UCDAVIS
UNIVERSITY OF CALIFORNIA

# Internet of Things

## Senior Design Project Course

## *Sensing – Part 2*

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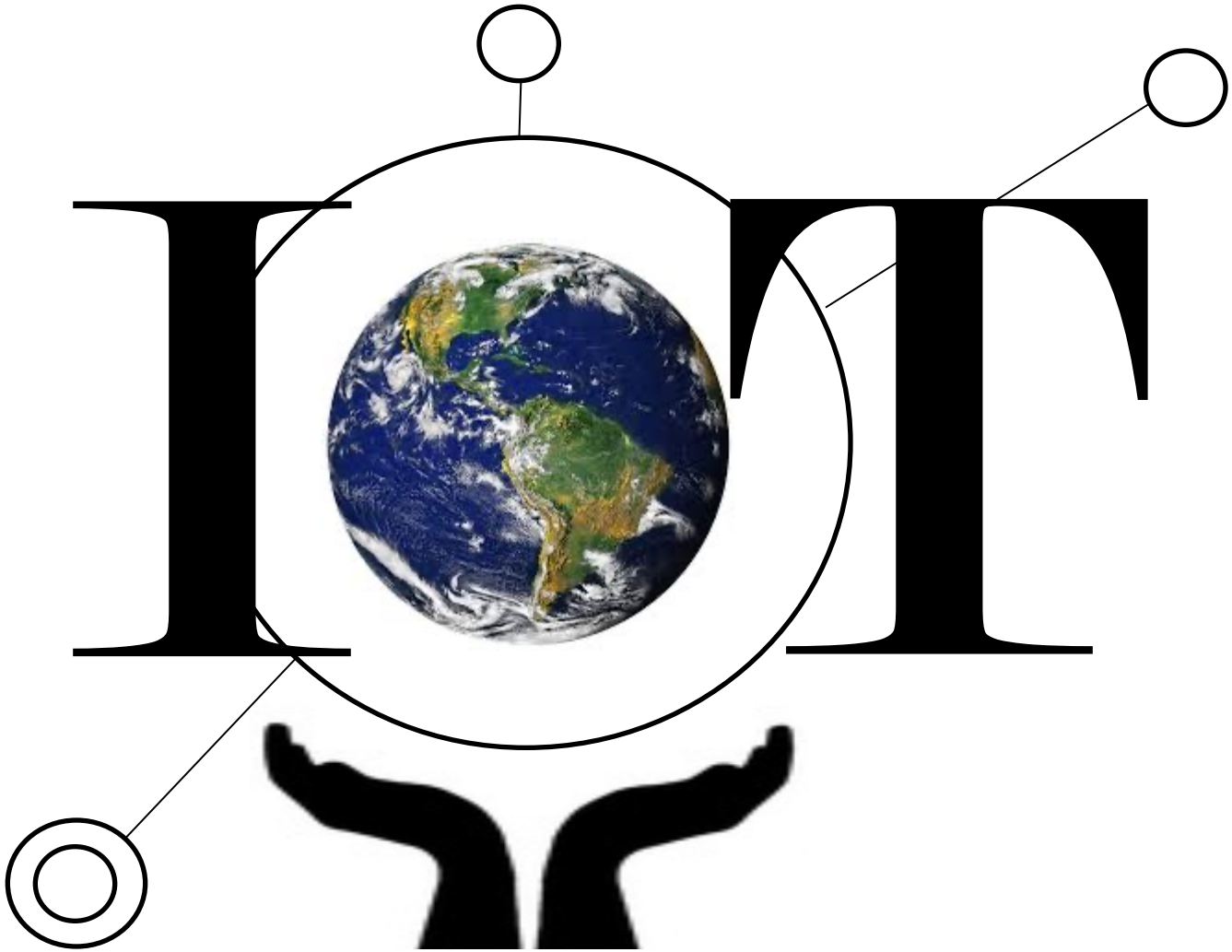
# An Example of Senior Project (speaker diarization)

- In a room multiple people are speaking simultaneously. We want to design an IoT system for voice recognition and noise cancellation.
- Use multiple microphones around the room (4)
  - Sensing
- Capture the data and communicate the data to a mobile phone, or a computer using a wireless protocol.
  - communication
- Use machine learning algorithm to generate multiple audio files, one for each person in the room, such that other conversations are cancelled.
  - Fog Computing
  - https://github.com/parthe/Speaker-Diarization-toolkit-MATLAB
- Or use a cloud service to do this for you
  - https://cloud.google.com/speech-to-text/docs/multiple-voices
  - Cloud Computing
- Convert the speech to text …
- And other cool things that you can do on top of this!

# Lets Get Started:



# Flow of Data in Internet of Things (Review)

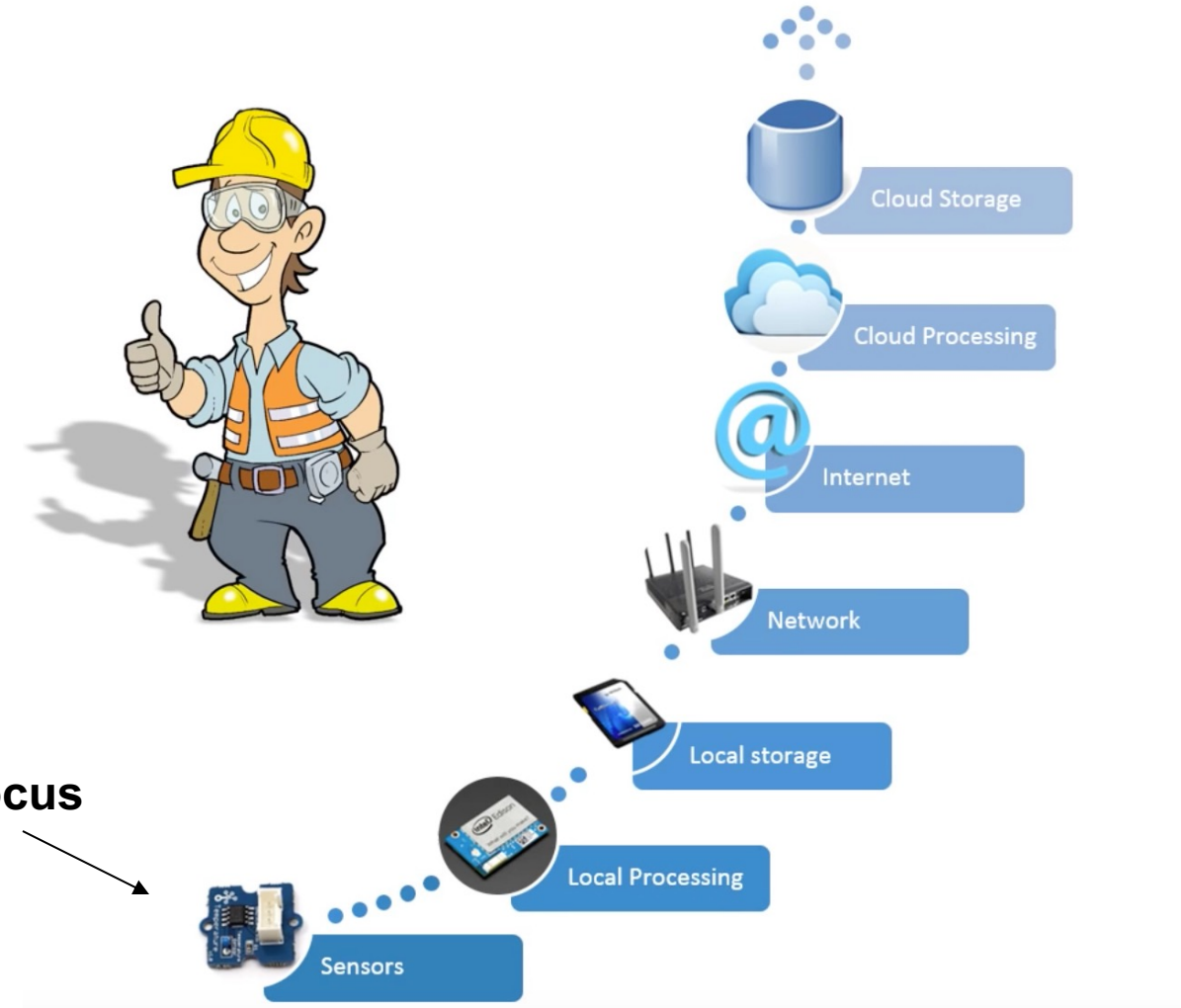
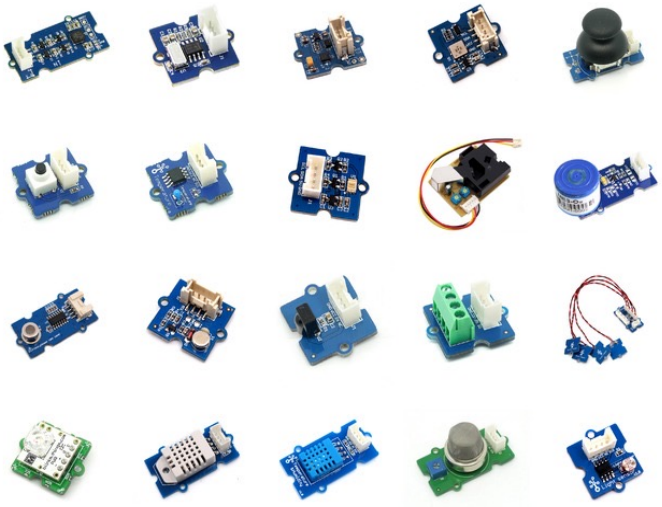



Image source: http://www.cchc.cl/informacion-a-la-comunidad/industria-de-la-construccion/personaje/

# Sensors (Review)

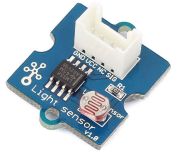
- Measure values
- Send raw data
- For IoT devices it is desired that sensors consume very Low power



# Sensor Types (Review!)

- **Analog**
  - 2 or 3 pins
  - Use pin functions
  - Following article show how analog sensor could be read by Arduino processor:
    - https://www.arduino.cc/en/Tutorial/AnalogInput

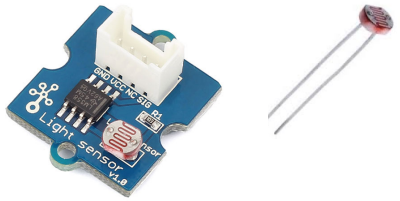
Two pins

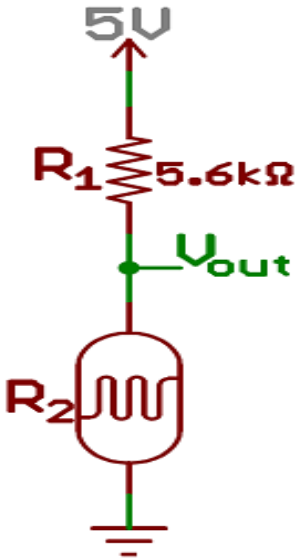


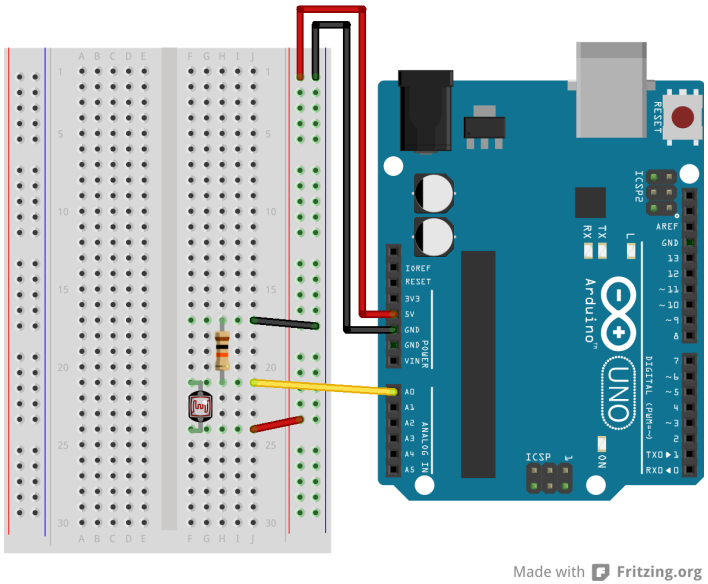
Three pins

# Measuring Analog

- In most cases we build a Voltage Divider
- We measure the voltage in $V_{out}$
- Rule of Thumb :
  - To minimize readout errors read many values and average them



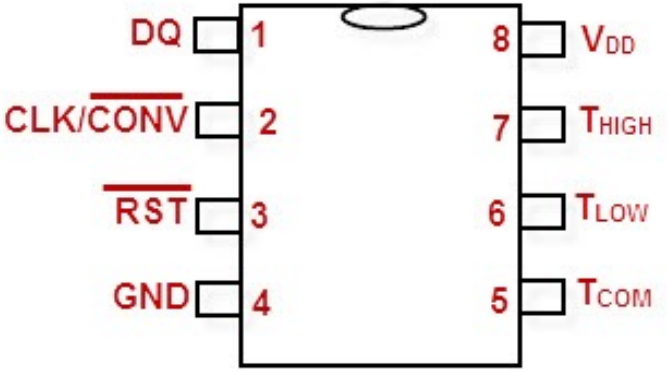




$$V_{out} = \frac{R_2}{(R_1 + R_2)} . V_{supply}$$

# Digital Sensors

- **Digital**
  - Use some digital protocol
  - Use libraries
  - Following article show how digital sensors could be read by Arduino processor:
    - https://www.arduino.cc/en/Tutorial/DigitalReadSerial

- **Examples of digital sensors:**
  - Digital Accelerometers
  - Digital Temperature Sensor
  - Digital Gyro
  - Camera




*Digital Temperature Sensor DS1620*

# Digital Sensors

- To read digital sensors you need to use the sensor's **interface protocols**

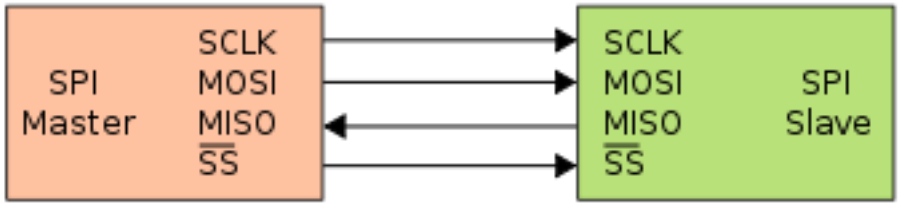
- Most common interface protocols are:
  - Serial Peripheral Interface **(SPI)**
    - Is an interface bus commonly used to send data between microcontrollers and small peripherals such as shift registers, sensors, and SD cards. It uses separate clock and data lines, along with a select line to choose the device you wish to talk to
    - https://en.wikipedia.org/wiki/Serial_Peripheral_Interface_Bus 

  - Inter-Integrated Circuit **(I2C)**
    - is a multi-master, multi-slave, packet switched, single-ended, serial computer bus used for attaching lower-speed peripheral ICs to processors and microcontrollers in short-distance, intra-board communication
    - https://en.wikipedia.org/wiki/I2C 

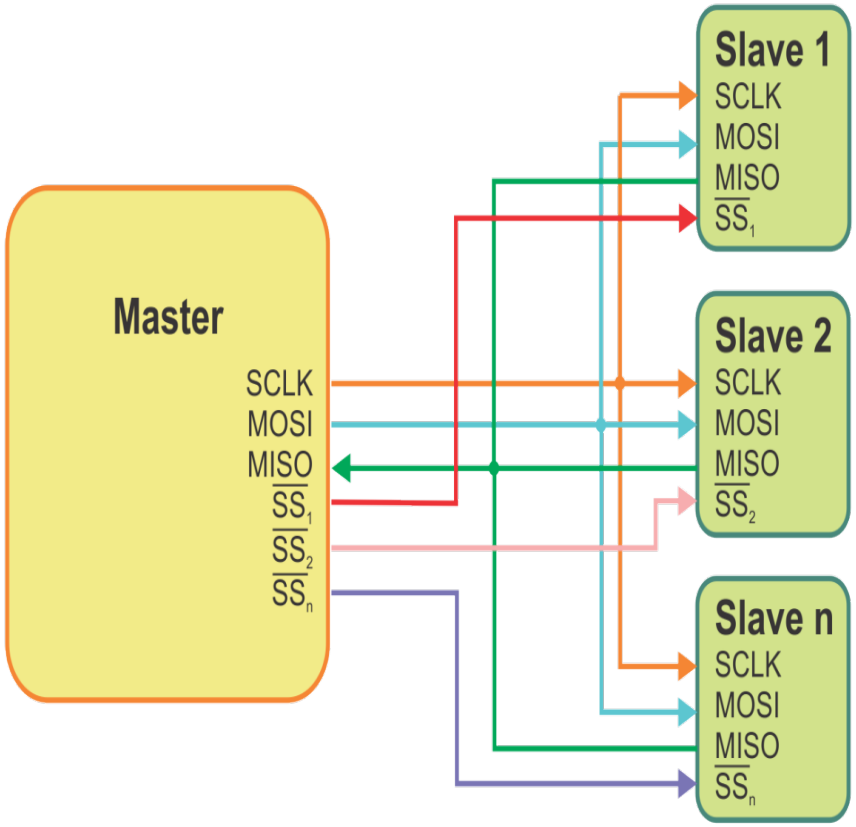
# SPI

We will cover the SPI protocol in more details in the next lecture!

- A Master/Slave protocol
  - **One Master**
  - Several slaves
  - Master always initiates communication




- Wires
  - MOSI – Master Out Slave In
  - MISO – Master In Slave Out
  - SCLK – SPI Clock
  - $SS_n$ – Slave Select

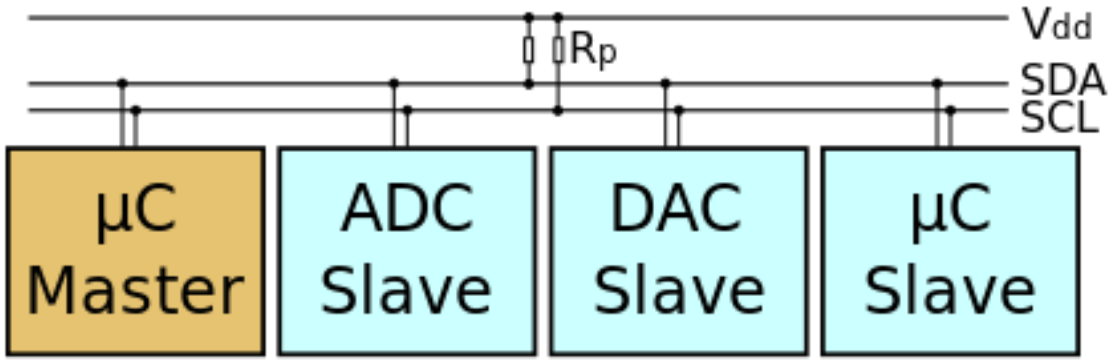



- **Speeds**
  - Up to 10MBs

# I2C

We will cover the I2C protocol in more details in the next lecture!

- A Master/Slave protocol
  - **One or more masters**
  - Several slaves
  - Master always initiates communication
  - Each device has an address
- Wires
  - SDA – Serial Data Line
  - SCL – Serial Clock Line
- **Speeds**
  - Standard 100 Kbit
  - Up to 3.4 Mbit



# Reading Digital Input (an example!):

- **Objective**:
  - Read the input from a push button (regulated by SR latch to produce digital output) and control an LED.

- **What do we need:**
  - Arduino or Genuino Board (our microprocessor)
  - SR debounced push button
  - built-in LED on pin 13 (already available on this board!)

# Example Continued!

- Busy waiting on the digital pin and using digital write to change the LED state!

```
int ledPin = 13; // LED connected to digital pin 13
int inPin = 7;   // pushbutton connected to digital pin 7
int val = 0;     // variable to store the read value

void setup()
{
  pinMode(ledPin, OUTPUT);      // sets the digital pin 13 as output
  pinMode(inPin, INPUT);      // sets the digital pin 7 as input
}

void loop()
{
  val = digitalRead(inPin);   // read the input pin
  digitalWrite(ledPin, val);    // sets the LED to the button's value
}
```

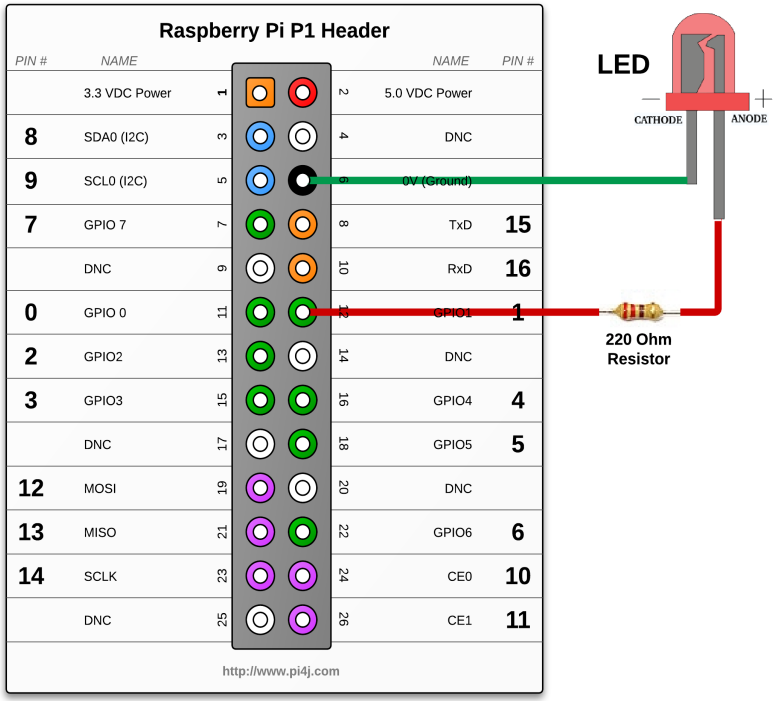
- If you like to use more complicated digital reads involving SPI libraries, look at the following example:
  - https://www.arduino.cc/en/Reference/SPISettings
  - https://www.youtube.com/watch?v=YE0wnom_7As

# We Sometimes Need to Actuate!

- **Actuators** do something in the physical world
- Examples of actuators are:
  - Engines
  - Lights
  - Displays
  - Speakers
  - …

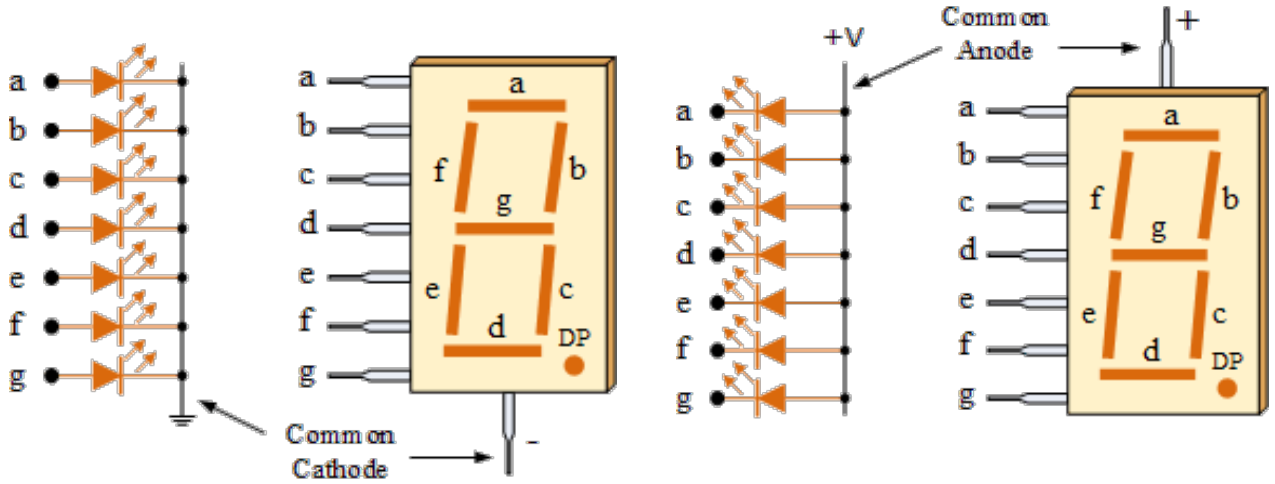
# LED

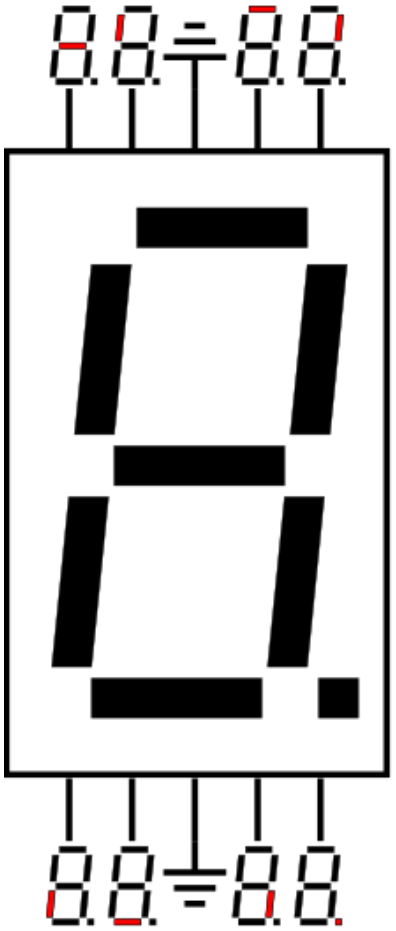
- Light Emitting Diode (**LED**):
  - Diode
  - Two legs
    - Anode (+)
    - Cathode (-)
  - Start lighting up if it has more than 0.6V
  - Infinite resistance up to 0.6 V
  - 0 resistance when it lights up



# 7 Segment Display

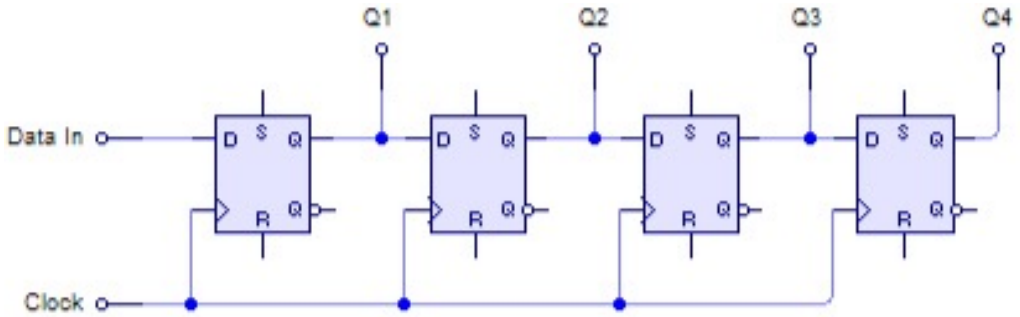
- Seven Segment LEDs
  - Common Cathode
    - Connect cathodes to 0, apply 1 to anode
  - Common Anode
    - Connect anodes to 1, apply 0 to cathode
  - Use multiplexing to reduce the number of pins if multiple seven segment LEDs are needed!

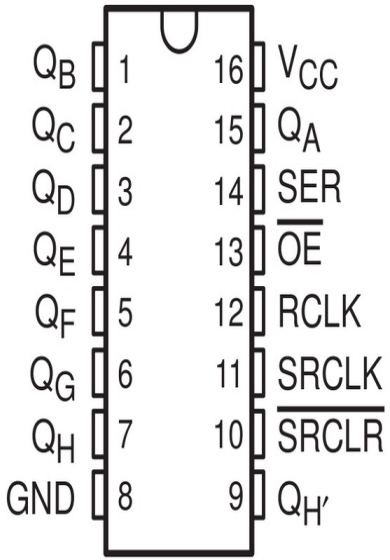


# Shift Register

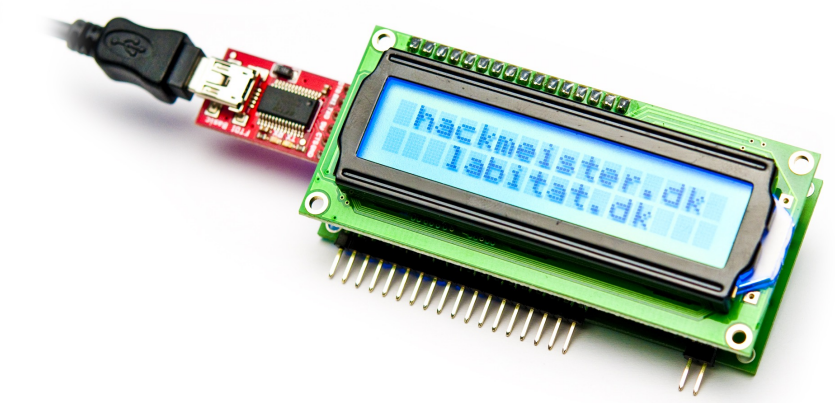
- Serial to Parallel Register
- Pins are limited
  - Use expanders
  - Shift register
- $Q_A$ .. $Q_H$ – data stored
- OE – enable (if 0)
- SEN – Serial input
- SRCLK – Serial clock
- RCLK – register clock (outputs)
- SRCLR – clear
- $Q_{H'}$ – shift output bit



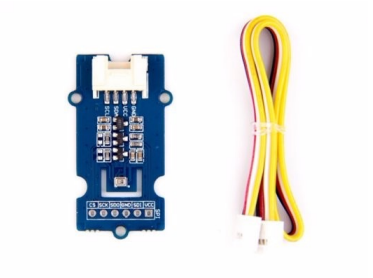



# LCD

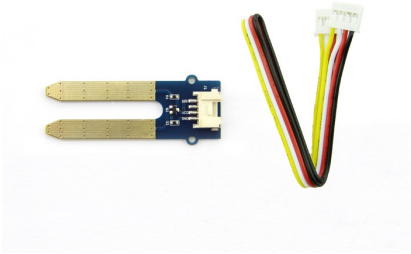
- Liquid Crystal Display (**LCD**)
  - 16 pins
  - Two data protocols
    - 4 bit
    - 8 bit
  - Microcontroller
  - I2C version (with an adapter)



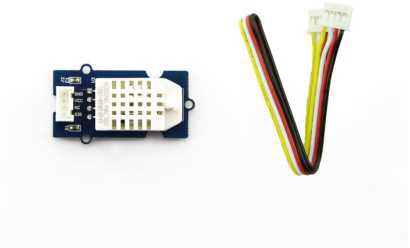
# More Sensors



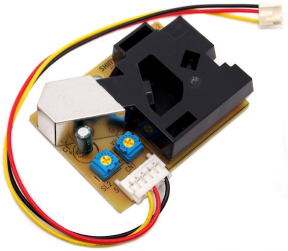
Barometer Sensor



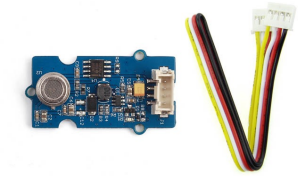
Moisture Sensor



Temp& Humidity sensor

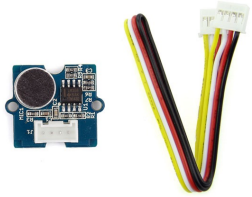


Dust Sensor



Air Quality Sensor

Gas Sensor



Sound Sensor

# Buy Them Chip! Build a Cool Project!

- Very chip to buy from Amazon or other vendors to build your cool projects.

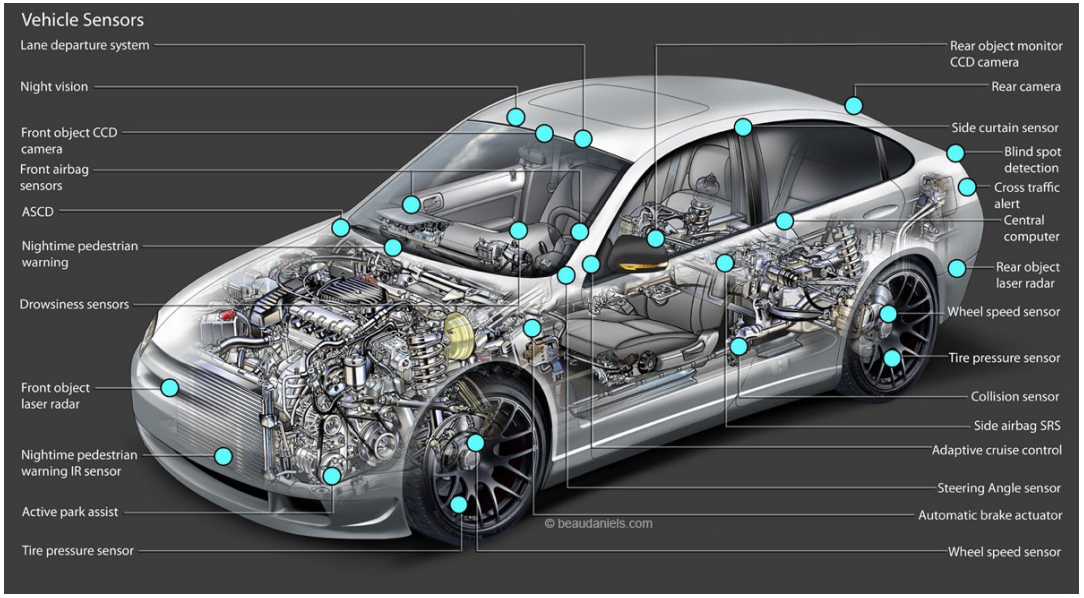
- Arduino Raspberry pi Sensor kit 


- SunFounder 37 Modules Sensor Kit 


- Sensor Kit For Arduino UNO R3 MEGA NANO Raspberry Pi 

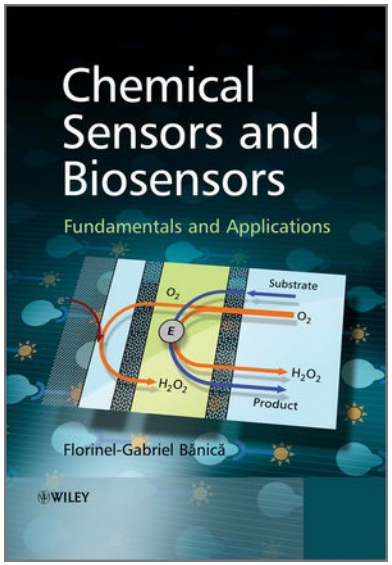

# More Sensors (Automotive, Transportation)

- Air flow meter
- Air–fuel ratio meter
- AFR sensor
- Blind spot monitor
- Crankshaft position sensor
- Curb feeler
- Defect detector
- Engine coolant temperature sensor
- Hall effect sensor
- Knock sensor
- MAP sensor
- Mass flow sensor
- Oxygen sensor
- Parking sensors
- Radar gun
- Speedometer
- Speed sensor
- Throttle position sensor
- Tire-pressure monitoring sensor
- Torque sensor
- Transmission fluid temperature sensor,
- Turbine speed sensor
- Variable reluctance sensor
- Vehicle speed sensor
- Water sensor
- Wheel speed sensor



# Chemical Sensors

- Breathalyzer
- Carbon dioxide sensor
- Carbon monoxide detector
- Catalytic bead sensor
- Chemical field-effect transistor
- Chemiresistor
- Electrochemical gas sensor
- Electronic nose
- Electrolyte–insulator–semiconductor sensor
- Fluorescent chloride sensors
- Holographic sensor
- Hydrocarbon dew point analyzer
- Hydrogen sensor
- Hydrogen sulfide sensor
- Infrared point sensor
- Ion-selective electrode
- Nondispersive infrared sensor
- Microwave chemistry sensor
- Nitrogen oxide sensor
- Olfactometer
- Optode
- Oxygen sensor
- Ozone monitor
- Pellistor
- pH glass electrode
- Potentiometric sensor
- Redox electrode
- Smoke detector
- Zinc oxide nanorod sensor



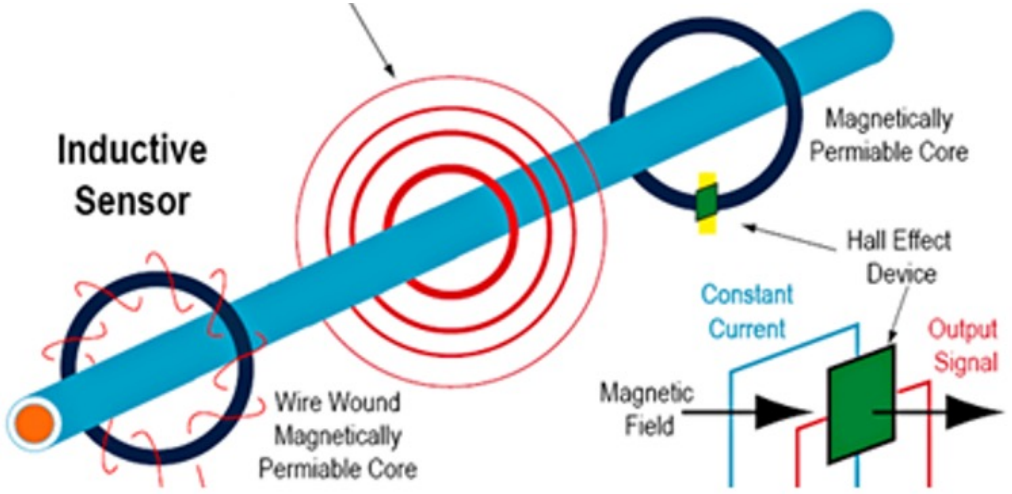

If you like to know more:
http://www.wiley.com/WileyCDA/WileyTitle/productCd-0470710675.html

# Electric & Magnetic Sensors

- Current sensor
- Daly detector
- Electroscope
- Electron multiplier
- Faraday cup
- Galvanometer
- Hall effect sensor
- Hall probe
- Magnetic anomaly detector
- Magnetometer
- Magnetoresistance
- MEMS magnetic field sensor
- Metal detector
- Planar Hall sensor
- Radio direction finder
- Voltage detector
- etc.

If you like to know more:

- **Electric and Magnetic Sensors and Actuators**
- http://digital-library.theiet.org/content/books/10.1049/sbcs502e_ch5
- **Sensor Magazine:**
  - http://www.sensorsmag.com/topic/electric-magnetic



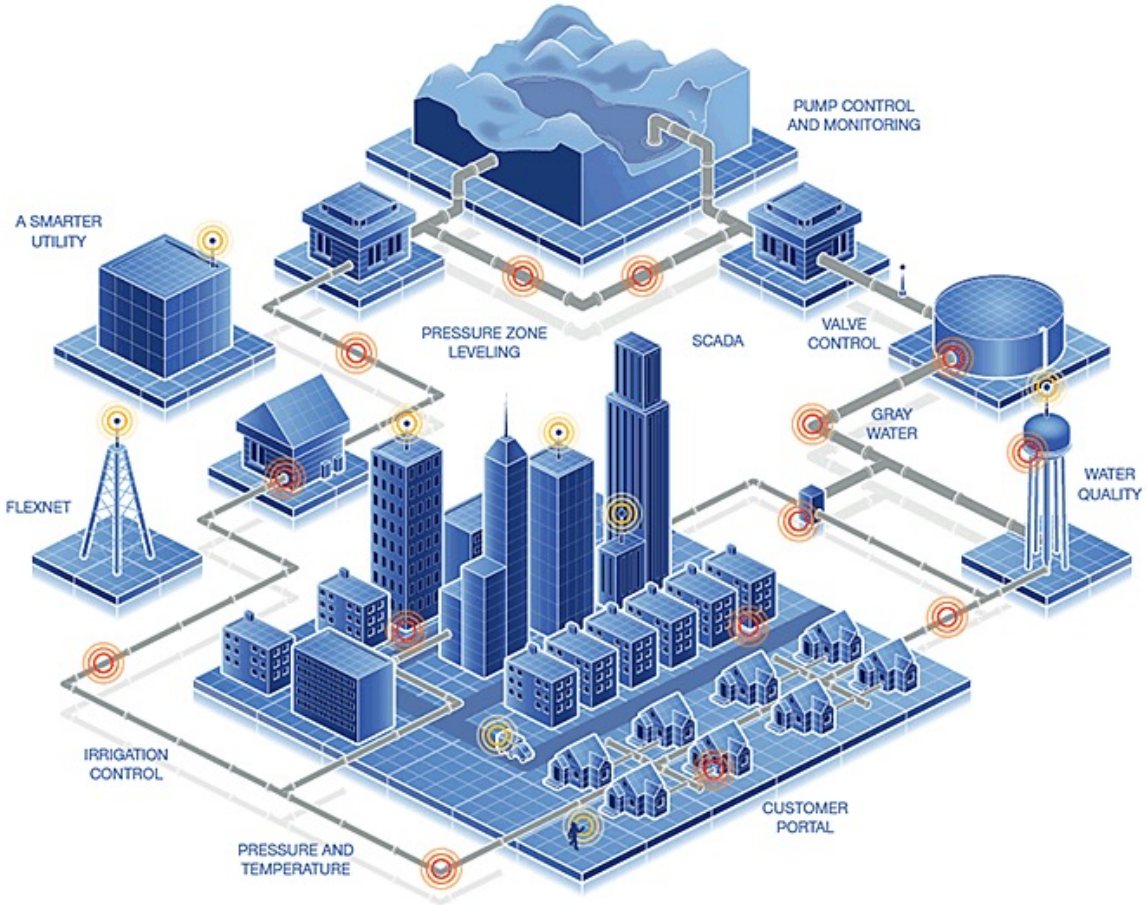
# Environmental Sensors

- Actinometer
- Air pollution sensor
- Bedwetting alarm
- Ceilometer
- Dew warning
- Electrochemical gas sensor
- Fish counter
- Frequency domain sensor
- Gas detector
- Hook gauge evaporimeter
- Humistor
- Hygrometer
- Leaf sensor
- Lysimeter
- Pyranometer
- Pyrgeometer
- Psychrometer
- Rain gauge
- Rain sensor
- Seismometers
- SNOTEL
- Snow gauge
- Soil moisture sensor
- Stream gauge
- Tide gauge


Interested to purchase some of this:
http://www.trossenrobotics.com/c/arduino-environmental-sensors.aspx

# Flow and Fluid Velocity Sensors

- Air flow meter
- Anemometer
- Flow sensor
- Gas meter
- Mass flow sensor
- Water meter



# Ionizing Radiation & Subatomic Particles Sensors

- Cloud chamber
- Geiger counter
- Geiger-Muller tube
- Ionisation chamber
- Neutron detection
- Proportional counter
- Scintillation counter
- Semiconductor detector
- Thermoluminescent dosimeter

# Navigation Sensor

- Air speed indicator
- Altimeter
- Attitude indicator
- Depth gauge
- Fluxgate compass
- Gyroscope
- Inertial navigation system
- Inertial reference unit
- Magnetic compass
- MHD sensor
- Ring laser gyroscope
- Turn coordinator
- TiaLinx sensor
- Variometer
- Vibrating structure gyroscope
- Yaw rate sensor

# Position, Angle, Displacement, … Sensors

- Auxanometer
- Capacitive displacement sensor
- Capacitive sensing
- Flex sensor
- Free fall sensor
- Gravimeter
- Gyroscopic sensor
- Impact sensor
- Inclinometer
- Integrated circuit piezoelectric sensor
- Laser rangefinder
- Laser surface velocimeter
- LIDAR
- Linear encoder
- Linear variable differential transformer (LVDT)
- Liquid capacitive inclinometers
- Odometer
- Photoelectric sensor
- Piezocapacitive sensor
- Piezoelectric accelerometer
- Position sensor
- Position sensitive device
- Rate sensor
- Rotary encoder
- Rotary variable differential transformer
- Selsyn
- Shock detector
- Shock data logger
- Stretch sensor
- Tilt sensor
- Tachometer
- Ultrasonic thickness gauge
- Variable reluctance sensor
- Velocity receiver

# Optical, Light, Imaging & Photon Sensors

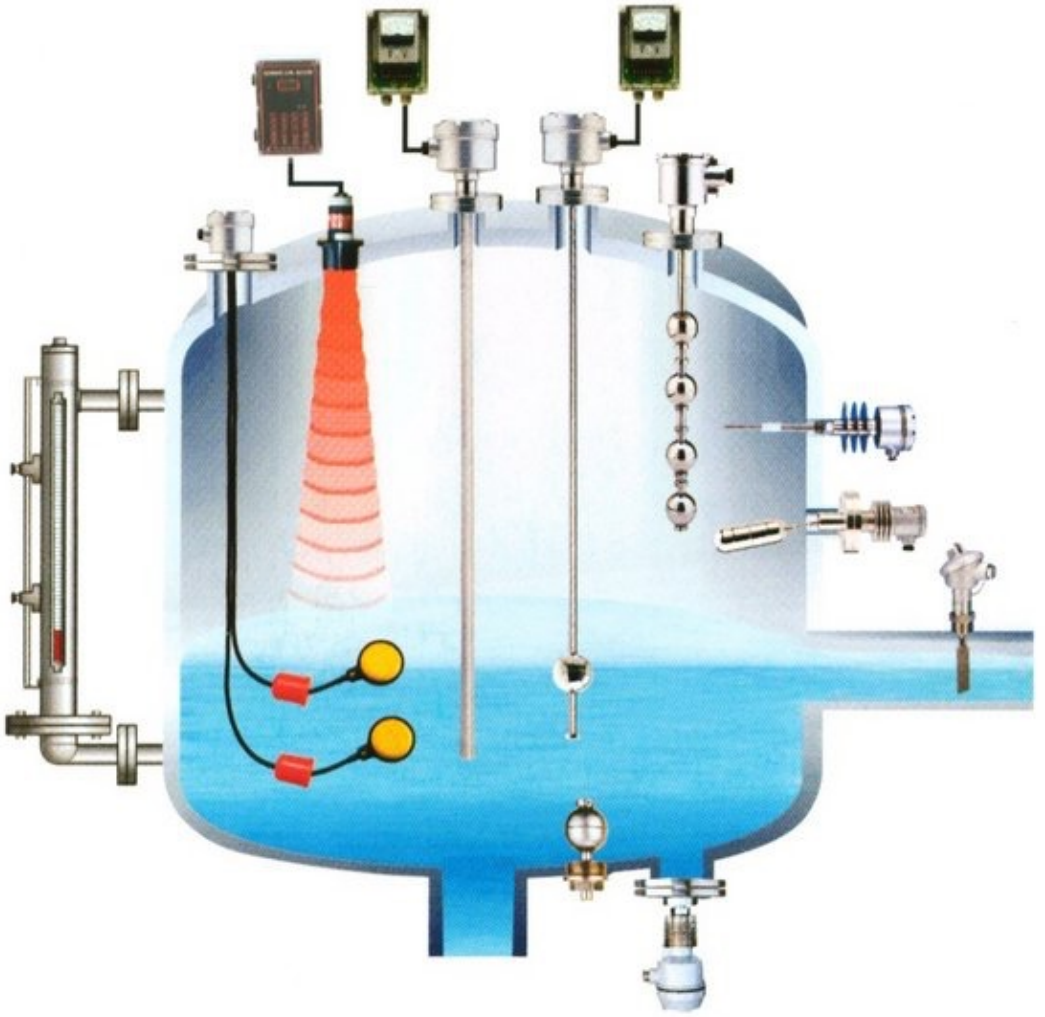
- Charge-coupled device
- CMOS sensor
- Colorimeter
- Contact image sensor
- Electro-optical sensor
- Flame detector
- Infra-red sensor
- Kinetic inductance detector
- LED as light sensor
- Light-addressable potentiometric sensor
- Nichols radiometer
- Fiber optic sensors
- Optical position sensor
- Thermopile laser sensors
- Photodetector
- Photodiode
- Photomultiplier tubes
- Phototransistor
- Photoelectric sensor
- Photoionization detector
- Photomultiplier
- Photoresistor
- Photoswitch
- Phototube
- Scintillometer
- Shack-Hartmann
- Single-photon avalanche diode
- Superconducting nanowire single-photon detector
- Transition edge sensor
- Visible light photon counter
- Wavefront sensor

# Pressure Sensor

- Barograph
- Barometer
- Boost gauge
- Bourdon gauge
- Hot filament ionization gauge
- Ionization gauge
- McLeod gauge
- Oscillating U-tube
- Permanent Downhole Gauge
- Piezometer
- Pirani gauge
- Pressure sensor
- Pressure gauge
- Tactile sensor
- Time pressure gauge

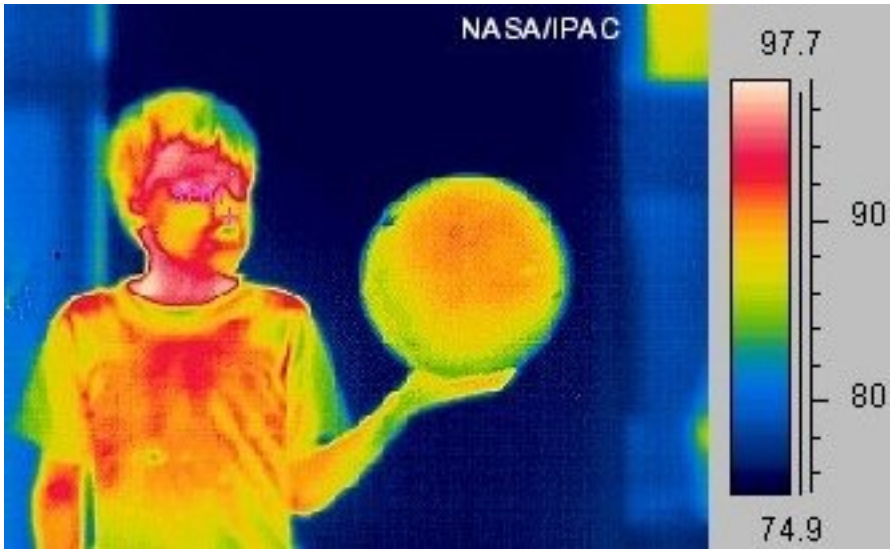
# Force, Density & Level Sensors

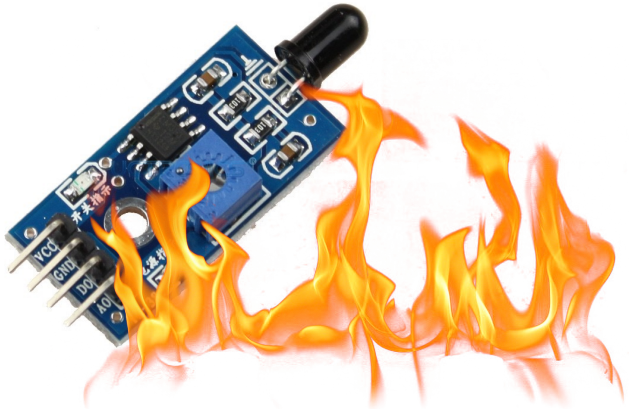
- Bhangmeter
- Hydrometer
- Force gauge and Force Sensor
- Level sensor
- Load cell
- Magnetic level gauge
- Nuclear density gauge
- Piezocapactive pressure sensor
- Piezoelectric sensor
- Strain gauge
- Torque sensor
- Viscometer



# Thermal, Heat & Temperature Sensor

- Bolometer
- Bimetallic strip
- Calorimeter
- Exhaust gas temperature gauge
- Flame detection
- Gardon gauge
- Golay cell
- Heat flux sensor
- Infrared thermometer
- Microbolometer
- Microwave radiometer
- Net radiometer
- Quartz thermometer
- Resistance thermometer
- Silicon bandgap temperature sensor
- Special sensor microwave/imager
- Temperature gauge
- Thermistor
- Thermocouple
- Thermometer
- Pyrometer

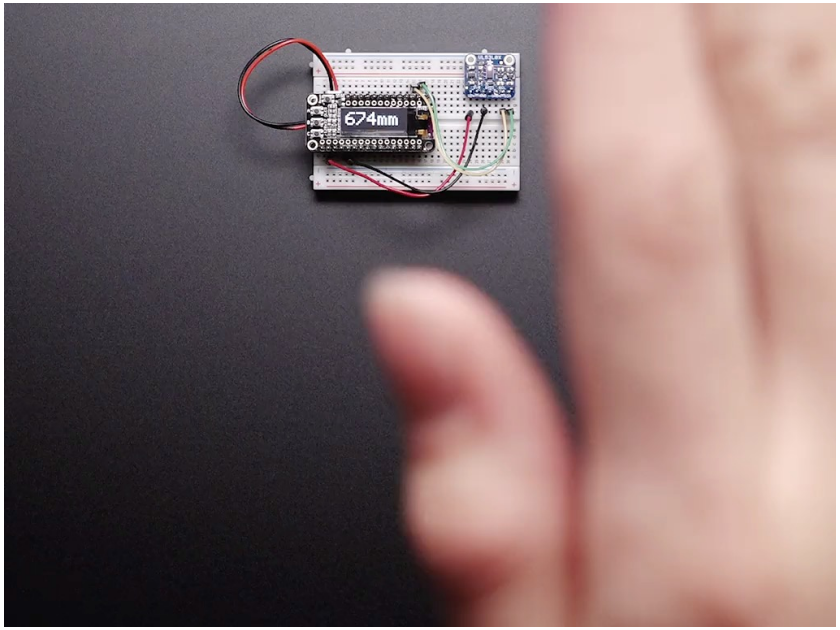


# Proximity & Presence Sensor

- Alarm sensor
- Doppler radar
- Motion detector
- Occupancy sensor
- Proximity sensor
- Passive infrared sensor
- Reed switch
- Stud finder
- Triangulation sensor
- Touch switch
- Wired glove

Video Source:
https://www.adafruit.com/product/3317?gclid=EAIaIQobChMIs-iJ1OGM1gIVBKxpCh1G7AZLEAQYAiABEgL9DPD_BwE



# More Sensors ….

**List goes on!**

**But wait!**

**Can we do better?**

- Lower power?
- Lower area?
- Lower latency?
- Higher reliability?
- Higher performance?

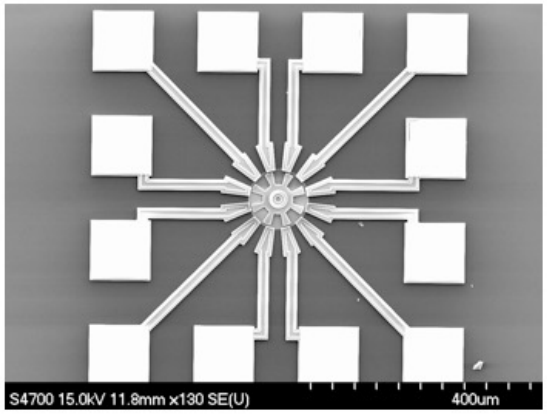
# MEM Sensors

- **M**icro **E**lectro **M**echanical or MEM Sensors:
  - Miniaturized mechanical and electro-mechanical elements
  - Is the technology of microscopic devices, particularly those with moving parts
  - There are at least some elements having some sort of mechanical functionality
- It merges at the nano-scale into nanoelectromechanical systems (NEMS)
- Components between 1 and 100 Micrometers in size
- MEM sensors could be integrated within CMOS, making it possible to have on die sensors
  - Extremely small
  - Extremely sensitive
  - Extremely low power

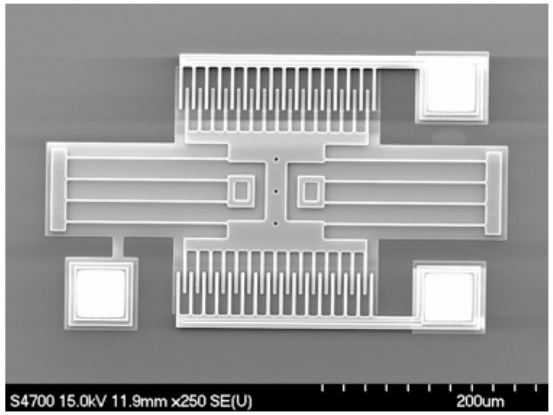
# Microelectromechanical (MEM) Sensors

- Use same fabrication process as CMOS
  - Very accurate
  - Very small
  - Very sensitive
  - Very inexpensive

- heterogeneous integration (CMOS + MEM + NEM) create many new and exciting opportunities

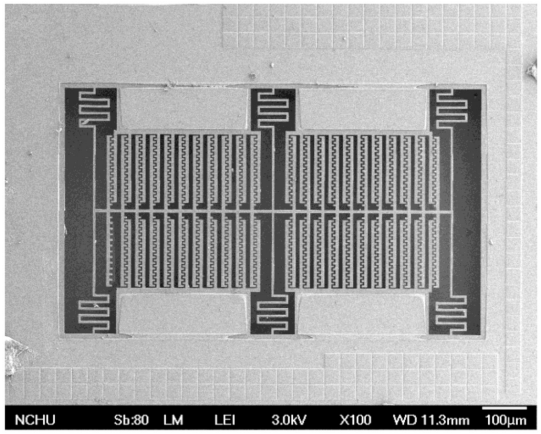



electro-statically-actuated micro-motor

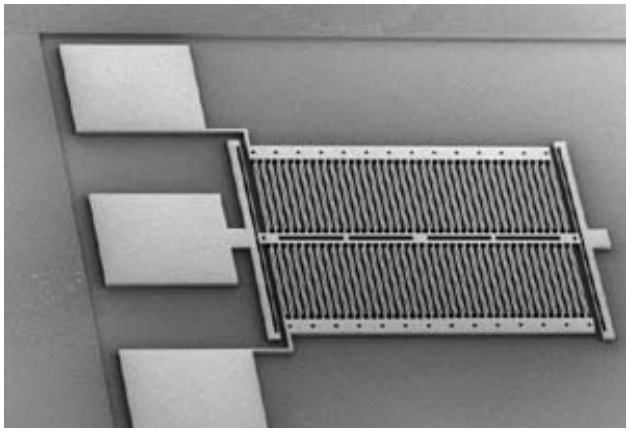



micromachined resonator

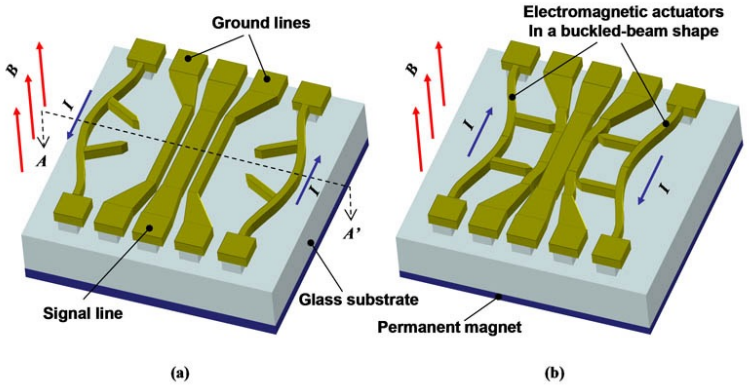
# MEM Device Examples




magnetic sensor



accelerometer

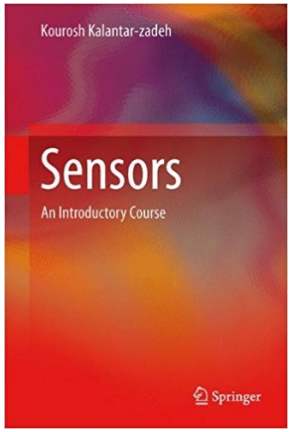


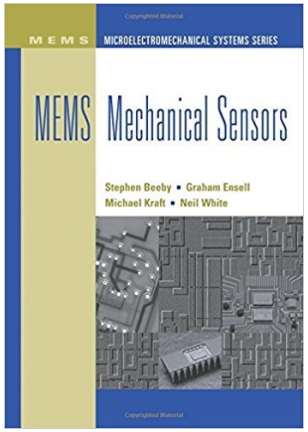

MEMS switch

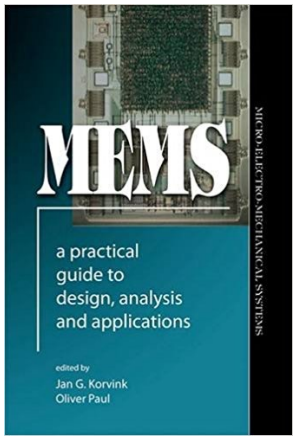
A quick read for interested students:
https://www.memsnet.org/mems/fabrication.html

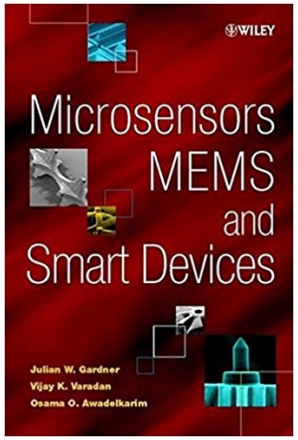
# How MEM Sensors Work?

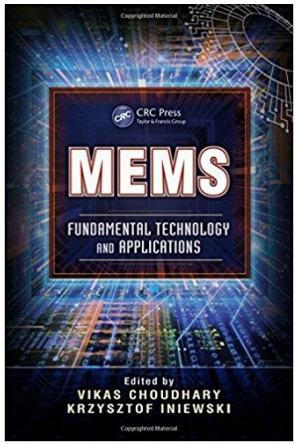
- Lets watch the following video:
- How MEMS Accelerometer Gyroscope Magnetometer Work:
  - https://www.youtube.com/watch?v=eqZgxR6eRjo
- How MEMs are made:
  - https://www.youtube.com/watch?v=EALXTht-stg



# Emerging Sensors

- Many new sensor technologies are becoming available.
- May be quite expensive now, but in a few years, you can use them at very low cost for building new and exciting IoT solutions

## Example 1: Electronic Nose

A sensing device intended to detect odors or flavors

- Technology exist today, however, miniaturization and cost reduction will make it available for use in IoT devices.
- **Applications**:
  - Quality Control
  - Health (detect harmful bacteria), lung cancer, viral infection,
  - Improving sense of smell through implants
  - Brain cancer cells
  - Security and Crime Prevention
  - Replacing police dogs in airports for bump or drug detection
  - Environmental Monitoring

# Emerging Sensors

- Many new sensor technologies are becoming available.
- May be quite expensive now, but in a few years, you can use them at very low cost for building new and exciting IoT solutions

## Example 2: Tactile Sensors

Measures information arising from physical interaction with environment (mimic human biological cutaneous touch)

- Technology exist today, however, miniaturization and cost reduction will make it available for use in IoT devices.
- **Applications**:
  - Robotic
  - Computer hardware
  - Security

# Emerging Sensors

- Many new sensor technologies are becoming available.
- May be quite expensive now, but in a few years, you can use them at very low cost for building new and exciting IoT solutions

## Example 3: Printed Sensors

Sensors printed on flexible substrate such as human skin

- Technology exist today, however, miniaturization and cost reduction will make it available for use in IoT devices.
- **Applications**:
  - Human-machine interface
  - Environmental sensing