3. Raspberry PI with IMU-1

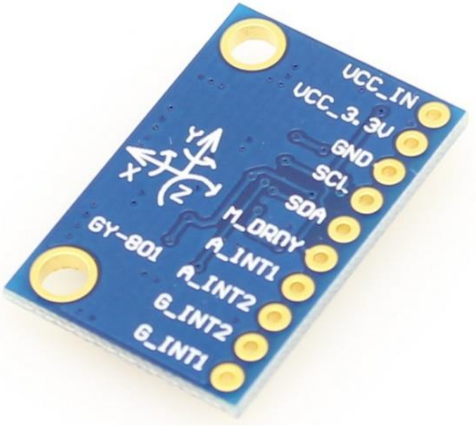
National Chiao Tung University

Outline

- 人體活動偵測應用
  - 加速度、陀螺儀…等

- GY801 (I2C sensor)
  - 3-axis Accelerometer, Gyroscope, magnetometer and pressure

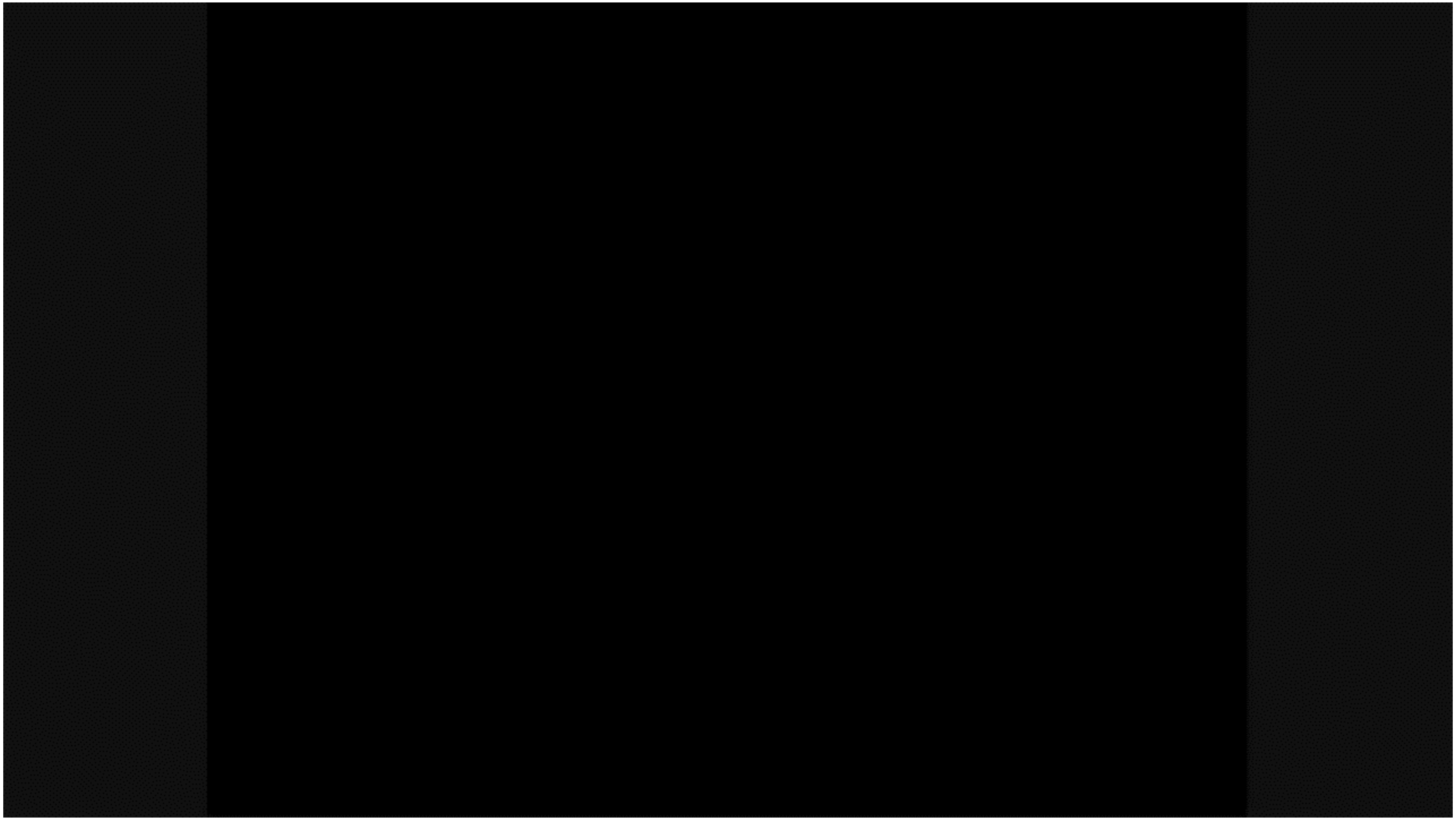
1. ADXL345：Accelerometer
2. L3G4200：Gyroscope
3. HMC5883：Magnetometer
4. BMP085：Pressure



https://www.youtube.com/watch?v=BXsGWoOMtmU

活動偵測應用

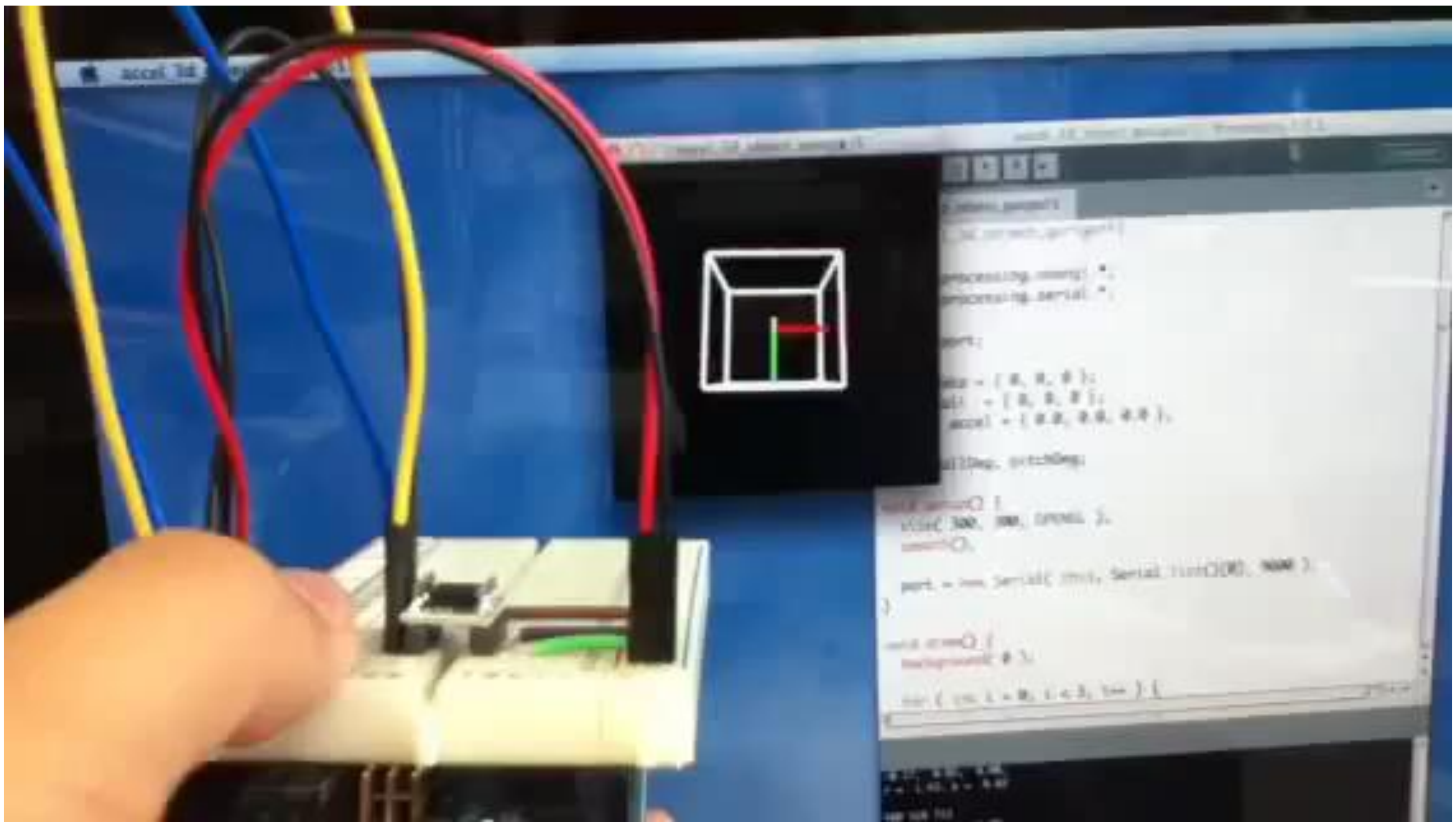
- Open Source IMU and AHRS Algorithm with x-IMU



https://www.youtube.com/watch?v=85rl3KVAEGU

活動偵測應用

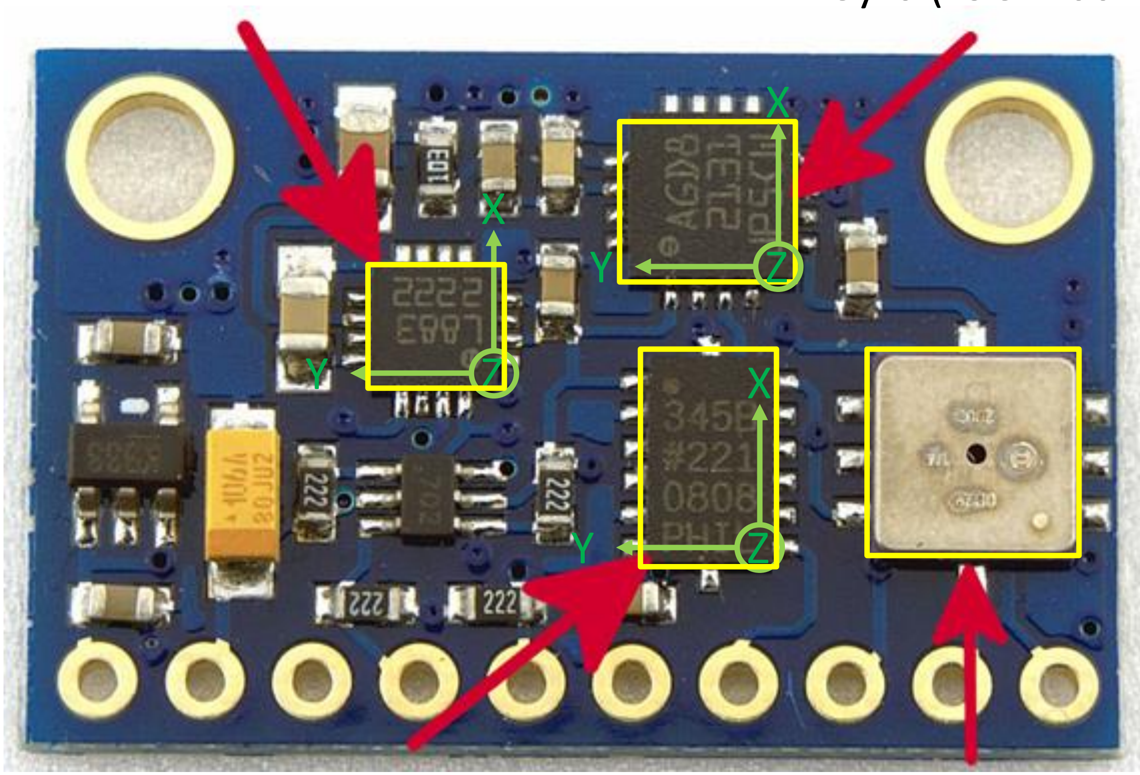
- 3D Box on screen rotated around its roll and pitch axes through an acceleration sensor



GY-801 (10 DoF sensor)

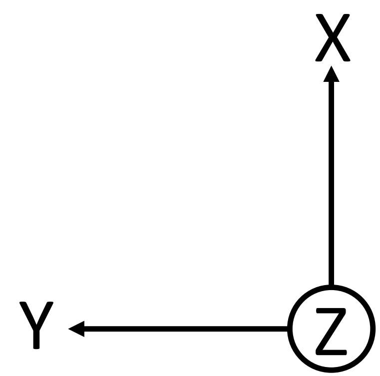
Compass (HMC5883L)

Gyro (L3G4200D)

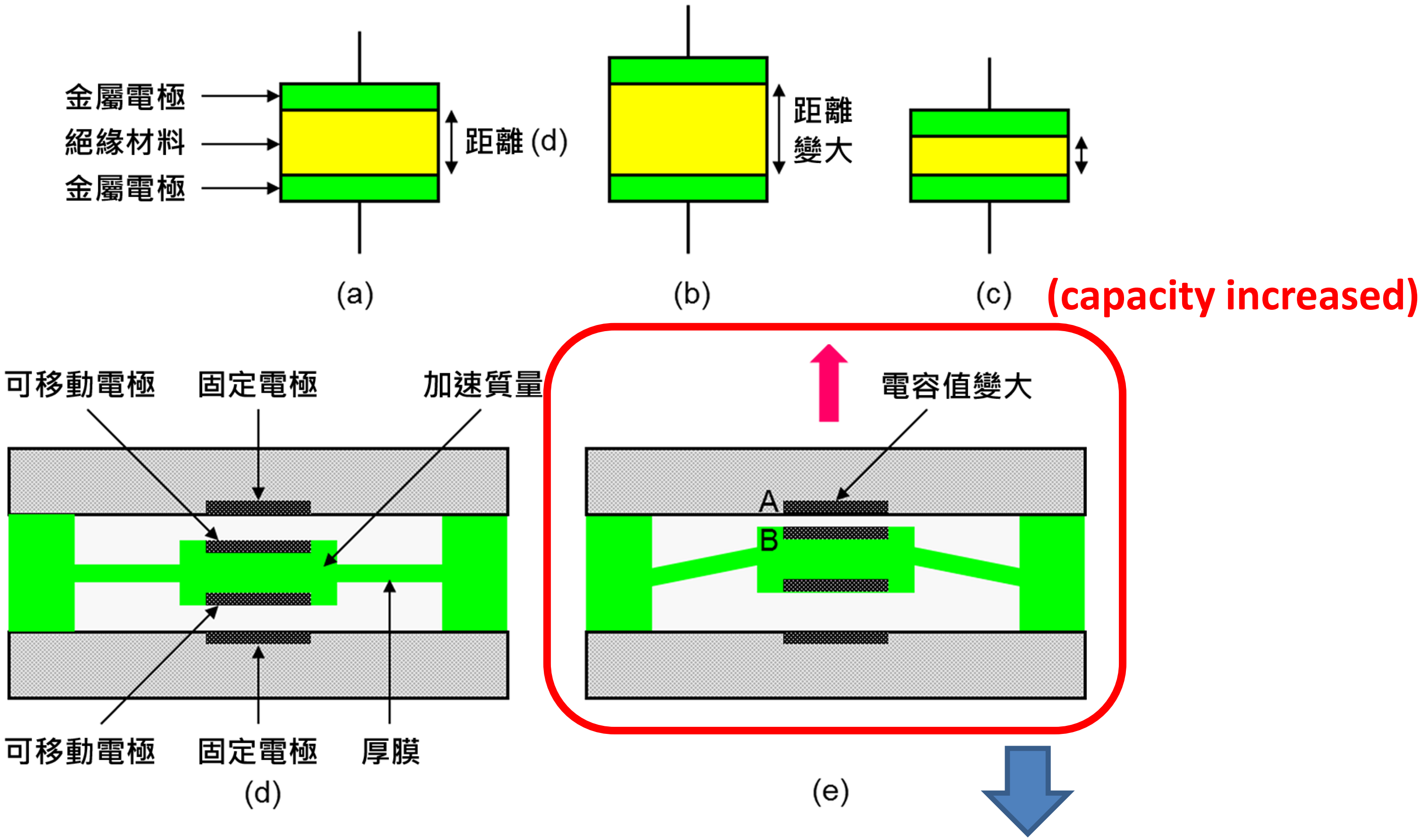


G-sensor (ADXL345)

Pressure (BMP085)



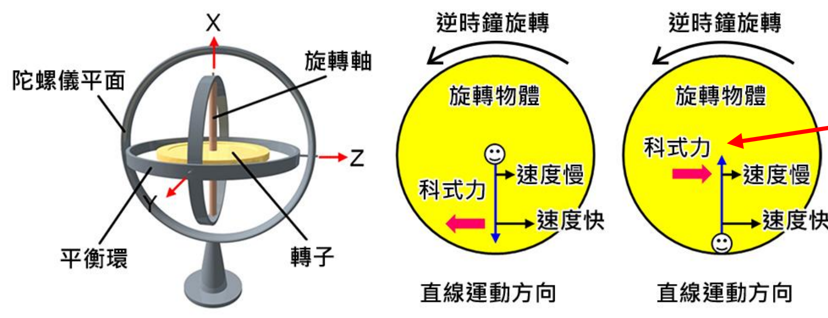
Sensor - Accelerometer



When you move the sensor, the distance (**capacity**) is changed.
We **use capacity to calculate acceleration**.

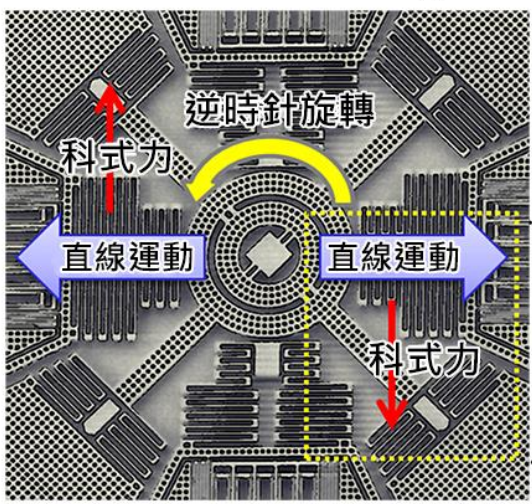
微陀螺儀的構造與原理
http://scimonth.blogspot.tw/2014/07/blog-post_94.html

Sensor - Gyro

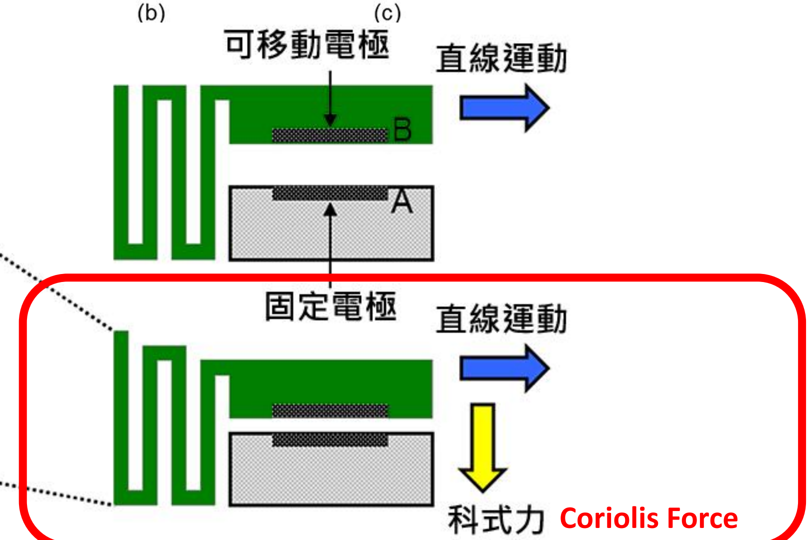


(a) (b) (c)

Coriolis Force
(科氏力)



(d)

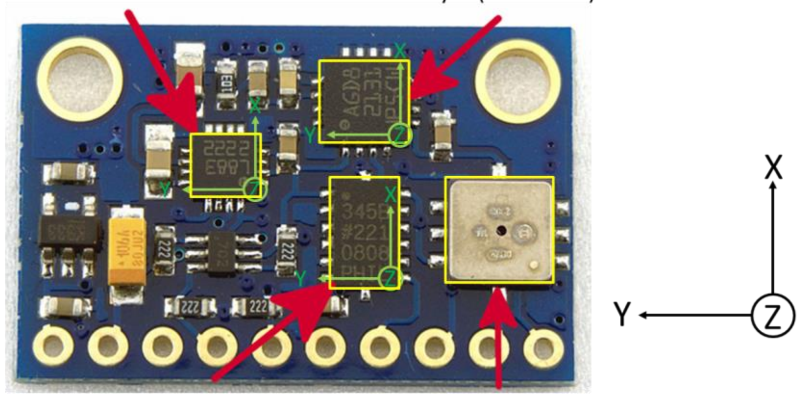


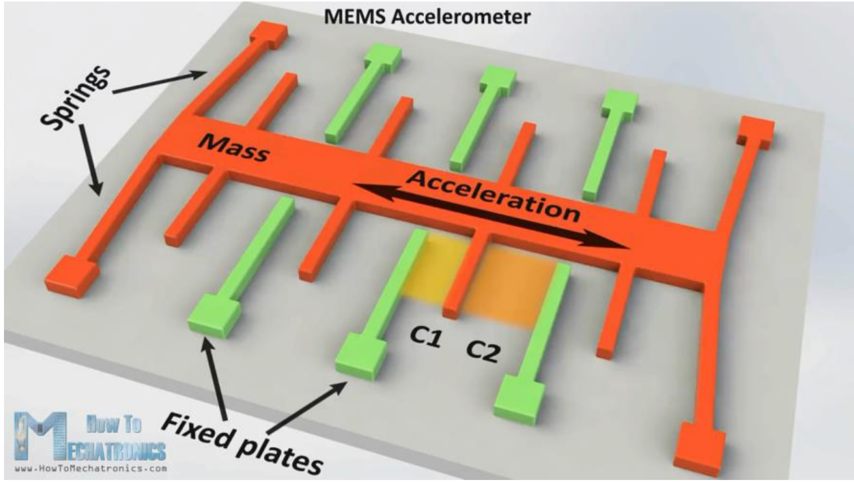
(e)

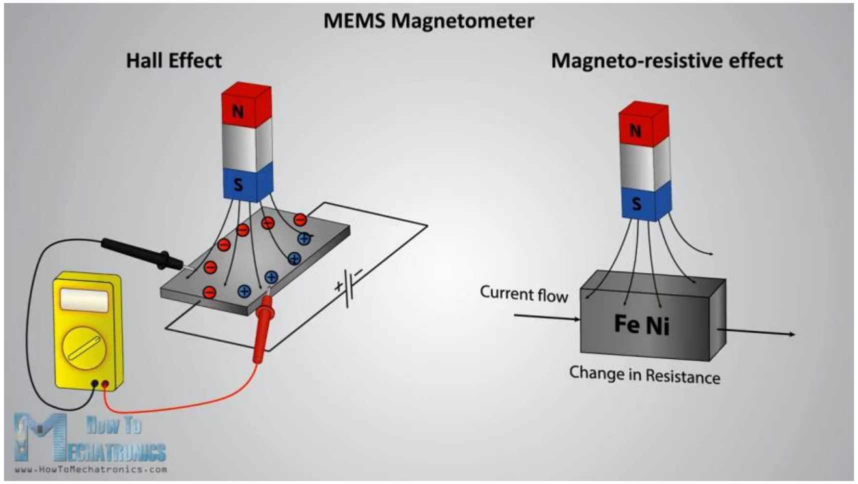
When you rotate the sensor, Coriolis Force change the distance (**capacity**).
We **use capacity to calculate Angular velocity (角速度).**

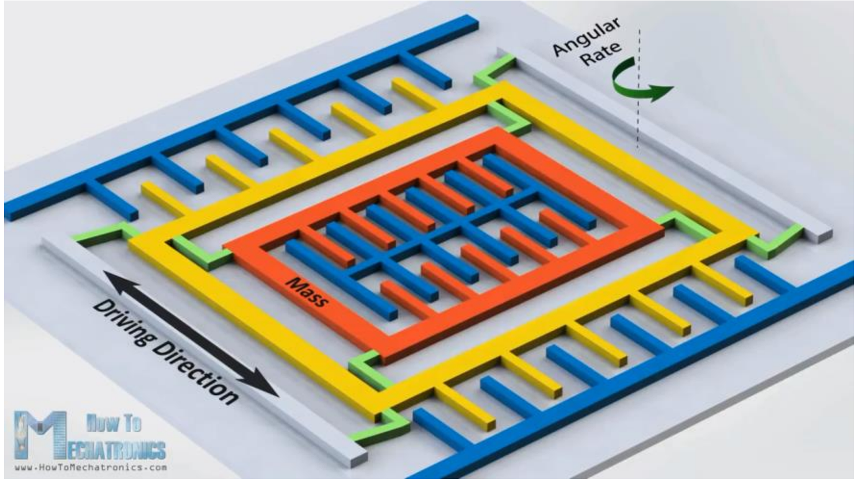
How MEMS Accelerometer, Gyroscope, Magnetometer Work

https://www.youtube.com/watch?v=eqZgxR6eRjo







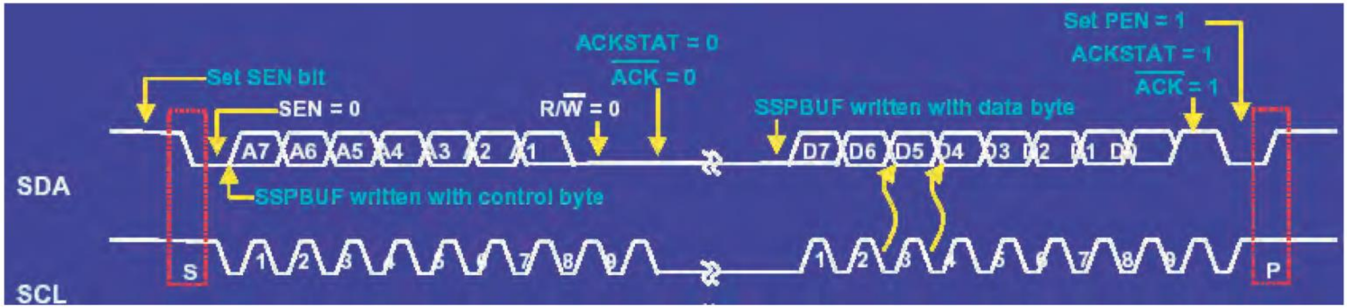


IMU. How MEMS Accelerometer Gyroscope Magnetometer Work & Arduino Tutorial

這個念square喔!!

I2C

- I2C全名為Inter-IC，它是一種半雙工同步多組設備匯流排，只需要兩條信號線：串列資料線 (SDA) 及串列時脈線 (SCL)。

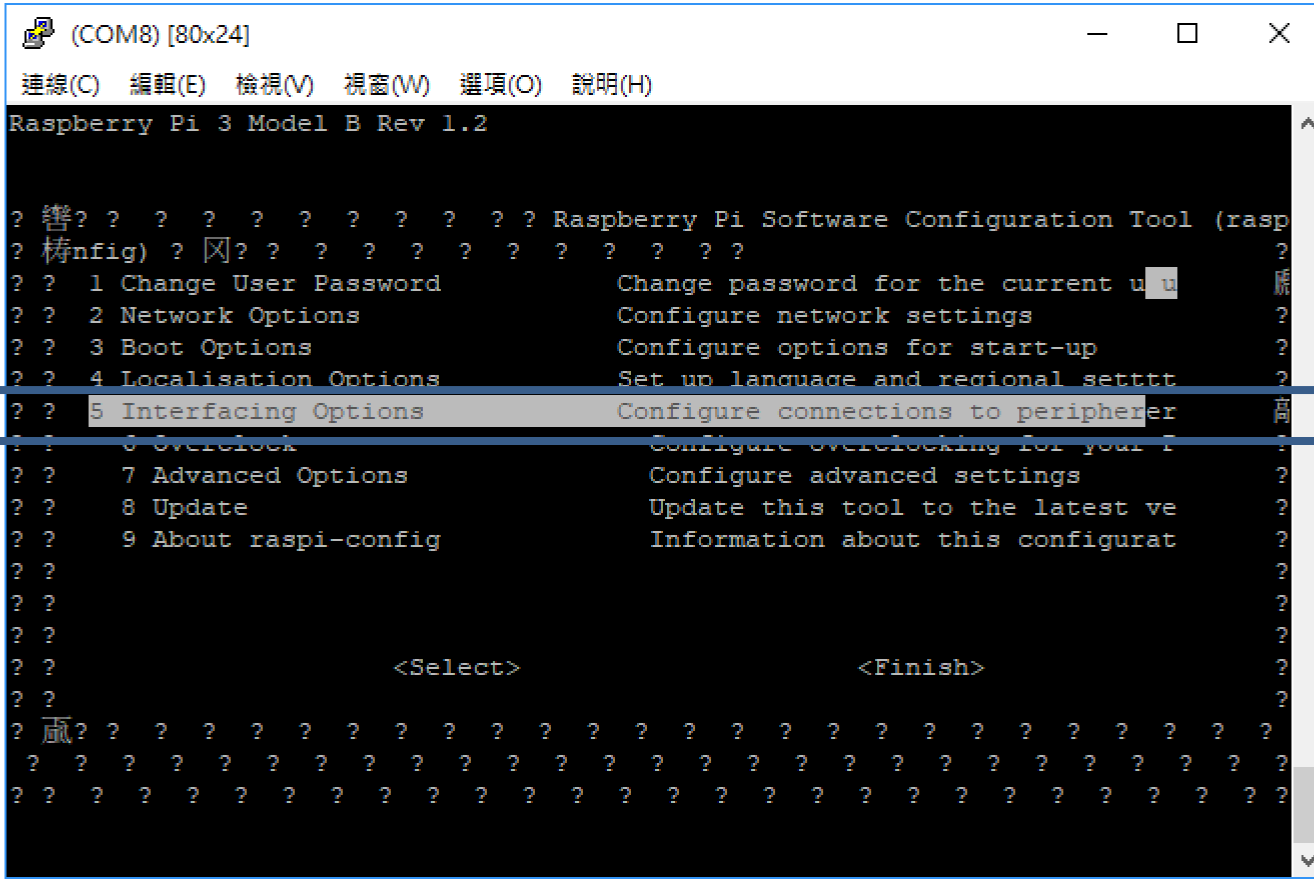


- 在傳送資料過程中共有三種類型信號，分別是：開始信號、結束信號和應答信號。
  - 開始信號：SCL為高電位時，SDA由高電位降為低電位，開始傳送資料。
  - 結束信號：SCL為高電位時，SDA由低電位升為高電位，結束傳送資料。
  - 應答信號：收到 8bit 資料後，向發送資料的IC發出特定的低電位脈衝
- 資料讀取方式：
  - 當 SCL 由低電位升為高電位時，讀取 SDA 的資料。

http://www.leaptronix.com/PDF/introducing_of_I2C.pdf

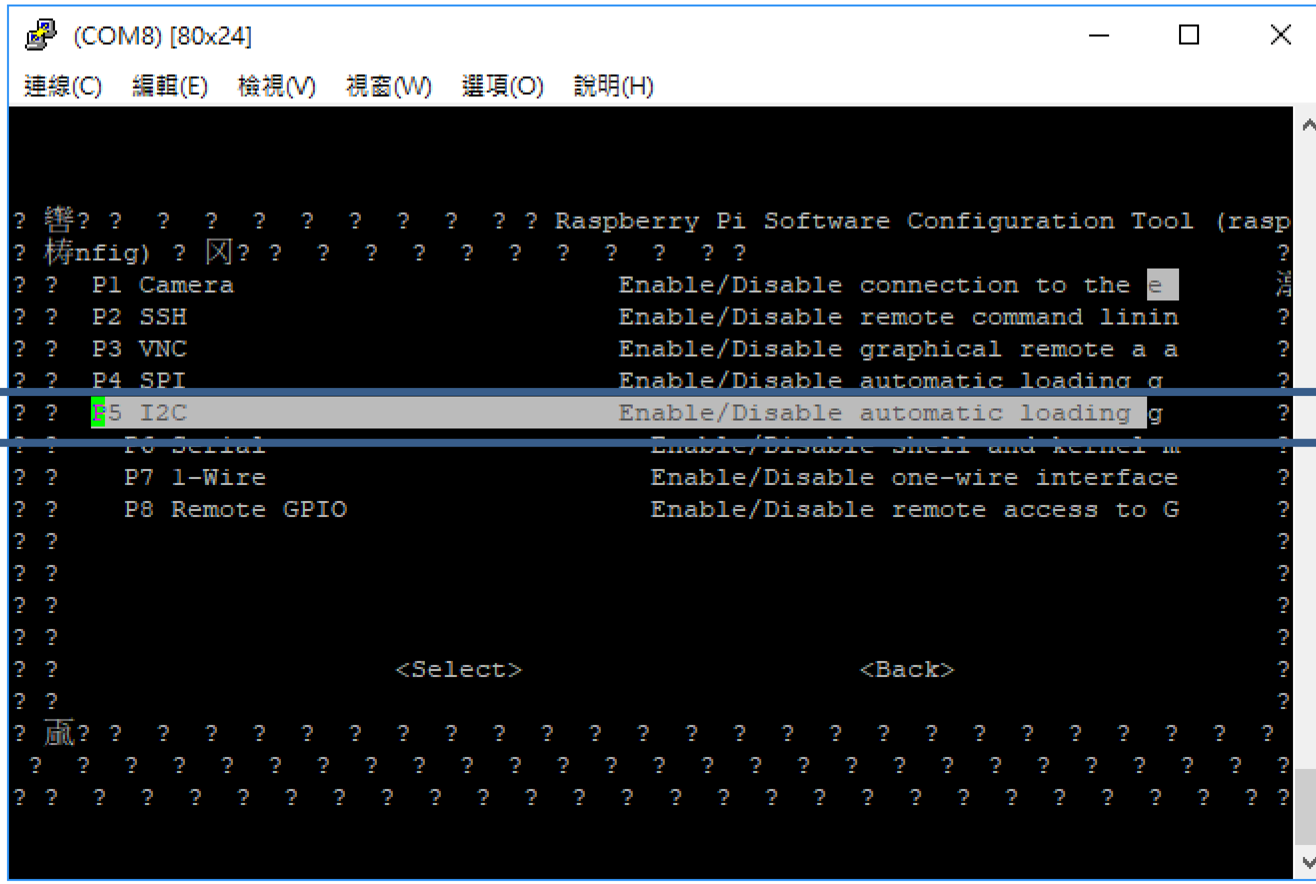
Enable I2C on Raspberry PI

- Enter the command：**sudo raspi-config**
  - Select **5 Interfacing Options**



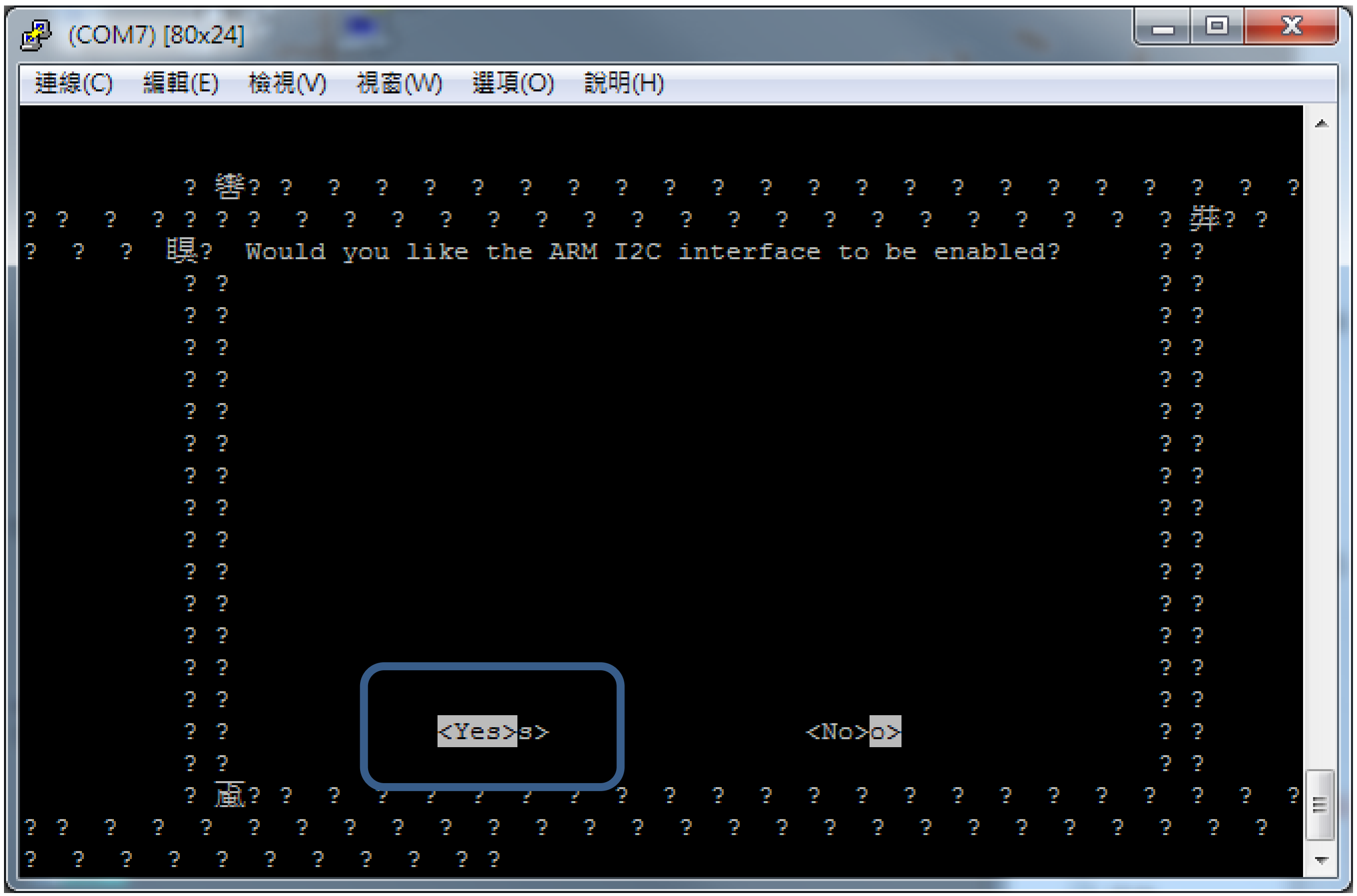
Enable I2C on RaspPI

- Select **P5 I2C**



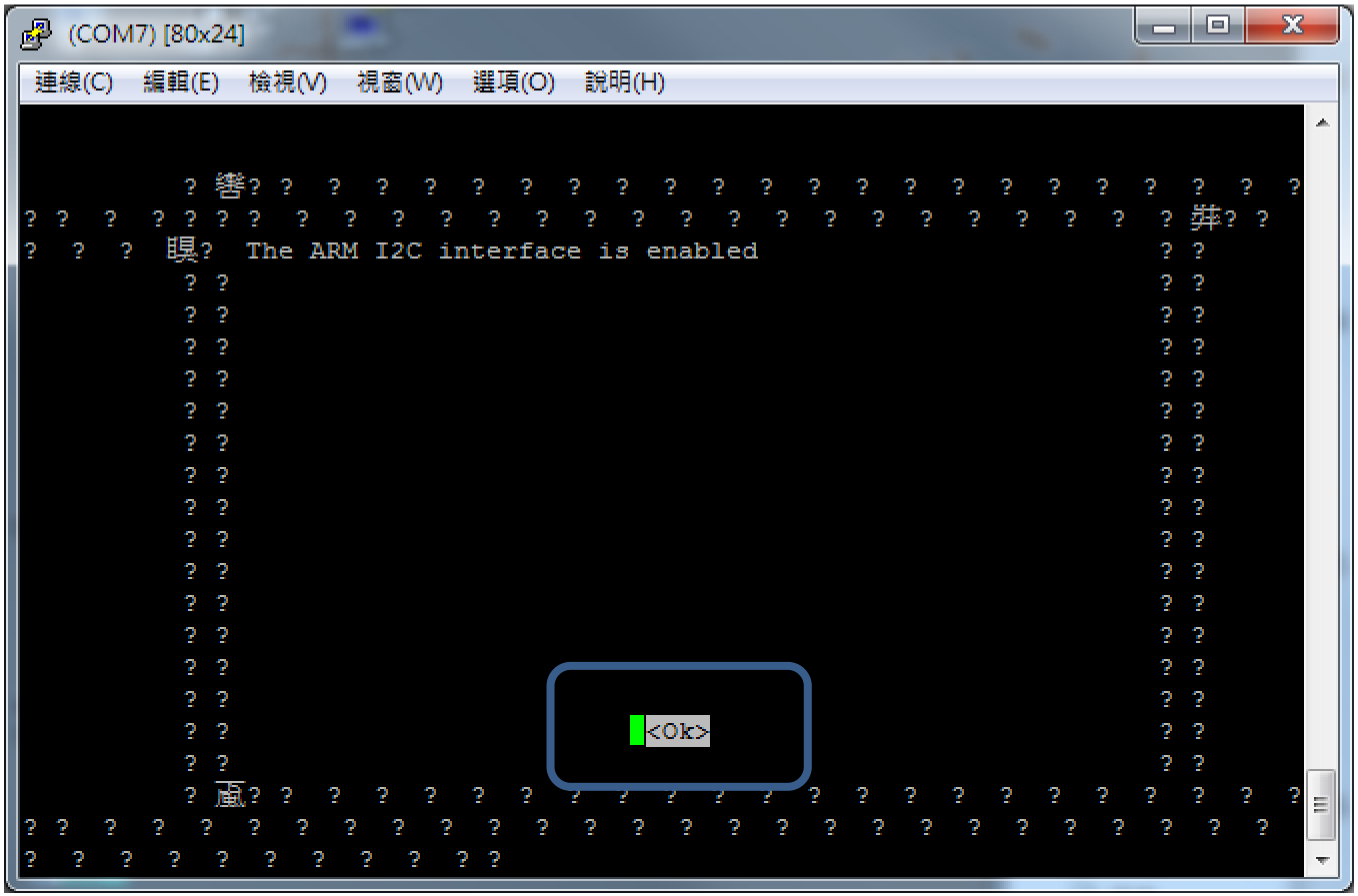
Enable I2C on RaspPI

- Choose **Yes**



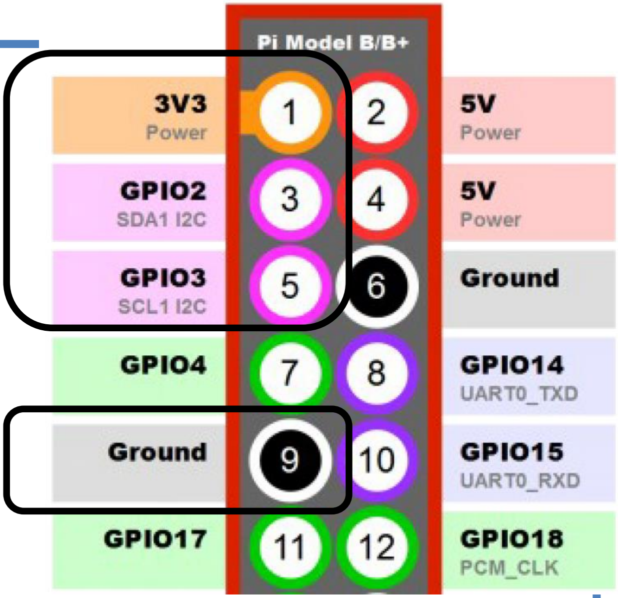
Enable I2C on RaspPI

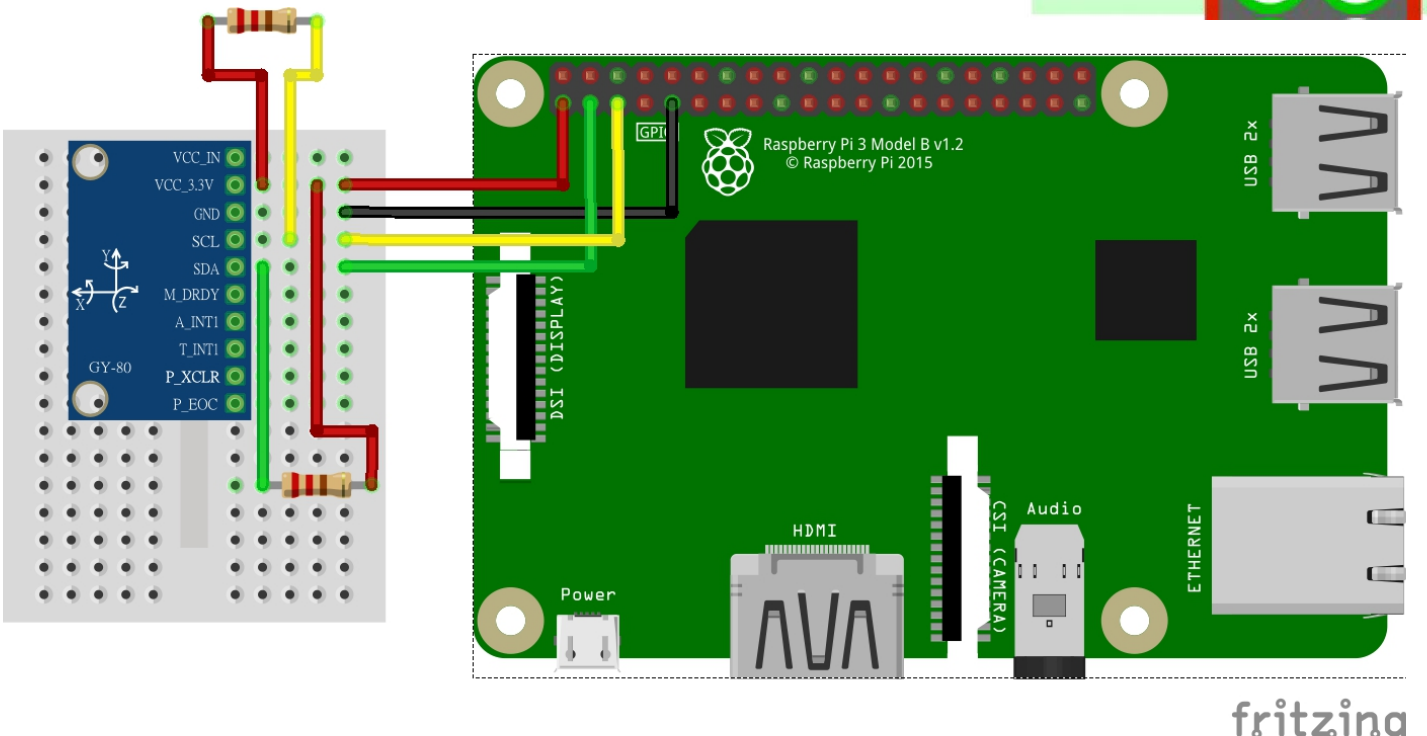
- I2C is enabled



Connect GY801

VCC	**Pin 1 (3.3V), Red line**
GND	**Pin 9 (Ground), Black line**
SCL	**Pin 5 (SCL), Yellow line**
SDA	**Pin 3 (SDA), Green line**





The resistors are build-in on circuit. (you can skip them)

After connecting GY801

- Install I2C tool to check the state:
  - **sudo apt-get install i2c-tools**
  - Command 1
    - **sudo ls -al /dev/*i2c***
  - Command 2
    - **sudo i2cdetect -y 1**

```
pi@raspberrypi:~$ sudo ls -al /dev/*i2c*
crw-rw---- 1 root i2c 89, 1 Mar 7 03:39 /dev/i2c-1
```

Show the I2C address

```
pi@raspberrypi:~$ sudo i2cdetect -y 1
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:          -- -- -- -- -- -- -- -- -- -- -- -- --
10: -- -- -- -- -- -- -- -- -- -- -- -- -- -- 1e --
20: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
30: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
40: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
50: -- -- -- 53 -- -- -- -- -- -- -- -- -- -- -- --
60: -- -- -- -- -- -- -- -- -- 69 -- -- -- -- -- --
70: -- -- -- -- -- -- -- 77
```

After connecting GY801

- If no I2C device
  - Command 1
    - sudo ls -al /dev/*i2c*

```
pi@raspberrypi:~$ ls -al /dev/*i2c*
ls: cannot access /dev/*i2c*: No such file or directory
```

  - Command 2
    - sudo i2cdetect -y 1

```
pi@raspberrypi:~$ sudo i2cdetect -y 1
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:          -- -- -- -- -- -- -- -- -- -- -- -- --
10: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
20: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
30: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
40: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
50: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
60: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
70: -- -- -- -- -- -- -- --
```

http://www.analog.com/media/en/technical-documentation/data-sheets/ADXL345.pdf
http://www.analog.com/media/cn/technical-documentation/data-sheets/ADXL345_cn.pdf

1. Accelerometer (ADXL345)

- ADXL345
  - Chipset：ADXL345
  - Power：3 ~ 5V
  - Protocol：I2C/SPI
  - Range：± 2g、± 4g、± 8g、± 16g

Parameter	Test Conditions	Min	Typ[1]	Max	Unit
OUTPUT RESOLUTION	Each axis				
All *g* Ranges	10-bit resolution		10		Bits
±2 *g* Range	Full resolution		10		Bits
±4 *g* Range	Full resolution		11		Bits
±8 *g* Range	Full resolution		12		Bits
±16 *g* Range	Full resolution		13		Bits
SENSITIVITY	Each axis				
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	All *g*-ranges, full resolution	230	256	282	LSB/*g*
	±2 *g*, 10-bit resolution	230	256	282	LSB/*g*
	±4 *g*, 10-bit resolution	115	128	141	LSB/*g*
	±8 *g*, 10-bit resolution	57	64	71	LSB/*g*
	±16 *g*, 10-bit resolution	29	32	35	LSB/*g*
Sensitivity Deviation from Ideal	All *g*-ranges		±1.0		%
Scale Factor at X_{OUT}, Y_{OUT}, Z_{OUT}	All *g*-ranges, full resolution	3.5	3.9	4.3	mg/LSB
	±2 *g*, 10-bit resolution	3.5	3.9	4.3	mg/LSB
	±4 *g*, 10-bit resolution	7.1	7.8	8.7	mg/LSB
	±8 *g*, 10-bit resolution	14.1	15.6	17.5	mg/LSB
	±16 *g*, 10-bit resolution	28.6	31.2	34.5	mg/LSB
Sensitivity Change Due to Temperature			±0.01		%/°C

1. Accelerometer code

- Download ADXL library

```
sudo apt-get install git build-essential python-dev
git clone https://github.com/adafruit/Adafruit_Python_ADXL345.git
cd Adafruit_Python_ADXL345
sudo python setup.py install

cd examples/
sudo python simplectest.py
```

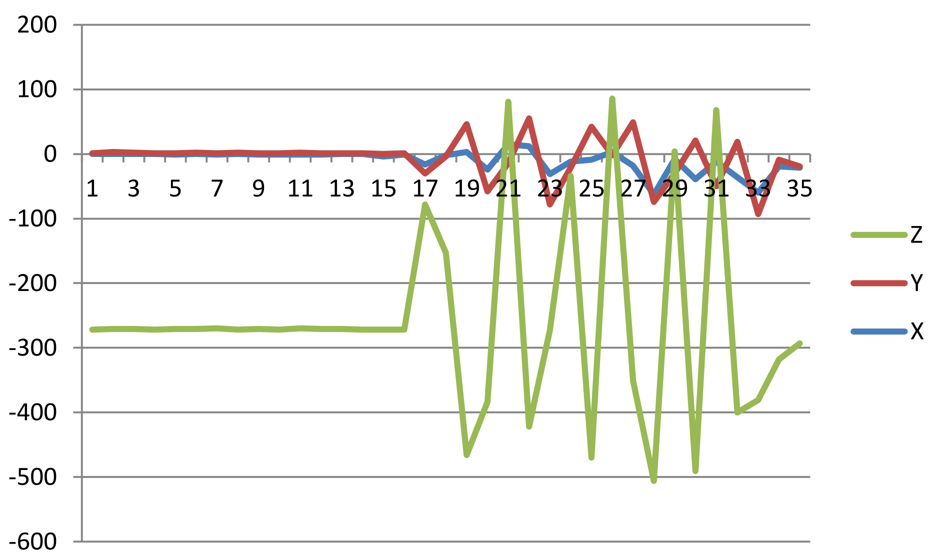
- Execution results

```
pi@raspberrypi:~/gy80/1.acc/examples$ sudo python simpletest.py
Printing X, Y, Z axis values, press Ctrl-C to quit...
X=-13, Y=-2, Z=-272
X=-12, Y=-3, Z=-272
X=-12, Y=-2, Z=-272
X=-11, Y=-3, Z=-271
X=-12, Y=-3, Z=-270
X=-12, Y=-1, Z=-272
```

1. Accelerometer code

- Execution results (by excel)

```
pi@raspberrypi:~/gy80/1.acc/examples$ sudo python simpletest.py
Printing X, Y, Z axis values, press Ctrl-C to quit...
X=-13, Y=-2, Z=-272
X=-12, Y=-3, Z=-272
X=-12, Y=-2, Z=-272
X=-11, Y=-3, Z=-271
X=-12, Y=-3, Z=-270
X=-12, Y=-1, Z=-272
```



1. Accelerometer code

- Sample code (simplectest.py)

Adafruit_ADXL345/ADXL345.py

```
import time
import Adafruit_ADXL345
accel = Adafruit_ADXL345.ADXL345()

print('Printing X, Y, Z axis values, press Ctrl-C to quit...')

while True:
  # Read the X, Y, Z axis acceleration values and print them.
  x, y, z = accel.read()
  print('X={0}, Y={1}, Z={2}'.format(x, y, z))

  # Wait half a second and repeat.
  time.sleep(0.5)
```

print the X, Y, Z axis acceleration values every half second.

1. Accelerometer code

- Adafruit_ADXL345/ADXL345.py

```
ADXL345_ADDRESS      = 0x53
ADXL345_REG_DEVID     = 0x00 # Device ID
ADXL345_REG_DATAX0     = 0x32 # X-axis data 0 (6 bytes for X/Y/Z)
ADXL345_REG_POWER_CTL  = 0x2D # Power-saving features control
...
```

```
def read(self):
    """Read the current value of the accelerometer and return it as a tuple
    of signed 16-bit X, Y, Z axis values.
    """
    raw = self._device.readList(ADXL345_REG_DATAX0, 6)
    return struct.unpack('<hhh', raw)
```

Referring to datasheet, read 6 bytes on register location (ADXL345_REG_DATAX0, 0x32) then transform to x/y/z value

When accessing I2C sensor, we have to write code based on datasheet. The code is already done for you.

1. Accelerometer spec.

REGISTER MAP

Table 19.

Address					
Hex	Dec	Name	Type	Reset Value	Description
0x32	50	DATAX0	R	00000000	X-Axis Data 0
0x33	51	DATAX1	R	00000000	X-Axis Data 1
0x34	52	DATAY0	R	00000000	Y-Axis Data 0
0x35	53	DATAY1	R	00000000	Y-Axis Data 1
0x36	54	DATAZ0	R	00000000	Z-Axis Data 0
0x37	55	DATAZ1	R	00000000	Z-Axis Data 1

Register 0x32 to Register 0x37—DATAX0, DATAX1, DATAY0, DATAY1, DATAZ0, DATAZ1 (Read Only)
These six bytes (Register 0x32 to Register 0x37) are eight bits each and hold the output data for each axis. Register 0x32 and Register 0x33 hold the output data for the x-axis, Register 0x34 and Register 0x35 hold the output data for the y-axis, and Register 0x36 and Register 0x37 hold the output data for the z-axis. The output data is twos complement, with DATAx0 as the least significant byte and DATAx1 as the most significant byte, where x represent X, Y, or Z. The DATA_FORMAT register (Address 0x31) controls the format of the data. It is recommended that a multiple-byte read of all registers be performed to prevent a change in data between reads of sequential registers.

1. Accelerometer code

- In default measurement range, it should report +/-2G (default, range=2), but the code shows the following data:

```
pi@raspberrypi:~/gy80/1.acc/examples$ sudo python simpletest.py
Printing X, Y, Z axis values, press Ctrl-C to quit...
X=-13, Y=-2, Z=-272
X=-12, Y=-3, Z=-272
X=-12, Y=-2, Z=-272
X=-11, Y=-3, Z=-271
X=-12, Y=-3, Z=-270
X=-12, Y=-1, Z=-272
```

- **How to transform the output to +/-2G?**

1. Accelerometer code

- Hint: according to datasheet, we can use the following formula to convert output (Raw_{Accel}) to +/-2G.

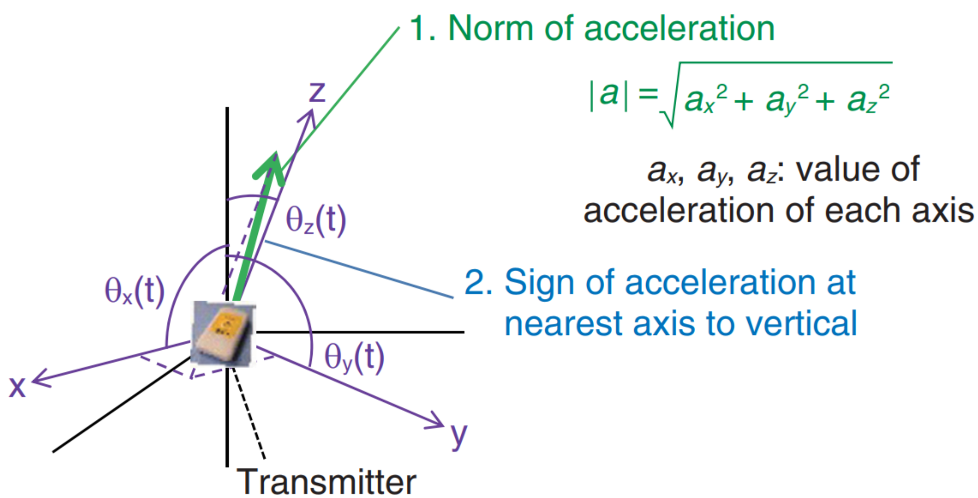
Parameter	Test Conditions	Min	Typ[1]	Max	Unit
OUTPUT RESOLUTION	Each axis				
All *g* Ranges	10-bit resolution		10		Bits
±2 *g* Range	Full resolution		10		Bits
SENSITIVITY	Each axis				
Sensitivity at X_{OUT}, Y_{OUT}, Z_{OUT}	All *g*-ranges, full resolution	230	256	282	LSB/*g*
	±2 *g*, 10-bit resolution	230	256	282	LSB/*g*

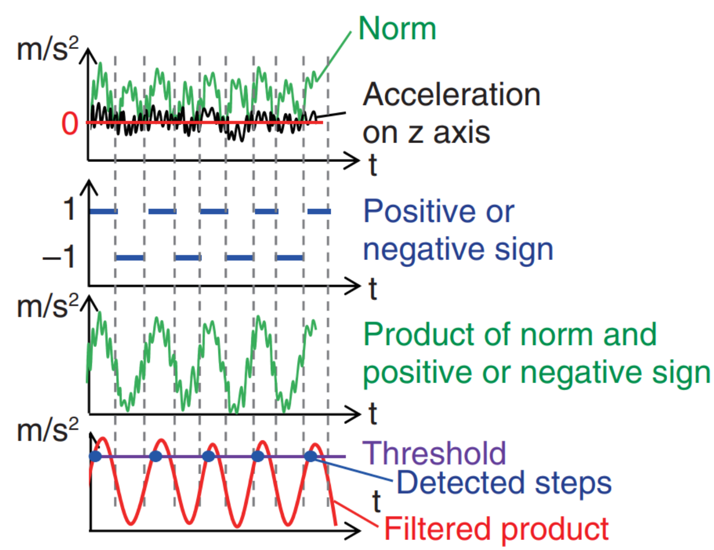
$$G_{Accel} = Raw_{Accel}/\mathbf{Sensitivity}$$

https://theccontinuum.com/2012/09/24/arduino-imu-pitch-roll-from-accelerometer/

Quiz 1

- Calculate the norm of acceleration |a|
  - Formula:
    |a| = sqrt(x^2 + y^2 + z^2)





Application: step detection

Gait Analysis Using a Wearable T-shirt Type Sensor
https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr201604ra1.html

Quiz 1

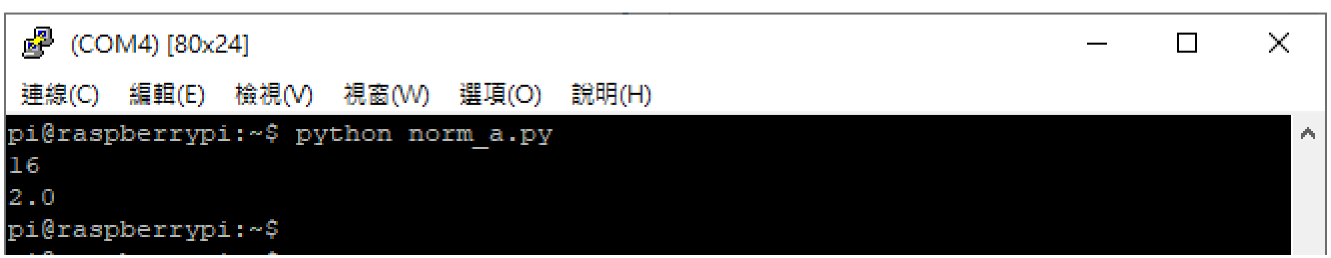
- Hold the sensor, do not move for 5 seconds, then **turn on LED!**
  Hint: use the norm of acceleration |a|, and set a variance.
  - If the norm does not exceed the variance for 5 second, we can treat it as stable.

Requirements
1. Convert output to +/-2G
2. Calculate norm

Quiz 1

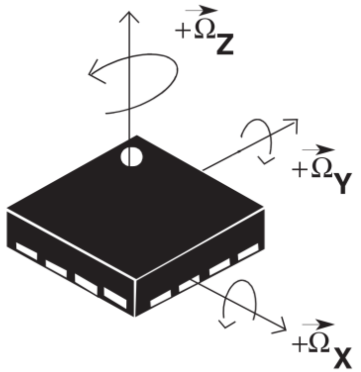
- Use python to calculate pow and sqrt

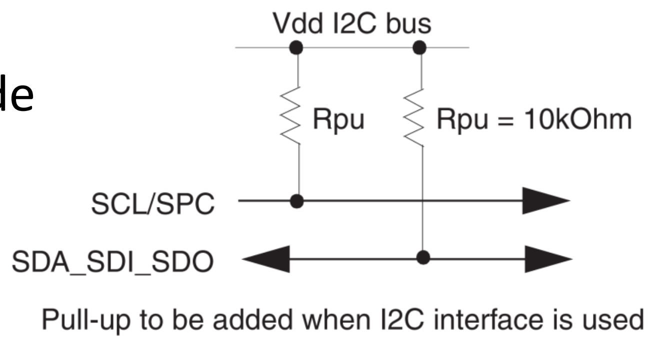
```
import numpy
x = 4

y = pow(x,2)
# y=16

z = numpy.sqrt(x)
# z=2

print y
print z
```



2. Gyroscope (L3G4200D)

- Features
  - 3-Axis angular rate sensor (yaw, pitch, and roll)
  - Supports I2C and SPI communications
  - Three selectable scales: 250/500/2000 degrees/sec (dps)
  - High shock survivability
  - Embedded temperature sensor -40 to +185 °F (-40 to + 85 °C)
  - Embedded power-down and sleep mode
  - 16 bit-rate value data output
  - 8-bit temperature data output





http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Gyros/3-Axis/17116.pdf
http://www.playrobot.com/gyro/284-sparkfun-tri-axis-gyro-breakout-l3g4200d.html

2. Gyroscope (L3G4200D)

- Download the library

```
cd ~
git clone https://github.com/bashardawood/L3G4200D-Python
cd L3G4200D-Python
sudo python gyro.py
```

- Execution

```
pi@raspberrypi:~/L3G4200D-Python$ sudo python gyro.py
     -1013        -256        1602
       946        -683        -195
       943        -681        -198
       947        -683        -193
       940        -679        -194
       947        -672        -192
       935        -680        -193
       948        -514        -192
```

2. Gyroscope code (L3G4200D)

```
#!/usr/bin/python

from time import sleep
import smbus
import string

def getSignedNumber(number):
  if number & (1 << 15):
    return number | ~65535
  else:
    return number & 65535

i2c_bus=smbus.SMBus(1)
i2c_address=0x69
i2c_bus.write_byte_data(i2c_address,0x20,0x0F)
i2c_bus.write_byte_data(i2c_address,0x23,0x20)
```

Load library

2's complement

Set register address (based on datasheet)

2. Gyroscope code (L3G4200D)

```
while True:
    i2c_bus.write_byte(i2c_address,0x28)
    X_L = i2c_bus.read_byte(i2c_address)
    i2c_bus.write_byte(i2c_address,0x29)
    X_H = i2c_bus.read_byte(i2c_address)
    X = X_H << 8 | X_L
    ....

    X = getSignedNumber(X)
    Y = getSignedNumber(Y)
    Z = getSignedNumber(Z)

    print string.rjust(`X`, 10),
    print string.rjust(`Y`, 10),
    print string.rjust(`Z`, 10)
    sleep(0.02)
```

Read 1st and 2nd byte, then combine byte value

2's complement
(def getSignedNumber(number):)

Put space before value

When accessing I2C sensor, we have to write code based on datasheet.
The code is already done for you.

2. Gyroscope (L3G4200D)

```
i2c_bus.write_byte_data(i2c_address,0x20,0x0F)
```

CTRL_REG1 (20h)

Table 20. CTRL_REG1 register

DR1	DR0	BW1	BW0	PD	Zen	Yen	Xen

Table 21. CTRL_REG1 description

DR1-DR0	Output Data Rate selection. Refer to *Table 22*
BW1-BW0	Bandwidth selection. Refer to *Table 22*
PD	Power down mode enable. Default value: 0 (0: power down mode, 1: normal mode or sleep mode)
Zen	Z axis enable. Default value: 1 (0: Z axis disabled; 1: Z axis enabled)
Yen	Y axis enable. Default value: 1 (0: Y axis disabled; 1: Y axis enabled)
Xen	X axis enable. Default value: 1 (0: X axis disabled; 1: X axis enabled)

2. Gyroscope (L3G4200D)

```
i2c_bus.write_byte_data(i2c_address,0x23,0x20)
```

CTRL_REG4 (23h)

Table 30. CTRL_REG4 register

BDU	BLE	FS1	FS0	-	ST1	ST0	SIM

Table 31. CTRL_REG4 description

BDU	Block Data Update. Default value: 0 (0: continous update; 1: output registers not updated until MSB and LSB reading)
BLE	Big/Little Endian Data Selection. Default value 0. (0: Data LSB @ lower address; 1: Data MSB @ lower address)
FS1-FS0	Full Scale selection. Default value: 00 (00: 250 dps; 01: 500 dps; 10: 2000 dps; 11: 2000 dps)
ST1-ST0	Self Test Enable. Default value: 00 (00: Self Test Disabled; Other: See *Table*)
SIM	SPI Serial Interface Mode selection. Default value: 0 (0: 4-wire interface; 1: 3-wire interface).

2. Gyroscope (L3G4200D)

```
i2c_bus.write_byte(i2c_address,0x28)
X_L = i2c_bus.read_byte(i2c_address)
i2c_bus.write_byte(i2c_address,0x29)
X_H = i2c_bus.read_byte(i2c_address)
X = X_H << 8 | X_L
.
.
.
```

OUT_X_L (28h), OUT_X_H (29h)

X-axis angular rate data. The value is expressed as two's complement.

OUT_Y_L (2Ah), OUT_Y_H (2Bh)

Y-axis angular rate data. The value is expressed as two's complement.

OUT_Z_L (2Ch), OUT_Z_H (2Dh)

Z-axis angular rate data. The value is expressed as two's complement.

2. Gyroscope (L3G4200D)

- The output is bit value, how to convert it to angular velocity?

```
pi@raspberrypi:~/L3G4200D-Python$ sudo python gyro.py
     -1013        -256        1602
       946        -683        -195
       943        -681        -198
       947        -683        -193
       940        -679        -194
       947        -672        -192
       935        -680        -193
       948        -514        -192
```

- Change output to DPS (degrees Per Second)
  - **DPS = (Raw * 70) / 1000**

Symbol	Parameter	Test condition	Min.	Typ.(2)	Max.	Unit
So	Sensitivity	FS = 250 dps		8.75		mdps/digit
		FS = 500 dps		17.50		
		FS = 2000 dps		70		

The mdps/digit stands for Milli Degrees Per Second

Quiz 2

- Rotate the sensor to control the LED
  - **Left: turn on LED**
  - **Right: turn off LED**

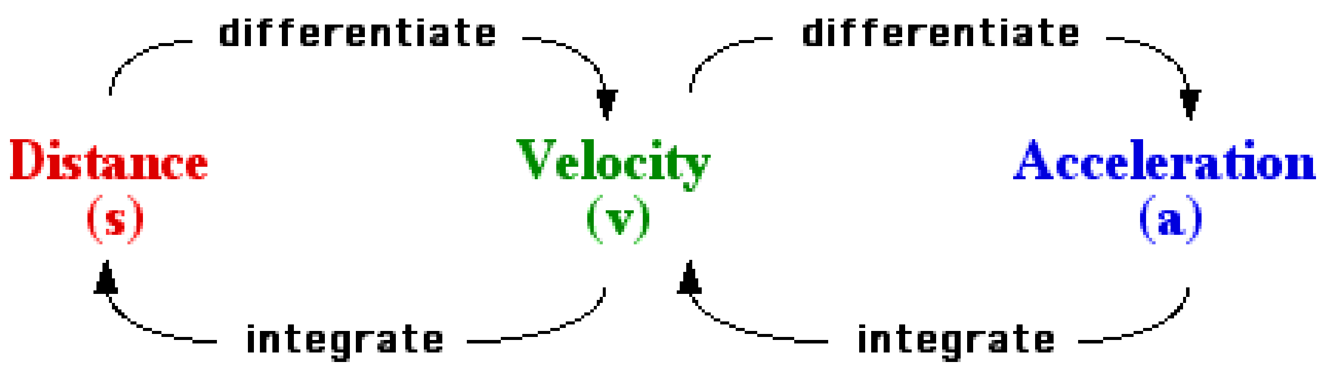
Discussion

- We can obtain ax/ay/az from sensor.
- How to calculate the distance based on accelerometer?
- **Is it possible? Why?**

$$\mathbf{s}(t) = \mathbf{s}_0 + \mathbf{v}_0 t + \tfrac{1}{2}\mathbf{a}t^2 = \mathbf{s}_0 + \frac{\mathbf{v}_0 + \mathbf{v}(t)}{2} t$$

$$\mathbf{v}(t) = \mathbf{v}_0 + \mathbf{a}t$$

$$v^2(t) = {v_0}^2 + 2\mathbf{a}\cdot[\mathbf{s}(t) - \mathbf{s}_0]$$



Summary

- Practice Lab (accelerometer, gyroscope)
- Write down the answer for discussion
  - Discussion: How to calculate the distance based on accelerometer?
- Write code for Quiz 1 - 2, then demonstrate it to TAs
  - Quiz1: Hold the sensor, do not move for 5 seconds.
  - Quiz2: Rotate the sensor to control the LED