IoT Physical Layer: Sensors, Actuators, Controllers and Programming

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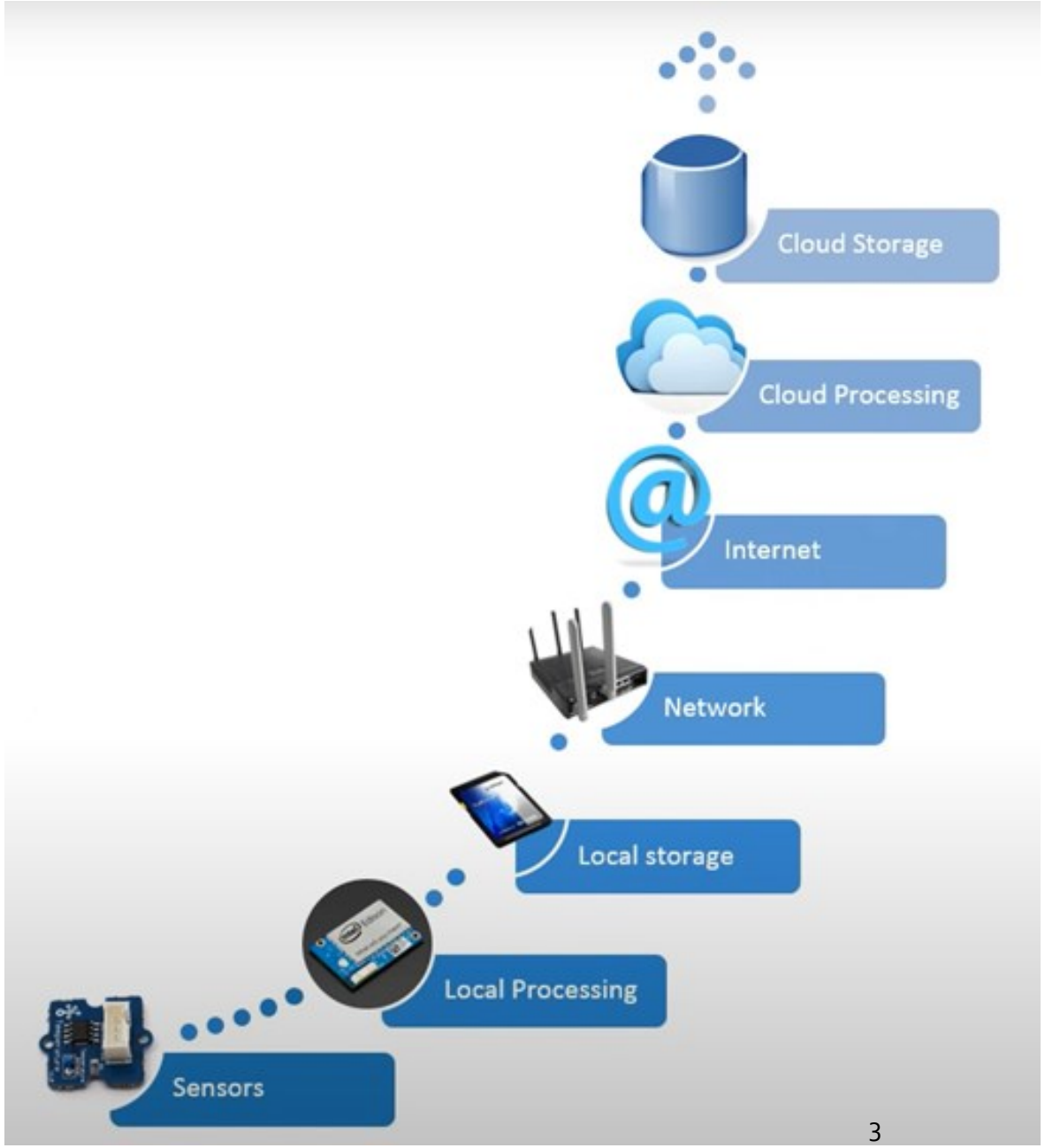
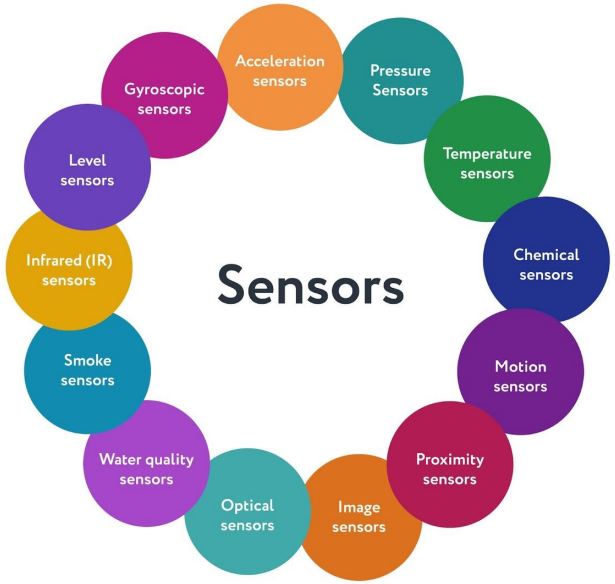
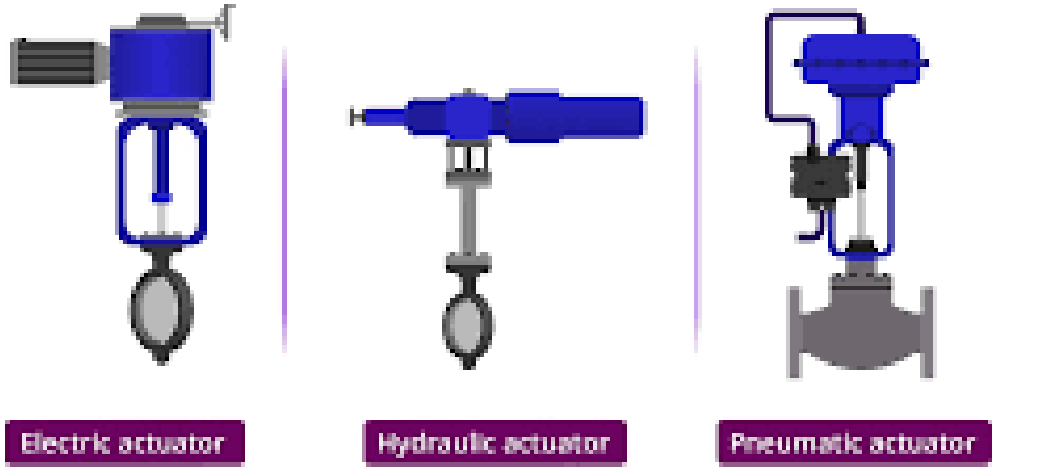
Course Outline

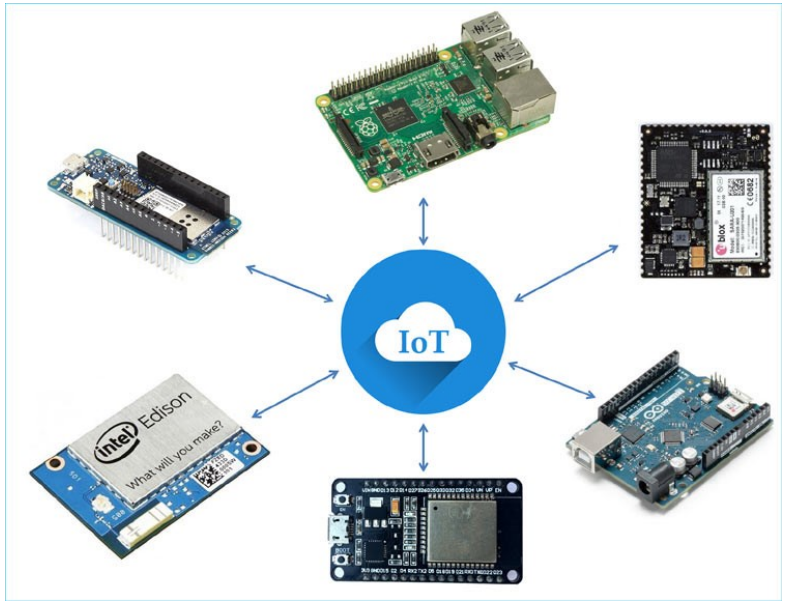
- IoT Introduction and Building Blocks
- IoT Physical Layer
- IoT Networking and Communication Layer
- IoT Cloud Computing, and Data Analytics
- IoT Case Studies and Real Applications
- IoT Security Introduction
- IoT Threat Modelling
- Targeting the IoT Ecosystem
- Intrusion Detection Systems

IoT Stack


Cloud Storage
Cloud Processing
Internet
Network
Local storage
Local Processing
Sensors

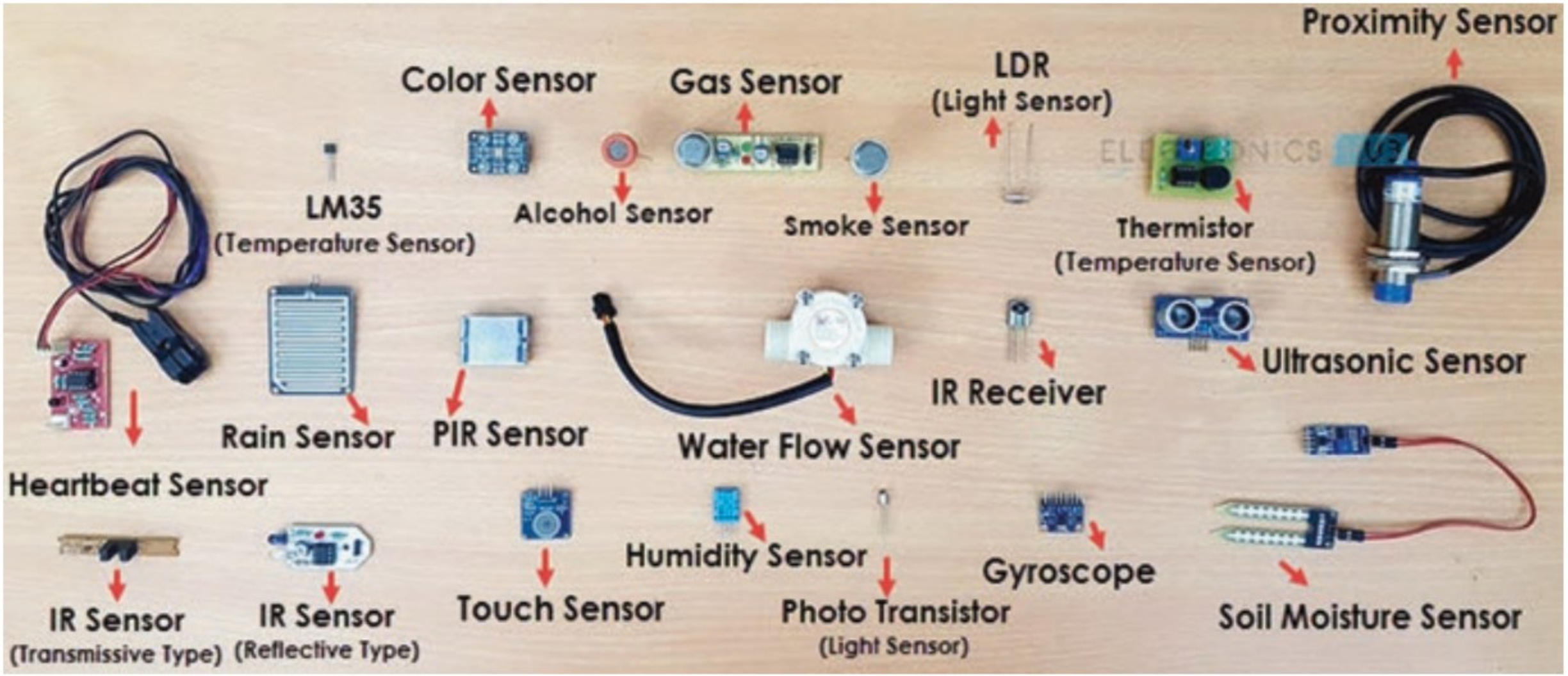

Sensors
Acceleration sensors
Pressure Sensors
Temperature sensors
Chemical sensors
Motion sensors
Proximity sensors
Image sensors
Optical sensors
Water quality sensors
Smoke sensors
Infrared (IR) sensors
Level sensors
Gyroscopic sensors


Electric actuator
Hydraulic actuator
Pneumatic actuator


IoT
intel Edison
What will you make?

IoT Physical Layer

- The physical layer is the most detailed level of abstraction in IoT.
- It mainly consists of **sensors** that acquire information for the system and **actuators** that do actions in response to instructions from the system.
- For example,
  - Sensors send feedback about the condition of the rooms and whether there are any people in the rooms or not, and accordingly, the controller sends its signals to the actuators to turn off unnecessary working devices such as the lights and the air conditioner.
- **Transducer** terminology is used for both sensors and actuators. It means a device that converts energy form to another.


Proximity Sensor
Color Sensor
Gas Sensor
LDR
(Light Sensor)
LM35
(Temperature Sensor)
Alcohol Sensor
Smoke Sensor
Thermistor
(Temperature Sensor)
Ultrasonic Sensor
IR Receiver
Rain Sensor
PIR Sensor
Water Flow Sensor
Heartbeat Sensor
Humidity Sensor
Gyroscope
Touch Sensor
Photo Transistor
(Light Sensor)
Soil Moisture Sensor
IR Sensor
(Transmissive Type)
IR Sensor
(Reflective Type)

Sensor

- A sensor is a device that **senses** and **measures** any **change (physical phenomena** or **property)** in the physical environment.
- It converts the **physical quantities** into an **electrical signal**.
- It takes any **input** from the real-world environment and feeds it into a system in the form of an electrical signal.
- It is connected at the **input** of a system, and it supplies all the necessary data for processing.

Actuator

- An actuator is a device that converts **electrical signal** into **mechanical** work. It converts electrical energy into mechanical energy.
- It is used for generating movement or a change in an environment.
- Actuators are connected at the **output** of a system. It takes electrical signal as its input and generates mechanical movement as its output.
- The actuator depends on the data provided by the sensor.

Sensor | Control Center | Actuator

Temperature sensor detects heat.

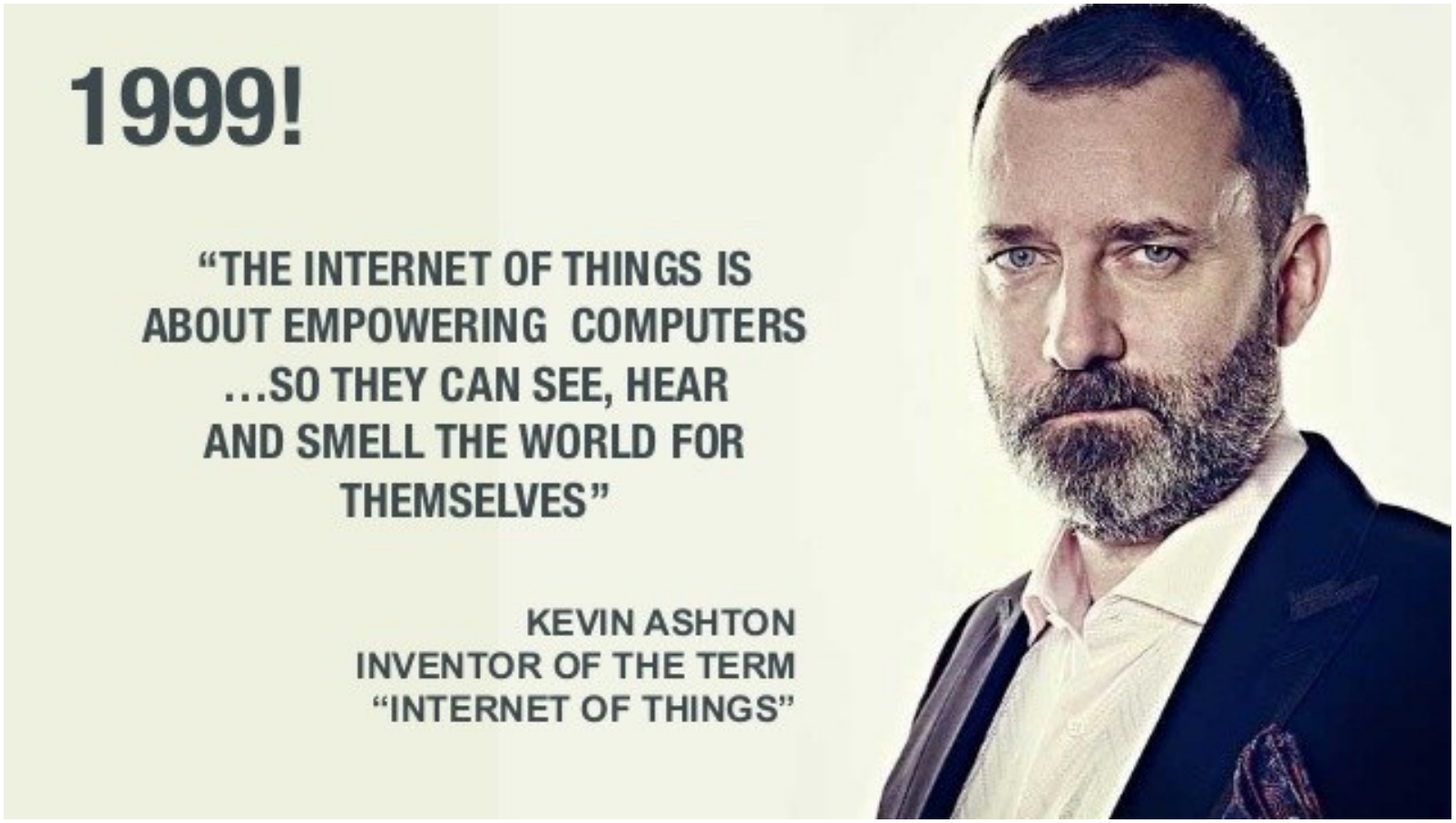
Sends this detect signal to the control center.

Control center sends command to sprinkler.

Sprinkler turns on and puts out flame.

Sensor to **Actuator** Flow

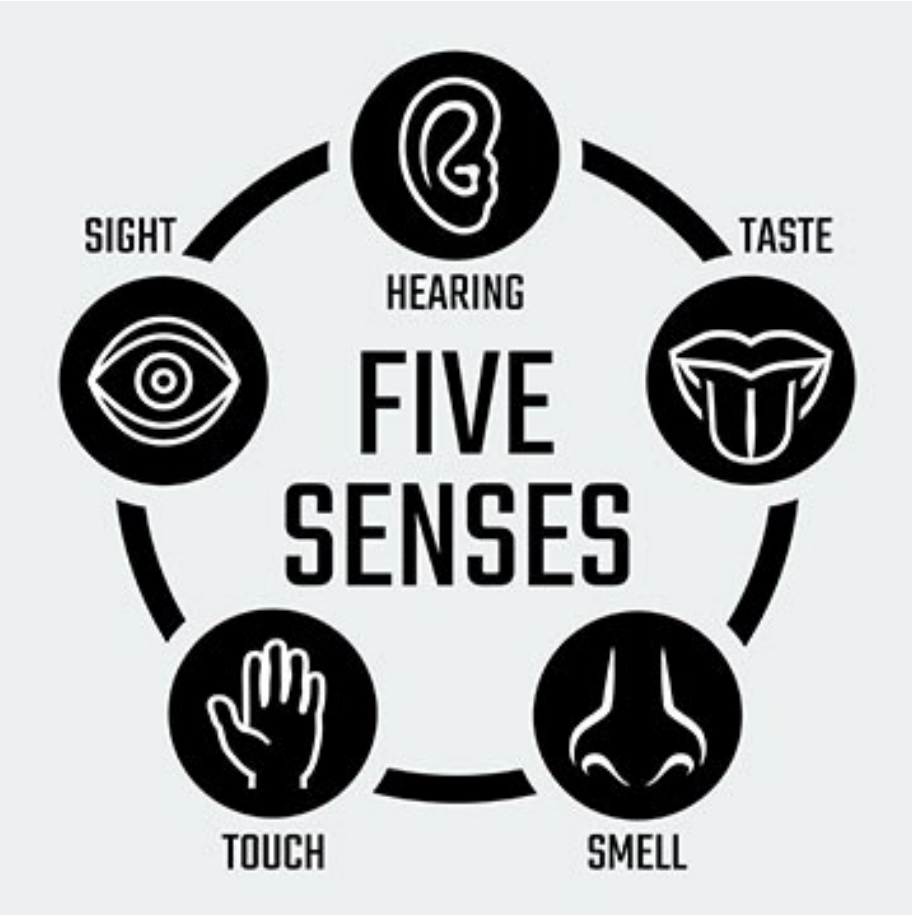
Sensors for IoT



Sensors

- Each sensor can only measure a **unique property**.
- Sensors **do not affect** the measured property.
- Sensors are manufactured in different shapes and sizes.
- They can be mechanical sensors, electrical sensors, and chemical sensors, etc.

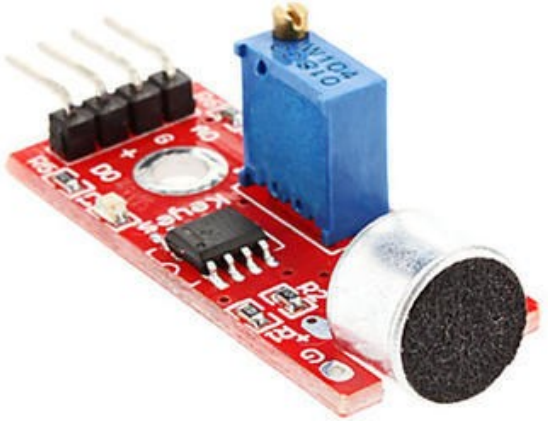
Sensors Mimic the Five Senses



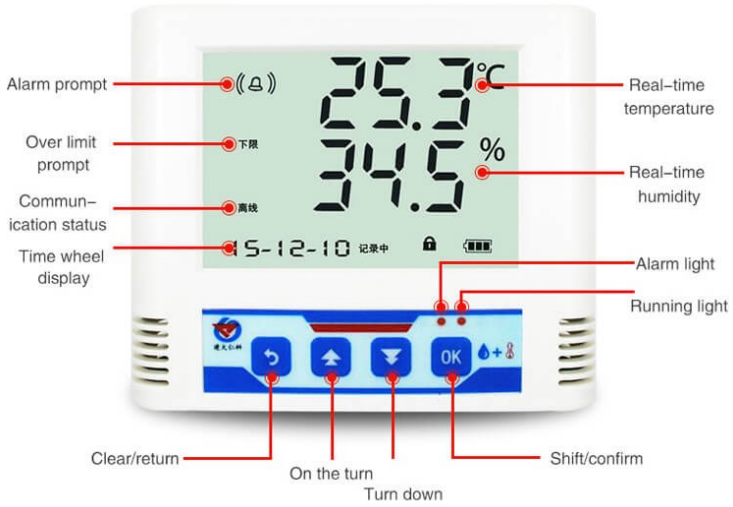
Smell Sensors

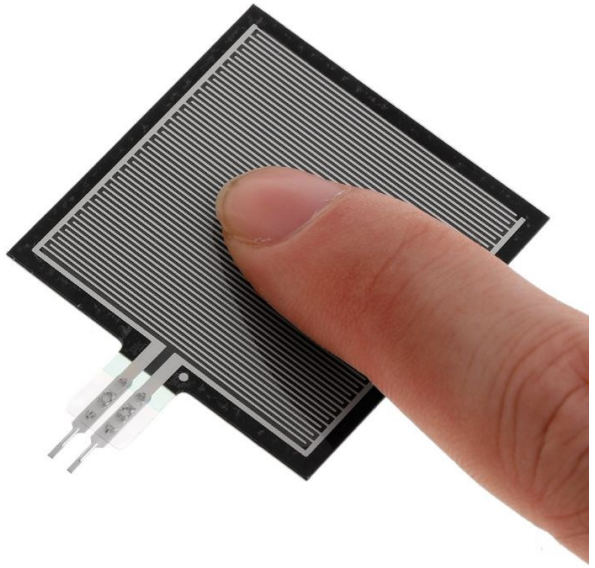
Taste Sensor

Auditory Sensor

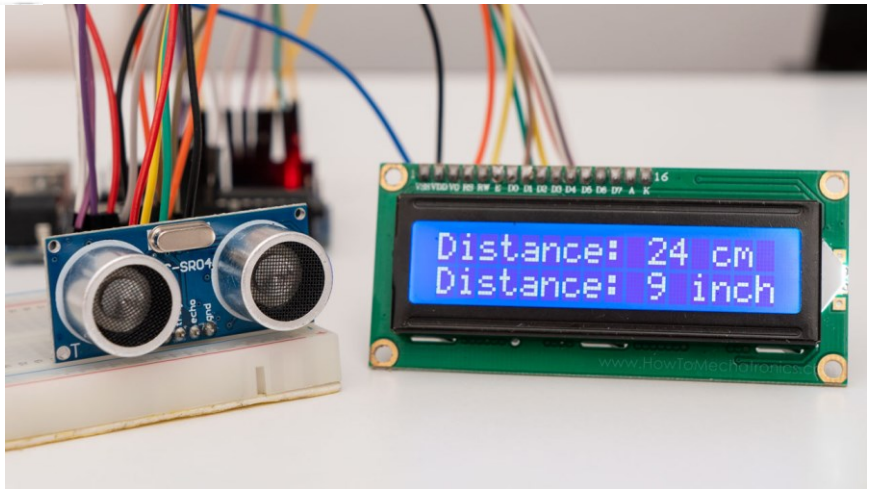


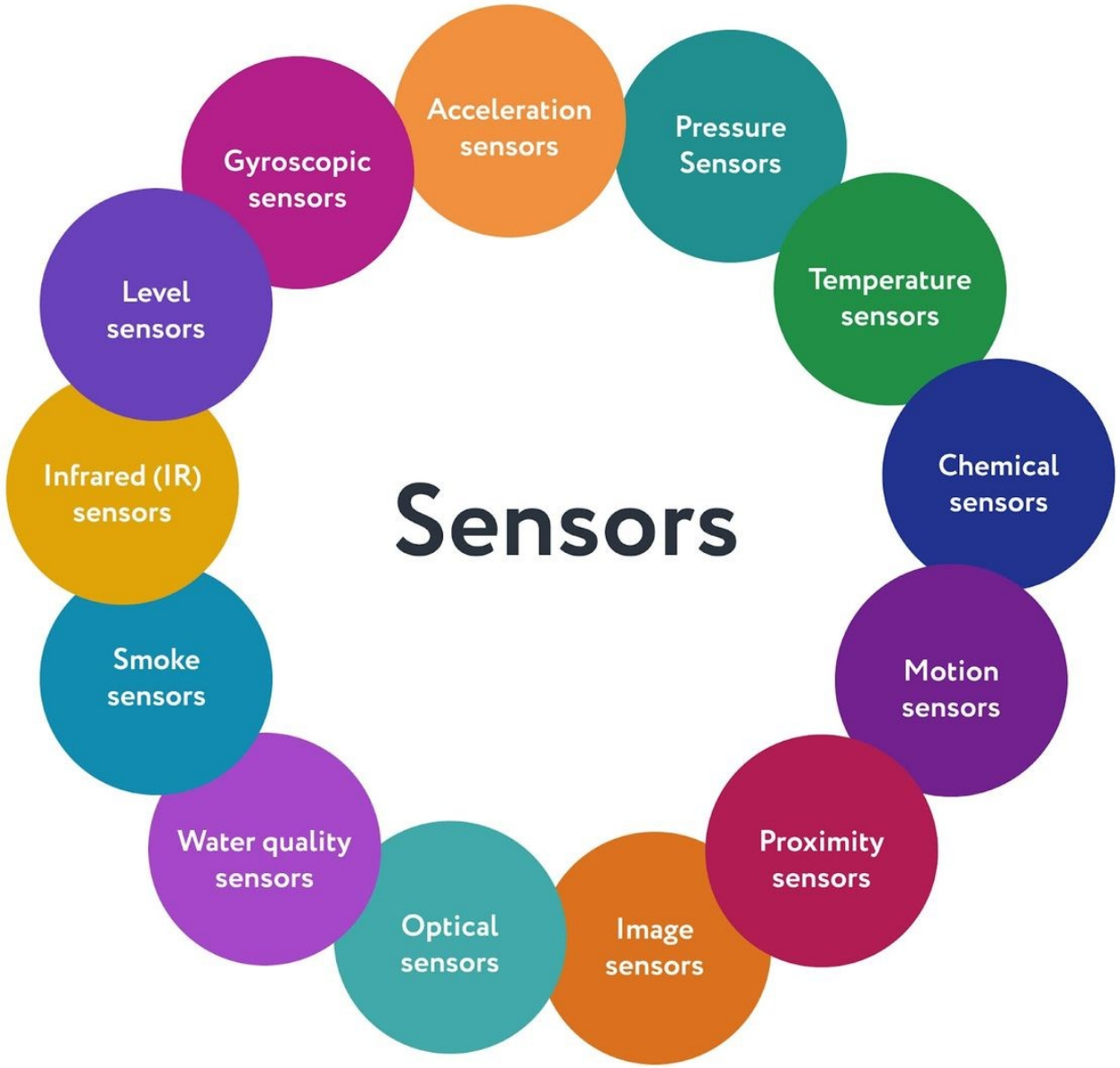
Touch Sensor





Visual Sensor

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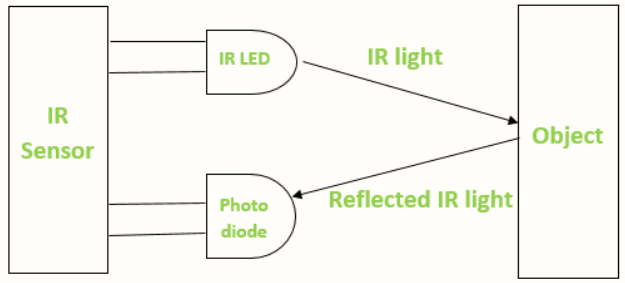
Level sensors
Gyroscopic sensors

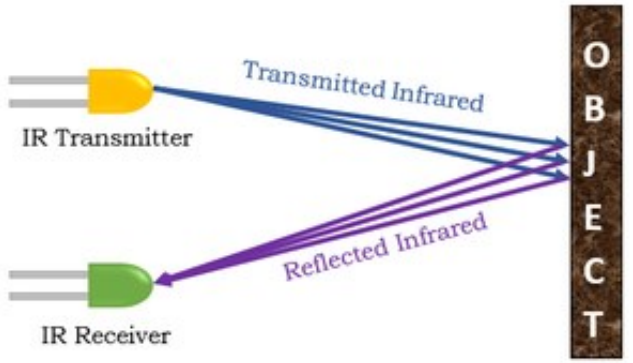
1- Vision and Imaging Sensors

- Vision and Imaging Sensors/Detectors are electronic devices that detect the presence of objects or colors within their fields of view and convert this information into a visual image for display.

Infrared (IR) Sensor



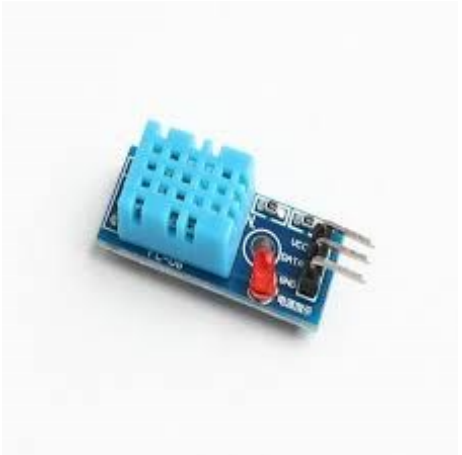
- Infrared sensor can measure **temperature sensitive physical properties** by the infrared ray.
- Infrared light has the physical properties of reflection, refraction, scattering, interference, and absorption. Anything, as long as it has a certain temperature above absolute zero, will be provided with infrared radiation.
- The infrared sensor measurement can be done without direct contact with the measured object directly, so there is no friction and has the advantages of high sensitivity, fast response and other advantages.




OK

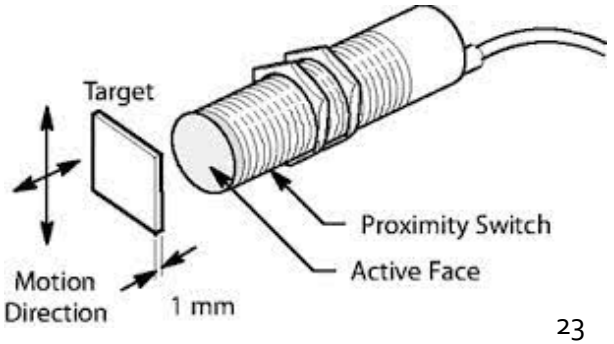
2- Temperature Sensors

- They are electronic devices that detect thermal parameters and provide signals to the inputs of control and display devices
- Temperature sensors are used to measure the thermal characteristics of gases, liquids, and solids in many process industries and are configured for both general- and special-purpose uses.



3- Proximity Sensors

- They are electronic devices used to detect the presence of nearby objects through non-contacting means.
- A proximity sensor creates a net of electric/magnetic field and detects an object which enters the field, just as a spider forms its web and catches its prey.
- A proximity sensor can detect the presence of objects usually within a range of up to several millimeters, and, doing so, produce a usually dc output signal to a controller.



LiDAR Sensor

- The LiDAR instrument emits rapid laser signals, sometimes up to 150,000 pulses per second.
- The signals bounce back from the obstacles.
- The sensor positioned on the instrument measures the amount of time it takes for each pulse to bounce back.
- Thus, the instrument can calculate the distance between itself and the obstacle with accuracy.
- It can also detect the exact size of the object.

RADAR Sensor

- The RADAR system works in much the same way as the LiDAR, with the only difference being that it uses **radio** waves instead of **laser**.
- In the RADAR instrument, the antenna doubles up as a radar receiver as well as a transmitter.
- However, radio waves have less absorption compared to the light waves when contacting objects.
- Thus, they can work over a relatively long distance.

4- Pressure Sensors

- They are electro-mechanical devices that detect forces per unit area in gases or liquids and provide signals to the inputs of control and display devices.
- Touch screen smartphones, tablets, and computers come with various pressure sensors.
  - Whenever slight pressure is applied on the touch screen through a finger, tiny pressure sensors determine where exactly pressure is applied and consequently generate an output signal that informs the processor.

5- Position Sensors

- They are devices that can detect the movement of an object or determine its relative position measured from an established reference point.

- Global Position System (GPS)
  - GPS is composed of a space satellite, a ground signal connecting point, and a user signal receiving device. It can provide users with high precision position, speed and temporal information.

6- Motion Sensors

- They are electronic devices that can sense the movement or stoppage of parts, people, etc.

7- Level Sensors

- They are electronic or electro-mechanical devices used for determining the height of gases, liquids, or solids in tanks or bins

8- Chemical Sensors

- Chemical sensors can detect the presence of chemical substances in the environment

Gas Sensor

- Gas sensor is capable of detection H2, LPG, CH_4, Alcohol and Smoke
- When any flammable gas flows through the sensor, the coil inside this sensors burns and so the resistance of the coil decreases, hence the output voltage starts increasing.

```
#include <ESP8266WiFi.h>
#include <EEPROM.h>
int val;

#define USE_SERIAL Serial
#define ldr A0

void setup()
{
  Serial.begin(115200);
  delay(10);

}

void loop()
{
   val=analogRead(ldr);
   Serial.print(val);
   Serial.println(" ");
   delay(5000);

}
```

9- Accelerometer

- It measures acceleration in one or more directions, and position can be deduced by integration.

Sensors' Requirements

- One of the most **sensors requirements** are
  - Accuracy,
    - Accuracy describes the amount of uncertainty that exists in a measurement with respect to the relevant absolute standard.
  - Resolution,
    - Resolution describes the degree to which a change can be detected.
  - Sensitivity
    - Sensitivity describes the smallest absolute amount of change that can be detected by a measurement.
    - Sensitivity is an absolute quantity; resolution is a relative quantity.

Sensors' Requirements

- One of the most **sensors requirements** are
  - Accuracy,
    - The closeness with which an instrument reading approaches the true value of the quantity being measured.
  - Resolution,
    - The smallest change in a measurement variable to which the instrument will respond.
  - Sensitivity
    - The ratio of change in the output to a change in the input or measure quantity.


Electric actuator
Hydraulic actuator
Pneumatic actuator
REALPARS

Actuators

- Actuators are basically performing some **actions** based on the readings of the sensors and the required specifications which differ from an application to another.
- Actuators convert energy to motion.
- An actuator is a device that converts an **electrical** signal into a **mechanical** signal or any other useful form of energy.
- There are four different types of actuators: **hydraulic**, **pneumatic**, **mechanical**, and **electrical;** depending on the power used.

1- Hydraulic Actuators

- Hydraulic actuators are simple devices with mechanical parts that are used on linear or quarter-turn valves. They are designed based on Pascal's law: When there is an increase in pressure at any point in a confined incompressible fluid, then there is an equal increase at every point in the container.
- Hydraulic actuators comprise a **cylinder or fluid motor** that utilizes hydraulic power to enable a mechanical process.
- Pros:
  - Force
  - Safety
  - Mobility
- Cons:
  - Initial investment
  - Maintenance
  - Leakage

2- Pneumatic Actuators

- Pneumatic actuators work on the same concept as hydraulic actuators except **compressed gas** are used instead of **liquid**.
- Pros:
  - Fast
  - Economical
  - Simple
- Cons:
  - Limited power
  - Shorter life cycle
  - Temperate

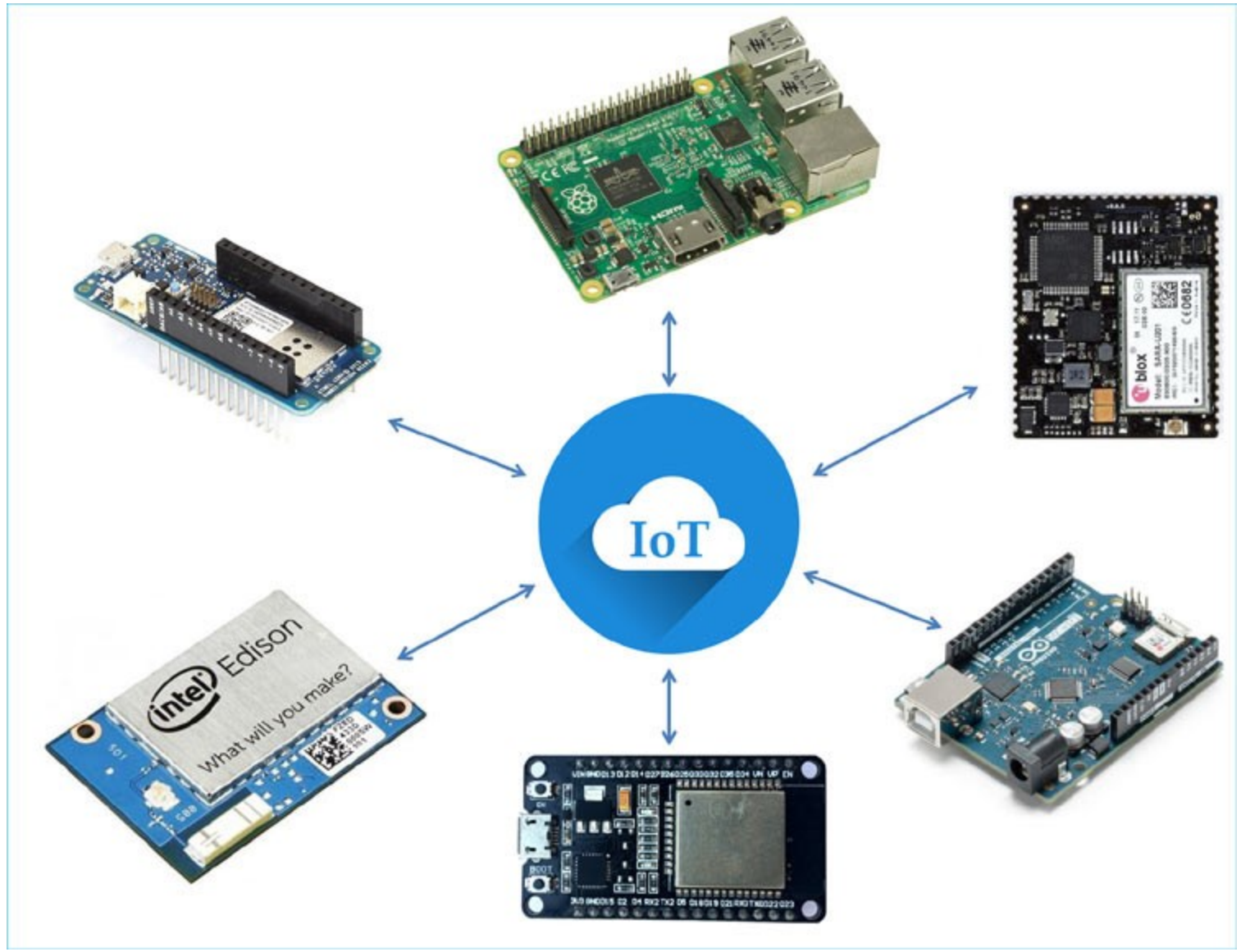
3- Electrical Actuators

- Electric actuators are devices driven by **small motors** that convert energy to mechanical torque.
- The created torque is used to control certain equipment.
- Pros:
  - Fast
  - Precise
  - Clean
- Cons:
  - Weak (compared to hydraulics or pneumatics)
  - Complicated
  - Costly

4- Mechanical Actuators

- Mechanical actuators convert **rotary** motion to **linear** motion.
- Devices such as screws and chains are utilized in this conversion.

  Pros:
  - Cost-effective
  - No power source needed
- Cons:
  - **No automation**


IoT
intel
Edison
What will you make?

IoT Hardware Platforms

- The controller is the device that **receives** the sensors' signals, **processes** them and makes computations on them, and then **sends** instruction signals to the actuators.
- Usually in control systems, these instruction signals are based on the **difference** between the sensors' readings and the desired values of the physical quantities, and thus these instruction signals are sent to the actuators in order to set the system back to the desired physical quantities' values.

IoT Hardware Platforms

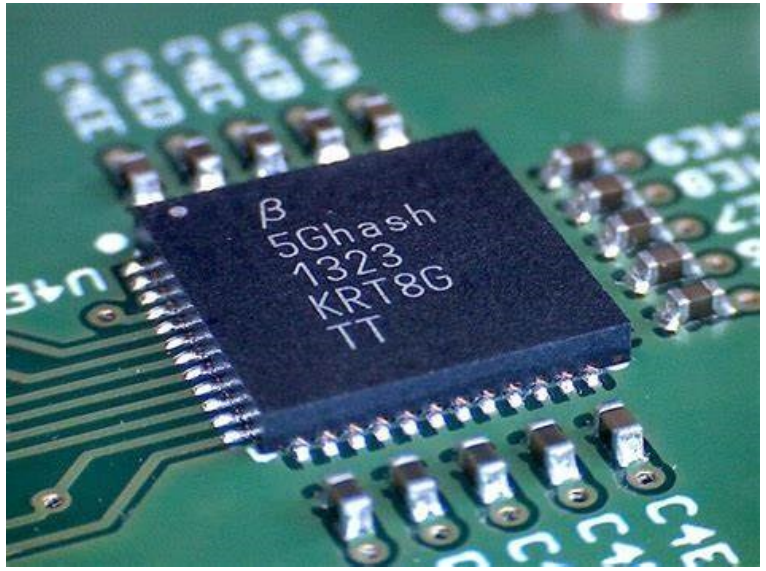
- Choosing which hardware platform is used is based on the **requirement of the IoT applications** and depends also on whether we need it for development only or mass production.
- The factors that define the hardware platform for IoT applications are:
  - **Reduction of employed transistors**: This will reflect on the die size, packaging, and unit cost. The progress made on transistor area decreases the cost, but leakage power dominates on the overall chip.
  - **Time-to-market**: It is the main factor that guides the design to the proper platform. The market requires a generic solution to apply its demands, therefore time is a very critical factor to choose what type of platform is needed, which might be in most cases an expensive one.
  - Software or hardware. This does not only imply sustainability in reliable systems, but also the a **Nonrecurring Engineering (NRE) costs**: It is the cost of the development process for the IoT platform, either ability to develop the platform in less time as much as possible.

IoT Hardware Platforms

- Application-Specific Integrated Circuit (ASIC)
- Field Programmable Gate Array (FPGA)
- Microprocessors

1- Application-Specific Integrated Circuit (ASIC)

- ASIC is a well-established process designed, as the name suggests, for a specific application.
- The fabricated ASIC chips give **very optimal performance** with the lowest number of transistors, and most importantly, the least power consumption.
- In addition, the technology is very cheap when mass produced.
- However, ASIC is not usually used, because it consumes time and resources to develop. In brief, it has large time-to-market, which makes the industry seek other faster generic solutions.



2- Field Programmable Gate Array (FPGA)

- FPGAs provide a more generic solution that is required in industry.
- They have less time-to-market and NRE costs to develop their products.
- However, they consume much more power than ASIC chips, which is one of the most challenging issues in IoT.
- In addition, they are very expensive, so they are used in applications with minimum number of units needed.

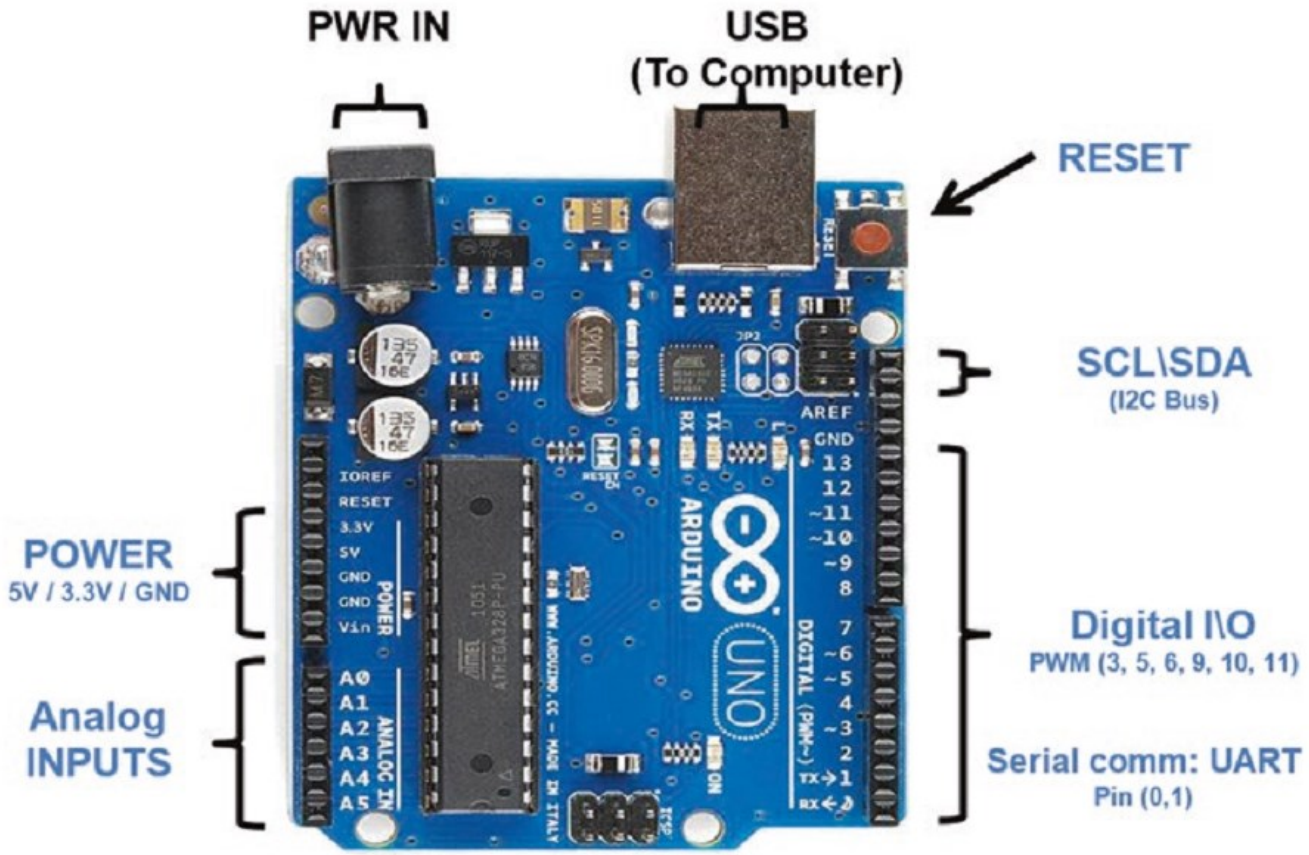
3- Microprocessors

- Microprocessors are used as a platform for building IoT devices. Some chips have the microprocessor together with other blocks such as RAMs and different other modules.
- In this technique, the whole system is built on the chip with all its peripherals. The system acts as a gateway for the local devices to the Internet.
- This requires that the chip must support several protocols to facilitate the communication between local devices and sensors with the microcontroller (Bluetooth, ZigBee) as well as sending and receiving data from the cloud (Wi-Fi, Ethernet).

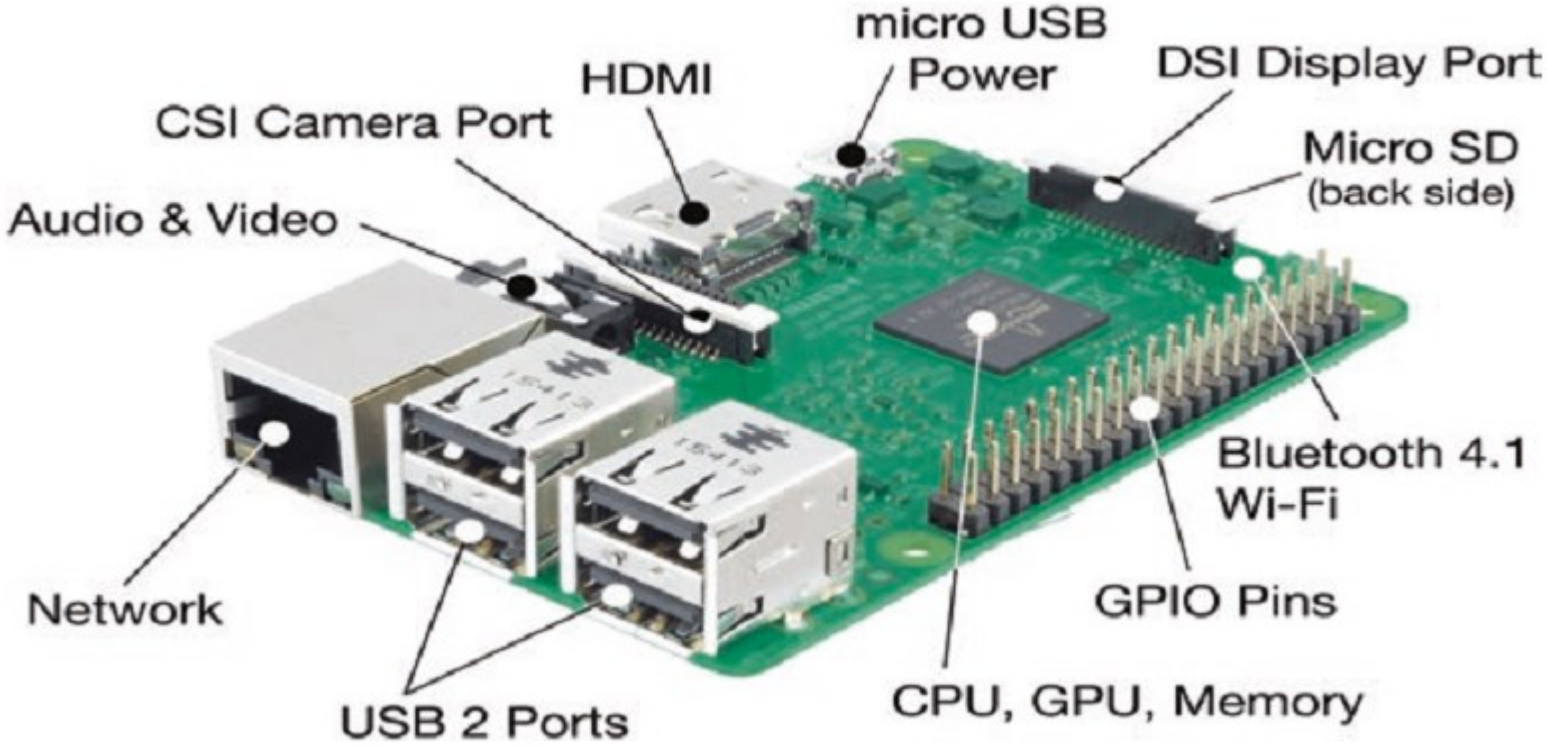
3- Microprocessors

- There are several systems used commercially for this purpose. Arduino family (Uno, Yun). Other chips are used such as Raspberry Pi.
- Compared to Arduino, Raspberry Pi is more powerful in terms of processing, memory, and features. So, it is useful in multimedia applications which need more resources. But, it comes with more cost.
- These platforms are generic and can be used for several applications. As a result, hardware overheads are installed. This increases the power consumption for the system.
- Therefore, more optimization is required to save the battery for the longest time.

Arduino


PWR IN
USB
(To Computer)
RESET
SCL\SDA
(I2C Bus)
POWER
5V / 3.3V / GND
Analog
INPUTS
Digital I\O
PWM (3, 5, 6, 9, 10, 11)
Serial comm: UART
Pin (0,1)

Raspberry Pi



IoT Hardware Options

Technology	Advantages	Disadvantages
A general-purpose microprocessor	- A short development cycle - Support for a variety of high-level languages such as Python, Java and C++	Serial execution Static hardware configuration To increase performance, you need to increase clock speeds which increase energy consumption
ASIC	Superior performance Area Power efficiency	Long development cycles Zero flexibility once Fabricated
FPGA	Flexibility	Cost

IoT Software and Programming

- In order for the hardware to perform well, **operating systems** should be installed.
- Operating systems organize the usage of hardware.
- For IoT applications, low-power and small hardware overhead operating systems should be used.
- Choosing the right operating system is a crucial move in order to build the optimal IoT system for the desired application.

IoT OS: Linux

- The **most used** operating system nowadays in IoT platforms is **Linux**. Linux is an open-source operating system that allows developers to modify it to give the best response. It supports C/C++ programming languages as well as multi-thread technology.
- It is now the most established and used software platform in IoT designs. However, it requires relatively large memory (RAM and ROM) to operate. The hardware overhead in memory as well as the more required power to operate is not ideal for real-time processing and thus hinder Linux implementation in various IoT devices.

IoT OS: RIOT

- One of the operating systems that are designed especially for IoT is **RIOT**.
- The smart operating system tries to **save the most possible power** and area for the smart device.
- RIOT is an open-source operating system which requires small RAM and ROM to boot.
- The architecture of RIOT is microkernel based, where the user application can address different layers in the operating system.


Thank
you!