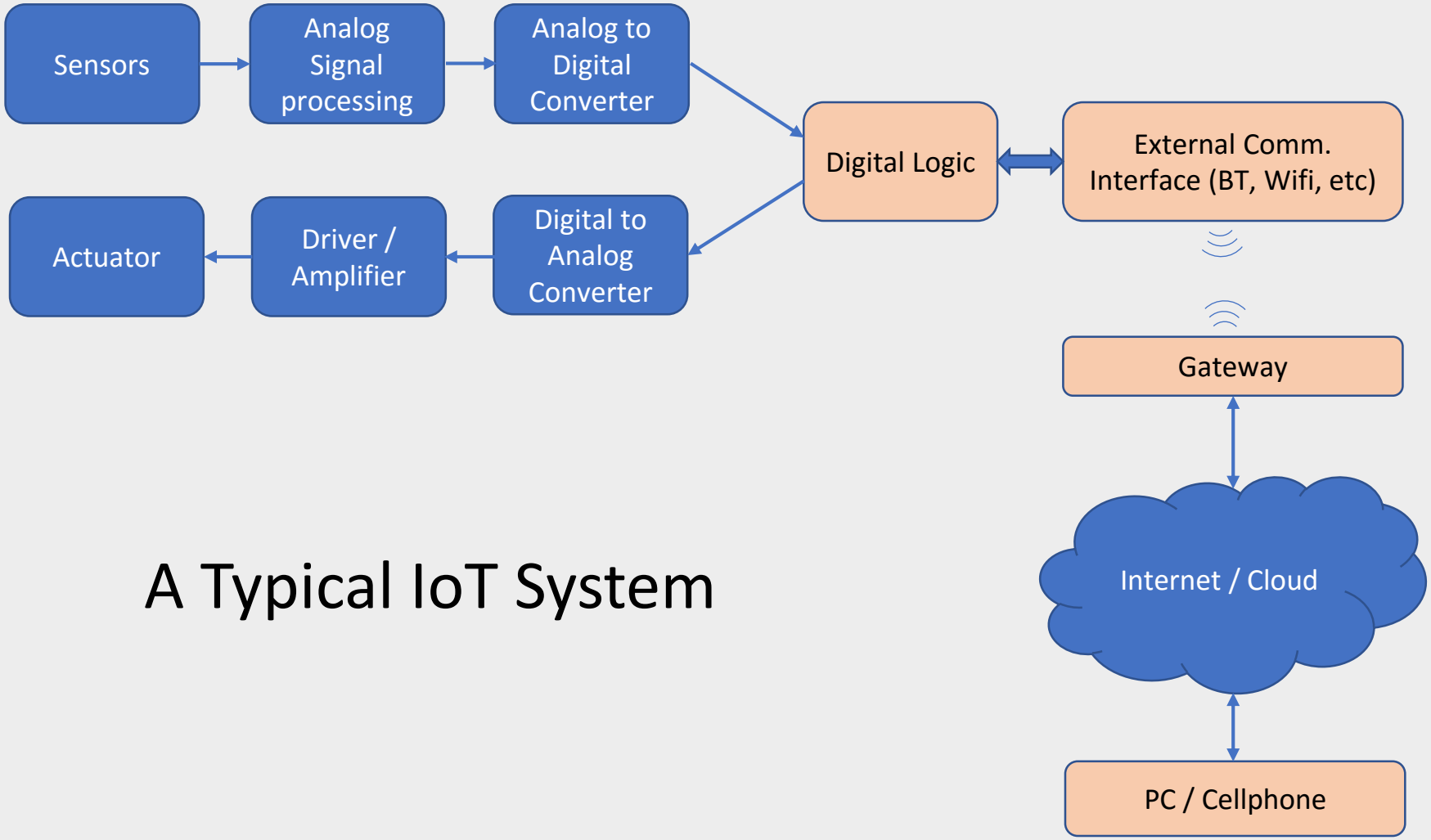
Sensors in IoT Systems

(Sense, Control and Actuate)

Capgemini

Introduction

A typical IoT device contains a sensor for collecting information, signal processing for the output of sensor, digital logic for decision making and connectivity to internet and signal processing to actuate the actuator in response to that of sensed input.



A Typical IoT System

Additional Requirements for IoT Sensors

The basic functionality of Sensors is to sense and convert physical parameters into electrical signals. However, for IoT, sensors need to add the following properties too:

- Low cost, to make IoT devices more economical for use in market
- Small formfactor, so as to reduce size of IoT device and easy mounting in any environment
- Wireless, for easy installation and to avoid issues with wired connectivity
- Self-identification and self-validation, so it can alarm for it's own failure
- Very low power, for long lasting battery operation or manage with energy harvesting
- Robust, to minimize or eliminate maintenance
- Self-diagnostic and self-healing, detects own health
- Self-calibrating, or accepts calibration commands via wireless link, for accurate results
- Data pre-processing, to reduce load on gateways, PLCs and cloud resources

In some of the applications single sensor may not be sufficient to do the job and hence multiple sensors can be combined and correlated to infer conclusions. For example, temperature sensor and vibration sensor data can be used to detect the onset of mechanical failure. In some cases, functions of different sensors are combined in software to achieve the required information.

Smart sensors

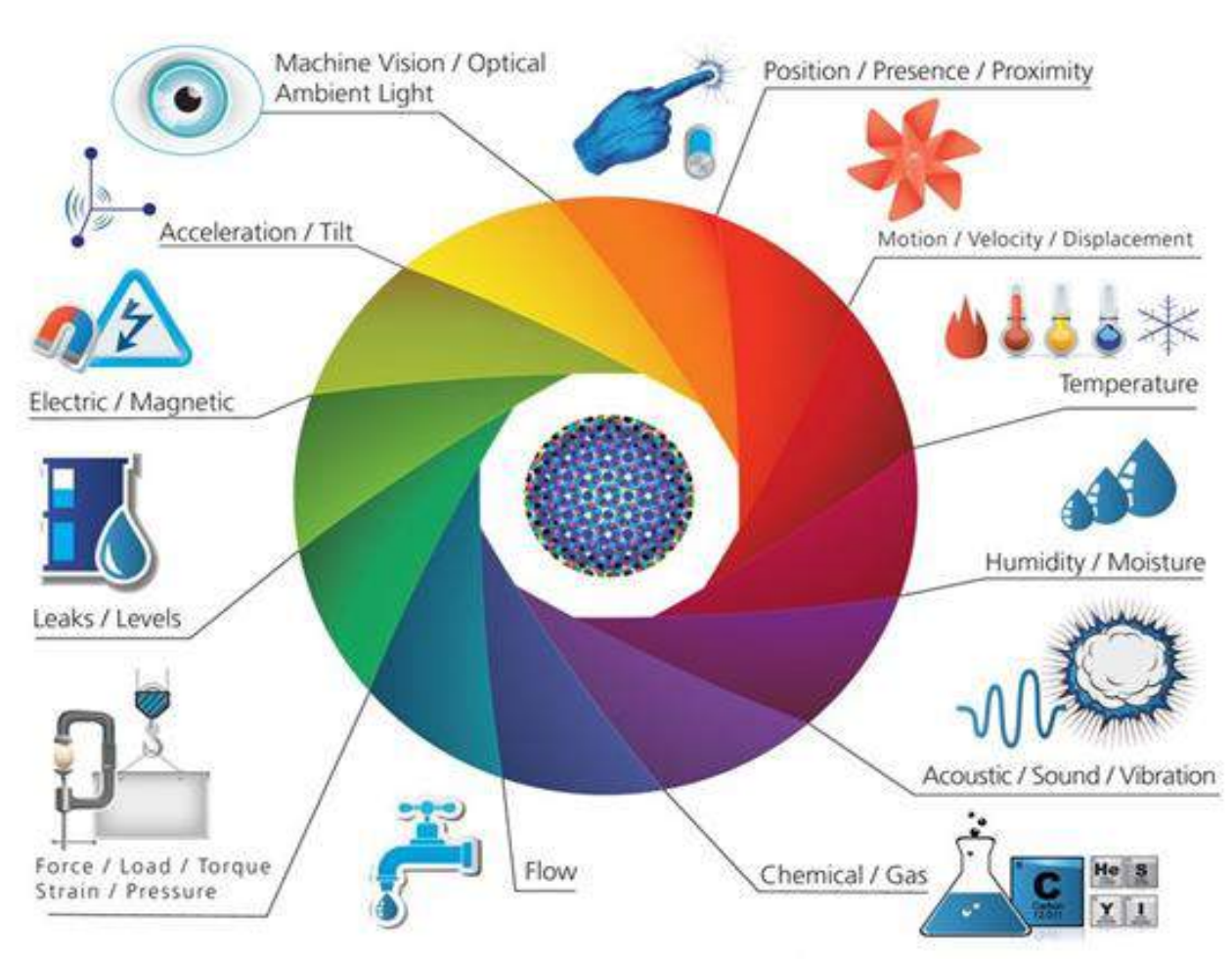
Smart sensors have intelligence of directly providing digital data ready to transmit to gateway for the parameters under measurement. The signal processing and digital logic are part of these sensors. The digital logic consists of microprocessor unit (MPU) performing the algorithmic functions like filtering, compensation and any other process-specific signal conditioning tasks.

Internal MPU of smart sensors can also be used for providing calibration data for sensor, monitoring drift in production parameters, making fast and emergency decisions to avoid catastrophic failures and providing alarms to prevent major failures. This will reduce the processing load on IoT systems digital processing CPU. Smart sensors normally communicate to central processing system for major failures or exceptions. This saves power used in frequent communication for sensor increasing battery life.

Some of the smart sensors have self-diagnostic capability which is achieved by having two sensing elements in the sensor. The results are sent by sensor to central processing unit only after comparing output of both the elements. This will help detecting failure of sensing elements or drift in their values over the period or due to environmental effects.

Basic Sensors and Their Types

Basic sensors were in use from long time but the invent of the Internet of Things has taken role of sensors and evolutions of sensors to a completely different level.



By combining a set of sensors and a communication network, IoT devices share information with one another and are improving their effectiveness and functionality. All this collected data makes it possible for devices to autonomously function, and the whole ecosystem is becoming “smarter” every day.

There are many different types of sensors like Flow sensors, Temperature sensors, Voltage sensors, Humidity sensors and the list goes on. However, same parameter can also be measured by using different type of sensor e.g. pressure can be measured using specific pressure sensors while it can also be measured using load cell which is used to measure weight.

Temperature Sensors

Temperature sensors have been deployed for a long time in a variety of devices, especially in air-conditioning, refrigeration and similar other devices used for environmental control. In IoT world, they have found their role in manufacturing processes, agriculture and health industry. In the manufacturing process, machines measure environmental temperature as well as machine temperature to keep the process optimal. On the other hand, in agriculture, the temperature of soil is crucial for crop growth helping the production of plants and maximizing the output.

Following are some sub-categories of Temp Sensors:

- **Thermocouples:** It is voltage devices that indicate temperature measuring with a change in voltage.
- **Resistor Temperature Detectors (RTD) and Thermistors:** Both of these type of sensors changes their resistance value as per the temperature. Thermistors are commonly made with ceramic or polymer materials while RTDs are made of pure metals. Thermistors are always better in performance on various parameters like accuracy, response time, etc.
- **IC (Semiconductor):** These sensors are in the form of semiconductor ICs and it takes advantage of the variable resistance properties of semiconductor materials. It can provide a direct temperature reading in digital form, especially at low temperatures.
- **Infrared sensors:** It detects temperature by intercepting a portion of emitted infrared energy of the object or substance, and sensing its intensity, can be used to measure temperature of solids and liquids only, Not possible to use it on gases because of their transparent nature.

Humidity Sensors

These sensors usually follow the use of temperature sensors, as many manufacturing processes require perfect working conditions. Through measuring humidity, you can ensure that the whole process runs smoothly, and when there is any sudden change, action can be taken immediately, as sensors detect the change almost instantaneously.

Their applications and use can be found in Industrial & residential domain for heating, ventilating, and air conditioning systems control. They can also be found in Automotive, museums, industrial spaces and greenhouses, meteorology stations, paint and coatings industries, hospitals & pharma industries to protect medicines.

Pressure Sensors

A pressure sensor is a device that senses pressure and converts it into an electric signal. 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.

Pressure sensors are widely used in small medical devices to huge water and heating systems in industrial environment..

Proximity Sensors

Proximity sensors detects the presence or absence of a nearby object without getting in contact with them. Proximity sensors are largely used for detection of presence of people in specific area and thereby controlling on/off of lights and AC to save energy. It is also been used in elevator doors to detect entry/exit of person before closing the doors.

Following are some of the Proximity Sensors sub-categories:

- **Inductive Sensors:** Inductive proximity sensors are used for detecting the presence of metallic objects using electromagnetic field or a beam of electromagnetic radiation. It can operate at higher speeds than mechanical switches and also more reliable because of its robustness.
- **Capacitive Sensors:** Capacitive proximity sensors can detect both metallic as well as non-metallic targets nearly all other materials has a dielectric different from air. It can be used to sense very small objects through a large portion of target So generally used in difficult and complicated applications.
- **Photoelectric Sensors:** Photoelectric sensor is made of light-sensitive parts and use a beam of light to detect the presence or absence of an object. Its an ideal alternative of inductive sensors when we require long sensing distances or for sensing non-metal object.
- **Ultrasonic Sensors:** Ultrasonic sensors are also used to detect the presence or to measure the distance of targets similar to radar or sonar. This makes a reliable solution for harsh and demanding conditions.

Water Quality Sensors

Water quality sensors are used to detect the water quality and Ion monitoring primarily in water distribution systems. They are used in water purifiers and medical devices used for diagnosis.

Following is a list of most common kind of water sensors in use.

- **Chlorine Residual Sensor:** It measure chlorine residual (i.e. free chlorine, monochloramine & total chlorine) in water and most widely used disinfectant because of its efficiency and cost.
- **Total organic carbon Sensor:** TOC sensor is used to measure organic element in water.
- **Turbidity Sensor:** Turbidity sensors measure suspended solids in water, typically it is used in river and stream gaging, wastewater and effluent measurement.
- **Conductivity Sensor:** Conductivity measurements are carried out in industrial processes primarily to obtain information on total ionic concentrations (i.e. dissolved compounds) in water solutions.
- **pH Sensor:** It is used to measure the pH level in the dissolved water, which indicates how acidic or basic (alkaline) it is.
- **Oxygen-Reduction Potential Sensor:** The ORP measurement provides insight into the level of oxidation/reduction reactions occurring in the solution.

Chemical Sensors

Chemical sensors indicate changes in liquid or air chemical changes. They play an important role in bigger cities, where it is necessary to track changes and protect the population. Main use cases of chemical sensors can be found in Industrial environmental monitoring and process control, intentionally or accidentally released harmful chemical detection, explosive and radioactive detection, recycling processes on Space Station, pharma industries and laboratory etc.

Following are most common kind of chemical sensors in use:

- Chemical field-effect transistor
- Chemiresistor
- Electrochemical gas sensor
- Fluorescent chloride sensors
- Hydrogen sulfide sensor
- Nondispersive infrared sensor
- pH glass electrode
- Potentiometric sensor
- Zinc oxide nanorod sensor

Gas Sensors

Gas sensors are similar to the chemical ones but are specifically used to monitor changes of the 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 gas, Hazardous gas monitoring in coal mines, Oil & Gas industries, chemical Laboratory research, Manufacturing – paints, plastics, rubber, pharmaceutical & petrochemical etc.

Following are some common Gas sensors:

- Carbon dioxide sensor
- Breathalyzer
- Carbon monoxide detector
- Catalytic bead sensor
- Hydrogen sensor
- Air pollution sensor
- Nitrogen oxide sensor
- Oxygen sensor
- Ozone monitor
- Electrochemical gas sensor
- Gas detector
- Hygrometer

Smoke Sensors

A smoke sensor is a device that senses smoke (airborne particulates & gases) and it's level. Smoke sensors are extensively used by manufacturing industry, HVAC, buildings and accommodation infra to detect fire and gas incidences. This serves to protect people working in dangerous environments, as the whole system is much more effective in comparison to the older ones.

Common Type of Smoke Sensors

- **Optical smoke Sensor (Photoelectric):** Optical smoke sensor used the light scatter principle trigger to occupants.
- **Ionization smoke Sensor:** Ionization smoke sensor work on the principle of ionization, kind of chemistry to detect molecules causing a trigger alarm.

IR Sensors

An infrared sensor is a sensor which is used to sense certain characteristics of its surroundings by either emitting or detecting infrared radiation. 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. Other common use includes Home appliances & remote control, Breath analysis, Infrared vision (i.e. visualize heat leaks in electronics, monitor blood flow, art historians to see under layers of paint), wearable electronics, optical communication, non-contact-based temperature measurements, Automotive blind-angle detection.

Their usage does not end there, they are also a great tool for ensuring high-level security in your home. Also, their application includes environment checks, as they can detect a variety of chemicals and heat leaks. They are going to play an important role in the smart home industry, as they have a wide-range of applications.

Level Sensors

Level sensors are primarily known for measuring fuel levels, but they are also used in businesses that work with liquid materials. For example, the recycling industry, as well as the juice and alcohol industry rely on these sensors to measure the number of liquid assets in their possession.

Best use cases of level sensor is, Fuel gauging & liquid levels in open or closed containers, Sea level monitoring & Tsunami warning, water reservoirs, Medical equipment, compressors, hydraulic reservoirs, machine tools, Beverage and pharmaceutical processing, High or low-level detection etc. With the use of these sensors, any product manager can precisely see how much liquid is ready to be distributed and whether the manufacturing should be stepped up.

There are two basic level measurement types:

- **Point level sensors:** Point level sensors usually detect the particular specific level and respond to the user if the sensing object is above or below that level. It is integrated into single device to get an alarm or trigger
- **Continuous level Sensor:** Continuous level sensors measure liquid or dry material levels within a specified range and provide outputs which continuously indicate the level. The best example of it is fuel level display in the vehicle.

Image Sensors

Image sensors is instruments which is used to convert optical images into electronic signals for display or storage files electronically. The major use of image sensor in Digital camera & modules, medical imaging and night vision equipment, thermal imaging devices, radar, sonar, media house, Biometric & IRIS devices.

Two main types of sensors are:

- **CCD (charge-coupled device)**
- **CMOS (complementary metal-oxide semiconductor)**

Both CCD and CMOS imagers use metal-oxide semiconductors, having the same degree of sensitivity to light, and no inherent quality difference.

One of the best-known uses includes the car industry, in which imagery plays a very important role. With these sensors, the system can recognize signs, obstacles and many other things that a driver would generally notice on the road. They play a very important role in IoT industry, as they directly affect the progress of driverless cars.

They are also implemented in improved security systems, where images help captures details about the perpetrator.

In the retail industry, these sensors serve to collect data about customers, helping businesses get a better insight into who is actually visiting their store, race, gender, age are only some of the useful parameters that retail owners get by using these IoT sensors.

Motion Detection Sensors

A motion detector is an electronic device which 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.

Motion detection plays an important role in the security industry. Businesses utilize these sensors in areas where no movement should be detected at all times, and it is easy to notice anybody's presence with these sensors installed. These are primarily used for intrusion detection systems, Automatic door control, Boom Barrier, Smart Camera (i.e. motion based capture/video recording), Toll plaza, Automatic parking systems, Automated sinks/toilet flusher, Hand dryers, energy management systems (i.e. Automated lighting, AC, Fan, Appliances control) etc.

Now-a-days, various controls are getting implemented by sensing human gestures. These are nothing but motion sensors.

Following are key motion sensor types widely used:

- **Passive Infrared (PIR):** It Detects body heat (infrared energy) and the most widely used motion sensor in home security systems.
- **Ultrasonic:** Sends out pulses of ultrasonic waves and measures the reflection off a moving object by tracking the speed of sound waves.
- **Microwave:** Sends out radio wave pulses and measures the reflection off a moving object. They cover a larger area than infrared & ultrasonic sensors, but they are vulnerable to electrical interference and more expensive.

Accelerometer Sensors

Accelerometer measure the physical or measurable acceleration experienced by an object due to inertial forces and converts the mechanical motion into an electrical output. These sensors are now present in millions of devices, such as smartphones. Their uses involve detection of vibrations, tilting and acceleration in general. This is great for monitoring your driving fleet or using a smart pedometer. In some instances, it is used as a form of anti-theft protection, as the sensor can send an alert through the system if an object that should remain stationary is moved.

They are widely used in cellular & media devices, vibration measurement, Automotive control and detection, free fall detection, aircraft and aviation industries, movement detection, sports academy / athletes behavior monitoring, consumer electronics, industrial & construction sites etc.

There are various kind of accelerometers and following are few mainly used in IoT projects:

- **Hall-effect accelerometers:** Hall-effect accelerometers are using Hall principle to measure the acceleration, it measure the voltage variations caused by changes in a magnetic field around them.
- **Capacitive accelerometers:** Capacitive accelerometers sensing output voltage dependents on the distance between two planar surfaces. Capacitive accelerometers are also less prone to noise and variation with temperature.
- **Piezoelectric accelerometers:** Piezoelectric sensing principle is working on the piezoelectric effect. Piezo-film based accelerometers are best used to measure vibration, shock, and pressure.

Each accelerometer sensing technology has its own advantages and compromises. Before selecting, it’s important to understand the basic differences of the various types and the test requirements.

Gyroscope Sensors

Gyrosensors measure the angular rate or angular velocity. It is used in devices which are primarily meant for navigation and measurement of angular and rotational velocity in 3-axis directions. The most important application is monitoring the orientation of an object.

Their main applications are in Car navigation systems, Game controllers, Cellular & camera devices, consumer electronics, Robotics control, Drone & RC control helicopter or UAV control, Vehicle control/ADAS and many more.

There are several different kinds of gyro sensors which is select by working mechanism, output type, power, sensing range and environmental conditions.

- Rotary (classical) gyroscopes
- Vibrating Structure Gyroscope
- Optical Gyroscopes
- MEMS(micro-electro-mechanical systems) Gyroscopes

These sensors are always combined with accelerometers. The use of these two sensors simply provides more feedback to the system.

Optical Sensors

An optical sensor 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. The technology behind this sensor allows it to monitor electromagnetic energy, which includes, electricity, light and so on.

These sensors are mainly used in healthcare, environment monitoring, energy, aerospace and many more industries. With their presence oil companies, pharmaceutical companies and mining companies are in a much better position to track environmental changes while keeping their employee's safety.

Their main use can be found in Ambient light detection, digital optical switches, optical fibres communications, due to Electrical isolation best suited for oil and gas applications, civil and transportation fields, High speed network systems, elevator door control, assembly line part counters and safety systems.

Following are key type of optical sensors:

- **Photodetector:** It uses light sensitive semiconductor materials like photocells, photodiodes or phototransistors to work as photodetector
- **Fiber Optics:** Fiber optics carry no current, so it is immune to electrical & electromagnetic interference and in damaged conditions no sparking or shock hazard.
- **Pyrometer:** It estimates the temperature of an object by sensing the color of the light as objects radiate light according to their temperature and produce same colors at same temperatures.
- **Proximity & Infrared:** Proximity use light to sense objects nearby and Infrared are used where visible light would be inconvenient.

Summary

Selection of sensors plays key role in IoT devices. One need to understand the application of the IoT device and select appropriate sensor. We also need to remember that same parameters can be sensed by different types of sensors. However, which type of sensor is right choice for a particular application is something to be evaluated while selecting sensors. The other factors like low cost, small formfactor, low power consumption, reliability are also some of the key factors to be considered while selecting sensors for IoT devices.

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