooth Low Energy is commonly known as BLE or Bluetooth 4.0 and marketed as Bluetooth Smart. It is a wireless standard and is intended to exchange data over short distances and build Personal Area Networks (PANs). Due to improved energy consumption, it is suited for sensors and other devices that require low power. Internet-enabled nodes often use BLE to act with local nodes and send collected data to the back-end for more actions. The devices usually transmit a small amount of data as bursts at 1 Mbps speed. However, it is not suitable for sending data in real-time. It is used in applications such as smart building, smart transportation, smartphones, fitness trackers and wearables. Some of the features of BLE are:

- Bluetooth Low Energy provides reduced power consumption, cost and plays an impor-

tant role in connecting IoT devices. Unlike classic Bluetooth, BLE remains in sleep mode constantly except for when a connection is initiated. It is used in applications that do not need to exchange large amount of data and can, therefore, run on battery power and at a cheaper cost, therefore it is used as one of the means of exchanging data between the devices.

- BLE is used in battery-powered devices developed for industries.
- Low cost, faster and secure connection.
- Compatibility with a large installed base of mobile phones, tablets and computers.

Advantages of BLE

- It offers very low power consumption, thus battery life is very long.
- BLE are inexpensive
- It offers reliability and enables digital life.
- Devices from different manufacturers are compatible with the others.

Disadvantages of BLE

- It can not be used for higher data rates as offered by WiFi and cellular technologies. It supports 1 Mbps and 2 Mbps data rates.
- It can not be used for long distance wireless communications unlike cellular and WiFi devices.
- It is open to interception and attack due to wireless transmission/reception.

☞ *Bluetooth is today commonly referred to as Classic Bluetooth, to distinguish it from Bluetooth low energy. BLE is an intelligent and low-power version of the classic Bluetooth wireless technology.*

1.12.3 WiFi(Wireless Fidelity)

WiFi is a wireless technology that allows an electronic device to exchange data wirelessly (using radio waves) over a computer network, including high-speed Internet connections (See Figure 1.9). It helps in sending and receiving data packets to enable communication between IoT devices. WiFi is the preferred choice for IoT integration for many electronic designers due to its existing infrastructure, fast data transfer rates, and ability to handle large amounts of data. Some of the features of WiFi are:

- WiFi technology enables IoT wireless connectivity over a LAN using IEEE 802.11 standards. WiFi standard 802.11 offers transfer rates of hundreds of megabits per second, making it ideal for data transfer but too power consuming for some IoT Applications. There are different WiFi transmission standards, IEEE 802.11a, b and g. Currently, the most common WiFi standard used in homes and many businesses is 802.11n, which offers serious throughput in the range of hundreds of megabit per second, which is fine for file transfers, but may be too power-consuming for many IoT applications.
- In car radios and TV sets, broadcasts are on different channels to avoid interference. 802.11 b and g have only 3 non-overlapping channels. To avoid interference, the radio power, and therefore transmission distances are short. Much longer links can be achieved with specialized antennae and amplifiers. Note that the distance is lower for higher frequency transmission. The frequency ranges are referred to as 2.4ghz and 5ghz. IEEE 802.11n has been agreed upon and standard products are expected. Speeds will be around 300 Mbps (100 effective) and distances increased.

☞ *WiFi is based on the IEEE 802.11 family of standards and is primarily a local area networking (LAN) technology designed to provide in-building broadband coverage.*

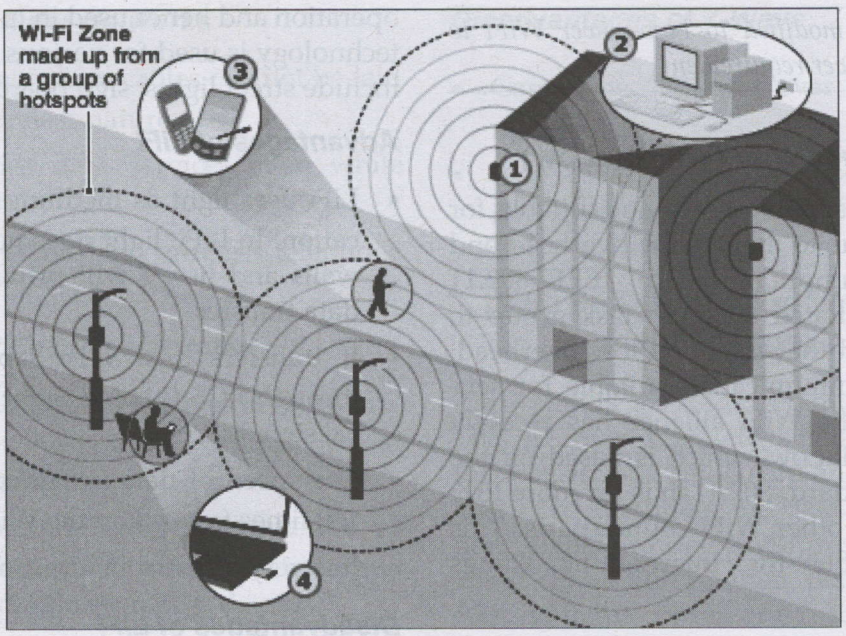

Figure 1.9 WiFi connection

Advantages of WiFi

- The main advantages of using WiFi technology is the lack of wires. This is a wireless connection that can merge multiple devices together.
- Wi-Fi allows managing or communicating network. It can reduce the cost of cables and laying charges.
- It is easy to setup WiFi and also you can add any number of WiFi clients.
- You can send and receive any amount of data in the air; its completely safe and it will not interfere with any network.
- WiFi networks are widely used to connect a variety of devices, not only between themselves but also to the Internet. And almost all modern laptops, tablets, and some mobile phones have this feature. It is very convenient and allows you to connect to the Internet almost anywhere, not just where the cables are laid.

Disadvantages of WiFi

- WiFi has a limited radius of action and it is suitable for home networking, which is more dependent on the environment. For example, a typical home router with WiFi in the room has a range of up to 45 meters and up to 450 meters outside.
- At high density WiFi-points operating in the same or adjacent channels, they can interfere with each other. This affects the quality of the connection. This problem is common in apartment buildings, where many residents are using this technology.
- WiFi technology is not perfect and has many flaws that limit its use.
- WiFi network implementation is more costly than wired network. There are some limit to transfer the data rate, it can't send the huge data compared to wired technology.
- WiFi will generates some radiation which effects on human health. Switch off the WiFi devices or equipment when it is not in use to reduce the radiation.
- Although WiFi is a highly suited protocol for communication between IoT devices, it consumes high power for its operations. However, it is the most powerful protocol for file transfer among most of the IoT devices at present.

☞ *WiFi has been modified to Low-power WiFi to suite the IoT power requirement.*

1.12.4 Low Power WiFi (WiFi-HaLow)

The original WiFi standards are not suitable for IoT applications due to their frame overhead and high power consumption. Hence, IEEE 802.11 working group initiated 802.11ah task group to develop a standard that supports low overhead, power friendly communication suitable for sensors and motes. The WiFi alliance has recently developed 'WiFi HaLow' which is based on the IEEE 802.11ah standard. 802.11ah is far more IoT-centric than many other WiFi counterparts. This protocol is suitable for Internet of Things applications.

Advantages of Low Power WiFi

- It consumes lower power than a traditional WiFi device
- The range of WiFi HaLow is nearly twice that of traditional WiFi.
- Designed specifically for low data rate, long-range sensors and controllers.

Disadvantages of Low Power WiFi

- Because of the relatively lower frequency, the range is longer since higher frequency waves suffer from higher attenuation.

1.12.5 LiFi(Light Fidelity)

It is a new wireless technology that offers high speed data transmission based on Visible Light Communication (VLC) principle. It uses two main components LiFi controller or coordinator and LiFi dongles. The technology uses LED lamps on source side and photo detector based LiFi dongles on destination side. Li-Fi can also utilize energy efficient Light-Emitting Diode (LED) lights to reduce energy costs. However, the Li-Fi scheme is limited to the line of sight and is subject to interference or failure due to objects blocking the light signals. The LiFi devices consume low power for operation and hence used in IoT applications. LiFi technology is used for various applications which include street lights, sign boards, Internet etc.

Advantages of LiFi

- LiFi uses light as medium for data communication. In LiFi, light does not pass through the walls and hence will provide a much secure data transfer.
- It transfers data very rapidly and securely through LOS (Line of Sight) operation of optical signals.
- The speed of data provided by these LEDs is 100 times faster than the WiFi speed.
- It is very efficient in terms of cost and energy.

Disadvantages of LiFi

- Internet cannot be used without a light source.
- A new infrastructure for Li-Fi is required to be constructed.

1.12.6 Cellular Networks

A cellular network is a radio network distributed over land through cells where each includes a fixed location transceiver known as *base station*. Cellular technology is the basis of mobile phone networks. These networks exists in various generations such as 3G and 4G of cellular network standards that are often employed in smartphones but are also suitable for IoT due to their high mobility and speed. Any IoT application that requires operation over longer distances can take advantage of GSM/3G/4G/5G cellular communication capabilities. However, Narrowband-IoT (NB-IoT) along with LTE-M are newer standards that were developed especially for running IoT systems using existing cellular networks. LTE-M is an abbreviation for LTE (Long Term Evolution) Cat-M1. This technology is for Internet of Things devices that need to connect directly to a 4G mobile network. It is a subset of the LTE cellular technology that is optimized for low data rate devices running from small batteries.

Advantages of Cellular Networks

- It is used in areas where cables can not be laid out due to its wireless nature.
- It provides voice/data services even while roaming.
- It connects both fixed and wireless telephone users.

Disadvantages of Cellular Networks

- The technology is able to transfer high quantities of data, but the power consumption and the expenses are high.
- The wireless communication is influenced by physical obstructions, climatic conditions and interference from other wireless devices.
- It offers less data rate compare to wired networks such as fiber optics, DSL etc. The data rate varies based on wireless standards such as GSM, CDMA, LTE etc.
- It requires higher cost in order to setup cellular network infrastructure.

1.12.7 Z-Wave

Z-Wave is a wireless network standard that consumes very low power and it is widely used for connecting smart devices in the Internet of Things (IoT) like home automation, lighting controls, security systems, Energy saving etc. Z-Wave devices can be attached to home appliances, which enable them to be controlled over the Internet. Z-Wave is a complete communications solution, which consists of everything from the Physical layer to the Applications layer.

Advantages of Z-Wave

- Easy to install the system.
- Easy to add or remove devices.
- Interoperable with other devices.
- Uses low-energy radio waves to communicate.
- Uses a simpler protocol than some others, which can enable faster and simpler development.

Disadvantages of Z-Wave

- Cannot be deployed over a wide area as the range is less.
- Applicable for less data speed and small data size applications.

1.12.8 RFID(Radio Frequency Identification)

RFID stands for Radio Frequency Identification. The acronym refers to small electronic devices that consist of a small chip and an antenna. RFID tags store identifiers and data. It uses electromagnetic signals to detect chips containing electronically stored information placed within objects. RFID systems consist of a reading device called a reader, and one or more tags. The reader is a powerful device with ample memory and computational resources. The RFID tag is attached to the object to be tracked and the reader detects and records its presence when the object passes by it. In this manner, object movement can be tracked and RFID can serve as a search engine for smart things. The typical range of RFID is less than a meter. RFID used to track consumer product worldwide. RFID is an intelligent barcode that can be operated using the networked system to track the product, vehicles or any object. But unlike a traditional bar code, it does not require line of sight communication between the tag and the reader and can identify itself from a distance even without a human operator. RFID is used in indoor moving navigation, smart parking, supply chain management, and battery-less remote control devices applications. RFID tags can be of following types:

- **Active:** An active tag has an on-board battery i.e., power source and periodically transmits its ID signal.
- **Passive:** Passive tags do not have any power source. Passive tags derive power from the electromagnetic waves emitted by the reader and are thus cheap and have a long lifetime. These tags are ideal for devices without batteries, as the ID is passively read by the reader.

- **Assisted passive:** Assisted passive tags become active when RFID reader is present.

Advantages of RFID

- They work on radio frequencies and do not require a direct line of site between tag and reader.
- Some RFID devices will only use battery power in the presence of an RFID reader which makes it ideal for lower power consumption applications.
- RFID is similar to a barcode reader based technology but the performance is more efficient
- RFID is inexpensive and uses very little power.
- Established and widely used technology.

Disadvantages of RFID

- Highly insecure.
- Tags need to be present as identifier and be handed over before.
- Not compatible with smartphones.

1.12.9 X-10

X-10 is a protocol for communication among IoT devices, mainly in the home automation sector. It is called as the *father of modern home automation*. The existing household wiring, which powers the house, acts as the physical layer to transmit and receive data. X-10 devices are connected to the plugs in the wall, like a normal electrical appliance. A remote interface could be provided so that lights and other appliances can be turned *on* and *off*. Depending on your budget, there are some very hi-tech approaches that can be adopted. For example, touch-screens to control X10 devices within the house.

☞ *X10 has become very popular with consumers who wish to use home automation to make life easier.*

Advantages of X-10

- The infrastructure for the medium of communication exists and thus needs less effort to set-up. And the equipment is also inexpensive.
- No new or specialised wiring is required.
- It is simple to install - no need for qualified engineers or professionals.

Disadvantages of X-10

- The data rate of signal transmission is very less, in the order of 20 bits/s. Thus, this technology facilitates for turning on and off devices only.
- Other electrical devices in the house can create interference on the power lines, which may prevent X10 signals being received by modules.
- It is not suitable as a safety device.
- There is a time delay in sending signals - up to one second.

1.12.10 Sigfox

Sigfox is a cellular style system that enables remote devices to connect using ultra-narrow band, to provide low power low data rate, and low cost communications for remote connected devices.

It a subscription based service that offers connectivity solutions over dedicated LPWAN networks. Sigfox uses a technology called Ultra Narrow Band (UNB) and is only designed to handle low data-transfer speeds of 10 to 1,000 bits per second. The concept behind Sigfox is to provide an effective connectivity solution for low-power M2M applications requiring low levels of data transfer for which the WiFi range is too short, and cellular range is too expensive. Sigfox is ideal for IoT applications that need to send infrequent and small bursts of data, such as alarm systems, smart meters, smart street lighting, patient monitors etc.

Advantages of Sigfox

- Sigfox offers significant cost and battery-life.

- The Sigfox network provides very long-range wireless connectivity for the Internet of Things.
- It is lightweight protocol which handles smaller messages efficiently.
- Due to less overhead, more space will be available for the user data to be transported.

Disadvantages of Sigfox

- Sigfox supports one way communication without acknowledgement. This necessitates multiple transmissions if server does not receive data without errors. Due to this, power consumption will increase which depends on number of re-transmissions.
- Due to low data rate support, it cannot be used for high data rate applications.
- Sigfox system works well in fixed location. There are issues such as interference and frequency inaccuracies in the mobility environments.

1.12.11 Zigbee

Zigbee is a low powered, low cost standard on a wireless mesh network designed for battery-powered devices and cheaper alternative to Bluetooth. It is based on the IEEE 802.15.4 communication protocol standard and is used for personal area networks or PANs. The range of Zigbee device communication is very small (10-100 meters). For example, if you just need to communicate inside a small building, you can use Zigbee. ZigBee devices often transmit data over longer distances by passing data through intermediate devices to reach remote ones, creating a mesh network. They can used in applications that require a low data rate, long battery life, and secure networking. Street lighting and electric meters which provides low power consumption, use the ZigBee communication protocol. It is also used with security systems, smart homes, remote controls, road map products-tracking and healthcare systems.

Advantages of ZigBee

- Low-power consumption, powerful and direct communication.
- It support a large number of nodes and these nodes are capable of multi-year battery lives.
- Zigbee has a flexible network structure.
- It is less complex than bluetooth.

Disadvantages of ZigBee

- Working on small distance with low speed.
- Its high maintenance cost.
- Low transmission, as well as low network stability.
- Zigbee is not secure like WiFi based secured system.

1.12.12 Low Range Wide Area Network(LoRaWAN)

LoRaWAN is a newly developed Long-Range Wide-Area Network Wireless technology designed for IoT applications with power saving, low cost, mobility, security, and bi-directional communication requirements. LoRaWAN defines the communication protocol and system architecture for the network in the Medium Access Control (MAC) layer protocol. It is ideal for smart cities and industrial applications.

Advantages of LoRaWAN

- Low-cost, mobile, and secure bi-directional communication.
- Low power consumption and supports large networks with millions of nodes.
- Battery life for the attached node is normally very long.
- It is easy to deploy due to its simple architecture.

Disadvantages of LoRaWAN

- It is not ideal to be used for real time applications.

- It can be used for applications requiring low data rate i.e., upto about 27 Kbps.

1.12.13 6LoWpan

6LoWPAN is an acronym of IPv6 over Low Power Wireless Personal Area Networks. It is a protocol that is primarily intended for long-range wireless battery-operated IoT devices in regional, national, or global networks. It is specifically known for its ability to communicate in long-range with the least power consumption and detects the signals below the noise level. This protocol is mainly used in smart cities, where there is a large network with millions and millions of devices connected to each other that function with less power, memory, low-cost mobile secure communication in IoT devices, and a wide range of industrial applications.
The 6LoWPAN group has defined encapsulation and header compression mechanisms that allow IPv6 packets to be sent to and received from over IEEE 802.15.4 based networks.

Advantages of 6LoWpan

- The 6LoWPAN standard enables any low-power radio to communicate to the internet, including 804.15.4, Bluetooth Low Energy and Z-Wave for home automation applications.
- 6LoWPAN uses reduced transmission time (typically short time pulses) and thus saves energy.
- 6LowPAN is a mesh network that is robust, scalable and self-healing.
- It offers one-to-many and many-to-one routing.

Disadvantages of 6LoWpan

- 6LoWPAN offers a secure and non-secure mode but the overall security in 6LoWPAN is still in progress. In comparison, Zigbee has more robust and tested security protocol.
- The greatest challenge to 6LoWPAN is the lack of application that utilizes 6LoWPAN because it require extensive training as it is complicated to work with and require extensive knowledge of IPv6 protocol.

1.12.14 5G

It is the fifth generation of wireless, popularly known as 5G. The "G" stands for a *generation of mobile technology*, installed in phones and on cellular networks. 5G is a medium range communication that offers many improvement over 4G(called LTE-Advanced), such as increased speed and better coverage. It enable a larger number of nodes to be connected with extra mobility.

Advantages of 5G

- Provides high data transfer rates.
- More effective and efficient.
- Easily manageable with the previous generations.
- Possible to provide uniform, uninterrupted, and consistent connectivity across the world.

Disadvantages of 5G

- Technology is still under process and research on its viability is going on.
- Developing infrastructure needs high cost.
- Many of the old devices would not be competent to 5G, hence, all of them need to be replaced with new one

1.12.15 Low Power Wide Area Networks (LPWAN)

It is a type of wireless network used for low power IoT and M2M applications. It defines Low Power Wide Area Networks (LPWAN) standard to enable IoT and can transmit data over long distances while having low power consumption. Mainly its aim is to guarantee interoperability between various operators in one open global standard.

Advantages of LPWAN

- The LPWAN network offers longer range from 5 Km to 30 Km.
- The LPWAN devices will consume low power and hence they offer longer life time.
- It offers simple network installation and easy network management due to smart architecture.
- It offers secured data communication between nodes and gateways due to use of encryption algorithms.

Disadvantages of LPWAN

- LPWAN supports low data rate, hence LPWAN can not be used for high data rate applications.
- It offers high latency between end to end nodes. Hence, LPWAN is not ideal for low latency applications.

1.12.16 Thread

A very new IP-based IPv6 networking protocol aimed at the home automation environment is Thread. Thread uses IPv6 for the Internet Protocol addressing and each of the devices is IP-addressable. Thread enables device-to-device and device-to-cloud communications and reliably connects hundreds (or thousands) of products and includes mandatory security features. Thread wireless connectivity has been developed specifically to support the Internet of Things, IoT, and as a result, it incorporates many features that have not been available in previous standards.
Thread is based on the broadly supported IEEE 802.15.4 radio standard, which is designed from the ground up for extremely low power consumption and low latency.

Advantages of Thread

- Thread guarantees to be a 'no single point of failure system'.
- Uses good security features such as proper authentication in order to join a network.
- IP-addressable devices.
- Simple Management i.e., creating a thread, switching between threads and synchronization between threads can all be done without the intervention of the kernel.

Disadvantages of Thread

- There is a lack of coordination between threads and operating system kernel.
- User-level threads require non-blocking systems call i.e., a multi-threaded kernel.

1.12.17 Near Field Communication (NFC)

NFC is a set of the communication-based protocol used for communication between two devices in the range of approximately 10 cm. All types of data can be transferred between two NFC enabled devices in seconds by bringing them close to each other. In this two-way, short-range communication, one of the devices must be portable for the purpose of finding a suitable location. NFC make it possible to use our phone as readers. You can extract information from certain objects just by tapping it or bringing our device close to it. The most used applications are smartphones, contactless payment systems, parking meters, E-ticket booking etc.

Advantages of NFC

- Offers a low-speed connection with extremely simple setup.
- NFC has a short range and supports encryption.
- Very easy to used.

Disadvantages of NFC

- Only works in short ranges. Short range might not be feasible in many situations.
- Low data transfer rate.
- NFC is an expensive technology.

1.12.18 GSM (Global System for Mobile communications)

GSM stand for Global System for Mobile communications. It is digital cellular phone technology

based on TDMA that is the predominant system in Europe. Developed in the 1980s, GSM was first deployed in seven European countries in 1992. Text Messaging GSM provides a *Short Messaging Service (SMS)* that enables text messages up to 160 characters in length to be sent to and from a GSM phone. It also supports data transfer to packet networks, ISDN and POTS users. GSM is a fast-growing communications technology.

The SIM Card GSM phones use a *Subscriber Identity Module (SIM)* smart card that contains user account information. Any GSM phone becomes immediately programmed after plugging in the SIM card, thus allowing GSM phones to be easily rented or borrowed. SIM cards can be programmed to display custom menus for personalized services.

☞ *GSM is an open, digital cellular technology used for transmitting mobile voice and data services.*

Advantages of GSM

- It provides very cost effective products and solutions.
- The GSM based networks (i.e. base stations) are deployed across the world and hence same mobile phone works across the globe.
- Advanced versions of GSM with higher number of antennas will provide high speed download and upload of data.
- It is easy to maintain GSM networks due to availability of large number of network engineers at affordable cost.
- The phone works based on SIM card and hence it is easy to change the different varieties of phones by users.

Disadvantages of GSM

- GSM provides limited data rate capability, for higher data rate GSM advanced version devices are used.
- GSM uses pulse based burst transmission technology and hence it interferes with certain electronics.

1.12.19 GPRS

GPRS stands for *General Packet Radio Service*. It is the first high-speed digital data service provided by cellular carriers that used the GSM technology. GPRS works on GPRS cellphones as well as laptops and portable devices that have GPRS modems. Users have typically experienced downstream data rates up to 80 Kbps.

Advantages of GPRS

- As GPRS is available in all the mobile devices, it provides wireless internet access.
- It allows simultaneous use of both voice and data services. Hence, user can have both voice call and data call together.

Disadvantage of GPRS

- Network can be affected, when more number of GPRS users in the same area utilize the GPRS services at the same time. This leads to congestion which results into slower data connection.

1.12.20 LTE-A

LTE-A, or LTE Advanced, delivers an important upgrade to LTE technology by increasing not only its coverage, but also reducing its latency and raising its throughput.

Long-term Evolution Advanced (LTE-A) is a collection of cellular networking standards that is designed to meet M2M and IoT requirements in such networks. It is one of the most scalable and cost effective standards compared to other cellular protocols.

Advantages of LTE

- LTE network uses all IP network architecture. Due to this fact, it is dedicated for packet switched operations. It supports data as well voice. The voice can be transported using voice over LTE protocols (i.e. VOIP) and fall-back to legacy networks (i.e. 2G/3G).
- As LTE supports MIMO, higher data rate can be achieved.
- LTE downloads the files faster.

Disadvantages of LTE

- The existing mobile phones can not be used to access LTE network features. The user need to have mobile phone which supports LTE functionality. This will incur cost to the user to avail the LTE service.
- LTE network is completely new network which requires installation of equipments and antennas to make it operational.
- LTE system is complex and hence requires skilled engineers to maintain and manage the system. They need to be paid higher salaries in order to retain them.

1.12.21 WSN (Wireless Sensor Network)

A Wireless Sensor Network (WSN) is the networks that are wireless in nature which comprises of distributed devices with sensors which are used to sense or monitor the environmental and physical conditions like temperature, gyroscope, pressure, etc., and make the embedded processing using these devices. They collect data about the environment and communicate it to gateway devices that relay the information to the cloud over the Internet. These devices are connected through different devices such as GPS, WiFi, RFID, etc. over the networks. For example Weather monitoring system, Soil moisture monitoring system, Surveillance system, Healthcare monitoring, Indoor air quality monitoring system etc.

Advantages of WSN

- WSN is the flexible network and it can adapt to the changes.
- WSN are used in very hard and poor environments where wired cannot be deployed.
- WSN save a lot of wiring cost.

Disadvantages of WSN

- It is not fully secure.
- In WSN communication speed is very poor, on the other hand, wired networks have good speed of communication.
- It is distracted by other wireless devices like bluetooth.

1.13 COMMUNICATION PROTOCOLS

Communication protocols form the backbone of IoT systems and enable network connectivity. Communication protocols allow devices to exchange data over the network.

By the term protocol, we mean the set of rules or standards designed to enable computers to connect with one another and to exchange information. Protocol can describe low-level details of machine-to-machine interfaces (e.g. the order in which bits and bytes are sent across a wire) or high-level exchange between allocation programs (e.g. the way in which two programs transfer a file across the Internet).

An example will be able to make the idea clear. Suppose, there are two people one speaks Hindi and the other French. Since they have no common language, they each engage a translator whose common language is English.

Protocols can include rules concerning any or all of the following functions:

- Data transmission mechanisms.
- Communication session initialization and termination.
- Addressing and routing.
- Authentication and verification.
- Encryption and compression.
- Error correction.

Protocols are usually classified according to the layer they correspond to in the *Open Systems Interconnection (OSI)* reference model for networking. Types of protocols include the following:

(a) Data-link protocols
(b) Communication or Network protocols
(c) Transport protocols
(d) Application layer protocols

Here, we discuss communication protocols in detail.

1.13.1 Application Layer Protocols

CoAP(Constrained Application Protocol)

CoAP is an internet-utility protocol created specifically for connecting devices with limited (con-

strained) resources such as a small memory or short battery life. This protocol is primarily used for Machine-to-Machine (M2M) communication and is particularly designed for IoT systems that are based on HTTP protocols. Using this protocol, the client can send a request to the server and the server can send back the response to the client in HTTP. It makes use of UDP *(User Datagram Protocol)* and reduces space usage. CoAP is an application layer protocol for IoT and uses request-response model, uses client/server architecture, and supports methods such as GET, POST, PUT and DELETE. CoAP protocol is used mainly in automation, mobiles, and microcontrollers.

Advantages of CoAP

- It has reduced power requirements as it operates over UDP.
- Has smaller packet size, leading to faster communication.
- It has lower latency and consumes less power compare to HTTP.

Disadvantages of CoAP

- CoAP is unreliable protocol due to use of UDP.
- It acknowledges each receipt of the message and hence increases processing time.
- It does not verify whether the received message has been decoded properly or not.

MQTT(Message Queue Telemetry Transport)

Message Queue Telemetry Transport (MQTT) is an open light-weight easy-to-implement messaging protocol for M2M communications. It is based on publish-subscribe model where the system consists of three main components: Publishers, Subscribers, and a Broker. The publisher collects data and sends it to subscribers. The broker tests publishers and subscribers, checking their authorization and ensuring security.

It is well suited for constrained environments where devices have limited processing, low memory and low bandwidth requirement particularly for sensors and mobile devices on unreliable networks. MQTT collects data from various electronic devices and supports remote device monitoring. MQTT is ISO-approved and offers low power consumption and efficient data distribution via its minimized packet system. This makes it a great option for industrial IoT and mobile applications. MQTT is mainly used in devices which are economical and requires less power and memory. For instance, fire detectors, car sensors, smart watches, and apps for text-based messaging.

> ☞ *MQTT-S/MQTT-SN is an extension of MQTT, which is designed for low power and low cost devices.*

Advantages of MQTT

- MQTT is bandwidth efficient, lightweigth and is best used when your internet connection is unreliable.
- MQTT is extremely simple, offering few control options and easy-to-implement.
- Low power consumption and efficient data distribution.
- MQTT is best used when your node sends data at irregular intervals of time.
- MQTT is an asynchronous messaging protocol. This is best used for real time systems.

Disadvantages of MQTT

- MQTT is a very light messaging protocol and cannot support heavy payloads.
- MQTT is best used to send your sensor data. You cannot send photos or video clips or audio using MQTT.

XMPP(Extensible Messaging and Presence Protocol)

The Extensible Messaging and Presence Protocol (XMPP) is an open technology for real-time communication originally designed for chats and messages exchange applications. It is used for applications such as instant messaging, presence, multi-party chat, voice and video calls etc. Other than the instant messaging apps such as Google Talk and WhatsApp, XMPP is also used in on-line gaming, news websites, and Voice over Internet Protocol (VoIP).

Advantages of XMPP

- XMPP offers an easy way to address a device.
- Like MQTT, XMPP also makes use of the publish/subscribe mechanism of data sharing.

Disadvantages of XMPP

- XMPP does not have a Quality of Service (QoS), like that of MQTT.
- Further, the text-based communication increases the overhead when compared to its binary based equivalent.

DDS(Data Distribution Service)

DDS (Data Distribution Service) is an IoT standard for real-time, scalable and high-performance machine-to-machine communication. It was developed by the *Object Management Group (OMG)*. It uses a publish/subscribe architecture where publishers create topics to which subscribers can use. In real-time distributed applications, publish/subscribe is the most efficient communication design pattern to use. It enables delivery of data to multiple destinations without having to add a lot of code to your applications to track all of these destinations.

DDS first gained widespread acceptance in aerospace and defense. DDS has now emerged as a standout technology for the Industrial Internet of Things (IIoT). DDS is a core connectivity standard for the rapidly growing Industrial Internet of Things (IIoT). IIoT has completely changed the industrial automation, healthcare, transportation, energy, smart cities etc. It is used in applications like financial trading, air-traffic control, smart grid management, and other big data applications.

Advantages of DDS

- DDS is a feature-rich standard that transparently handles much of an IoT system's data connectivity complexity, therefore, easing developer efforts.
- DDS provides low-latency, high-throughput, scalable, real-time and reliable communication.
- DDS can be used in small devices which occupies less area and as well as in the cloud.
- DDS implementations provide high-performance data communications, suitable for real-time.

Disadvantages of DDS

- DDS is too heavyweight to be used in embedded systems.
- DDS does not interface with web services.
- DDS always consumes approximately twice the bandwidth when compared against MQTT.

AMQP(Advanced Message Queuing Protocol)

bussiness msgs passing

Advanced Message Queuing Protocol (AMQP) is an open source published standard for asynchronous messaging by wire. AMQP enables encrypted and interoperable messaging between organizations and applications. The protocol is used in client/server messaging and in IoT device management. Advanced Messaging Queuing Protocol used for business messaging. AMQP doesn't require the systems to be simultaneously available and works reliably over a distance or over poor networks. Like MQTT, AMQP also supports the publish/subscribe protocol of communication. It also has the Quality of Service (QoS) implemented, ensuring the safe passage of important data.

Advantages of AMQP

- Like MQTT, AMQP also makes use of the publish/subscribe mechanism of data sharing.
- AMQP is a wire-level protocol (data send as stream of bytes), ensuring interoperability.
- Simple peer-to-peer and communication with intermediaries possible.

Disadvantage of AMQP

- Backward compatibility with older versions is not supported.

WebSocket

WebSocket is a protocol that provides bi-directional, full-duplex communications channels, over a single Transmission Control Protocol (TCP) socket. It is designed to be implemented in

web browsers and web servers, but it can be used by any client or server application. It is part of the HTML 5 specification.

Advantages of WebSocket

- Supports Duplex communication.
- With WebSockets, you can send and receive your data immediately.
- Faster than HTTP.

Disadvantages of WebSocket

- Browser must be fully HTML5 compliant.
- Takes over the communications protocol between the client and the server for a particular connection.

HTTP (HyperText Transfer Protocol)

HyperText Transfer Protocol is the best example of IoT network protocol. HTTP is the foundation of the client-server model used for data communication over the web. It is the most common protocol that is used for IoT devices when there is a lot of data to be published. HTTP is common application layer protocol in the TCP/IP stack to transfer web content over the internet. HTTP works as a request-response protocol between a client and server. It defines what actions browsers and servers should take in response to certain commands or messages. A web browser may be the client, and an application on a computer that hosts a web site may be the server. For example, when you enter a URL in your browser, this actually sends an HTTP command to the web server directing it to fetch and transmit the requested web page.

☞ *HTTPS is the more secure version of HTTP, where S stands for secure.*

Advantages of HTTP

- HTTP is a TCP/IP based communication protocol, that is used to deliver data (HTML files, image files, query results, etc.) on the World Wide Web.
- HTTP is a generic and stateless protocol which can be used for other purposes as well using extensions of its request methods, error codes, and headers.

Disadvantages of HTTP

- HTTP protocol is not preferred because of its cost, battery-life, energy saving, and more constraints.
- HTTP does not encrypt the data while transferring data between client and server. The data transferred over HTTPS gets encrypted.
- HTTP saves cookies/data on the client system.

1.13.2 Transport Layer Protocol

Transmission Control Protocol (TCP)

TCP is a standard that defines how to establish and maintain a network conversation via which application programs can exchange data. TCP works with the Internet Protocol (IP), which defines how computers send packets of data to each other. TCP is based on a client-server communication model by which a user (client) receives a service such as a loaded web page from a server in the same network. TCP is not suited for IoT applications as IoT devices offer a varying traffic pattern due to their limitations.

Advantages of TCP

- Ensures reliable transmission and ensures that data which arrives out of sequence should put back into order.
- Provides Error Detection.
- Capability to ensure no duplicacy of packets and retransmit lost packets.
- It helps you to establish/set up a connection between different types of computers. It operates also independently of the operating system.

Disadvantages of TCP

- The speed for TCP is slower.
- You can't use for broadcast or multicast transmission.