CSCi 4907
Introduction to IoT and Edge Computing Applications

Prof. Kartik Bulusu, CS Dept.

Week 3 [02/10/2023]	• IoT Architecture and Ecosystem • Layers in IoT systems - 3 level layer model • Sensors • Sensor types and considerations	• Setting up the Edge Lab • In-class Raspberry Pi Lab (Ultrasound sensors) • Proxmity sensing using Thonny IDE • Proxmity sensing using bash script • Proxmity sensing on boot

```
git clone git@github.com:gwu-csci3907/Spring2024.git

git clone https://github.com/gwu-csci3907/Spring2024.git
```

School of Engineering
& Applied Science
THE GEORGE WASHINGTON UNIVERSITY

Spring 2024

Photo: Kartik Bulusu

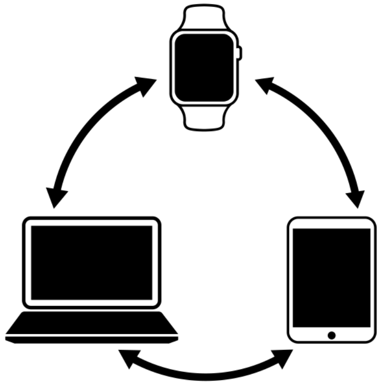
Short walk back
- What's the "thing" in IoT?

Sources:
Calculator by Markus from https://thenounproject.com/browse/icons/term/calculator/
internet of things by Davo Sime from https://thenounproject.com/browse/icons/term/internet-of-things/
L. Bernardi, S. Sarma and K. R. Traub, The Inversion Factor: How to Thrive in the IoT Economy

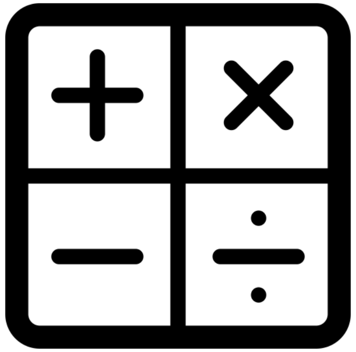
Paradigm #1

- A **thing** is self-contained and only operates within the confines of its physical shell.
  - **Thing** carries out only those functions that its designer envisioned when it was fabricated.
- The **thing** contains a powerful computer inside but is completely hidden from the user.
- The **thing** has firmware (not called software).

Paradigm #2



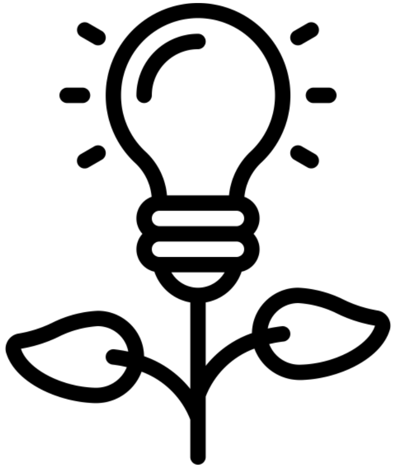
+



Paradigm #3

Icon source: https://thenounproject.com/icon/clean-energy-4339399/

Two questions up for discussion



1. How should we start perceiving an IoT system, physically ?

2. How / Where do we place the “thing” in that system ?

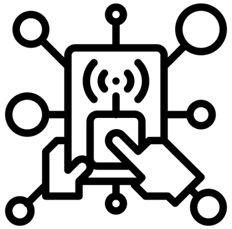
Keywords:
Small, functional, re-envisioning applications, efficient, sensor-driven, smart-sensors, connectivity, autonomy, data-driven, durability, fault tolerance, interoperability

Proximity to data, compute-power, network, distributed-network etc.

Building up the IoT Architecture and Ecosystem

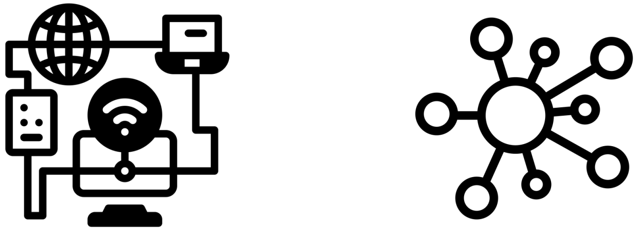
Icon Sources:
sensor by Carolina Cani:, sensor by Pham Duy Phuong Hung, sensor by Tippawan Sookruay, sensor by Lorenzo: https://thenounproject.com/browse/icons/term/sensor
fire sensor by LAFS : https://thenounproject.com/browse/icons/term/fire-sensor/
Ultrasound by Shocho: https://thenounproject.com/browse/icons/term/ultrasound/
Network by Solikin:, Network by Tippawan: https://thenounproject.com/browse/icons/term/network
application by Chaowalit Koetchuea: https://thenounproject.com/browse/icons/term/application/

Information–layer



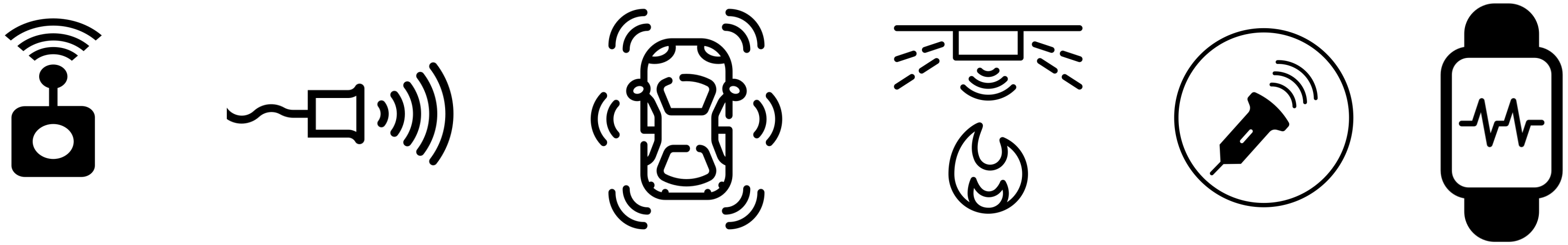
Data

Communication–layer



Connectivity

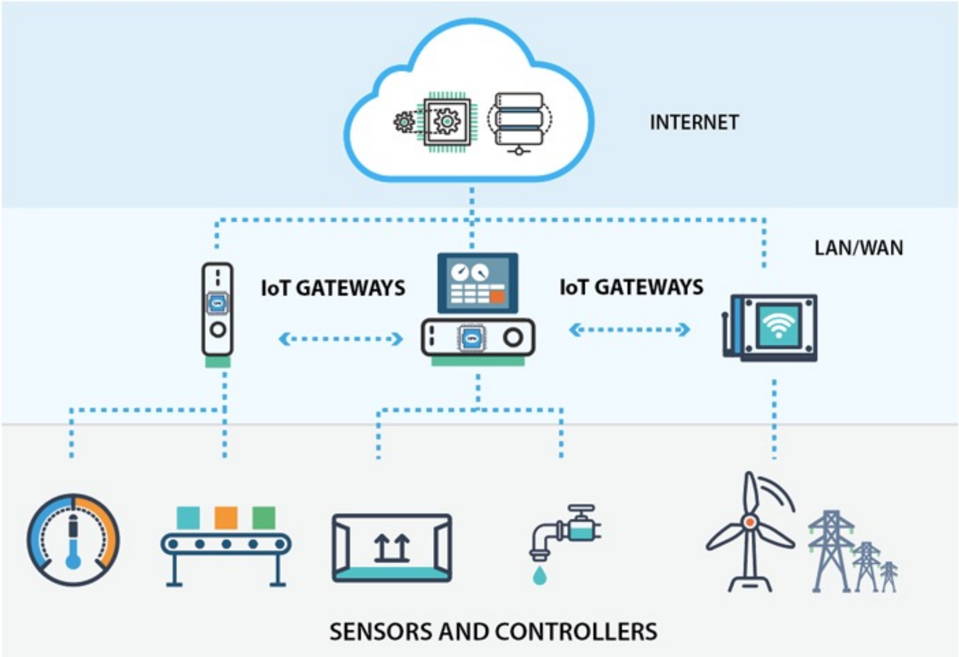
Sensor–layer

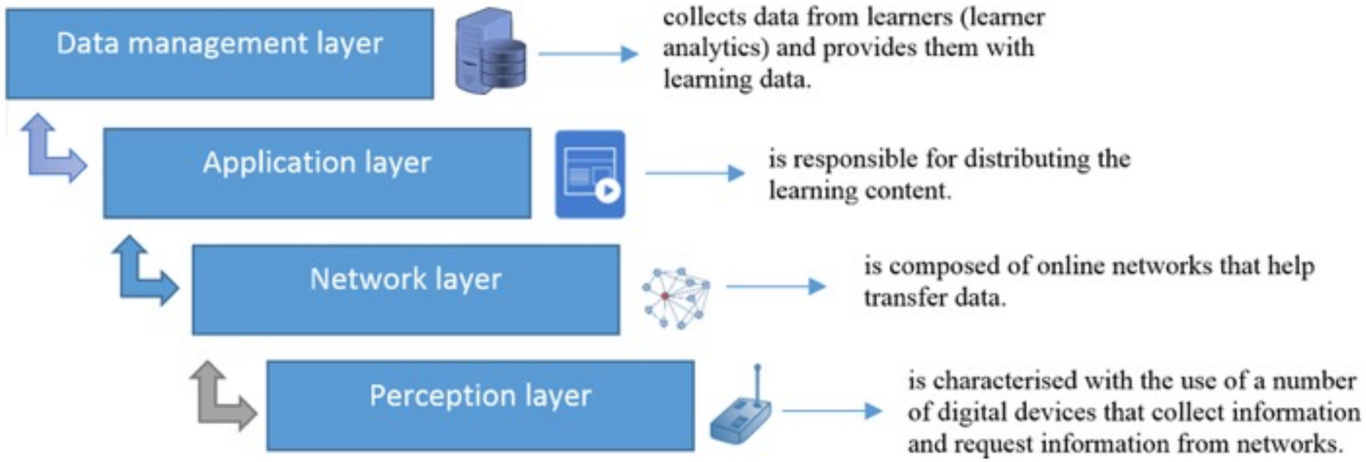


Things

Refining and defining the 3-Layer IoT Architecture

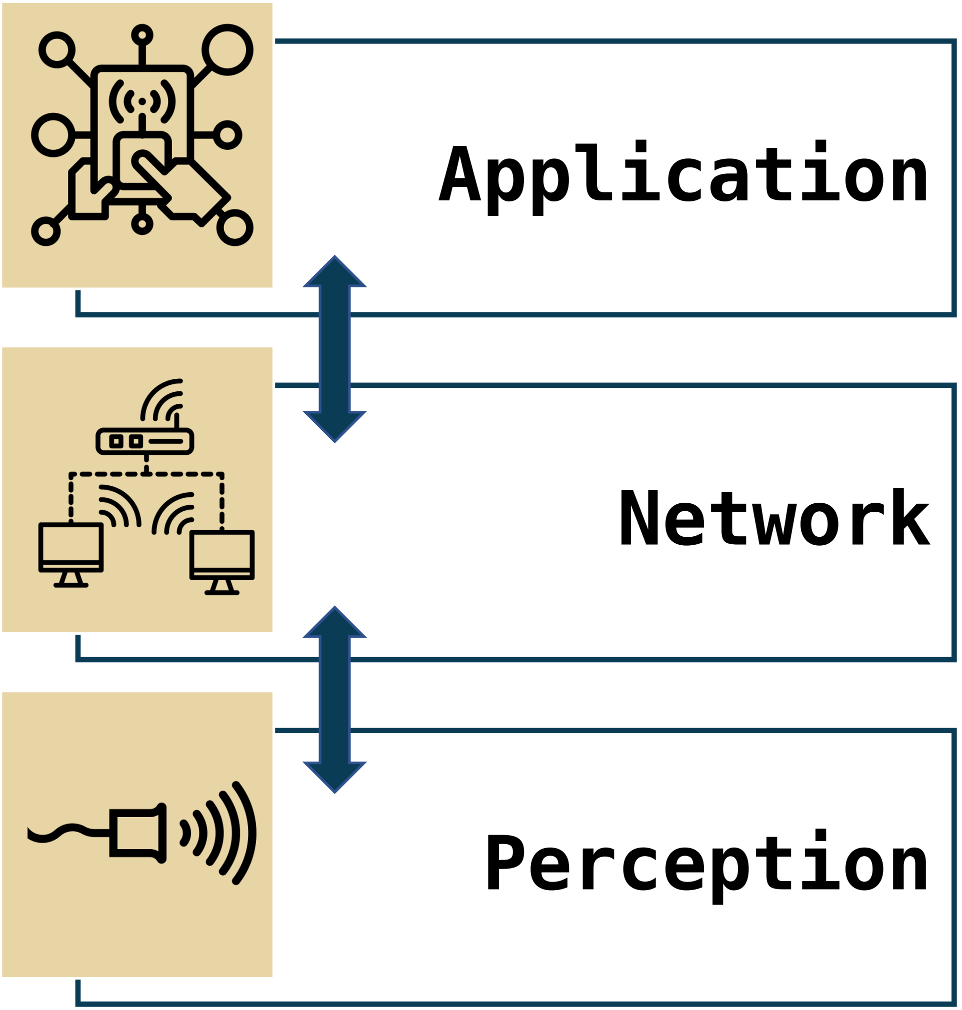
Sources:
Internet of Things, IoT Architecture: https://www.zibtek.com/blog/iot-architecture/





The 3-Layer IoT Architecture

Icon Sources:
sensor by Carolina Cani:, sensor by Pham Duy Phuong Hung, sensor by Tippawan Sookruay, sensor by Lorenzo: https://thenounproject.com/browse/icons/term/sensor
wifi network by Matthias Hartmann:: https://thenounproject.com/browse/icons/term/wifi-network/
application by Chaowalit Koetchuea: https://thenounproject.com/browse/icons/term/application/



Sensors and the IoT perception layer

Perception

Sources:
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Opem
Workflow by Nithinan: https://thenounproject.com/browse/icons/term/workflow/

What is a sensor?

A device that receives a stimulus and responds with an electrical signal.

Reference: Fraden, Jacob, Handbook of Modern Sensors, 4th ed. New York: Springer, 2010.

A device that responds to a physical input of interest with a recordable, functionally related output that is usually electrical or optical.

Reference: Jones, Deric P., Biomedical Sensors, 1st ed. New York: Momentum Press, 2010.

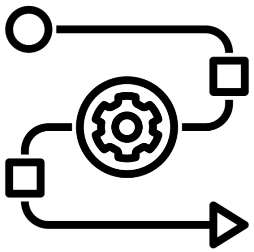
A sensor generally refers to a device that converts a physical measure into a signal that is read by an observer or by an instrument.

Reference: Chen, K. Y., K. F. Janz, W. Zhu, and R. J. Brychta, “Redefining the roles of sensors in objective physical activity monitoring,” Medicine and Science in Sports and Exercise, vol. 44, pp. 13–12, 2012.

A device which provides a usable output in response to a specific measurand.

Reference: ANSI, Americian National Standards Institute, “ISA S37.1–1975 (R1982),” ed, 1975.

Key idea



Energy conversion

What is a transducer?

A converter of any one type of energy into another [as opposed to a sensor, which] converts any type of energy into electrical energy.

Reference: Fraden, Jacob, Handbook of Modern Sensors, 4th ed. New York: Springer, 2010.

A sensor differs from a transducer in that a sensor converts the received signal into electrical form only.

A sensor collects information from the real world. A transducer only converts energy from one form to another.

Reference: Khanna, Vinod Kumar, Nanosensors: Physical, Chemical, and Biological. Boca Raton: CRC Press, 2012.

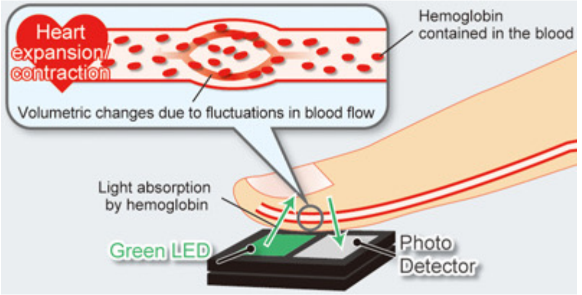
Sources:
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Opem
https://www.rohm.com/sensor-shield-support/heart-rate-sensor
Adafruit: https://www.adafruit.com/product/1075?gclid=CjwKCAiA85efBhBbEiwAD7oLQBeaVzL3TCUexZkYZQqnzdLQuRU2b_M6Ygk-0GHJRMqjL_GfdS17tRoC9MwQAvD_BwE
Homedics: https://www.homedics.com/infrared-ear-and-forehead-thermometer/
Healthline: https://www.healthline.com/diabetesmine/glucose-test-strips-diabetes-uses-accuracy-costs

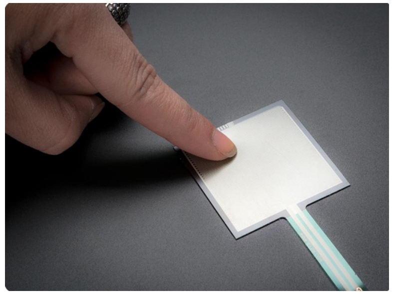
Sensor measurement classification-based on proximity to the measurand

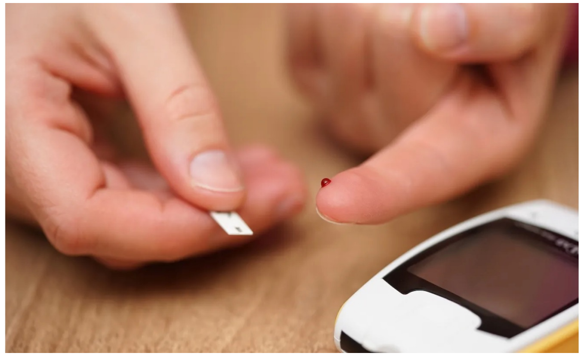
Contact: require physical contact with the quantity of interest.

Non-contact: do not require physical contact with the quantity of interest.

Sample removal: involves an invasive collection of a representative sample by a human or automated sampling system.







Sources:
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Open
Misra, S., Mukherjee, A and Roy, A, Introduction to IoT, Cambridge University Press (2021)
Electronics hub: https://www.electronicshub.org/different-types-sensors/

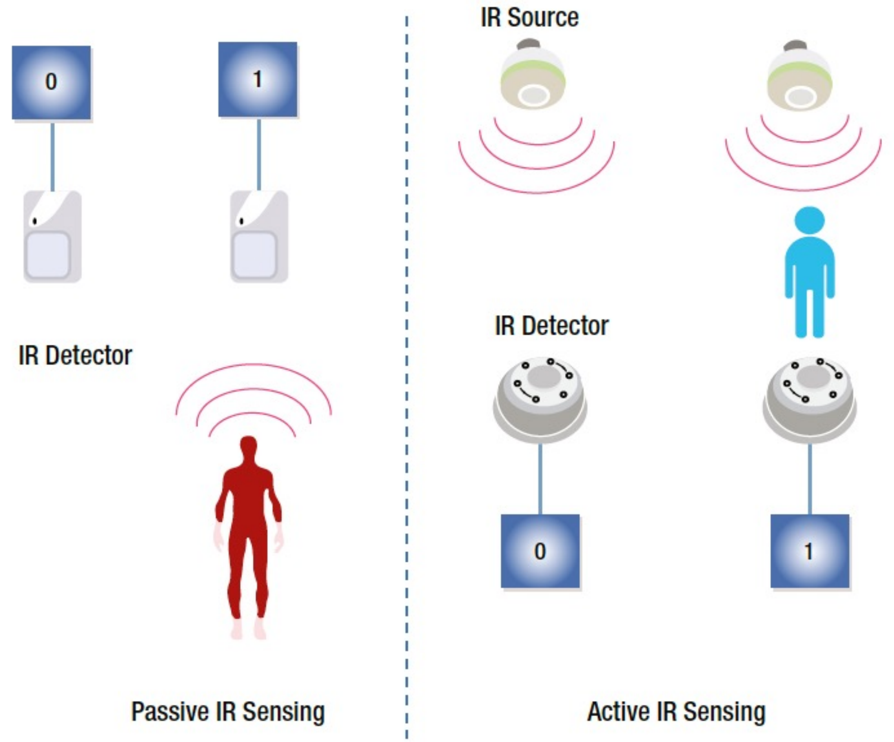
Sensor classification-based on power requirements

Active sensors

- require an external circuitry or mechanism to power them up.

Passive sensors

- do not require external circuitry provide it with power
- directly respond to the external stimuli from its ambient environment and converts it into an output signal.

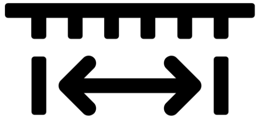


Sources:
resolution by Smashicons: https://thenounproject.com/browse/icons/term/resolution/
range by Adrien Coquet: https://thenounproject.com/browse/icons/term/range/
Energy by scarlett mckay: https://thenounproject.com/browse/icons/term/energy/
size by Woof Print Shop: https://thenounproject.com/browse/icons/term/size/
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Opem

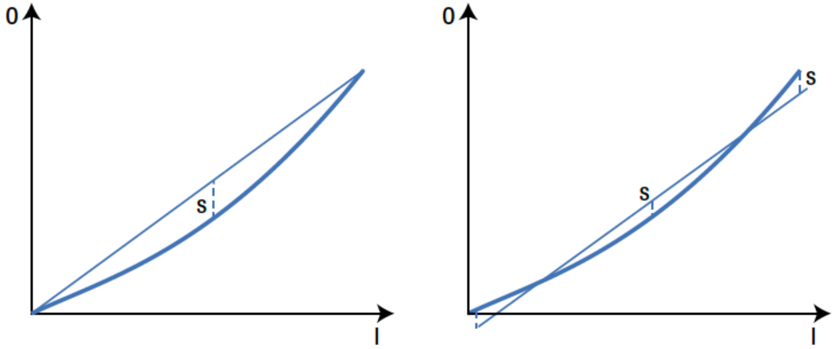
Sensing considerations

Resolution:
Minimum discernable measurement

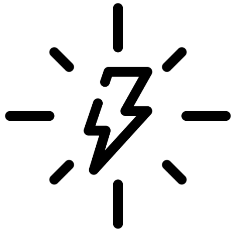
Sensing range:
Maximum and minimum of the possible measurement



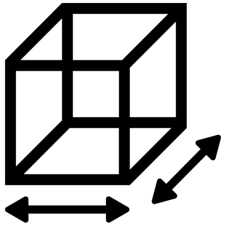
Linearity and the transfer function



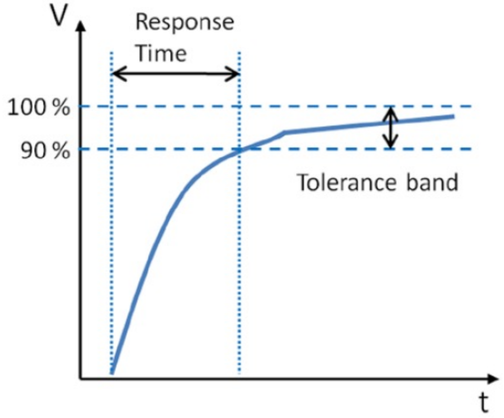
Energy consumption



Device size and form factor



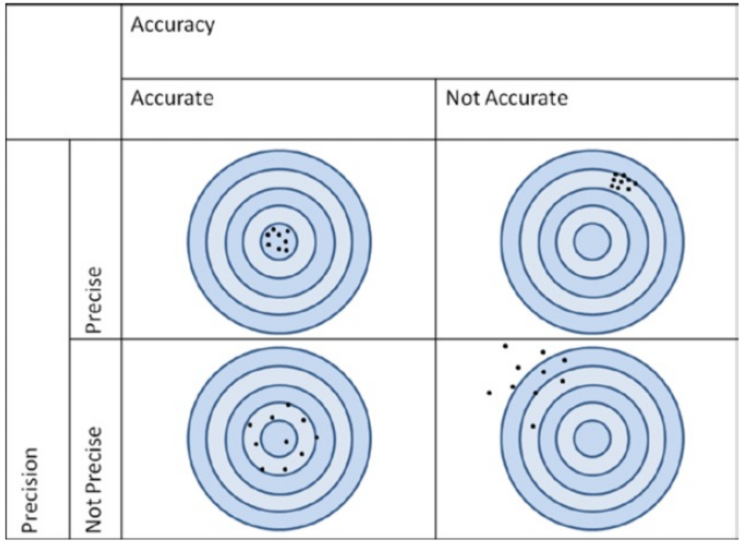
Response time



Sources:
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Open
Misra, S., Mukherjee, A and Roy, A, Introduction to IoT, Cambridge University Press (2021)

Sensing errors

Accuracy and Precision



$$Percentage\ Relative\ Error = \frac{(Measured\,Value - True\,Value)}{(True\,Value)} \times 100$$

$$Percentage\ Standard\ Deviation = \frac{(Standard\ Deviation)}{(Mean)} \times 100$$

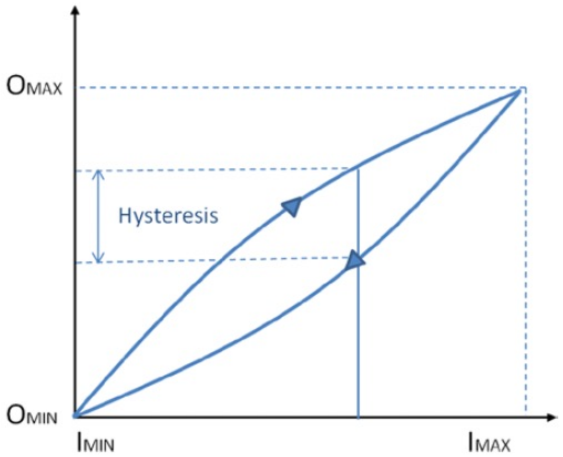
Systematic Errors
Systematic errors are reproducible inaccuracies that can be corrected with compensation methods, such as feedback, filtering, and calibration

Reference: *Wilson, Jon S., Sensor Technology Handbook. Burlington, MA: Newnes, 2004.*

Random error
Random error (also called noise) is a signal component that carries no information.

The quality of a signal is expressed quantitatively as the signal-to-noise ratio (SNR), which is the ratio of the true signal amplitude to the standard deviation of the noise.

Hysteresis



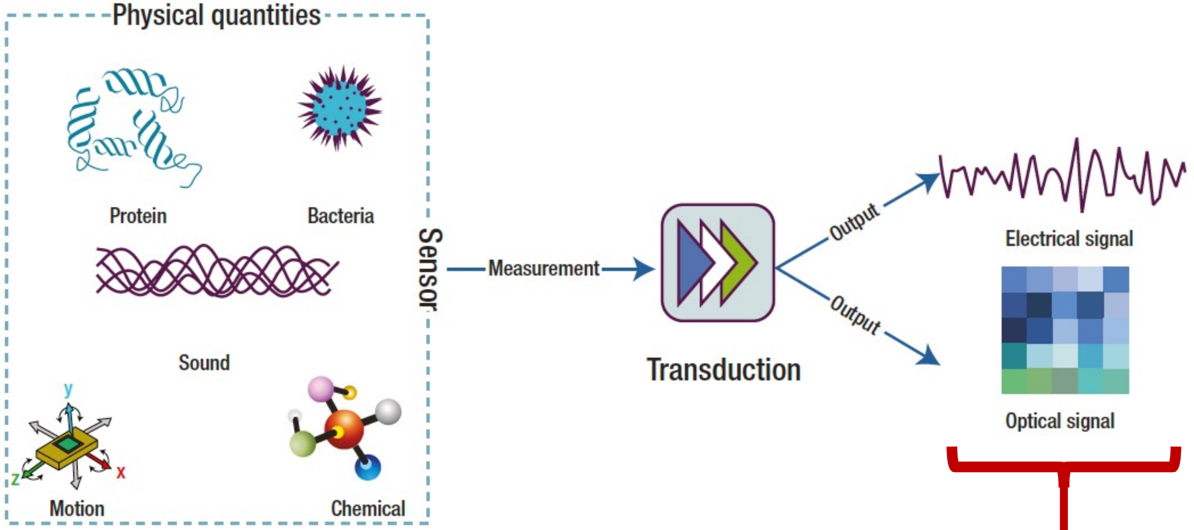
Repeatability

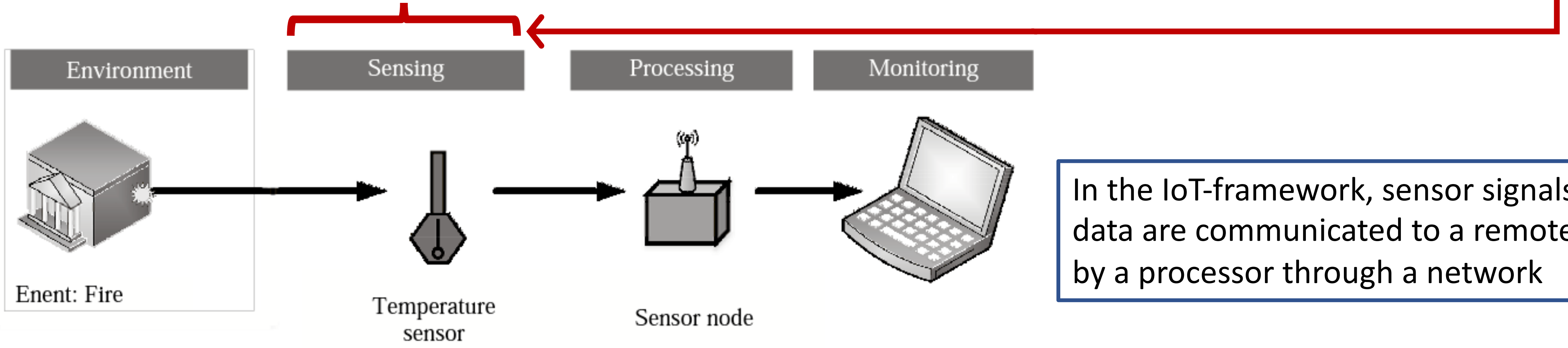
Repeatability is the ability of a sensor to produce the same output when the same input is applied to it.

Sources:
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Open
Misra, S., Mukherjee, A and Roy, A, Introduction to IoT, Cambridge University Press (2021)

Outline of a Sensing Operation

Sensor measurements are converted by a transducer into a signal that represents the quantity of interest to an observer or to the external world.

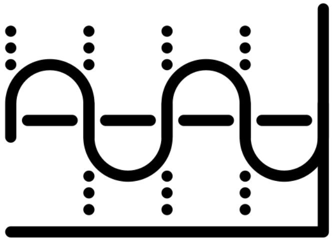




In the IoT-framework, sensor signals and data are communicated to a remote monitor by a processor through a network

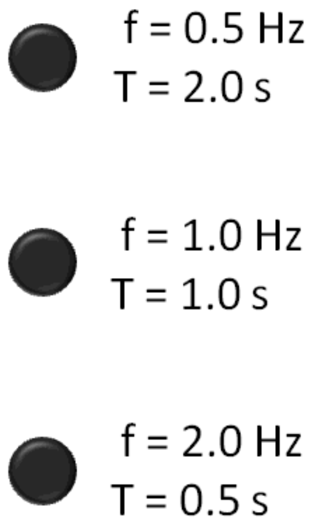
Icon Sources:
analog by I Putu Dicky Adi : https://thenounproject.com/browse/icons/term/analog/
Digital signal by Arthur Shlain: https://thenounproject.com/browse/icons/term/digital-signal

Digitization of Sensor Measurands



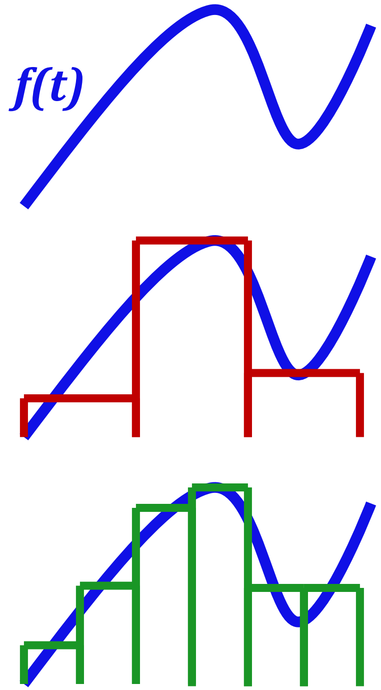
Frequency of signals and measurements

Frequency is the number of occurrences of a repeating event per unit **time**.



Wikimedia Commons

The **sampling frequency** or **sampling rate, f_s,** is the average number of samples obtained in one second (*samples per second*), thus **$f_s = 1/T$**.



The general range of hearing for young people is 20 Hz to 20000 Hz.

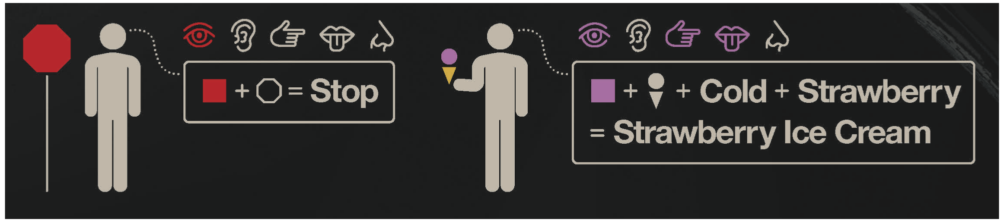
Audio CD, most commonly used with MPEG-1 audio is sampled at 44100 Hz

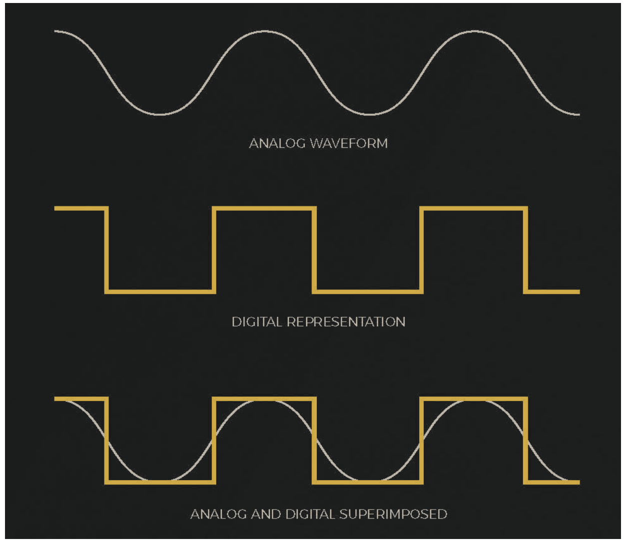
HD DVD (High-Definition DVD) audio tracks are sampled at 98000 Hz

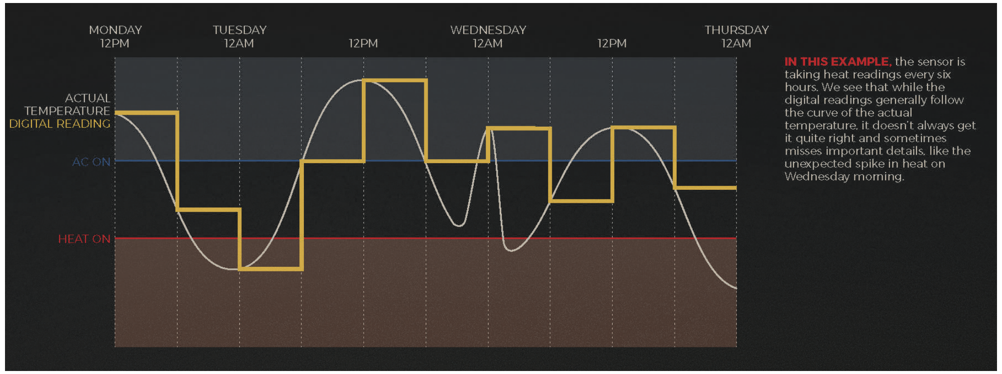
The approximately double-rate requirement is a consequence of the Nyquist theorem.

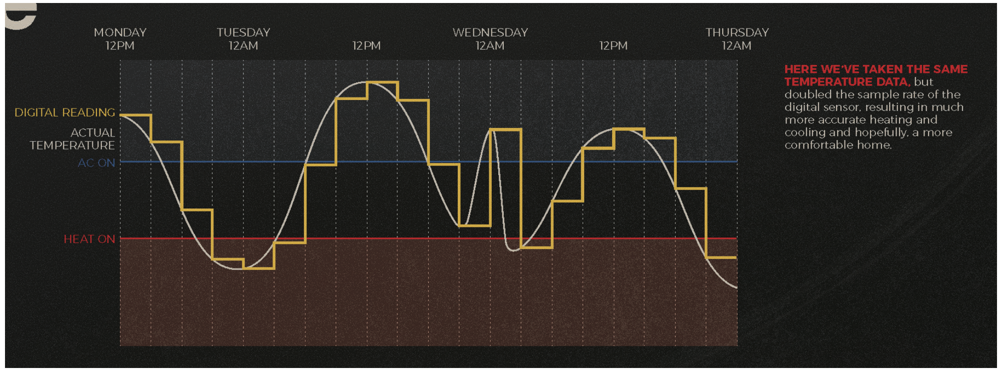
Source:
SparkFun: https://learn.sparkfun.com/

From Analog to the Digital World







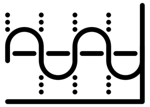


Sources:

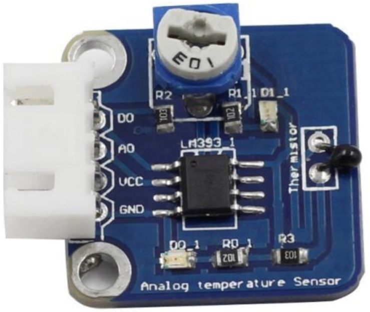
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Open
Misra, S., Mukherjee, A and Roy, A, Introduction to IoT, Cambridge University Press (2021)
analog by I Putu Dicky Adi : https://thenounproject.com/browse/icons/term/analog/
Digital signal by Arthur Shlain: https://thenounproject.com/browse/icons/term/digital-signal
Sunfounder: http://wiki.sunfounder.cc/index.php?title=Analog_Temperature_Sensor_Module
Sunfounder: https://www.sunfounder.com/products/analog-200nm-370nm-uv-detection-sensor-module

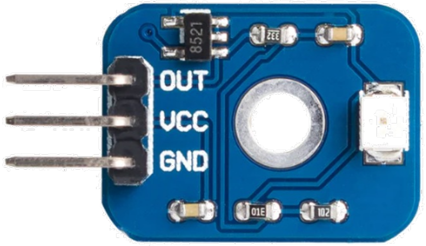
Sensor classification-based on output

Analog sensors



- Output signals are proportional (linearly or non-linearly) to the quantity being measured
- continuous in time and amplitude

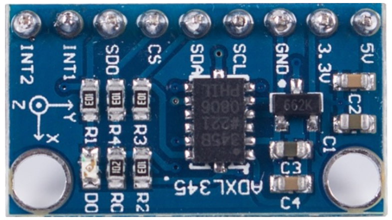




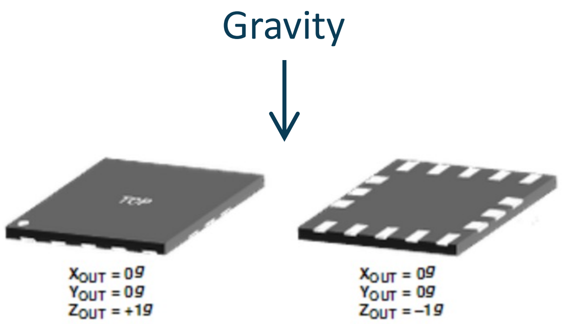
UV detection sensor module

Digital sensors

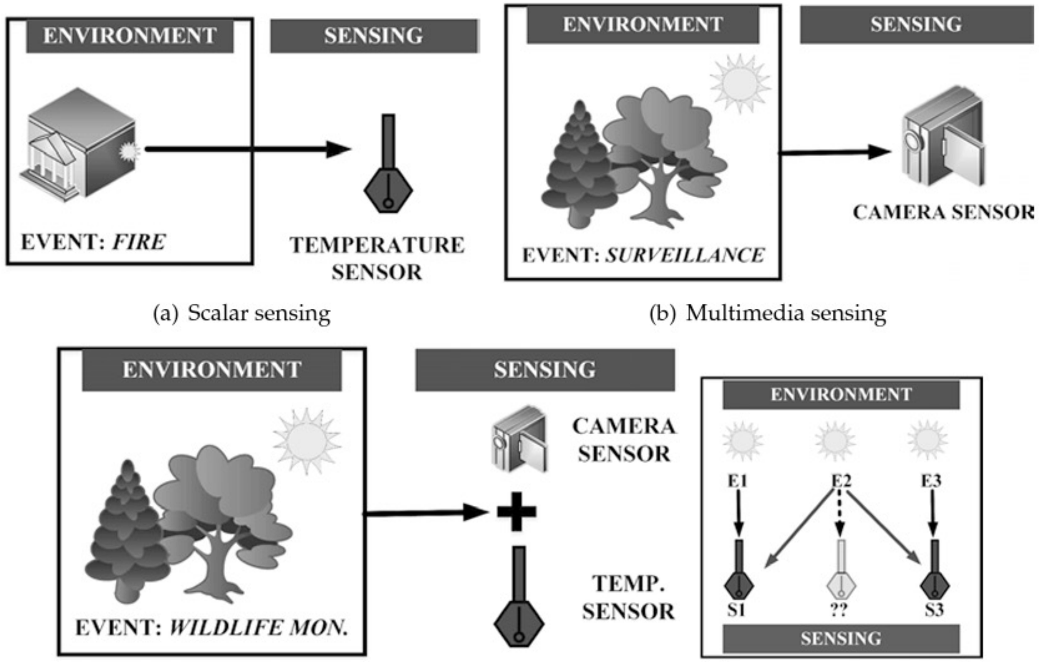
- Discrete time representation of the quantity being measured
- Binary signals in the form of logic-1 and logic-0
- Output as a single bit (serial transmission) or eight-bit (byte, parallel transmission)



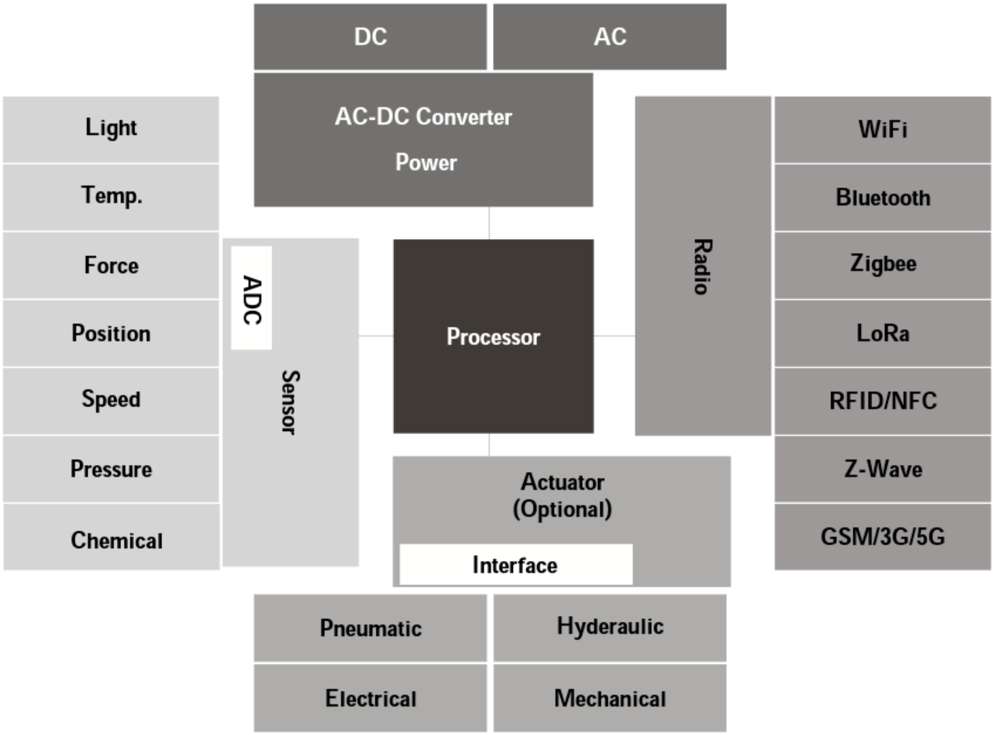
Digital Accelerometer module



Sensing strategies leading into IoT



(a) Scalar sensing (b) Multimedia sensing
(c) Hybrid sensing (d) Virtual sensing

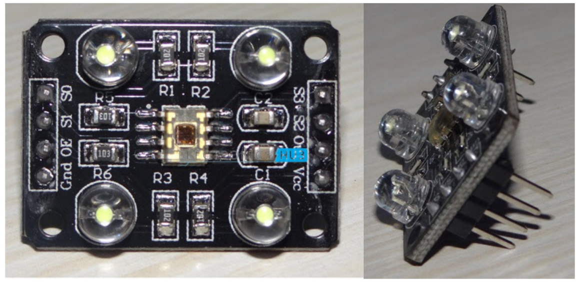


Sources:
McGrath, M. J. and Scanaill, C. N., Sensor Technologies - Healthcare, Wellness and Environmental Applications, Apress Open
Misra, S., Mukherjee, A and Roy, A, Introduction to IoT, Cambridge University Press (2021)
Electronics hub: https://www.electronicshub.org/arduino-based-color-detector/

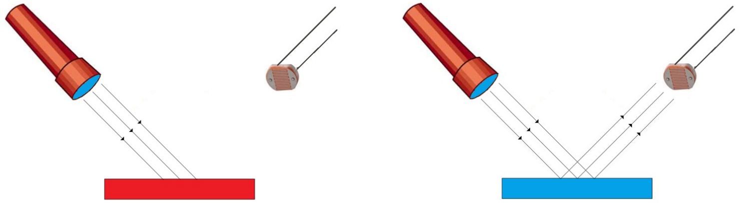
Sensor classification-based on measured quantity

Scalar sensors

- Output signals are proportional to the magnitude of the quantity being measured
- Scalar quantities are those where magnitude is sufficient to describe a phenomenon

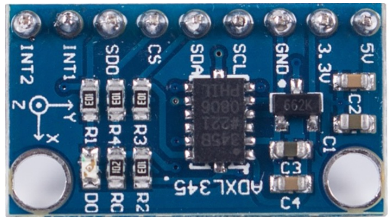


Color sensor module

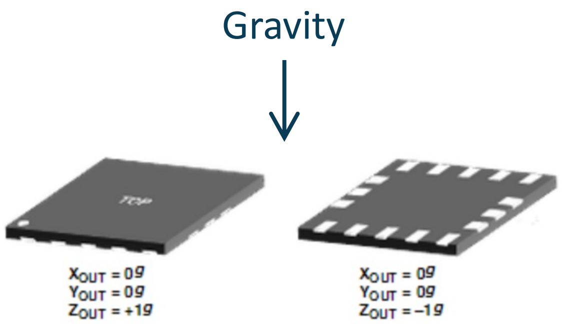


Vector sensors

- Measure magnitude and direction of the measured quantity



Digital Accelerometer module



Take a tiny quiz on `Sensors & IoT` and feel good!

Use the following link:

http://tinyurl.com/498raxh4

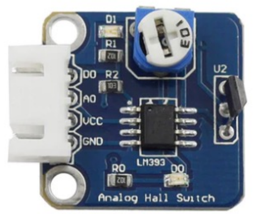
OR

Some rules to observe:

- 5 minutes restriction
- Unlimited responses
- You can discuss with your colleagues in-class
- Watch real-time results and calibrate

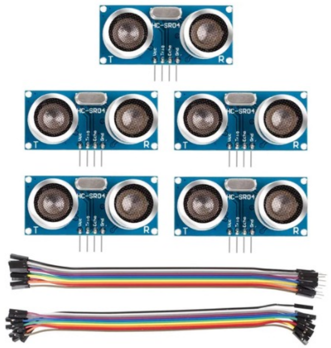
Common types of commercially available sensors (Sunfounder kit)

Source:
Sunfounder:
https://www.sunfounder.com/collections/raspberry-pi-store



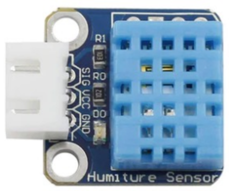
SUNFOUNDER

Analog Hall Sensor Module



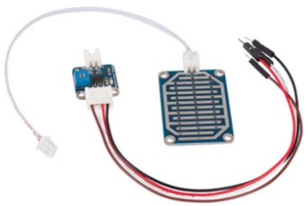
SUNFOUNDER

5pcs HC-SR04 Ultrasonic Module Distance Sensor



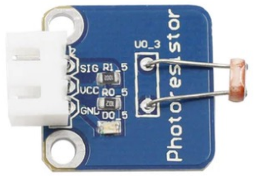
SUNFOUNDER

Humiture Sensor Module



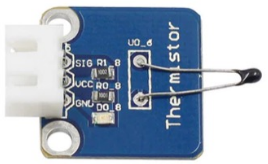
SUNFOUNDER

Raindrop Sensor Module



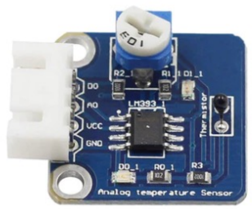
SUNFOUNDER

Photoresistor Sensor Module



SUNFOUNDER

Thermistor Sensor Module

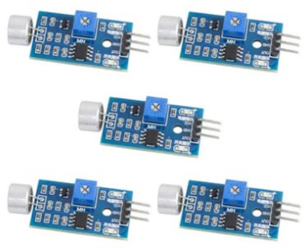


SUNFOUNDER

Analog Temperature Sensor Module

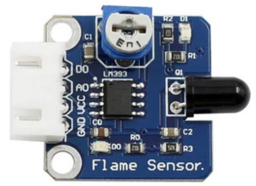
SUNFOUNDER

HHC MQ-2 Gas Sensor Module



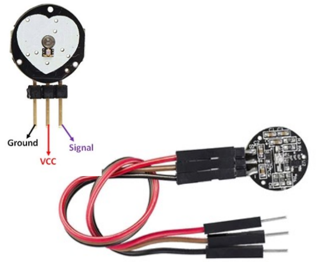
SUNFOUNDER

Sound Sensor Module (5



SUNFOUNDER

Flame Sensor Module

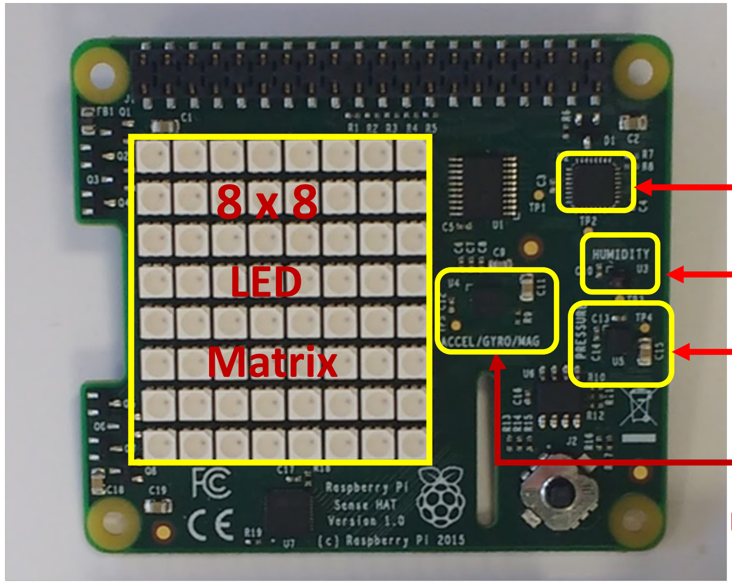


SUNFOUNDER

PulseSensor Heart Rate Monitoring Sensor Module

Other types of commercially available sensors and modules

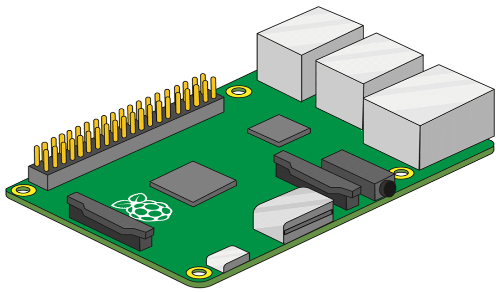
Image and animation source:
https://projects.raspberrypi.org/en/projects/getting-started-with-the-sense-hat/2
http://wiki.sunfounder.cc/index.php?title=Main_Page
https://www.adafruit.com/product/3100#description

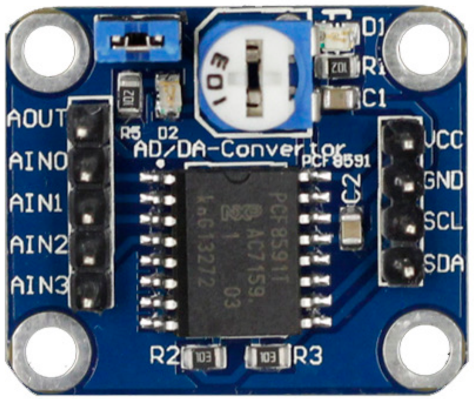


IMU
Inertial Measurement Unit

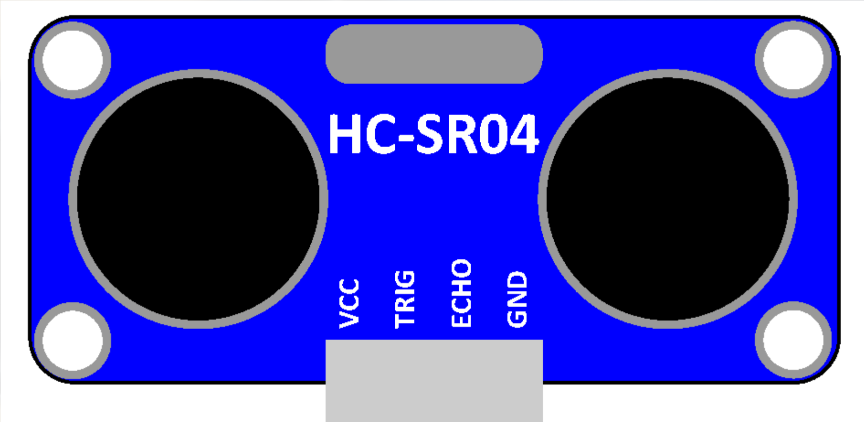
- The Sense HAT has a variety of sensors that can be read from:

"Temperature"	reads temperature in degrees Celsius
"Humidity"	reads humidity in % RH
"Pressure"	reads atmospheric pressure in millibars
"Rotation"	reads gyroscopic motion in revolutions per second
"Acceleration"	reads acceleration in terms of standard accelerations due to gravity on Earth's surface
"Orientation"	reads orientation relative to magnetic north in degrees
"Magnetic Field"	reads strength and direction of a magnetic field around the sensor in microteslas





Know your Ultrasonic Sensor



The Ultrasonic sensor sends out ultrasonic waves to detect objects and measure distances.

Connectors:
4-pin jumper cables

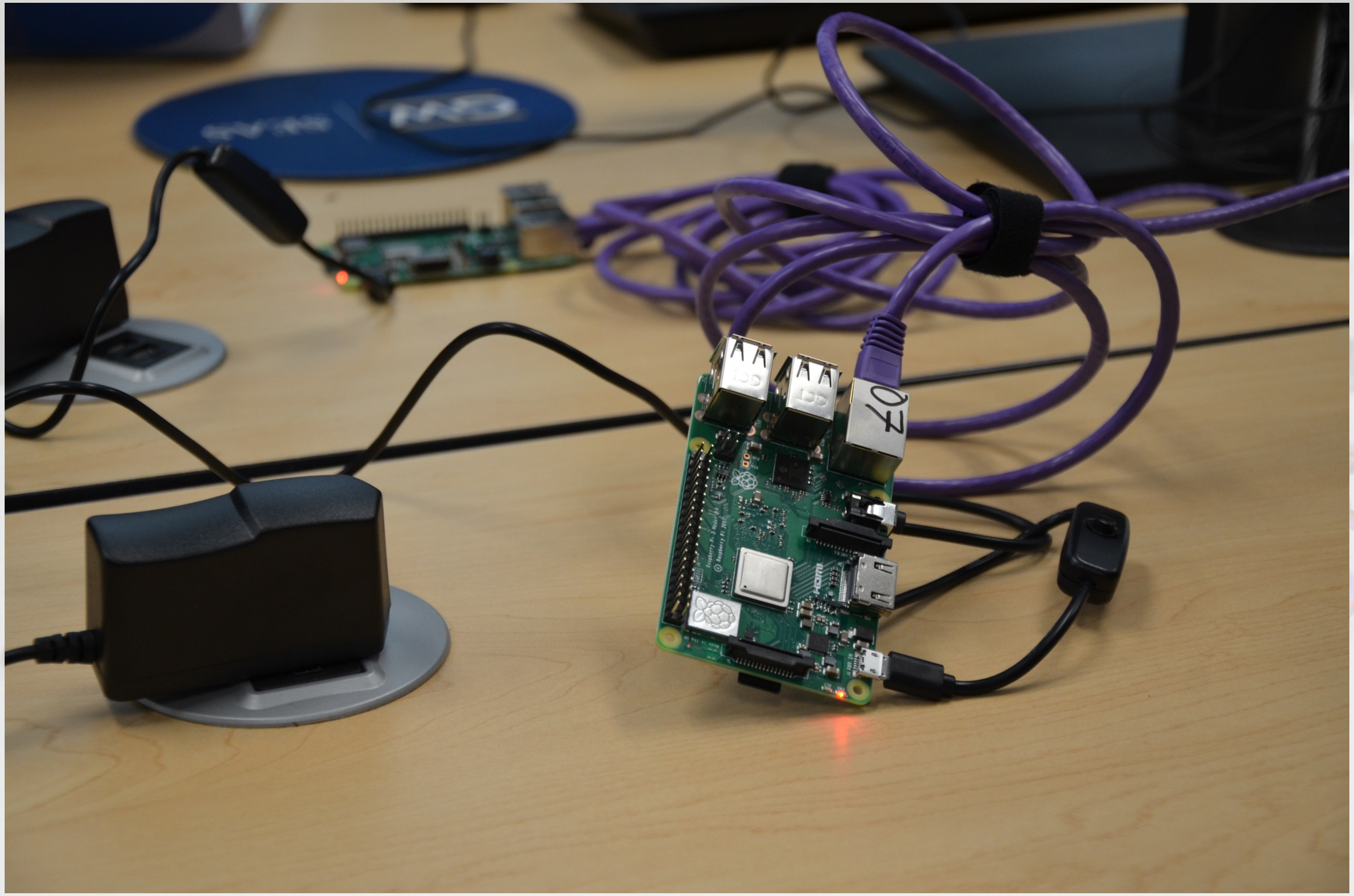
Goal of the lab segment:

- Co-work
  - Observe, ask and try in groups
- Make
  - Build-a-hack
  - Ultrasound sensors and Raspberry Pi 3B + boards
- Analyze data using Python

Photo: Kartik Bulusu

Set up lab the Edge–lab

STEP [1]:
Connect the RPis to each desk power outlet as shown



- Make sure there is a microSD card installed in the RPi
- Connect the RPi using the microUSB cable provided
- Connect the purple colored ethernet cables specifically for RPi connections
- LEDs on the RPi will start blinking indicating that it is booting up

STEP [2]:
Access the RPi in the Edge–lab

2.1 Open up remote desktop connection (using the VNC server)

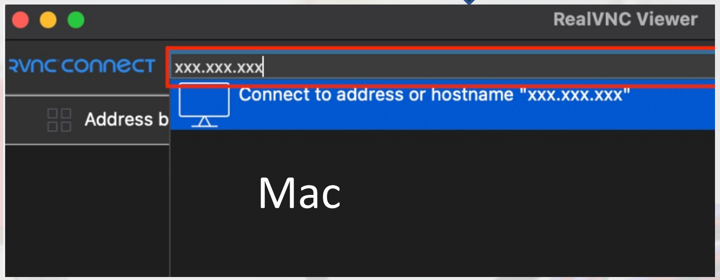
Each RPi has unique alpha–numeric name (e.g., Pi07, Pi152 etc)

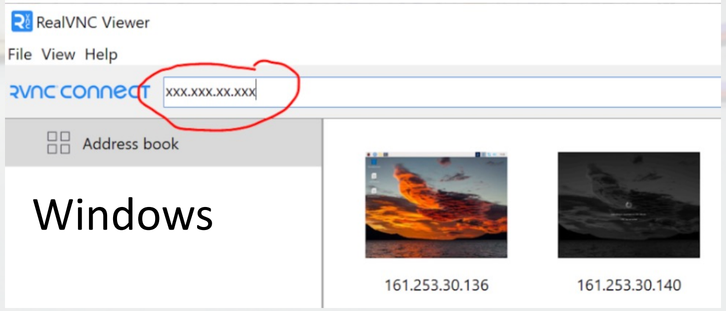
- Locate the Pi–name and the IP address on the <128.164.139.xx>

OR

Each RPi connected using an ethernet cable directly to your laptops

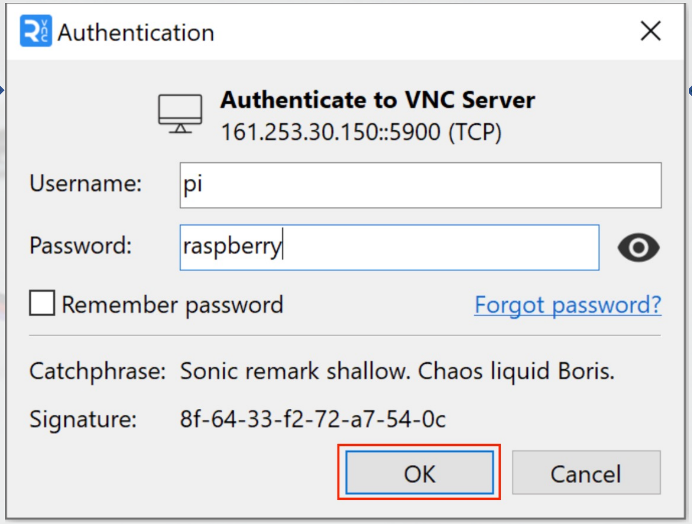
- raspberrypi.local





2.2 Once you are connected you will

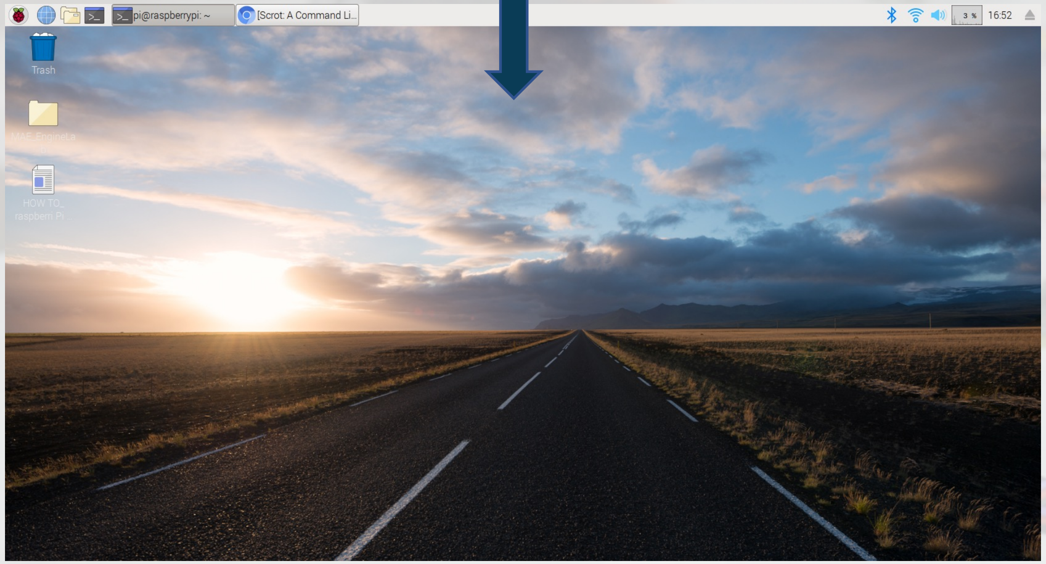
- See Authentication box below
- Type in the Username and Password



STEP [3]:

Now that you accessed the RPi…

You will see a screen like the one shown below

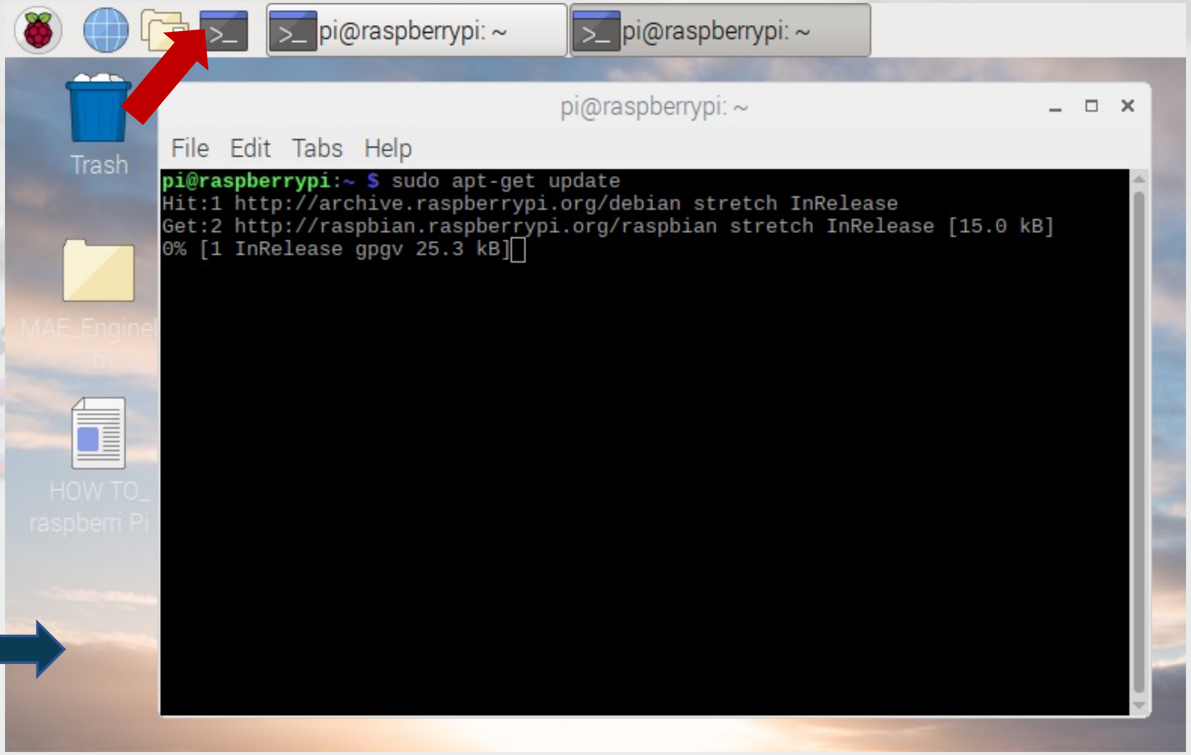


3.2 Testing is complete when you get to this step.

- Students should get the RPis to this step before the laboratory modules begin.

3.1 Click on terminal(shown with a red arrow below)

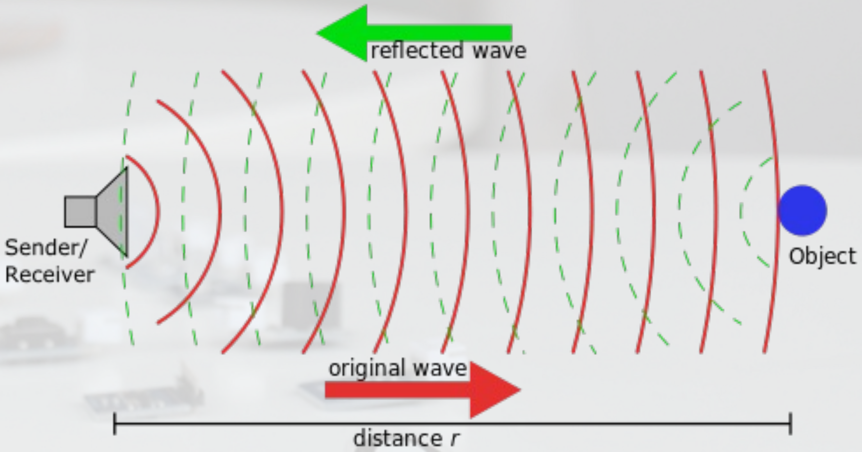
- At the prompt type: sudo apt-get update
- Wait for the updates to complete
- Then type: sudo apt-get upgrade
- If you get the following prompt
    - Do you want to continue [Y/n]
    - Type: y
    - And hit "Enter" on your keyboard and let the upgrades complete

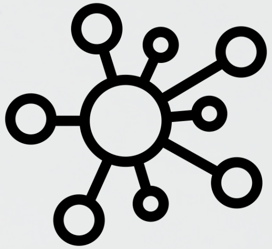


Icon Sources:
sensor by Carolina Cani:, sensor by Pham Duy Phuong Hung, sensor by Tippawan Sookruay, sensor by Lorenzo: https://thenounproject.com/browse/icons/term/sensor
fire sensor by LAFS : https://thenounproject.com/browse/icons/term/fire-sensor/
Ultrasound by Shocho: https://thenounproject.com/browse/icons/term/ultrasound/
Network by Solikin:, Network by Tippawan: https://thenounproject.com/browse/icons/term/network
application by Chaowalit Koetchuea: https://thenounproject.com/browse/icons/term/application/

Ultrasound Signals and its Applications

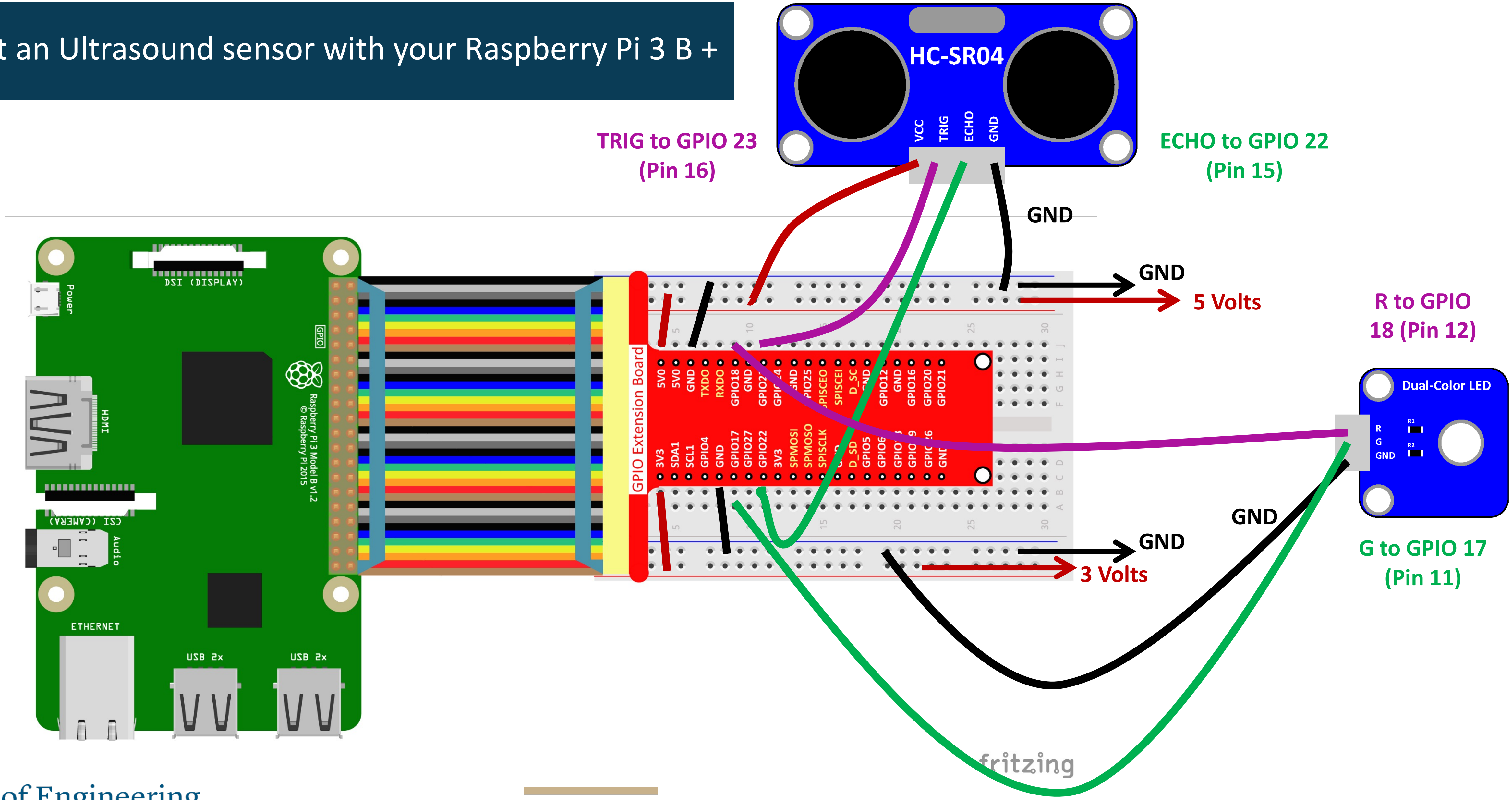
Source: https://youtu.be/J-VVh5ezqGA?si=G9iu055uV3MinyUA



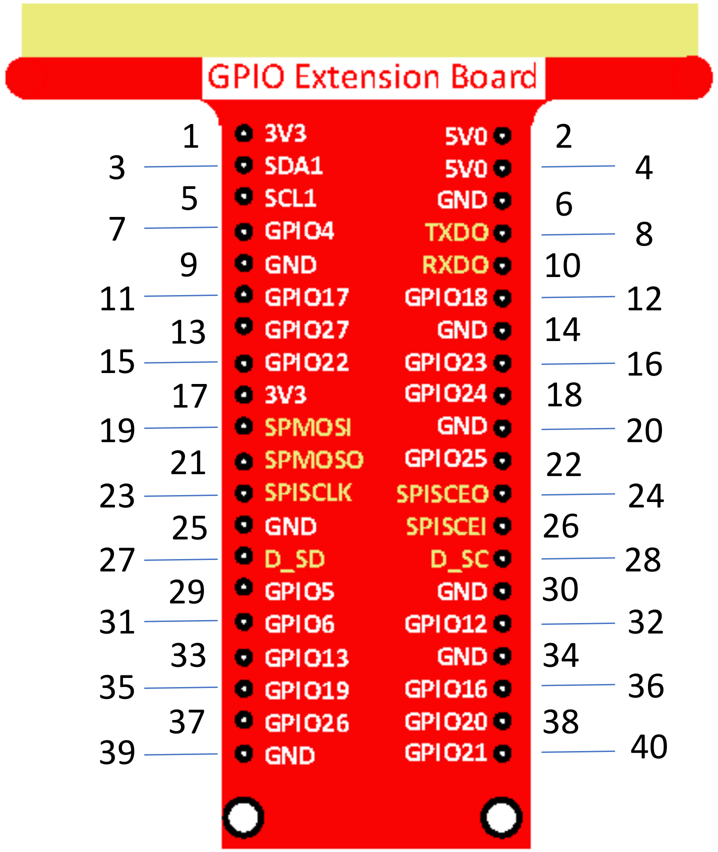


$$Distance\ traversed = (Speed\ of\ sound) \times (Time\ elapsed/2)$$

Start an Ultrasound sensor with your Raspberry Pi 3 B +



Pseudo-code to kick start your Raspberry Pi Model 3 B+ (RPi)




```
import LIBRARY as NAME
import ANOTHER_LIBRARY
```

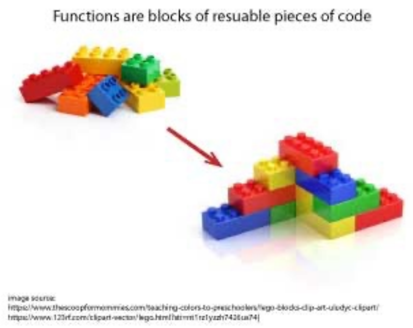
```
INITIALIZE GPIO CHANNELS

DEFINE SETUP FUNCTION
    GPIO.setmode(GPIO.BOARD)
    GPIO.setup(CHANNEL-1, GPIO.OUT)
    GPIO.setup(CHANNEL-2, GPIO.IN))
```

```
DEFINE DISTANCE FUNCTION
return (TIME_ELAPSED / 2) * 340 * 100
```

```
DEFINE LOOP FUNCTION
    while True:
        ...
```

```
DEFINE DESTROY FUNCTION
    CLEAN UP GPIO CHANNELS
```

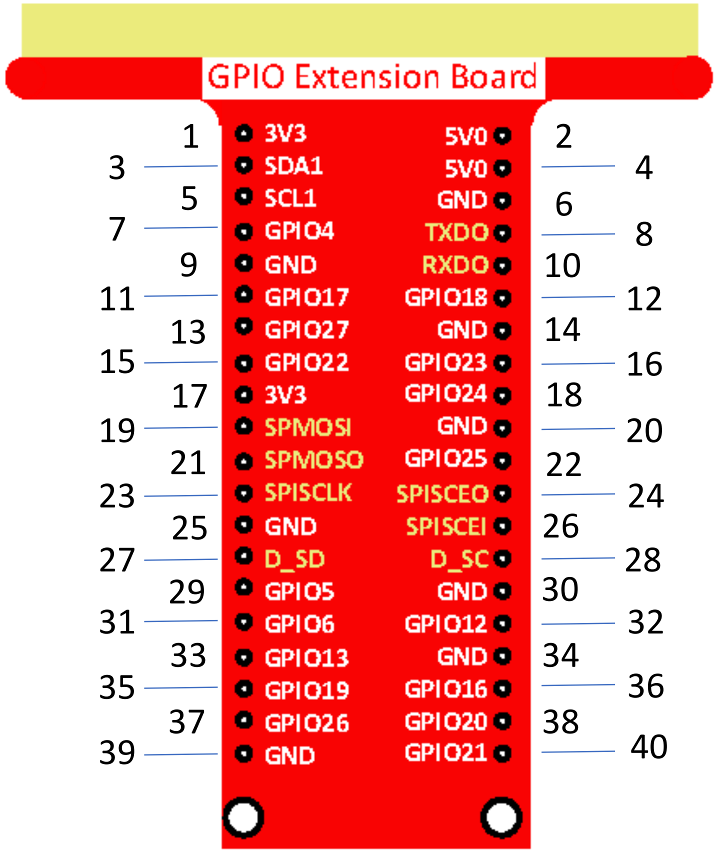
User defined functions




```
if __name__ == "__main__":
    setup():
    try:
        loop()
    except KeyboardInterrupt:
        destroy()
```

Entry point into the program – pulls in all user defined functions

A simple python code to kick start your Raspberry Pi Model 3 B+ (RPi)




```python
import RPi.GPIO as GPIO
import time
```

```python
TRIG = 16
ECHO = 15
def setup():
    GPIO.setmode(GPIO.BOARD)
    GPIO.setup(TRIG, GPIO.OUT)
    GPIO.setup(ECHO, GPIO.IN))
```

```python
def distance():
    GPIO.output(TRIG, 0)
    time.sleep(0.000002)
    GPIO.output(TRIG, 1)
    time.sleep(0.00001)
    GPIO.output(TRIG, 0)

    while GPIO.input(ECHO) == 0:
        time1 = time.time()

    while GPIO.input(ECHO) == 1:
        time2 = time.time()

    during = time2 - time1
    return (during / 2) * 340 * 100
```

```python
def loop():
    while True:
        dist = distance()
        print(dist, 'cm')
        print('')
        time.sleep(0.1)
```

```python
def destroy():
    GPIO.cleanup()
```

```python
if __name__ == "__main__":
    setup():
    try:
        loop()
    except KeyboardInterrupt:
        destroy()
```

Graded Lab Activity (10 points)

```
git clone git@github.com:gwu-csci3907/Spring2024.git

git clone https://github.com/gwu-csci3907/Spring2024.git
```

Goal-1

Set up a Python virtual environment
- “Sandbox” your Python project

Goal-2

Demonstrate your `python` script at boot
Using `cron`, the UNIX scheduler