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UNIT II **(CO2)**

Internet of Things: Sensor, Basic components and challenges of a sensor node, Sensor features, Sensor resolution; Sensor classes: Analog, Digital, Scalar, Vector Sensors; Sensor Types, Bias, Drift, Hysteresis error, Quantization error; Actuator; Actuator types: Hydraulic, Pneumatic, Electrical, Thermal/magnetic, Mechanical actuators, Soft actuators.

Sensors: Definitions and Basic Components of Sensors

A sensor is any physical device that converts one form of energy into another. So, the sensor converts some physical phenomenon into an electrical impulse that can then be interpreted to determine a reading. A microphone is a sensor that takes vibration energy (sound waves) and converts it into electrical energy in a useful way for other components in the system to correlate back to the original sound.

Digital Sensors:

Electronic sensors or electrochemical sensors in which data conversion and data transmission take place digitally are called digital sensors. These digital sensors are replacing analog sensors as they are capable of overcoming the drawbacks of analog sensors. The digital sensor consists of majorly three components: sensor, cable, and transmitter. In digital sensors, the signal measured is directly converted into digital signal output inside the digital sensor itself and this digital signal is transmitted through cable digitally. There are different types of digital sensors that overcome the disadvantages of analog sensors.

Components of a sensor node

The main components of a sensor node are a controller, transceiver, external memory, power source, and one or more sensors as described below:

Controller

The controller performs tasks, processes data, and controls the functionality of other components in the sensor node. While the most common controller is a microcontroller, other alternatives that can be used as a controller are a general-purpose desktop microprocessor, digital signal processors, FPGAs and ASICs. A microcontroller is often used in many embedded systems such as sensor nodes because of its low cost, flexibility to connect to other devices, ease of programming, and low power consumption. A general-purpose microprocessor generally has a higher power consumption than a microcontroller, therefore it is often not considered a suitable choice for a sensor node. Digital Signal Processors may be chosen for broadband wireless communication applications, but in Wireless Sensor Networks the wireless communication is often modest: i.e., simpler, easier to process modulation, and the signal processing tasks of actual sensing of data is less complicated. Therefore, the advantages of DSPs are not usually of much importance to wireless sensor nodes. FPGAs can be reprogrammed and reconfigured according to requirements, but this takes more time and energy than desired.

Transceiver

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Sensor nodes often make use of the ISM band, which gives free radio, spectrum allocation, and global availability. The possible choices of wireless transmission media are radio frequency (RF), optical communication (laser), and infrared. Lasers require less energy but need line-of-sight for communication and are sensitive to atmospheric conditions. Infrared, like lasers, needs no antenna but it is limited in its broadcasting capacity.

Radio frequency-based communication is the most relevant that fits most of the WSN applications. WSNs tend to use license-free communication frequencies: 173, 433, 868, and 915 MHz; and 2.4 GHz. The functionality of both transmitter and receiver are combined into a single device known as a transceiver. Transceivers often lack unique identifiers. The operational states are: transmit, receive, idle, and sleep. Current generation transceivers have built-in state machines that perform some operations automatically.

External memory

From an energy perspective, the most relevant kinds of memory are the on-chip memory of a microcontroller and Flash memory—off-chip RAM is rarely if ever, used. Flash memories are used due to their cost and storage capacity. Memory requirements are very application-dependent. Two categories of memory based on the purpose of storage are user memory used for storing application-related or personal data, and program memory used for programming the device. Program memory also contains identification data of the device if present.

Power source

A wireless sensor node is a popular solution when it is difficult or impossible to run a main supply to the sensor node. However, since the wireless sensor node is often placed in a hard-to-reach location, changing the battery regularly can be costly and inconvenient. An important aspect in the development of a wireless sensor node is ensuring that there is always adequate energy available to power the system. The sensor node consumes power for sensing, communicating, and data processing.

Sensors

Sensors are used by wireless sensor nodes to capture data from their environment. They are hardware devices that produce a measurable response to a change in a physical condition like temperature or pressure. Sensors measure physical data of the parameter to be monitored and have specific characteristics such as accuracy, sensitivity, etc. The continual analog signal produced by the sensors is digitized by an analog-to-digital converter and sent to controllers for further processing. Some sensors contain the necessary electronics to convert the raw signals into readings that can be retrieved via a digital link (e.g. I2C, SPI), and many converts to units such as °C. Most sensor nodes are small in size, consume little energy, operate in high volumetric densities, be autonomous and operate unattended, and be adaptive to the environment. As wireless sensor nodes are typically very small electronic devices, they can only be equipped with a limited power source of less than 0.5-2 ampere-hour and 1.2-3.7 volts.

Challenges of a sensor node

Following are the challenges of sensor node:

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1. Challenges in real-time:

In many cases, sensor data must be delivered within time constraints so that appropriate observations can be made, or actions are taken. Very few results exist to date regarding meeting real-time requirements in WSN. Most protocols either ignore real-time or simply attempt to process as fast as possible and hope that this speed is sufficient to meet deadlines. Some initial results exist for real-time routing. To date, the limited results that have appeared for WSN regarding real-time issues have been in routing.

2. Challenges in power management:

Low-cost deployment is one acclaimed advantage of sensor networks. Limited processor bandwidth and small memory are two arguable constraints in sensor networks, which will disappear with the development of fabrication techniques. However, the energy constraint is unlikely to be solved soon due to slow progress in developing battery capacity.

3. Network Scale and Time-Varying:

Characteristics of WSN Under severe energy constraints, Sensor nodes operate with limited computing, storage, and communication capabilities. Depending upon the application, the densities of the WSNs may vary widely, ranging from very sparse to very dense. In these sensor nodes, the behavior of sensor nodes is dynamic and highly adaptive, as they need to self-organize and conserve energy forces sensor nodes to adjust their behavior constantly in response to their current level of activity.

4. Management at a Distance:

Sensor nodes will be deployed at our door field such as a subway station. It is difficult for managers or operators to manage the network directly. Thus, the framework should provide an indirect remote control/ management system.

Sensor features

A sensor is a device that can detect changes in an environment. By itself, a sensor is useless, but when we use it in an electronic system, it plays a key role. A sensor can measure a physical phenomenon (like temperature, pressure, and so on) and transform it into an electric signal.

These three features should be at the base of a good sensor:

- It should be sensitive to the phenomenon that it measures.
- It should not be sensitive to other physical phenomena.
- It should not modify the measured phenomenon during the measurement process.

There is a wide range of sensors we can exploit to measure almost all the physical properties around us. A few common sensors that are widely adopted in everyday life include thermometers, pressure sensors, light sensors, accelerometers, gyroscopes, motion sensors, gas sensors, and many more. A sensor can be described using several properties, the most important being:

- Range: The maximum and minimum values of the phenomenon that the sensor can measure.
- Sensitivity: The minimum change of the measured parameter that causes a detectable change in output signal.

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- Resolution: The minimum change in the phenomenon that the sensor can detect.

Sensor Resolution

The resolution of a sensor is the smallest change it can detect in the quantity that it is measuring. The resolution of a sensor with a digital output is usually the resolution of the digital output. The resolution is related to the precision with which the measurement is made, but they are not the same thing.

Resolution is an important specification because without sufficient resolution you may not be able to reliably make the needed measurement and an over-performing sensor will burden your budget. Resolution is only meaningful within the context of the system bandwidth, the application, and the measurement method and unit of measure used by the sensor manufacturer. A simple “resolution spec” in a datasheet rarely provides enough information for a fully informed sensor selection. Understanding this important specification will empower you to confidently make the right displacement sensor choice.

The resolution is also not accurate. An inaccurate sensor could have high resolution, and a low-resolution sensor may be accurate in some applications.

It is not the least significant digit in a display or the least significant bit in a conversation between the digital and analog worlds. Digital devices have a resolution specification based on the least significant bit, and if insufficient, may further degrade the overall sensor resolution, but the fundamental limit of a sensor’s resolution is determined in the analog world the battle for higher resolutions in sensor design is primarily a fight against electrical noise.

Sensor classes: Classification of Sensors

Category of the sensor in the form of classes are:

1. Analog

These types of sensors produce a continuous o/p signal which is normally proportional to the quantity which is being measured. Generally, physical quantities are temperature, pressure, speed, orientation, displacement is the type of analog quantity.

2. Digital

These types of sensors give the output in discrete form, which is in the form of voltage. This sensor produces the output in True/False or ON/OFF or 0/1 depending on the application. The advantage of this type of output is, we can store the output.

Scalar

The sensors produce the signal which is proportional to the magnitude of the quantity being measured. The signal like temperature, color, strain, and pressure are comes under this type of quantity.

E.g., the temperature of a place can be measured using a sensor, which response to temperature changes irrespective of the orientation of the sensor.

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Vector

These sensors produce a signal which is proportional to the magnitude, direction, or orientation. Physical quantity just like sound, image, orientation, and velocity are all vector quantities. So here only magnitude is not sufficient to convey the complete information, e.g. the acceleration of the car can be measured using an acceleration sensor by calculating x, y, and z axes.

Type of Sensor

IoT platforms function and deliver various kinds of intelligence and data using a variety of sensors. They serve to collect data, push it and share it with a whole network of connected devices. All this collected data makes it possible for devices to autonomously function, and the whole ecosystem is becoming “smarter” every day. By combining a set of sensors and a communication network, devices share information and are improving their effectiveness and functionality. Let’s take a look at some of the key sensors, extensively being used in the IoT world.

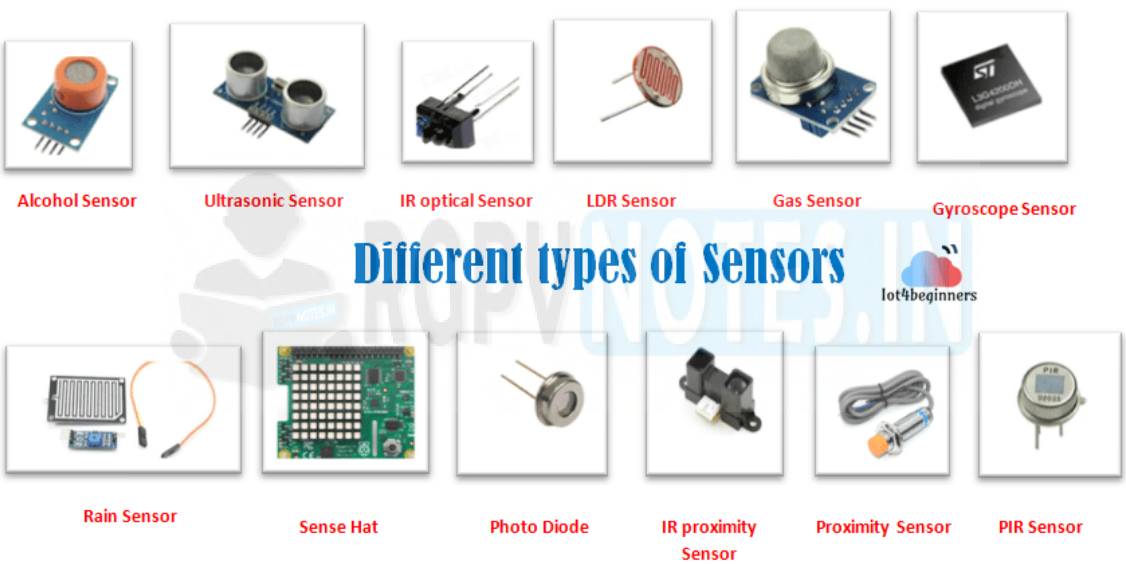

Figure 2.1: Types of Sensor

IR sensor

IR (infrared) sensor is an electronic device that emits light to sense some object of the surroundings. An IR sensor can measure the heat of an object as well as to detect motion. Usually, in the infrared spectrum, all the objects radiate some form of thermal radiation. These types of radiations are invisible to our eyes, but the infrared sensor can detect these radiations. An infrared sensor is a sensor that 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.

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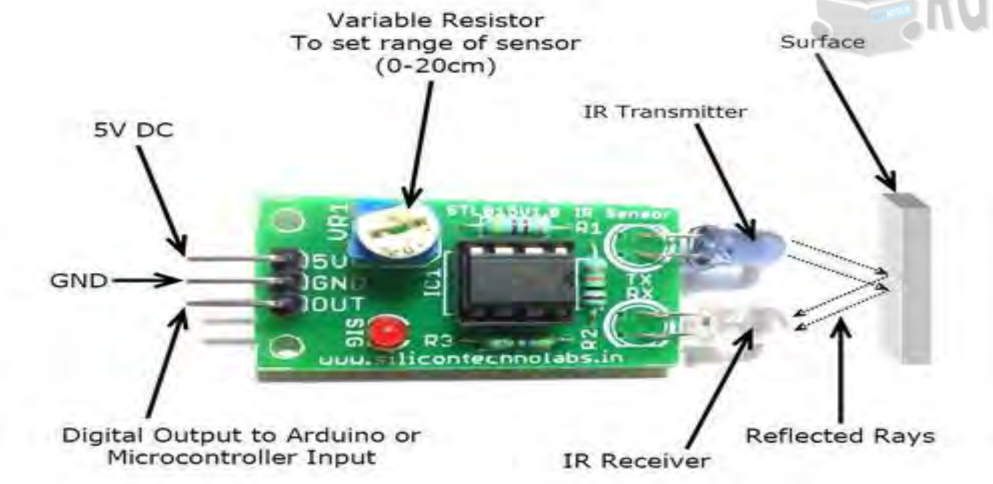

Figure2.2: Working of IR sensor

The emitter is simply an IR LED (Light Emitting Diode) and the detector is simply an IR photodiode. The photodiode is sensitive to IR light of the same wavelength which is emitted by the IR LED. When IR light falls on the photodiode, the resistances and the output voltages will change in proportion to the magnitude of the IR light received. There are five basic elements used in a typical infrared detection system: an infrared source, a transmission medium, an optical component, infrared detectors or receivers, and signal processing. Infrared lasers and Infrared LEDs of specific wavelengths are used as infrared sources.

Types of IR Sensor

There are two types of IR sensors are available and they are,

- Active Infrared Sensor
- Passive Infrared Sensor

Active Infrared Sensor

Active infrared sensors consist of two elements: an infrared source and an infrared detector. Infrared sources include the LED or infrared laser diode. Infrared detectors include photodiodes or phototransistors. The energy emitted by the infrared source is reflected by an object and falls on the infrared detector.

Passive Infrared Sensor

Passive infrared sensors are Infrared detectors. Passive infrared sensors do not use an infrared source and detector. They are of two types: quantum and thermal. Thermal infrared sensors use infrared energy as the source of heat. Thermocouples, pyroelectric detectors, and bolometers are the common types of thermal infrared detectors. Quantum-type infrared sensors offer higher detection performance. It is faster than thermal-type infrared detectors. The photosensitivity of quantum type detectors is wavelength-dependent.

Applications of IR Sensor are as follows:

- Night Vision Devices
- Radiation Thermometers
- Climatology
- Meteorology

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- Photo bio modulation
- Flame Monitors
- Gas detectors
- Water analysis
- Moisture Analyzers
- Anesthesiology testing
- Petroleum exploration
- Rail safety
- Gas Analyzers

Gyroscope sensor:

A sensor or device which is used to measure the angular rate or angular velocity is known as gyro sensors, Angular velocity is simply defined as a measurement of the speed of rotation around an axis. It is a device used primarily for navigation and measurement of angular and rotational velocity in 3-axis directions. The most important application is monitoring the orientation of an object.

Gyroscope sensors are also called Angular Rate Sensors or Angular Velocity Sensors. These sensors are installed in applications where the orientation of the object is difficult to sense by humans. Gyroscope sensors can also measure the motion of the object. For more robust and accurate motion sensing, in consumer electronics Gyroscope sensors are combined with Accelerometer sensors.

Working principle gyroscope sensor

The concept of Coriolis force is used in Gyroscope sensors. In this sensor to measure the angular rate, the rotation rate of the sensor is converted into an electrical signal. The working principle of the Gyroscope sensor can be understood by observing the working of the Vibration Gyroscope sensor.

This sensor consists of an internal vibrating element made up of crystal material in the shape of a double T-structure. This structure comprises a stationary part in the center with 'Sensing Arm' attached to it and 'Drive Arm' on both sides.

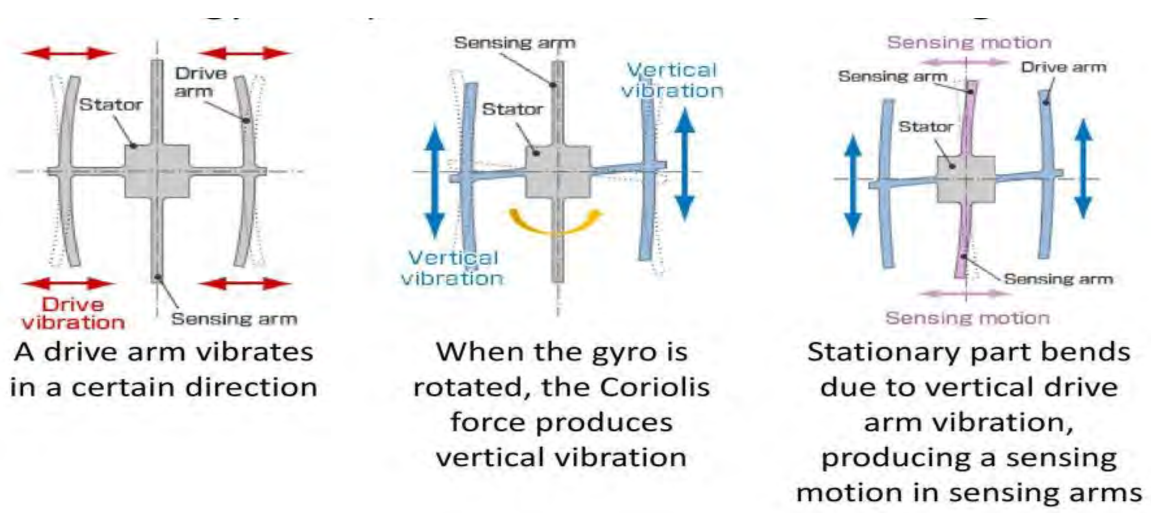

Figure 2.3 : Working principle gyroscope sensor

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Applications of gyroscope sensors are as follows:

- Ring laser Gyros are used in Aircraft and Source shuttles whereas Fiber optic Gyros are used in racecars and motorboats.
- Vibration Gyroscope sensors are used in the car navigation systems, Electronic stability control systems of vehicles, motion sensing for mobile games, camera-shake detection systems in digital cameras, radio-controlled helicopters, Robotic systems, etc
- The main functions of the Gyroscope Sensor for all the applications are Angular velocity sensing, angle sensing, and control mechanisms. Image blurring in cameras can be compensated by using Gyroscope Sensor-based optical image stabilization system.

Temperature sensor

By definition, "A device, used to measure the amount of heat energy that allows detecting a physical change in temperature from a particular source and converts the data for a device or user, is known as a Temperature Sensor."

Proximity sensor

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

Pressure sensor

A pressure sensor is a device that senses pressure and converts it into an electric signal. Here, the amount depends upon the level of pressure applied. There are plenty of devices that rely on liquid or other forms of pressure. These sensors make it possible to create IoT systems that monitor systems and devices that are pressure-propelled.

Water quality sensor

Water quality sensors are used to detect the water quality and Ion monitoring primarily in water distribution systems. Water is practically used everywhere. These sensors play an important role as they monitor the quality of water for different purposes. They are used in a variety of industries.

Chemical sensor

Chemical sensors are applied in many 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.

Gas sensor

Gas sensors are similar to chemical ones but are specifically used to monitor changes in air quality and detect the presence of various gases. Like chemical sensors, they are used in numerous industries such as manufacturing, agriculture, and health and used for air quality monitoring, detection of toxic or combustible

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gas, hazardous gas monitoring in coal mines, oil & gas industries, chemical laboratory research, manufacturing – paints, plastics, rubber, pharmaceutical & petrochemical, etc.

Smoke sensor

A smoke sensor is a device that senses smoke (airborne particulates & gases), and its level. They have been in use for a long period. However, with the development of IoT, they are now even more effective, as they are plugged into a system that immediately notifies the user about any problem that occurs in different industries.

IR sensor

An infrared sensor is a sensor that 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.

Level sensor

A sensor that is used to determine the level or amount of fluids, liquids, or other substances that flow in an open or closed system is called a Level sensor. Like IR sensors, level sensors are present in a wide array of industries. They are primarily known for measuring fuel levels, but they are also used in businesses that work with liquid materials.

Image sensor

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

Motion detection sensor

A motion detector is an electronic device that is used to detect the physical movement (motion) in a given area and it transforms motion into an electric signal; motion of any object or motion of human beings.

Accelerometer sensor

The accelerometer is a transducer that is used to measure the physical or measurable acceleration experienced by an object due to inertial forces and converts the mechanical motion into an electrical output. It is defined as the rate of change of velocity with respect to time.

Gyroscope sensor

A sensor or device which is used to measure the angular rate or angular velocity is known as Gyro sensors, Angular velocity is simply defined as a measurement of the speed of rotation around an axis. It is a device used primarily for navigation and measurement of angular and rotational velocity in 3-axis directions. The most important application is monitoring the orientation of an object.

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Humidity sensor

Humidity is defined as the amount of water vapor in an atmosphere of air or other gases. The most commonly used terms are “Relative Humidity (RH).

Optical sensor

A sensor that measures the physical quantity of light rays and converts it into an electrical signal which can be easily readable by the user or an electronic instrument/device is called an optical sensor.

Sensor Bias :

When looking at the inertial sensor data of gyroscopes and accelerometers you can see that there is often a small offset in the average signal output, even when there is no movement. This is what is also known as Sensor Bias.

The gyroscopes and accelerometers used in the MTi's are MEMS (Micro Electro-Mechanical Systems) sensors. The physical properties of these sensors change over time which results in different characteristics over time. Depending on sensor usage and time the internal sensor biases will increase.

Outputting inertial data

When outputting the inertial data (gyroscope and accelerometer data), in most cases you will see sensor bias in your output. You can measure the biases when the MTi is laying still. Remember that the biases change, so there is no fixed value you can use to correct the bias for a longer period.

Outputting orientation

If not corrected and you would use only the gyroscopes to calculate the orientation, the orientation would drift because of the sensor bias.

Sensor Drift

This is the low-frequency change in a sensor with time. It is often associated with the electronic aging of components or reference standards in the sensor. Drift generally decreases with the age of a sensor as the parts mature. A smoothly drifting sensor can be corrected for drift. e.g. Sea-Bird temperature sensors that are drifting about 1 mºC/yr (and have been smoothly changing for several years) allow one to correct for the drift and get more accurate readings. Drift is also caused by biofouling that can’t be properly corrected for, but we often try.

Hysteresis error of Sensor

The hysteresis error of a pressure sensor is the maximum difference in output at any measurement value within the sensor’s specified range when approaching the point first with increasing and then with decreasing pressure.

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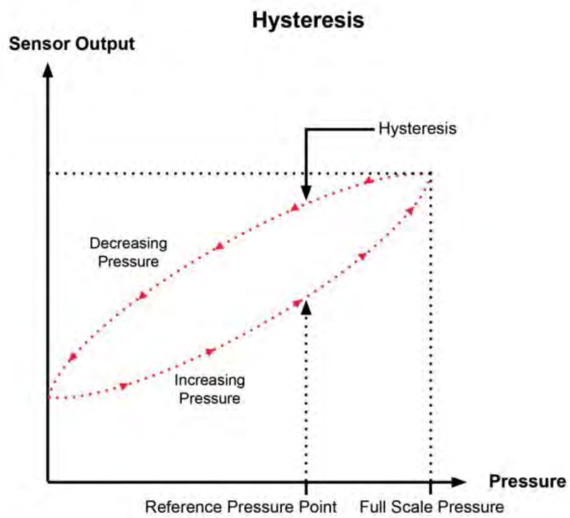

Figure 2.4: Hysteresis error of the sensor

The hysteresis error value is normally specified as a positive or negative percentage of the specified pressure range. If a sensor is only used over half of the specified range the hysteresis error is calculated from this value. By using the maximum working pressure, the accuracy is, of course, better than specified by the manufacturer (for example the percentage of working pressure). Also, the hysteresis error is usually expressed as a combination of mechanical and temperature hysteresis.

Mechanical hysteresis

Mechanical hysteresis is the output deviation at a certain input pressure when that input is approached first by increasing and then by decreasing pressure.

Temperature hysteresis

Temperature hysteresis is the output deviation at a certain input pressure, before and after a temperature cycle. Hysteresis errors are not always specified separately but combined in a total figure for linearity, hysteresis, and repeatability.

Quantization error

Quantization error is the difference between the analog signal and the closest available digital value at each sampling instant from the A/D converter. Quantization error also introduces noise, called quantization noise, to the sample signal.

The higher the resolution of the A/D converter, the lower the quantization error and the smaller the quantization noise. The relationship between resolution (in bits) and quantization noise for an ideal A/D converter can be expressed as Signal to Noise (S/N) = -20*log (1/2^n) where n is the resolution of the A/D converter in bits. S/N is the signal to noise and is expressed in dB. This relationship can also be approximated as S/N = 6*n. Typical S/N ratios for ideal A/D converters are 96dB for 16 bits, 72dB for 12 bits, and 48dB for 8 bits.

Actuator:

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An actuator operates in the reverse direction of a sensor. It takes an electrical input and turns it into physical action. For instance, an electric motor, a hydraulic system, and a pneumatic system are all different types of actuators.

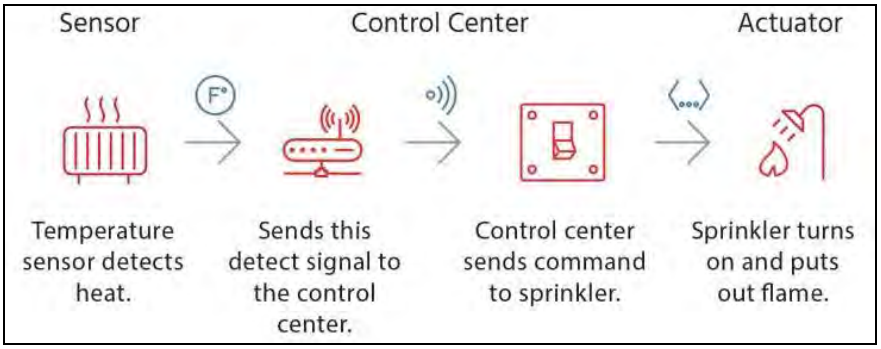

Figure 2.5: IOT System actuator

There are many different types of sensors in an IoT system. Flow sensors, temperature sensors, voltage sensors, humidity sensors, and the list goes on. In addition, there are multiple ways to measure the same thing. For instance, the airflow might be measured by using a small propeller-like the one you would see on a weather station. Alternatively, as in a vehicle measuring the air through the engine, airflow is measured by heating a small element and measuring the rate at which the element is cooling.

Types of Actuators with their functions

Different types of Actuators with their functions or applications are as follows:

Hydraulic actuator

• This actuator converts mechanical motion into linear, rotary, or oscillatory motion.
• The hydraulic actuator consists of a cylinder or fluid motor which uses hydraulic power to help mechanical operation.
• Liquids are nearly impossible to compress; hydraulic actuator maintains considerable force. Limited acceleration of actuator restricts its usage.
Example: Hydraulic brake in a vehicle.

Pneumatic actuator

• This actuator converts energy formed by vacuum or compressed air at high pressure into linear or rotary motion.
• They are responsible to convert pressure into force.

Advantages:

1. Pneumatic energy responds quickly to start and stop signals.
2. It does require a power source to be stored in reserve for its operation.
3. Pneumatic actuators produce large forces from relatively small pressure changes.

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Examples:
1. Rack and Pinion actuators used for valve controls of pipes.
2. Pneumatic brakes are very responsive to small pressure changes applied by the driver.

Electrical actuator

• It is powered by a motor which converts electrical energy into mechanical torque.
• Electrical energy is used to actuate equipment (e.g. solenoid valves) which control water flow in pipes with response to electrical signals.
• **Advantages:** cheap, clean, speedy type of actuator.
• **Examples:** Solenoid based electric bell-ringing mechanism

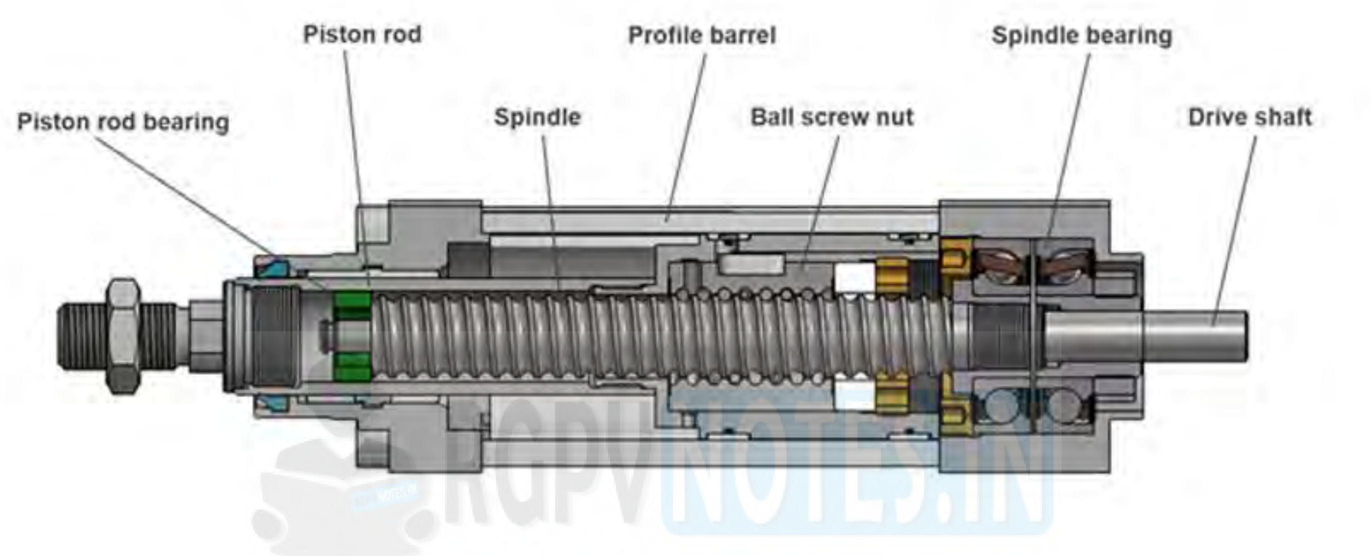

Figure 2.6: IOT Electrical actuator

An electric motor will create rotary motion as the spindle, or rotor rotates. The motor spindle is directly coupled to a helical screw, via the driveshaft, which in turn rotates in a ball screw nut.
As the spindle rotates the ball screw nut is driven forwards, or backward, along the helical screw. A hollow piston rod is attached to the ball screw nut and this creates the linear motion out of, or into the linear actuator as the motor rotates clockwise or anti-clockwise.

Mechanical actuator

A mechanical actuator is a device designed to remotely control or move a secondary mechanism via an external power source, which may include electric current and high-pressure oil or gas. The internal mechanisms used to convert the input power to a working motion differ according to the intended output orientation and the specific power source used. They include gear trains, hydraulic pistons, and lead screws. The orientation of the output motion is either linear or rotary and is dictated by the specifics of the secondary or actuated mechanism. The mechanical actuator is generally more powerful than electromagnetic types and, typically, the preferred choice for high-torque applications such as industrial and earth-moving machinery parts.

• It converts rotary motion into linear motion.
• It consists of gears, pulleys, rails, chains, and other devices for its operation.
Examples: Rack and pinion mechanism and Crankshaft.

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Thermal or Magnetic actuator

- This actuator can be actuated by the application of thermal or magnetic energy.
- This actuator uses shape-memory materials e.g. shape memory alloys.
- Advantages: Compact, light in weight, economical, offers high power density.

Examples: Thermal actuator is thermostat; magnetic actuator is an electromagnet.

Soft actuator

It is polymer-based and is designed to handle fragile objects like fruit harvesting in agriculture or manipulating the internal organs in biomedicine. Examples: Shape Memory polymers, Photopolymers Shape memory polymer is functioning similar to our muscles.

It also responds to a range of stimuli e.g. light, electrical, heat, magnetic, pH, moisture changes, etc. The advantages of such polymers are low density, high strain recovery, biocompatibility, biodegradability, etc. Photopolymers are known as light-activated polymers. They are a special type of shape memory polymers that are activated by light.

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