SENSORS

OVERVIEW

What can we sense?

Types of sensors

Sensor types

Sensor data

Filters

SENSORS

As humans, we are very good at recognizing the context of a situation, and we are able to react to it.

Computers use sensors to do the same thing.

Definition: a sensor converts a physical signal into an electrical signal that can be manipulated symbolically on a computer

WHAT CAN WE SENSE?

OCCUPANCY AND MOTION

Air pressure sensors

Capacitive sensors

Acoustic sensors

Photoelectric and laser-based sensors

Optoelectric sensors

Pressure mat switches and strain gauges.

Contact and non-contact (magnetic) switches.

Vibration detectors.

Infrared motion detectors.

Active microwave and ultrasonic detectors.

POSITION

Global Positioning Satellite (GPS) devices are useful for sensing street-level movement but are limited to outdoor application.

No indoor tracking standard has gained the popularity of GPS

- High accuracy indoor tracking can be done with cameras
- Also possible (but not necessarily accurate) with:
  - RF
  - Magnetic positioning
  - WiFi
  - Bluetooth

MOVEMENT AND ORIENTATION

Most movement and orientation sensors do not rely on external infrastructure (other than gravity :-)).

Accelerometers, gyroscopes and magnetometers

TOUCH

Force sensors can be used to sense touch with good dynamic range and form factors.

- E.g. FSRs, strain gauges, PVDF (thermoplastics).

Capacitive sensing is based on the fact, that charge will flow between two objects when touching or in close proximity.

Resistive touch screens use two large transparent conductive overlays that vary in resistance.

GAZE AND EYETRACKING

Gaze detection refers to determining where a person is looking and is principally the domain of computer vision.

Usually, these techniques are based on precise tracking of multiple reflections of an infrared illuminant off the eye’s cornea.

Eye-tracking systems require careful per- user calibration

GESTURES

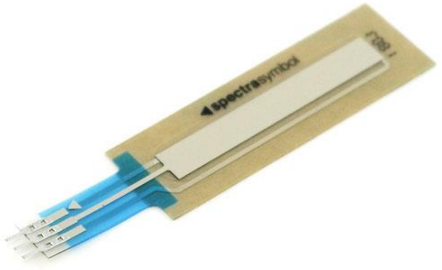
A gesture can be thought of as a specific hand pose, a spatial trajectory of the hands or stylus, pointing or other motion to indicate an object, or the quality of a motion of almost any body part as it relates to a given application context (McNeill, 1992).

Accelerometers or gyros can capture motion information useful in recognizing many gestures.

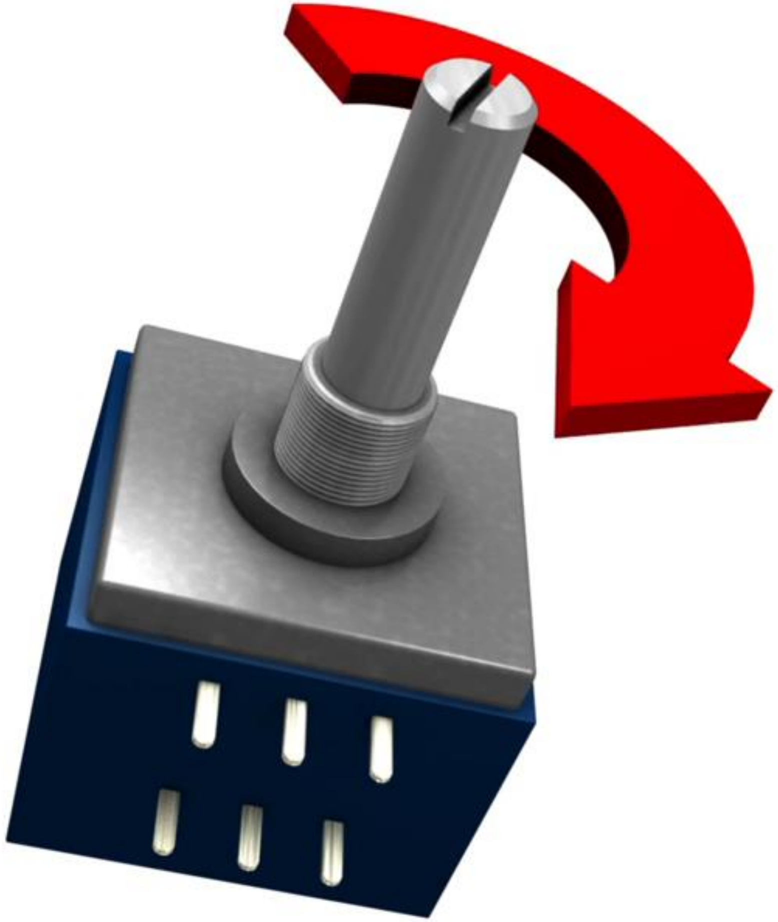
Computer vision techniques also can be used to track body parts.

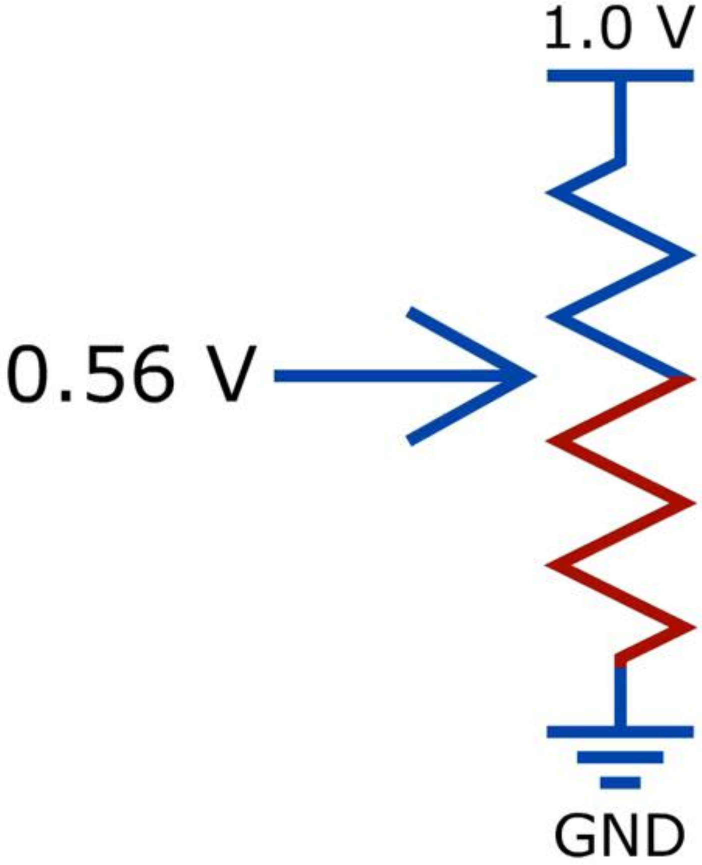
TYPES OF SENSORS

POTENTIOMETERS



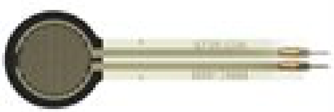
- Potentiometers are 3 terminal devices
- Used for position detection or linear user input
- Slide pots sense linear position, rotary sense rotation
- Soft potentiometers, or “softpots”, are very thin potentiometers “wiped” by pressing down on various parts of the strip.
- The resistance between the wiper and either of the other two terminals varies.
- By applying a voltage across the two outside terminals, the middle terminal can produce a voltage somewhere in the applied range.





https://vimeo.com/95189804

FORCE SENSORS

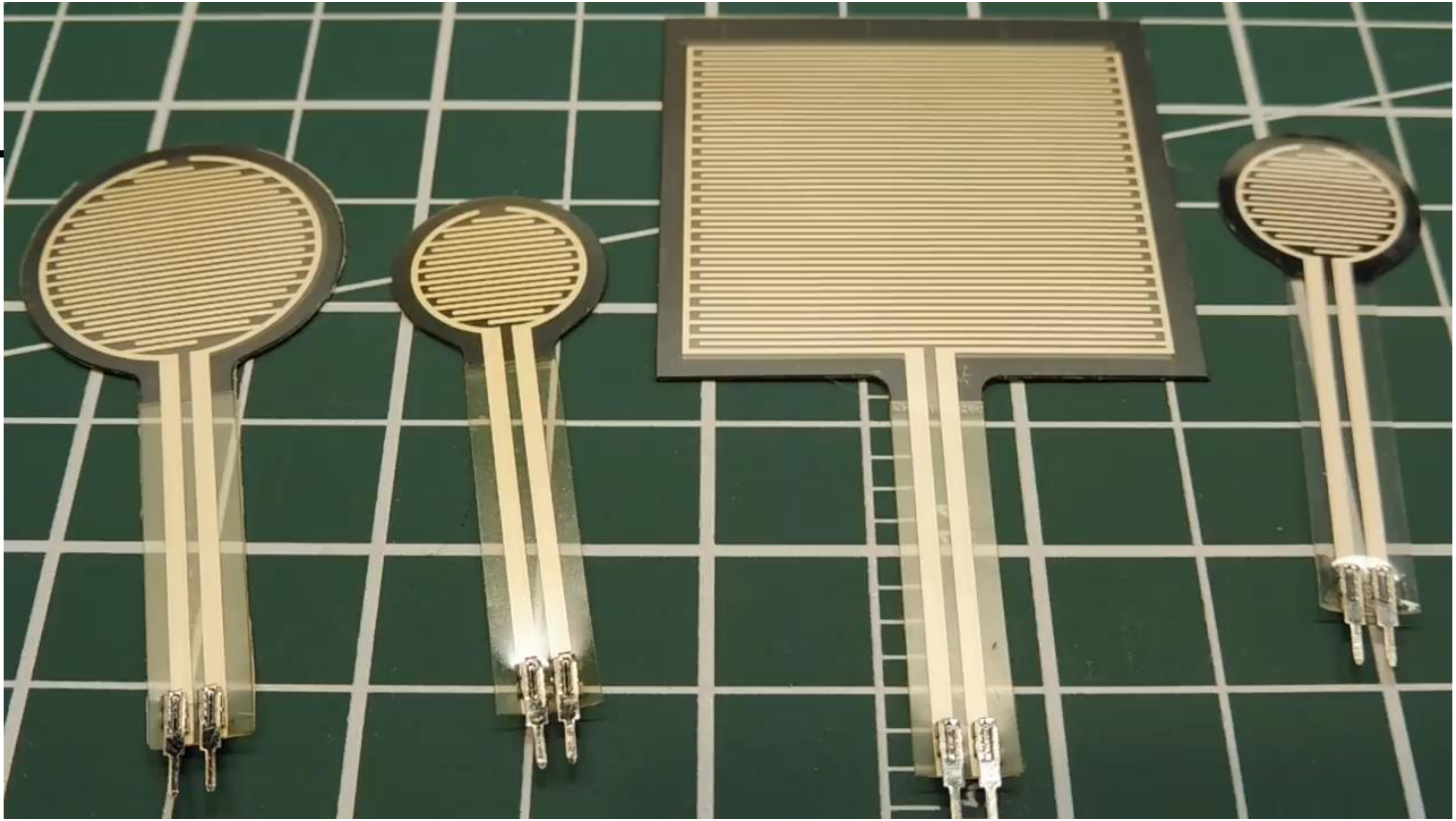


Force sensitive resistors (FSRs), stretch, and flex sensors are also variable resistors

FSR - the resistance decreases as force increases

Flex – resistance increases as it bends

Stretch – resistance increases as it is stretched



CAPACITIVE SENSORS

Capacitive sensing may be used in any place where low to no force human touch sensing is desirable.

A capacitive sensor is a proximity sensor that detects nearby objects by their effect on the electrical field created by the sensor.

Touch increases capacitance

CAPACITIVE TOUCH

Measure how long it takes to load a piece of wire electrically.

When a touch is detected, the output pin goes LOW.

There are many ways to do capacitive sensing:

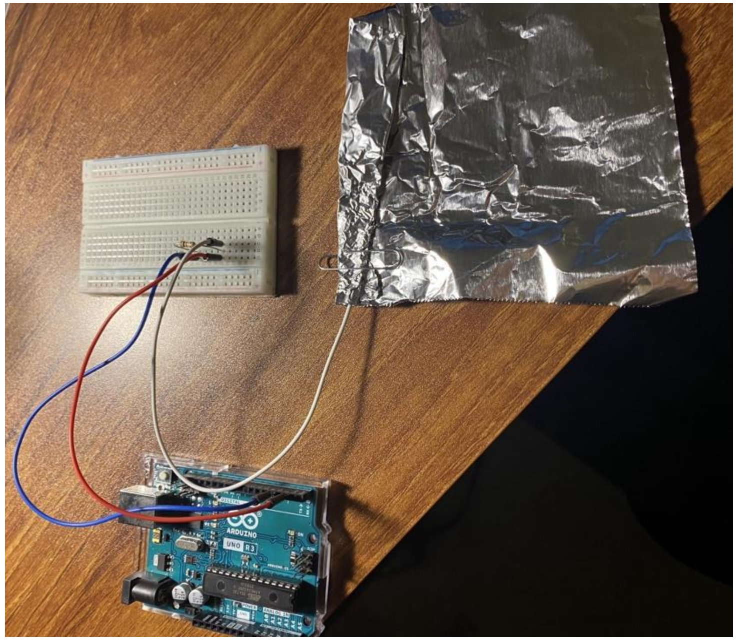
- A piece of wire and a simple timer
- A piece of wire and CapSense library
- A specialized chip (like QT113)

Mobile touchscreens are capacitive

Remember to ground your sensor.

https://dumblebots.com/2019/06/19/arduino-tutorial-touch-and-capacitive-sensing/

https://create.arduino.cc/projecthub/amalmathewtech/touch-controlled-light-using-arduino-d2f878



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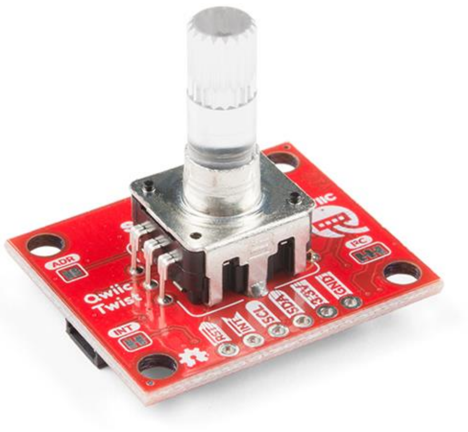
ROTARY ENCODER

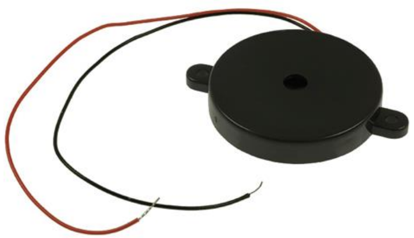


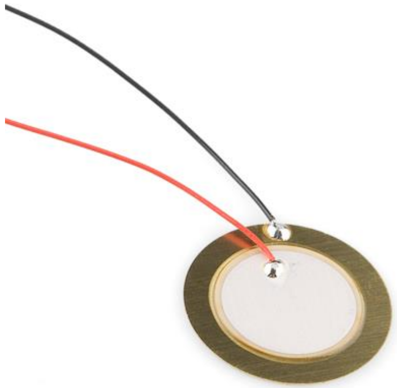
Senses rotations or rotational position (like a rot pot)

Can often handle multiple or endless rotations – most potentiometers max out at 180-270 degrees.

Can feature LEDs and comes in multiple shapes and sizes.

PIEZOS





Piezo sensors are flexible devices that generate electric charge when they're stressed.

This characteristic makes piezos an ideal solution for low-power flex, touch, and vibration sensing.

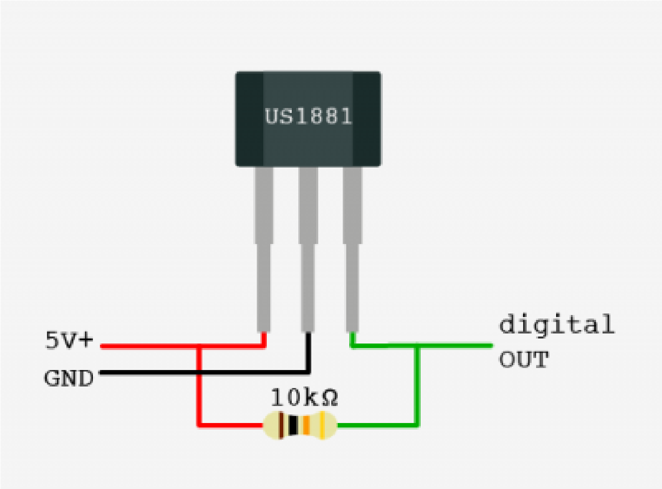
HALL EFFECT SENSORS

Reacts to a magnetic field.

The most common reaction, in Interactive Systems, being the sensor acting as a digital switch "turning on" in the presence of a strong enough magnetic field.

Hall effect sensors are all rated to work with a specific strength of magnet field (measured in Gauss) which dissipates with distance from the magnet.

Photo by ElectroPeak



MAGNETOMETER

A magnetometer is a measuring instrument used to measure the strength and the direction of magnetic fields.

Often used as compasses in consumer devices such as mobile phones and tablet computers.

ACCELEROMETER

An accelerometer is a device that measures proper or g-force acceleration.

Accelerometers are often built into devices to detect the orientation.

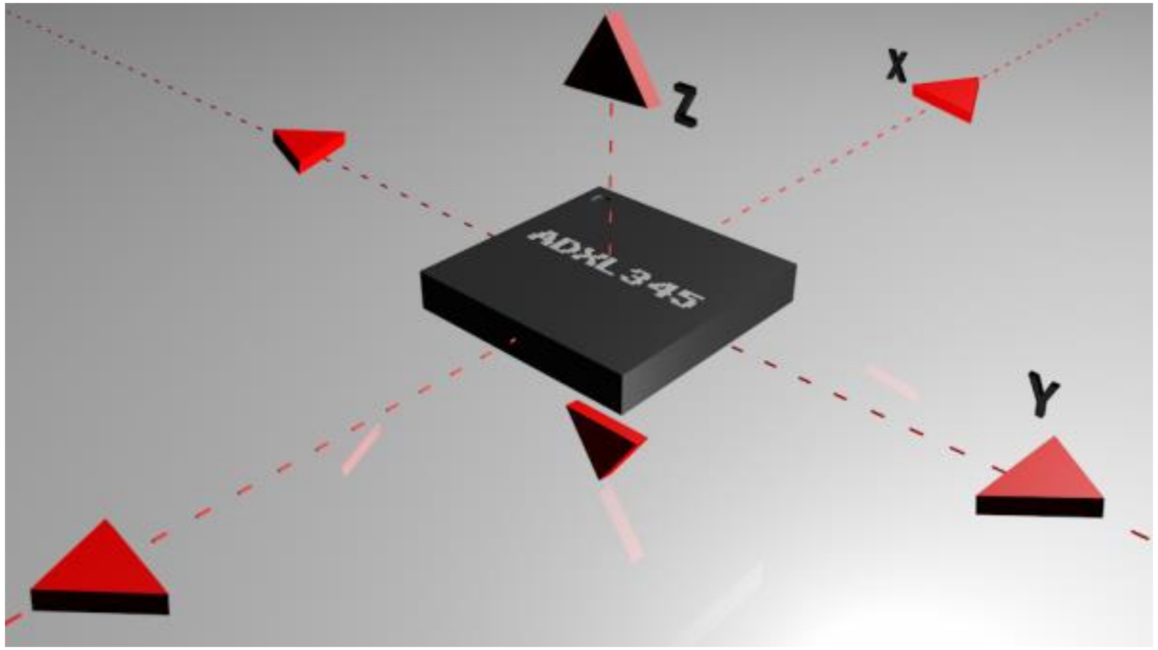


Image from Sparkfun

ACCELEROMETER

Sense either static or dynamic forces of acceleration.

- Static – gravity
- Dynamic - vibrations and movement.

Accelerometers usually contain capacitive plates

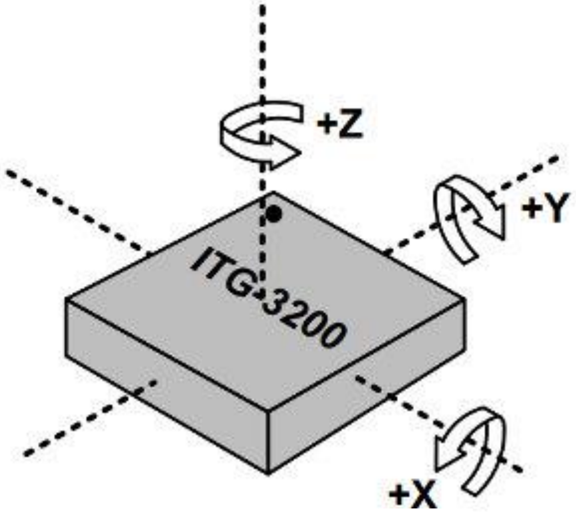
- Some attached to springs

As the plates move, the capacitance between them changes. These changes can be used to calculate acceleration.

GYROSCOPE

A gyroscope measures orientation, using the principles of angular momentum.

Gyroscopes are often combined with accelerometers for more robust motion- sensing.



GYROSCOPE

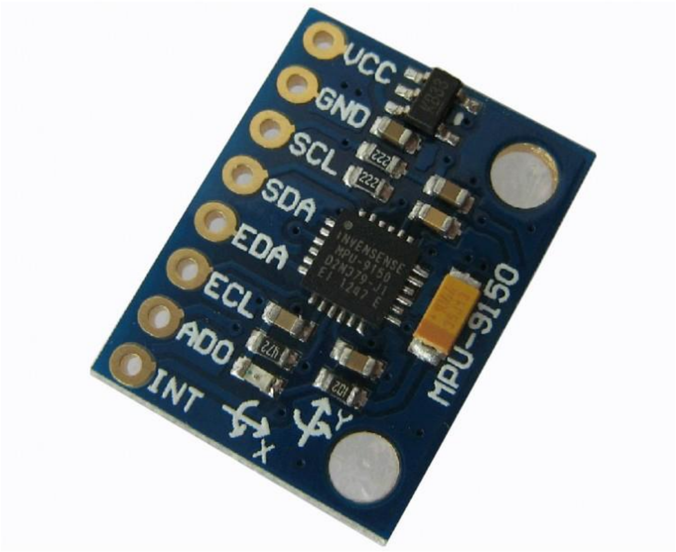
Gyroscopes can be used to help with stabilization and well as changes in direction and orientation.

Unlike accelerometers, gyroscopes do not have a fixed reference, and only measure changes.

The units of angular velocity are measured in degrees per second (°/s) or revolutions per second (RPS).

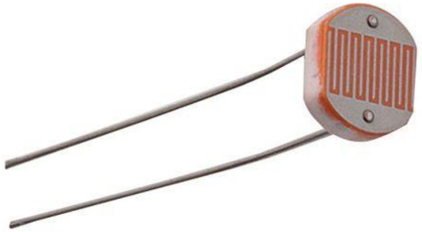
IMU

IMUs (which combine both accelerometers and gyroscopes) are used to give a complete understanding of a device’s acceleration, speed, position, orientation and more.



ADDITIONAL CHOMSKY SENSORS

PHOTORESISTORS



Light-dependent resistor (LDR), also known as “photocells” or “photoresistors.”

Provide a resistance that decreases as more light falls on them

- This means that the fixed resistor in the voltage divider can’t be too small
  - keep it above 200 ohms at 5 V.

LDRs vary a lot from one to the next in terms of their maximum resistance in the dark

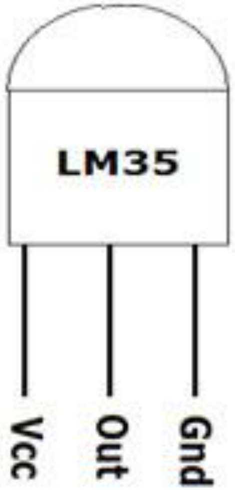
Best for red/green, not blue light

THERMOMETER

E.g. LM35

Retrieve the voltage with analog Read()

Calculate the temperature in degrees Celsius as voltage * 100C/V.

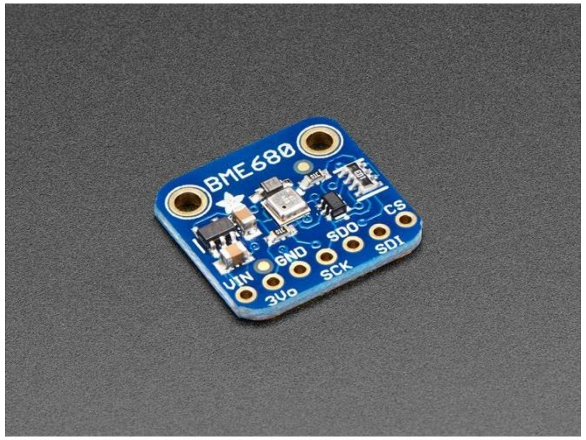


AIR QUALITY SENSOR

BME680 – digital via SPI or I2C

Measures air quality, air pressure, humidity, and volatile organic compound gases (take it with a grain of salt)

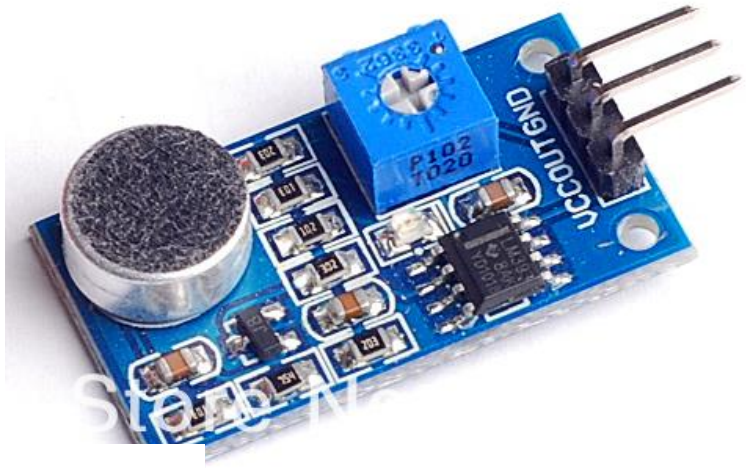
Used in many cheap air quality monitor devices



SOUND DETECTOR

The Sound Detector has three different outputs: binary sound detection, audio envelope, and a true audio output.

The 3 outputs are simultaneous and independent, so you can use as many or as few as you want at once.



LINE BREAK SENSOR (ANALOG)

IR light sensor – analog value based on amount of IR light hitting it

3.3V and 5V.

Small form factor – could be problematic and requires calibration

https://www.sparkfun.com/products/9453

GSR SENSOR (ANALOG)

Galvanic Skin Response sensor

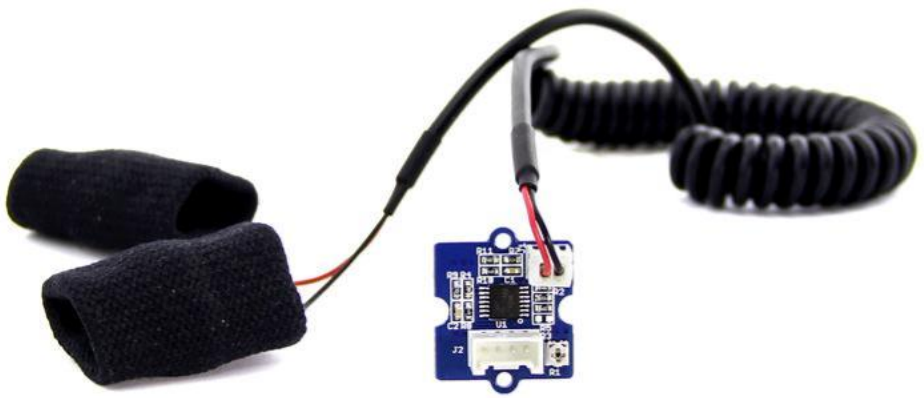
Measures electrical conductance of skin

Measures “strong emotion”

Sweat

Mounted to two fingers

http://wiki.seeedstudio.com/Grove-GSR_Sensor/



DHT22 + DS18B20 (DIGITAL)

DHT22: Digital Temp + Humidity

Lowcost

Small form factor

Precision is so and so…

DS18B20: Digital Temp sensor (waterproof)

Surprisingly precise
…Waterproof
Durable and sturdy

https://www.adafruit.com/product/385 https://lastminuteengineers.com/ds18b20-arduino-tutorial/

OPTICAL DUST + CO2 SENSOR (ANALOG)

Optical Dust Sensor - GP2Y1010AU0F

Lowcost

So and so performance

Useful in very specific contexts

MG-811 CO2 Sensor
A bit tricky to work with
Low cost air pollution “indication”

Surprisingly expensive

Not to scale

https://www.sparkfun.com/products/9689 https://www.instructables.com/id/Air-Pollution-Detector-a-CO2-Level-Using-MG-811/

PULSE SENSOR (ANALOG)

Activity tracking

Can be mounted multiple different places

Small form factor

Acceptable performance

Can be easily tweaked

https://www.sparkfun.com/products/11574

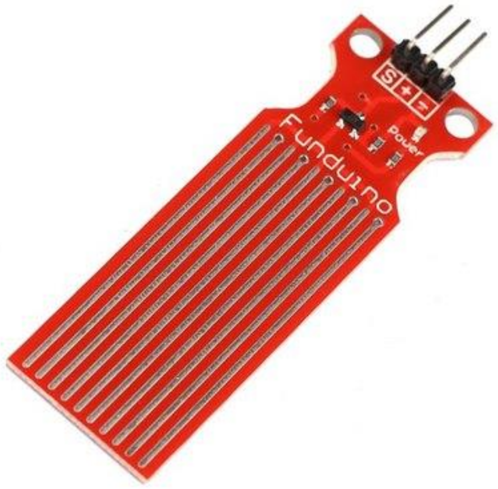
WATER LEVEL SENSOR (ANALOG)

Simple but rigid setup

Works well!

Unfortunately sparse info and datasheets online

http://www.kevingulling.com/2017/02/funduino-analog-water-sensor-arduino-test-review/



WATER FLOW SENSOR

Basically a Hall Effect sensor with plastic...

Good for specific use cases, and prototyping

"Easy" to DIY

https://www.seeedstudio.com/G3-4-Water-Flow-Sensor-p-1083.html

ELECTRET MICROPHONE

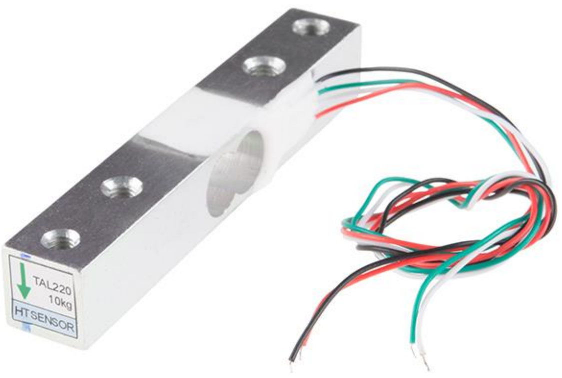
Tiny microphone, works best as binary switch

Can be DIP (Dual in-line package) or with a board attached

Competition: SparkFun/Adafruit boards and the MAX4466

https://www.sparkfun.com/products/12758

LOAD CELLS



Weight/force sensor – sometimes called strain gauge

10kg and 50kg variants in stock

With this gauge you will be able to tell just how heavy an object is, if an object's weight changes over time, or if you simply need to sense the presence of an object by measuring strain or load applied to a surface.

SENSOR DATA

YOU SHOULD KNOW....

What type of raw data comes from the sensor

- Format
- Type

How to convert the raw data into something meaningful

- Check the datasheet for conversions

ACCELERATION AND ANGULAR VELOCITY

Acceleration is the rate at which an object's velocity changes.

Angular velocity measures the rotational speed of an object, as well as the axis that it's rotating around.

Acceleration is measured in g

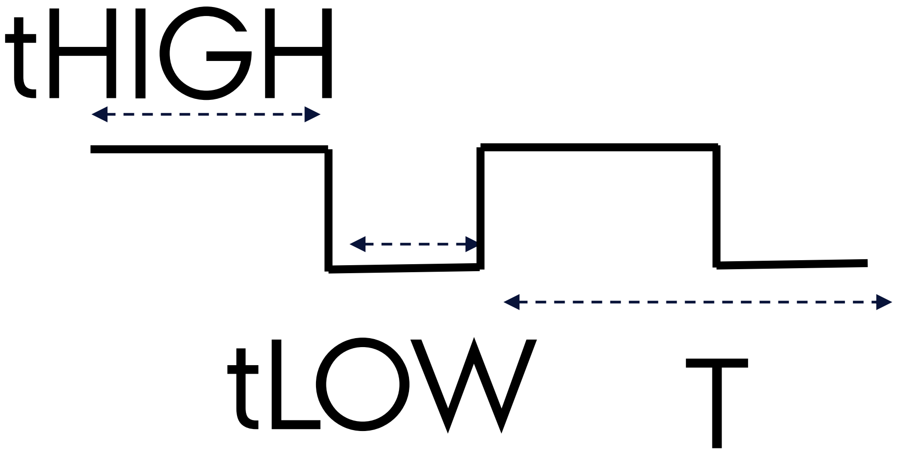
- as a multiple of the acceleration caused by Earth's gravity.

Another commonly used unit of acceleration is meters per second squared (m/s2).

- Free- fall acceleration (1 g) is 9.81 m/s2.

Sensor	Measures	Meaning	Unit	Gravity
Accelerometer	Acceleration	Change of velocity, speeding up or braking	$m/s / s = m/s^2$	Yes, 1 g down
Gyroscope	Angular velocity	Change of angle, spinning	rad/s (SI), often deg/s or RPM	Ignores gravity

ACCELEROMETER EXAMPLE



Imagine we have a simple two-axis acceleration sensor

- In this case, a MX2125.

The MX2125 outputs raw data in the form of a pulse length
Consecutive HIGH and LOW signals form a 100 Hz square wave.

The time taken by one wave (HIGH+LOW) is called period (T).

- the time of HIGH part = tHIGH
- dutyCycle = tHIGH / T

According to the data sheet and other documents, the period T is set to 10 ms by default:

- dutyCycle = tHIGH / 10 ms

Acceleration formula from the data sheet:

- A = (tHIGH/T-0.50)/12.5%

ACCELEROMETER EXAMPLE

A = (tHIGH/T-0.50) /0.125

Consider tHIGH of 6.25 ms

- A = ((6.25/10)-0.5)/0.125 = 1

Thus, a 6.25 ms pulse means 1 g acceleration.

FILTERS

FILTERS

Digital Filtering Techniques

Remove noise from a sensor signal

Pre-processing step

Definition - a digital filter performs mathematical operations on a sampled, discrete-time signal to reduce or enhance certain aspects of that signal

MEDIAN FILTERS

Good at rejecting outlier values

- Helps you to find out what value is the 'most seen value’

The filter sorts the readings and chooses the center value dynamically

Big sample size = latency

```
unsigned int ADCmedian(int pin, int count) {

  int values[count], last;
  uint8_t j, i = 0;
  values[0] = 0;

  while (i < count) {
    last = analogRead(pin);
    if (i > 0) {
       for (j = i; j > 0 && values[j - 1] < last; j--)     // Insertion sort loop.
   values[j] = values[j - 1];                             // Shift ping array to correct position for sort insertion.
    } else j = 0;                                         // First ping is starting point for sort.
    values[j] = last;                                     // Add last ping to array in sorted position.
    i++;                                                  // Move to next ping.
    if (i < count) delay(1);
   }
   return (values[count/2]); // Return the median.
}
```

See also https://playground.arduino.cc/Main/RunningMedian/

MOVING AVERAGE

Used to smooth out a signal

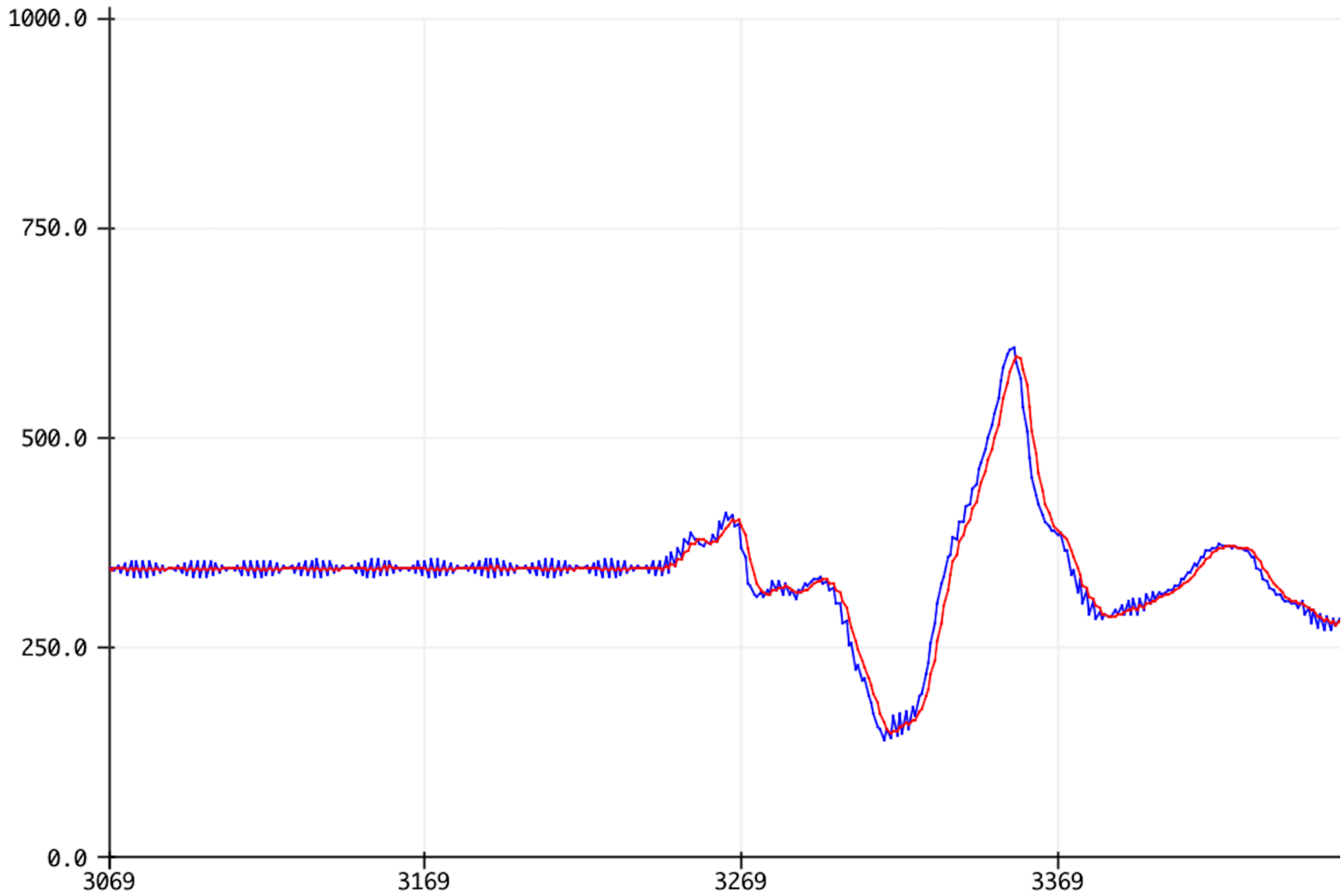
Simplified form of a low pass filter –

- Low pass filter allows you to focus on a desired frequency
- Moving average filter simply smoothes out

Takes the average of the last "X" amount of readings and averages them to produce the output.

You can change the size of the window (the number of previous readings that can be averaged together) sketch_sep22a §

```
#define IN_PIN A0
#define WINDOW_SIZE 50

int INDEX = 0;
int VALUE = 0;
int SUM = 0;
int READINGS[WINDOW_SIZE];
int AVERAGED = 0;

void setup() {

  pinMode(IN_PIN, INPUT);
  Serial.begin(9600);
}

void loop() {

  SUM = SUM - READINGS[INDEX];       // Remove the oldest reading from the sum
  VALUE = analogRead(IN_PIN);        // Read the next sensor value
  READINGS[INDEX] = VALUE;           // Add the newest reading to the window
  SUM = SUM + VALUE;                 // Add the newest reading to the sum
  INDEX = (INDEX+1) % WINDOW_SIZE;   // Increment the index, and wrap to 0 if it's bigger than the window size

  AVERAGED = SUM / WINDOW_SIZE;      // Divide the sum of the window by the window size

  Serial.print(VALUE);
  Serial.print(",");
  Serial.println(AVERAGED);

  delay(25);
}
```


1000.0
750.0
500.0
250.0
0.0
3069
3169
3269
3369

MOVING AVERAGE

If the window size is too large, there will be noticeable latencies

If the window size is too small, the signal will still be noisy

There's a good explanation here - https://maker.pro/arduino/tutorial/how-to-clean-up-noisy-sensor-data-with-a-moving-average-filter

LAB LIBRARY

https://github.com/LabToolsAU/LabLib/tree/master/filtering

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