Sensing

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Outline

- Definitions
- Sensor Classification
- **Sensor Characteristics**
- **Sensor Working Principles**

Sensitivity

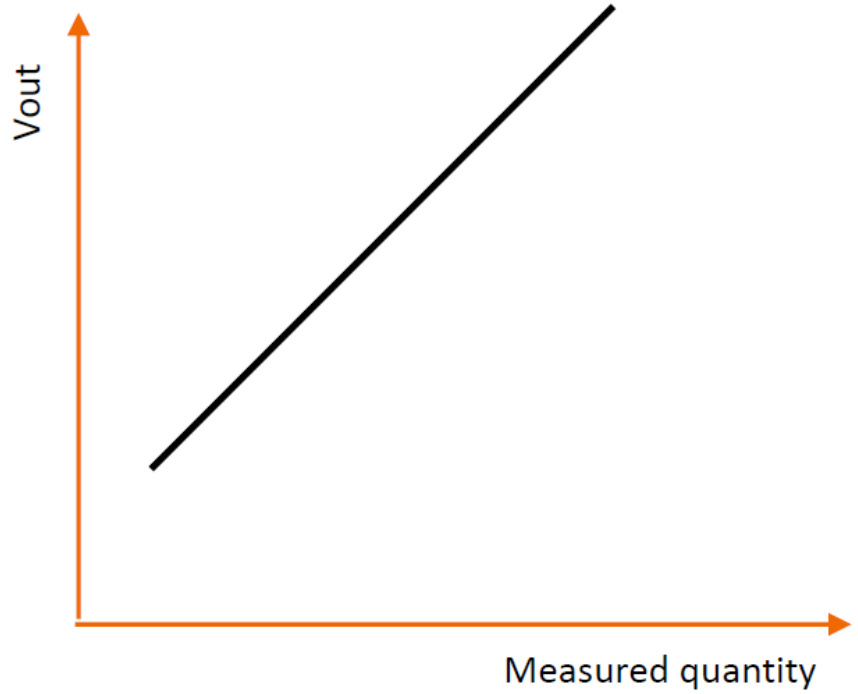
- Ratio of change in output to change in input.
  If Y is the output quantity in response to input X, then sensitivity S can be expressed as

$$S = \frac{dY}{dX} = \frac{\Delta Y}{\Delta X}$$

It is also the slope of the calibration curve

Linearity

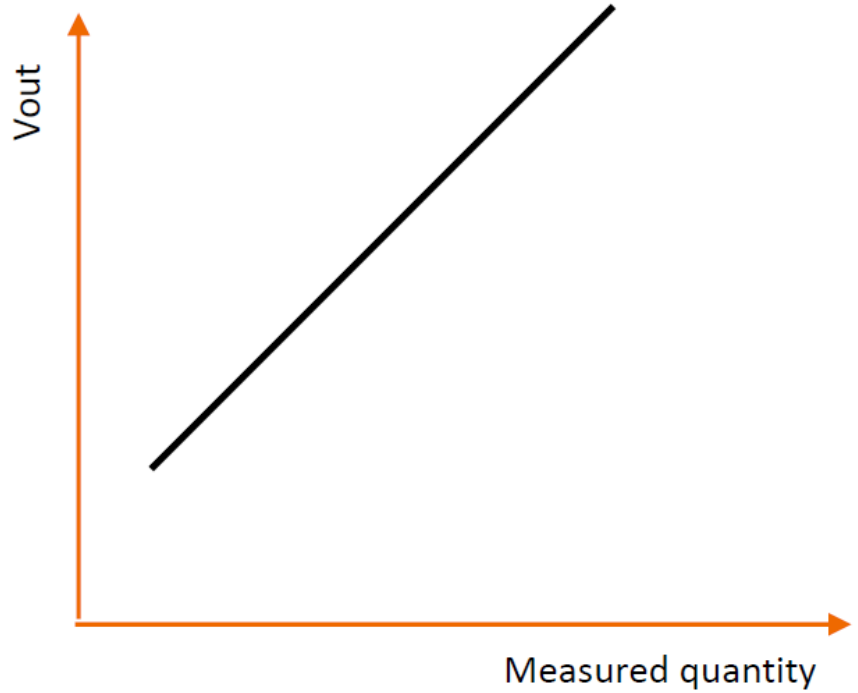
- Assume we can successfully convert the physical quantity into electrical and proportional voltage
- Characteristics of this sensor can be plotted as measured quantity in X axis and output voltage in Y axis
- Hope is that we get a linear characteristic – but why is this so important?



Sensor Characteristic

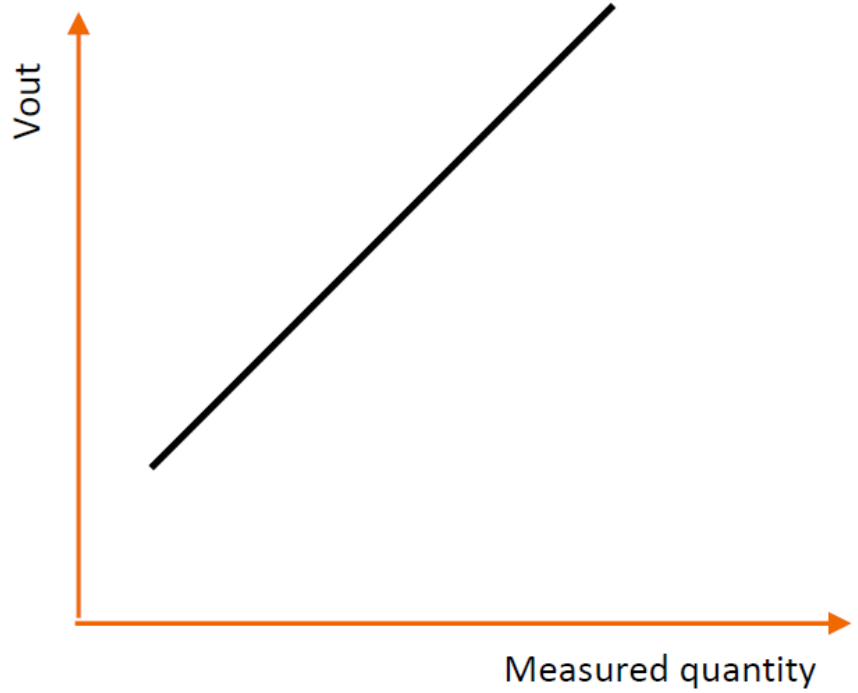
- Need to find the value of measured quantity (MQ) based on the reading of voltage
- Need a function which maps Vout to the MQ
- Easiest to have a linear equation as below

$$MQ = \frac{V_{out}}{slope} + C$$



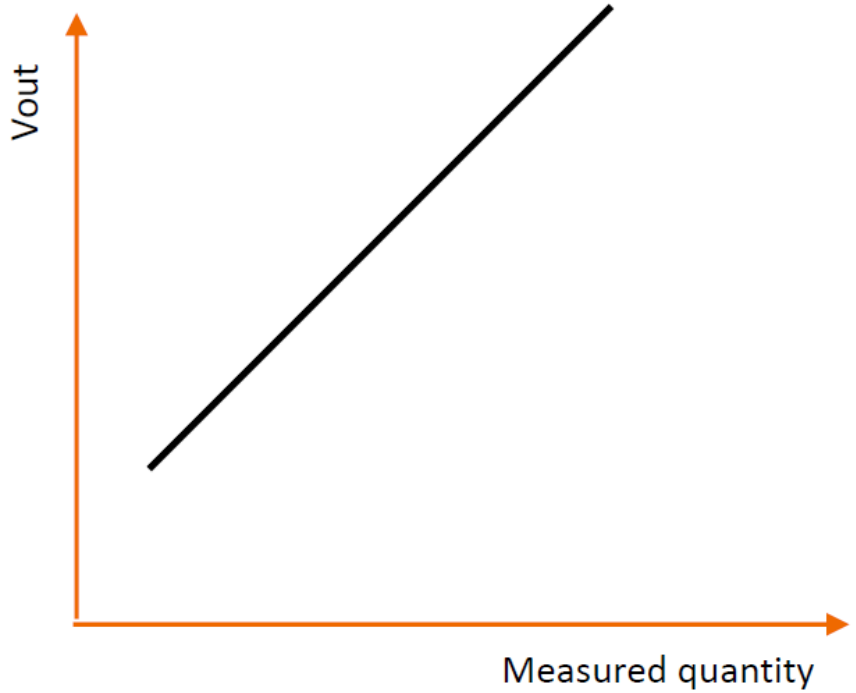
Sensor Calibration

- Two unknown quantities, once known, can calculate MQ for any Vout
- Provided by sensor manufacturer, but the problem is these values shift over time
- Calibration involves finding these values or verifying already given values
- One method → Subject the sensor to a known stimulus and measure Vout
- Two points are sufficient to get the function



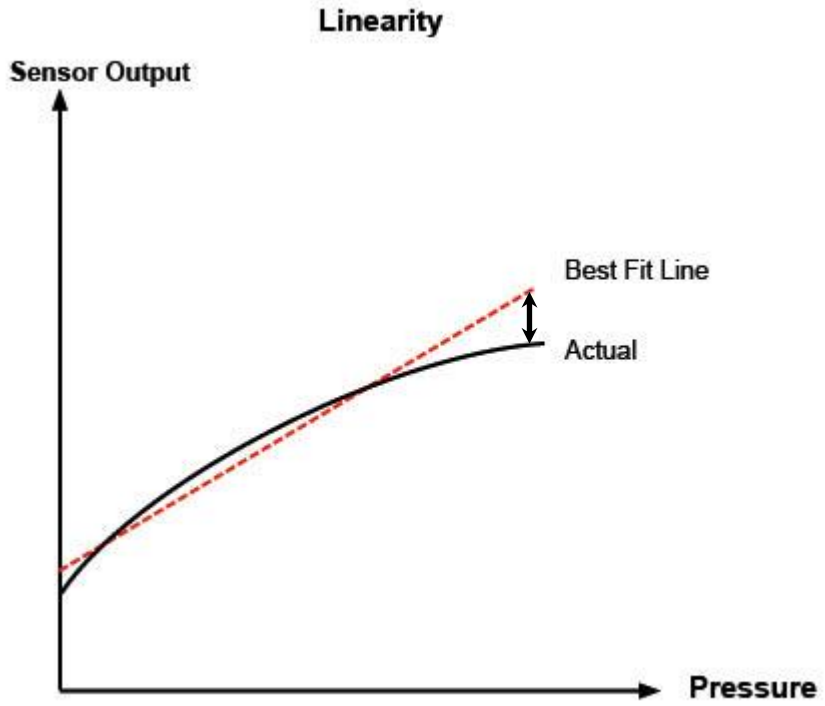
Sensor Calibration

- Biggest challenge in IoT deployments → Sensor calibration drifts with time, i.e., value of C and slope are functions of time
- Strategies to address this
  - Know the drift in advance and program into system logic
  - Recalibrate the sensor over the air based on a gold standard
  - Recalibrate by bringing the sensor to a conditioned ambient



Linearity

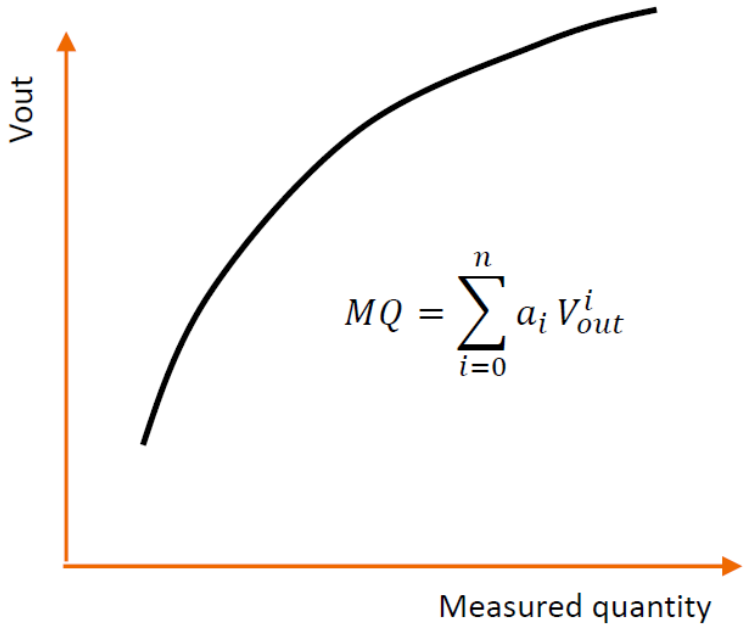
- Maximum deviation between the measured values of a sensor from ideal curve



Source: https://appmeas.co.uk/resources/pressure-measurement-notes/linearity-or-nonlinearity/

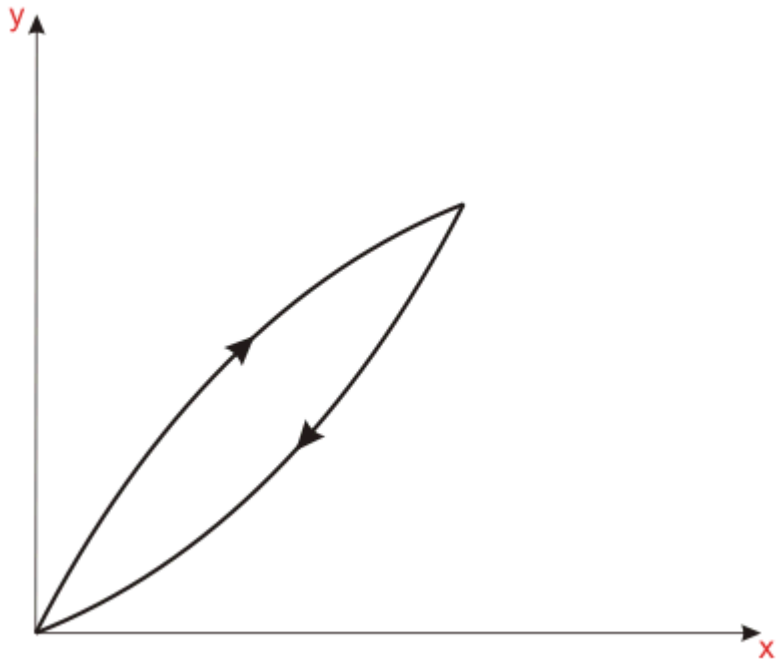
Non-linear systems

- Some systems give non-linear response
- Require multiple parameters to determine the calibration
- Strategies:
  - Use of ML algorithms to determine the sensed quantity



Hysteresis

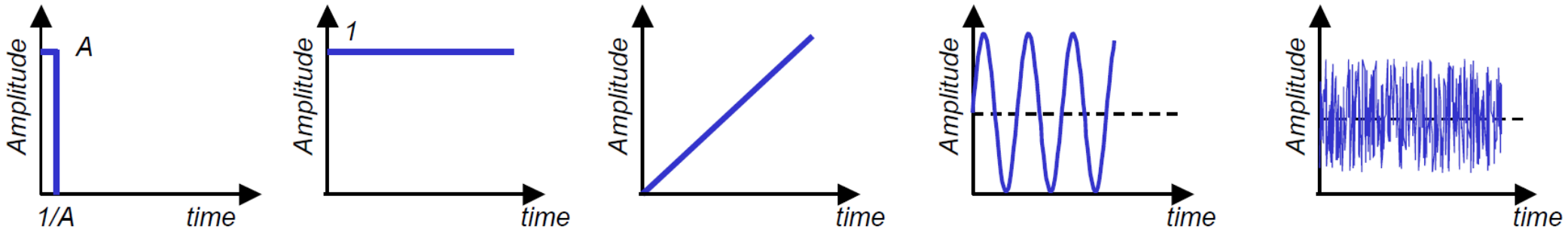
- Difference in output for same input when the input is reached at from different trajectories



Source: https://www.electrical4u.com/characteristics-of-sensors/

Dynamic Characteristics

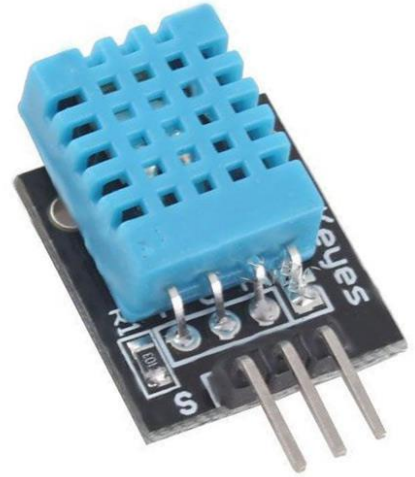
- Sensor response to a variable input is different from what is seen when the input signals are constant (described by static characteristics)
- Dynamic Characteristics are determined by analyzing the response of the sensor to a family of variable input waveforms



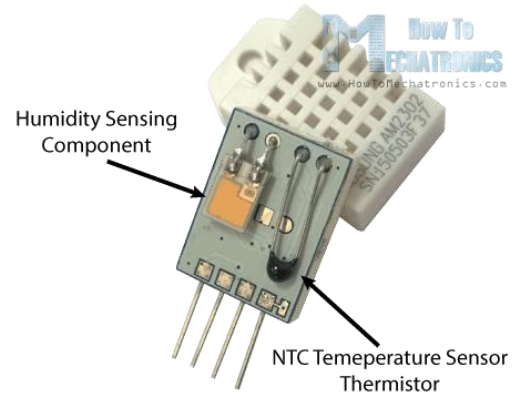
Source: https://www.philadelphia.edu.jo/academics/kaubaidy/uploads/Sensor-Lect2.pdf

DHT11 sensor

- Basic low cost digital temperature and humidity sensor
- Uses capacitive humidity sensor and a thermistor to measure the surrounding air and outputs a digital signal on the data pin
- Easy to use, can receive data once in every second
- Consists of a humidity sensing component, a NTC temperature sensor (thermistor) and an IC on the back side.



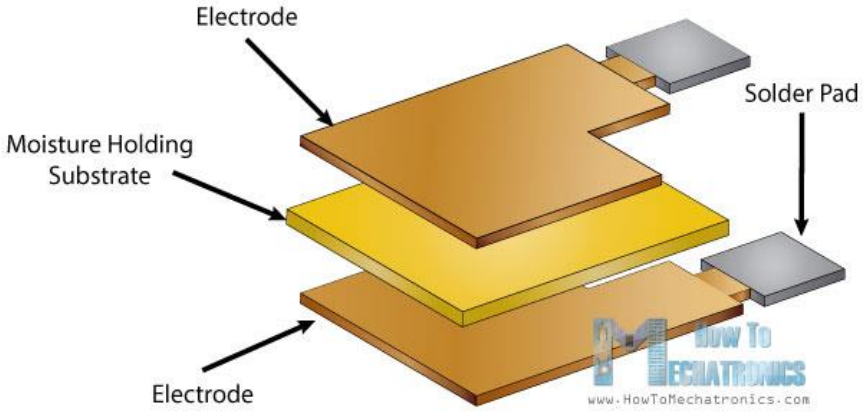
Source: https://components101.com/dht11-temperature-sensor



Source: http://robocraft.ru/files/datasheet/DHT11.pdf

DHT11 working principle

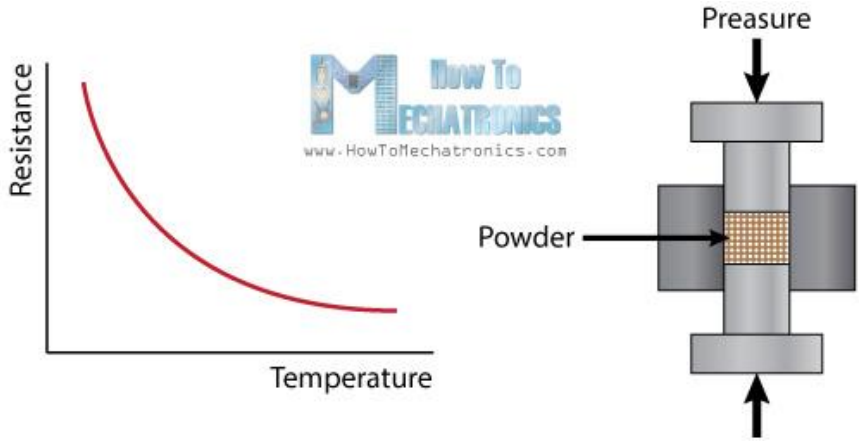
- A humidity sensing component is used which has two electrodes and a moisture holding substrate between them
- Change in humidity → Conductivity of substrate changes or the resistance between the electrodes changes
- IC measures and processes this change and makes it ready to read



Source: https://howtomechatronics.com/tutorials/arduino/dht11-dht22-sensors-temperature-and-humidity-tutorial-using-arduino/

DHT11 working principle

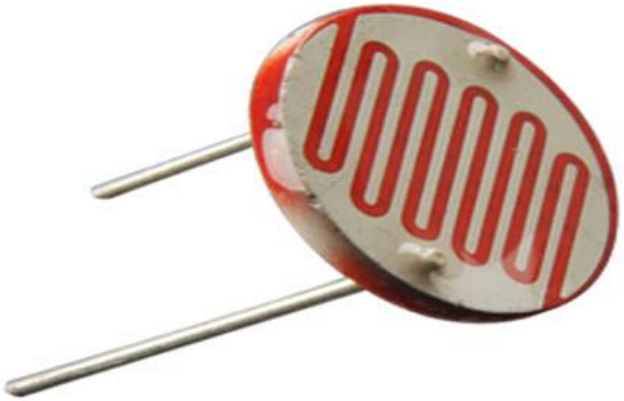
- A thermistor is a variable resistor that changes its resistance with changes in temperature
- The term NTC refers to "negative temperature coefficient" → resistance decreases with increase of temperature

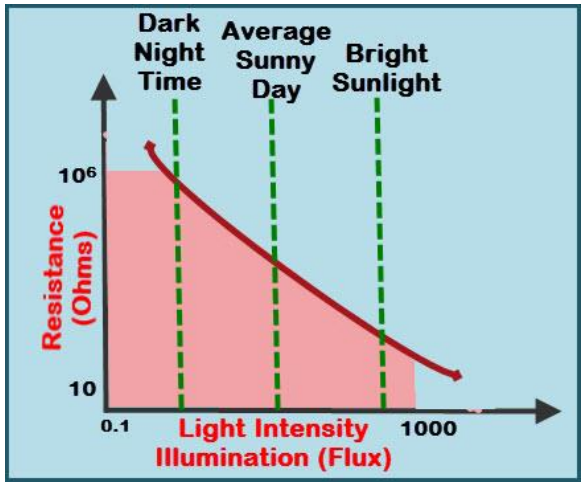


Source: https://howtomechatronics.com/tutorials/arduino/dht11-dht22-sensors-temperature-and-humidity-tutorial-using-arduino/

LDR sensor

- A Light Dependent Resistor (LDR) or a photoresistor is a device made up of high resistance semiconductor material
- Passive sensor
- Resistance changes with the change in light intensity
- Cadmium Sulfide used as the semiconductor material
- Preferred for outdoor lighting and automatic street lighting circuits





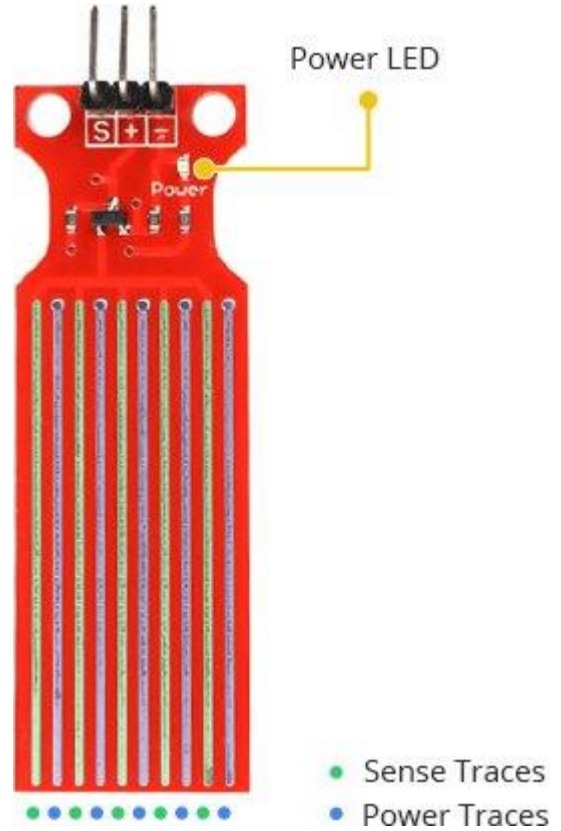
Source: https://www.elprocus.com/ldr-light-dependent-resistor-circuit-and-working/

LDR Working Principle

- Based on the principle of photoconductivity → conductivity of a material enhances when light falls on it
- Electrons in the valence band of the material jump to the conduction band provided the photons have energy required to excite the electrons across the bandgap of the material
- Sensitivity of LDR varies with wavelength of the light incident on device
- Latency of LDR → Time taken to respond to changes by the component
- Significant time from light changes to LDR getting its last value → Not used for scenarios with quick changes of light values
- Few tens of milliseconds when light is given after complete darkness, but can take upto a second when light is removed

Water Level Sensor

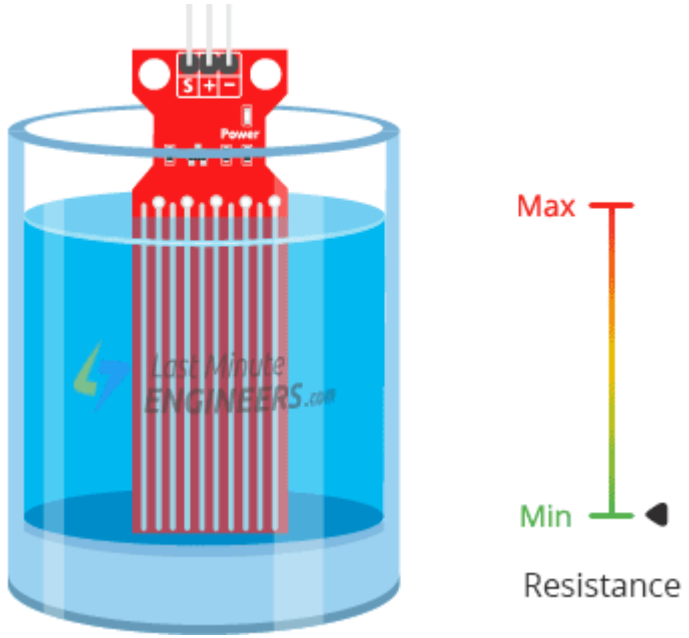
- Presence of 10 exposed copper traces – 5 are power traces and 5 are sense traces
- One sense trace in between every two power traces
- These traces are bridged when submerged in water



Source: https://lastminuteengineers.com/water-level-sensor-arduino-tutorial/

Water Level Sensor working principle

- The parallel conductors act as a variable resistor and resistance varies according to water level
- Resistance inversely proportional to the height of the water
- More the immersion, better the conductivity and lower the resistance and vice versa
- Produces an output voltage according to resistance
- Issue: short lifespan as exposed to moist environment



Source: https://lastminuteengineers.com/water-level-sensor-arduino-tutorial/

HC-SR04 Ultrasonic Sensor

- Ultrasound is high-pitched sound wave with inaudible frequencies – Frequency of over 20000 Hz
- Consists of 2 ultrasonic transducers – one acts as a transmitter and another as a receiver
- Transmitter converts electrical signal to 40 KHz ultrasonic sound pulses
- Receiver listens for the pulses and produces output pulses with width corresponding to distance
- Non contact range of 2 cm to 400 cm with an accuracy of 3 mm

HC-SR04 Ultrasonic Sensor

- Trig (Trigger): Pin to trigger ultrasonic sound pulses
- Echo: Output pulse produced at this pin when reflected signal is received

HC-SR04 Ultrasonic Sensor working principle

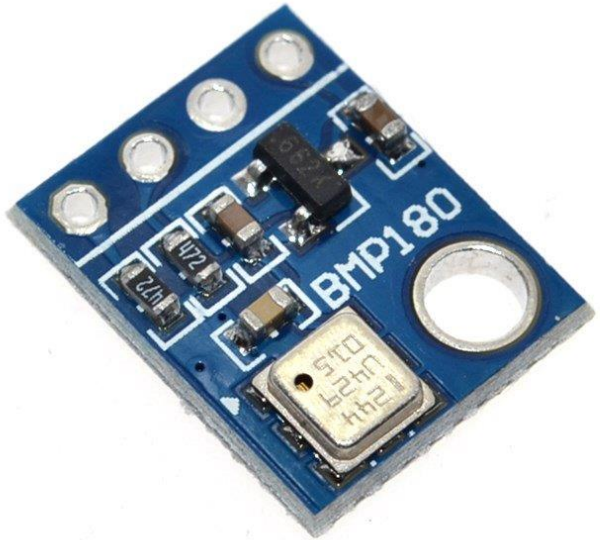
- A pulse of at least 10 microsecond applied to Trigger pin
- Sensor transmits burst of 8 ultrasonic sound pulses at 40 KHz
- 8-pulse pattern makes an ultrasonic signature allowing receiver to differentiate from ambient ultrasonic noise
- As the ultrasonic pulses travel, the ECHO pin goes high
- If the pulses are not reflected, then ECHO signal will timeout in 38 msec and become low → indicates no obstruction or obstacle in the range
- If the pulses are received, the ECHO signal becomes low as soon as the signal is received
- A pulse produced whose width varies between 150 microseconds and 25 msec depending upon the time it took

PIR Motion Sensor

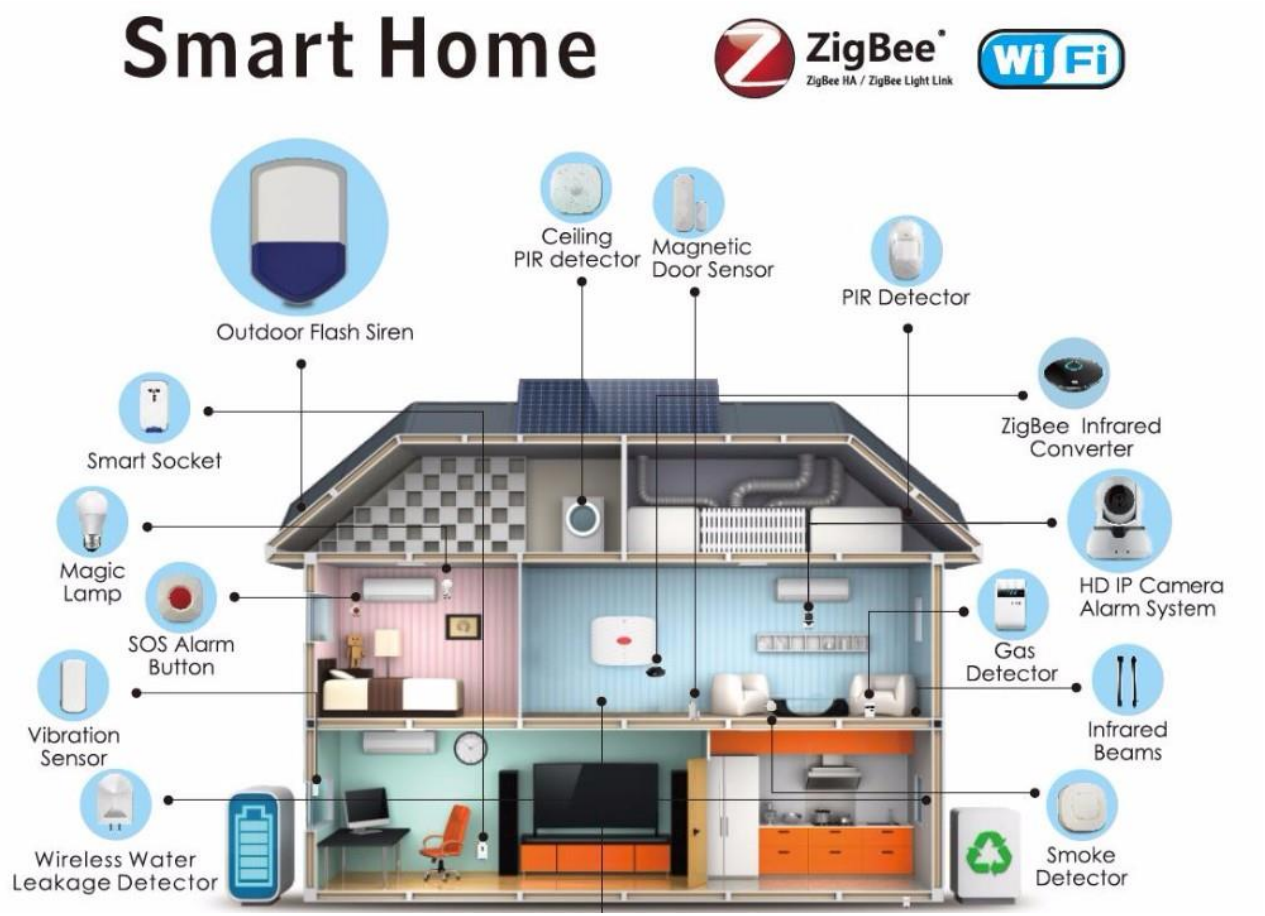
- Every object/animal/human emits a certain amount of IR radiation
- PIR sensors can detect this IR radiation
- Use a pair of pyroelectric sensors to detect heat energy in the environment
- 2 sensors sit besides each other and when something enters the range, the differential between the sensors changes
- Sensors use a series of lenses which widen the sensing area

Digital Barometric Sensor

- A piezoresistive sensor that detects pressure
- Measures both pressure and temperature

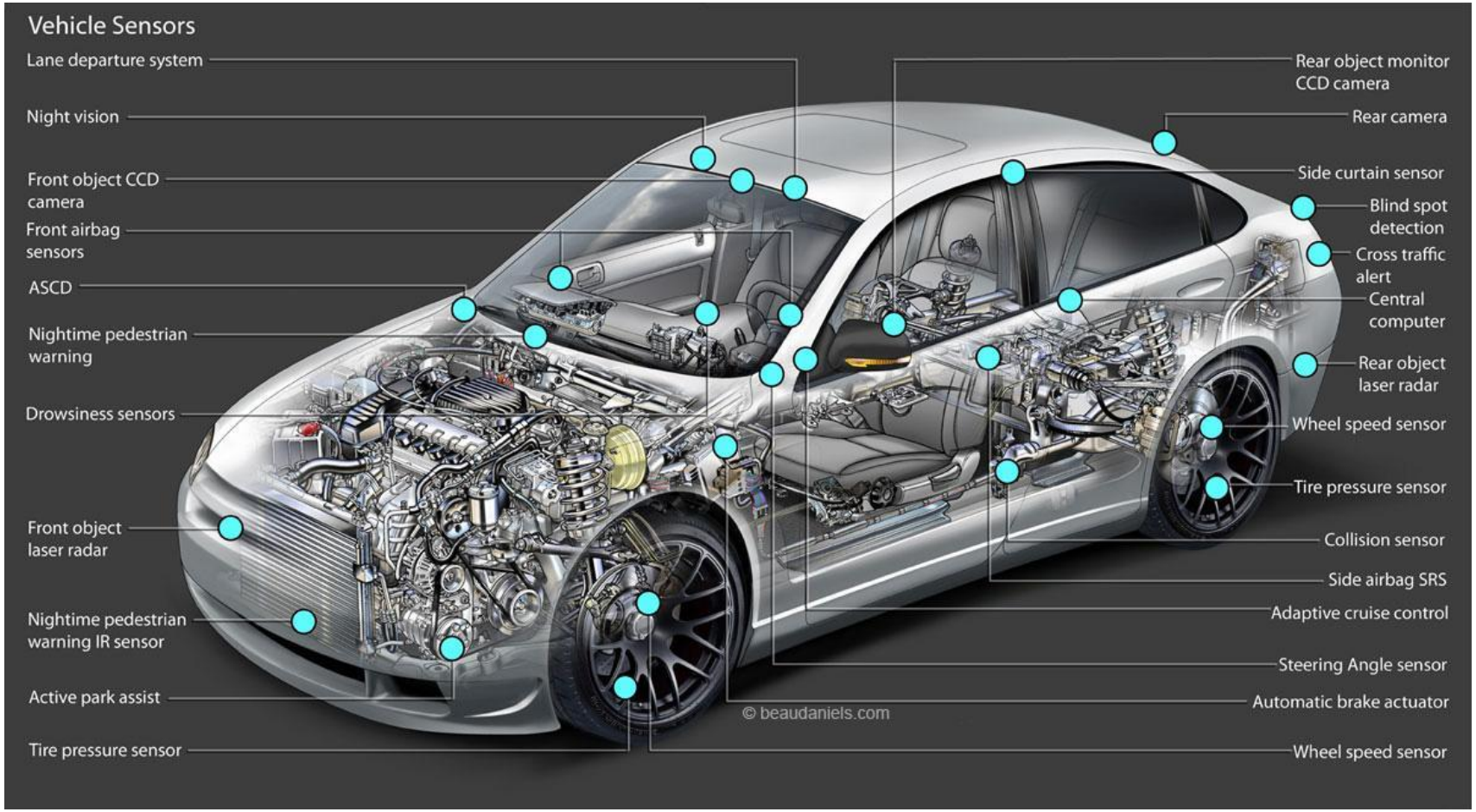


Smart Home Sensors



Source: https://www.alibaba.com/product-detail/Smart-Home-2-4G-ZigBee-Indoor_60643366019.html

Sensors in a modern car



Source: https://carfromjapan.com/article/car-maintenance/types-of-sensors-used-in-automobile-engine/