嵌入式系統設計概論與實作

曾煜棋、吳昆儒

National Yang Ming Chiao Tung University

Last week

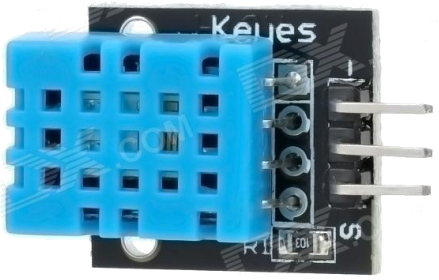
- 嵌入式應用
  - 距離資訊 (ex: 倒車雷達...)
  - 溫溼度資訊 (ex: 空氣清淨機, 寶寶攝影機...)

- Raspberry PI
  - GPIO introduction
  - Python
  - 超音波: HC-SR04
  - 溫溼度: DHT-11

HC-SR04

Ultrasonic

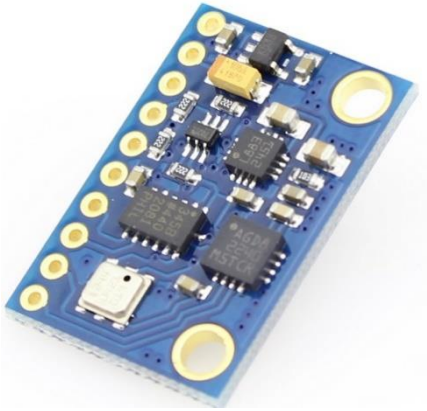
DHT-11



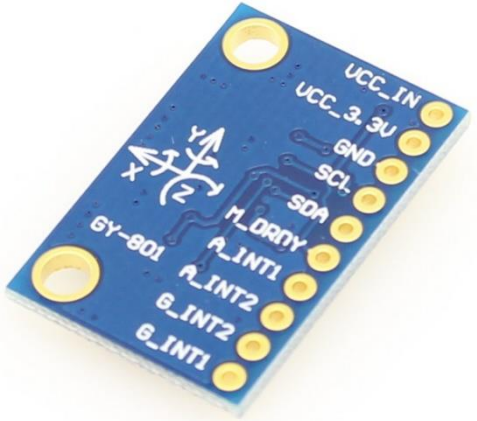
Thermometer + Hygrometer

This week

- 嵌入式應用: 人體活動偵測
  - 加速度、陀螺儀...等

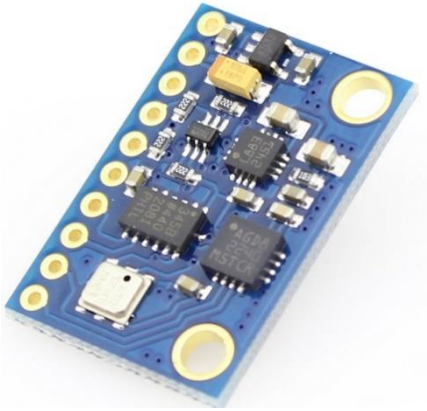


- GY801 (I2C sensor)
  - 3-axis Accelerometer, Gyroscope, magnetometer and pressure
  1. ADXL345：Accelerometer
  2. L3G4200：Gyroscope
  3. HMC5883：Magnetometer
  4. BMP085：Pressure

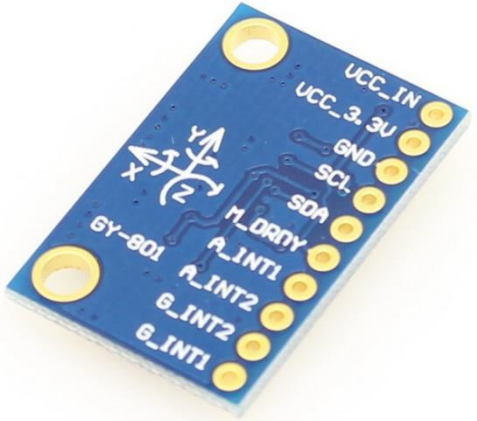


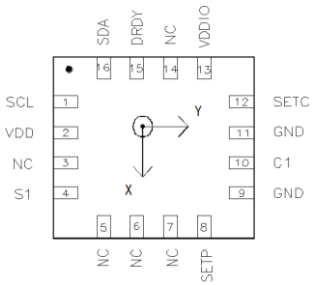
Outline

- 嵌入式應用: 人體活動偵測
  - 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

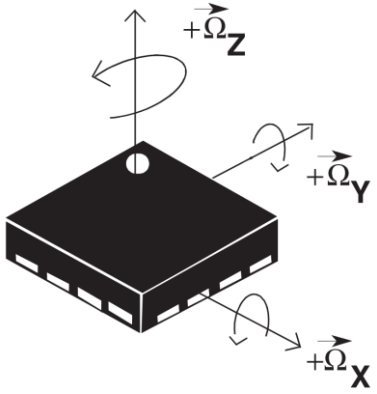


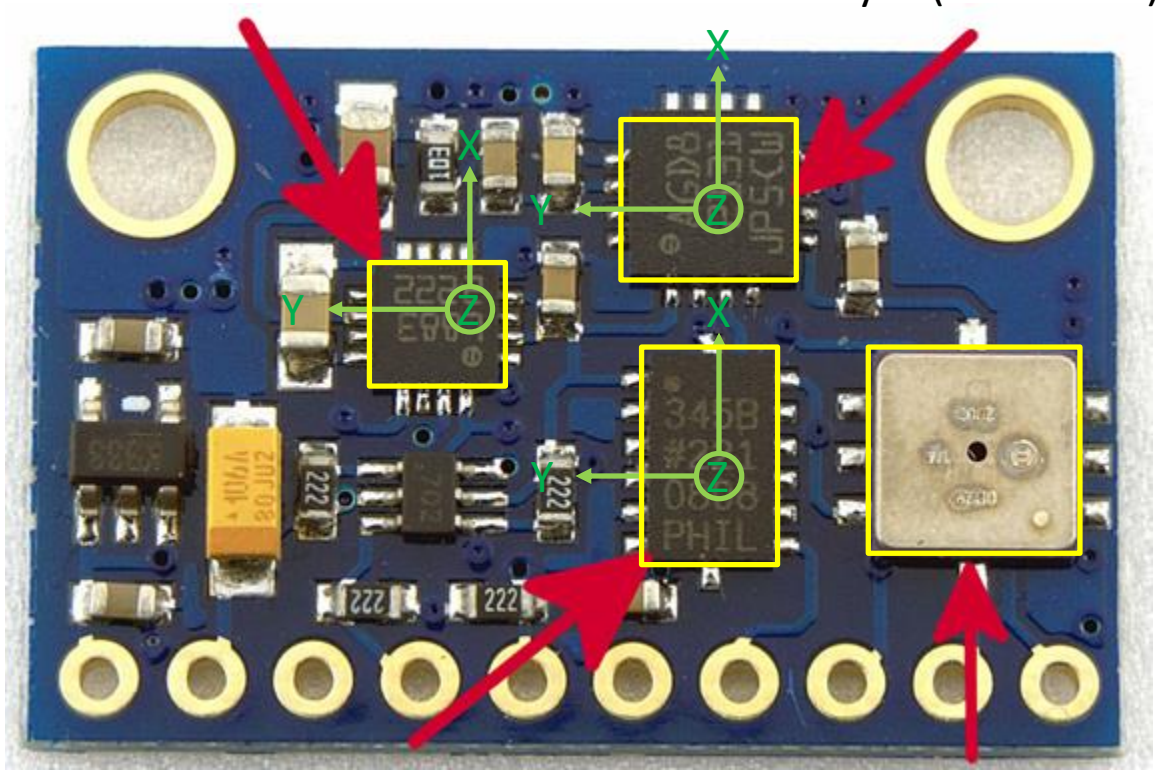


GY-801 (10 DoF sensor)

Compass (HMC5883L)

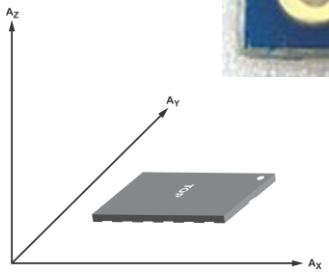
Gyro (L3G4200D)

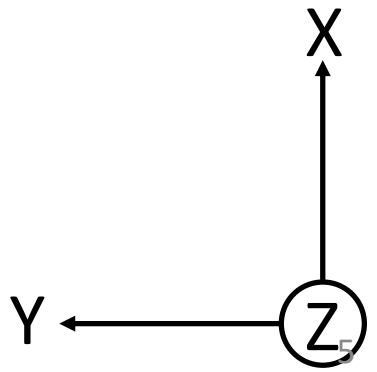




G-sensor (ADXL345)

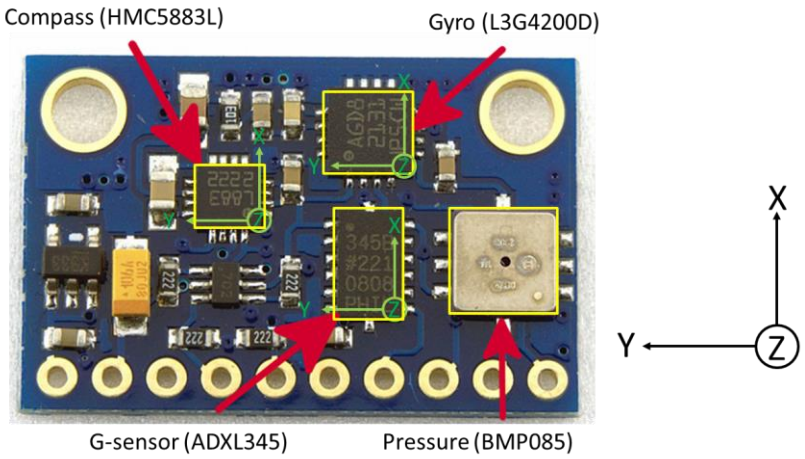
Pressure (BMP085)

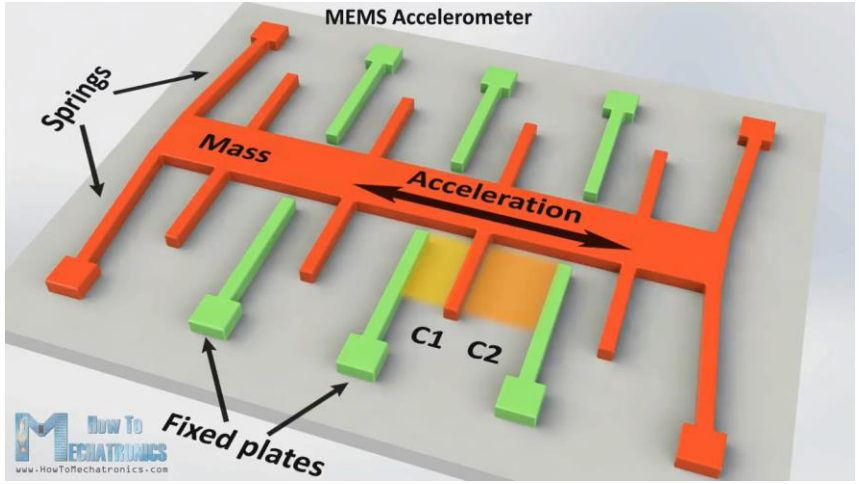


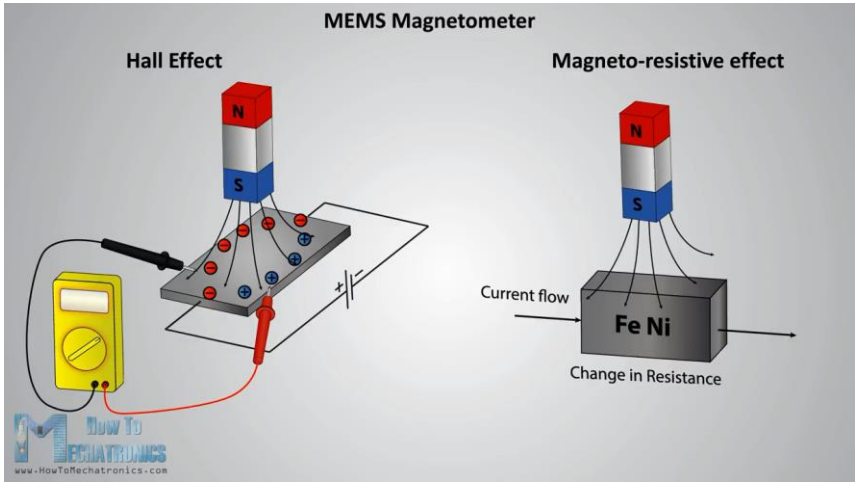


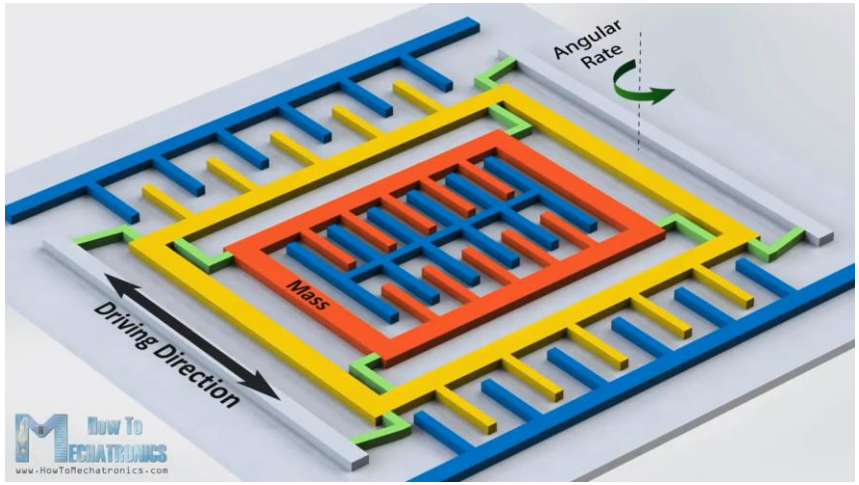
https://www.youtube.com/watch?v=eqZgxR6eRjo

How MEMS Accelerometer, Gyroscope, Magnetometer Work



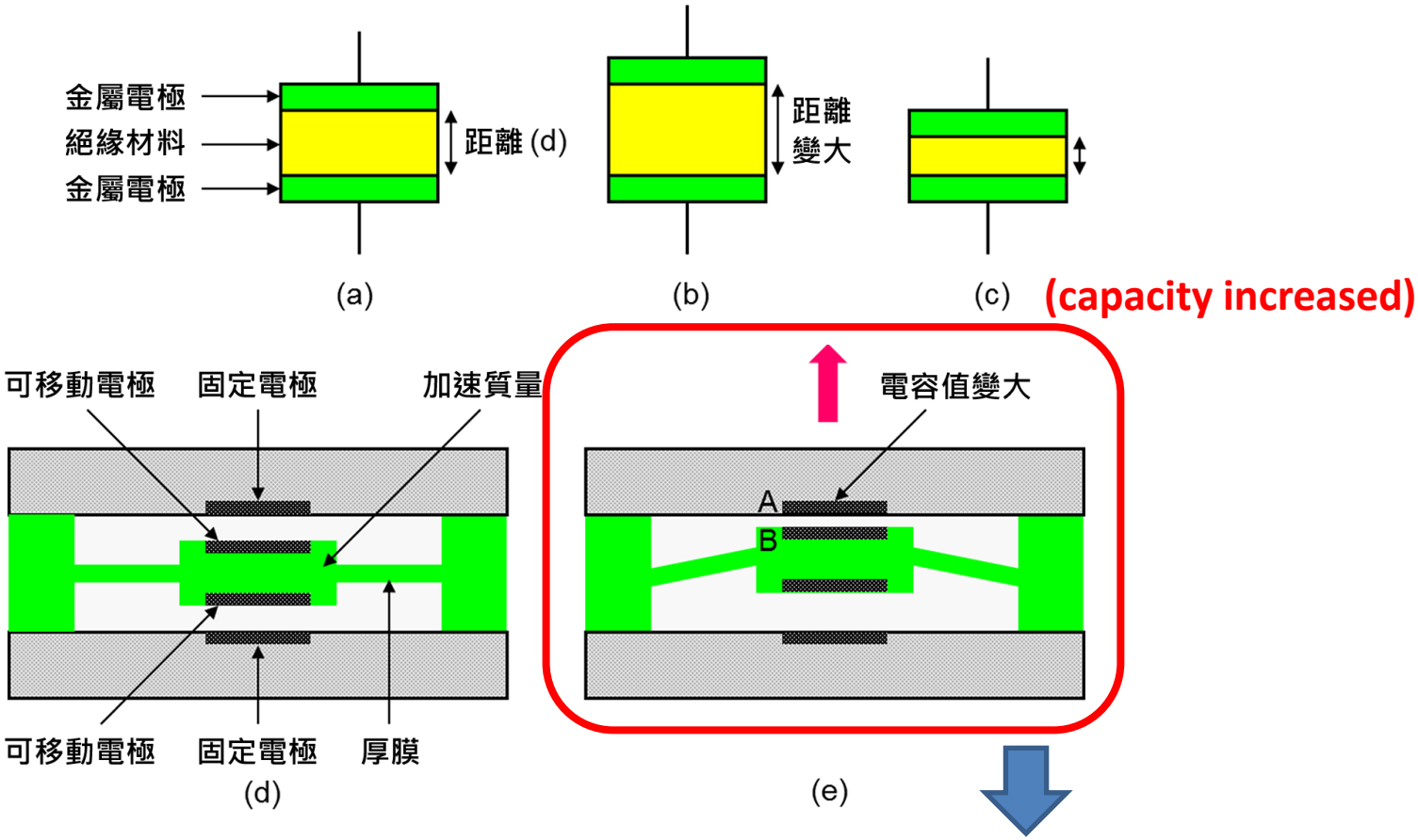






電容微加速度器的構造與原理
http://scimonth.blogspot.tw/2014/07/blog-post_94.html

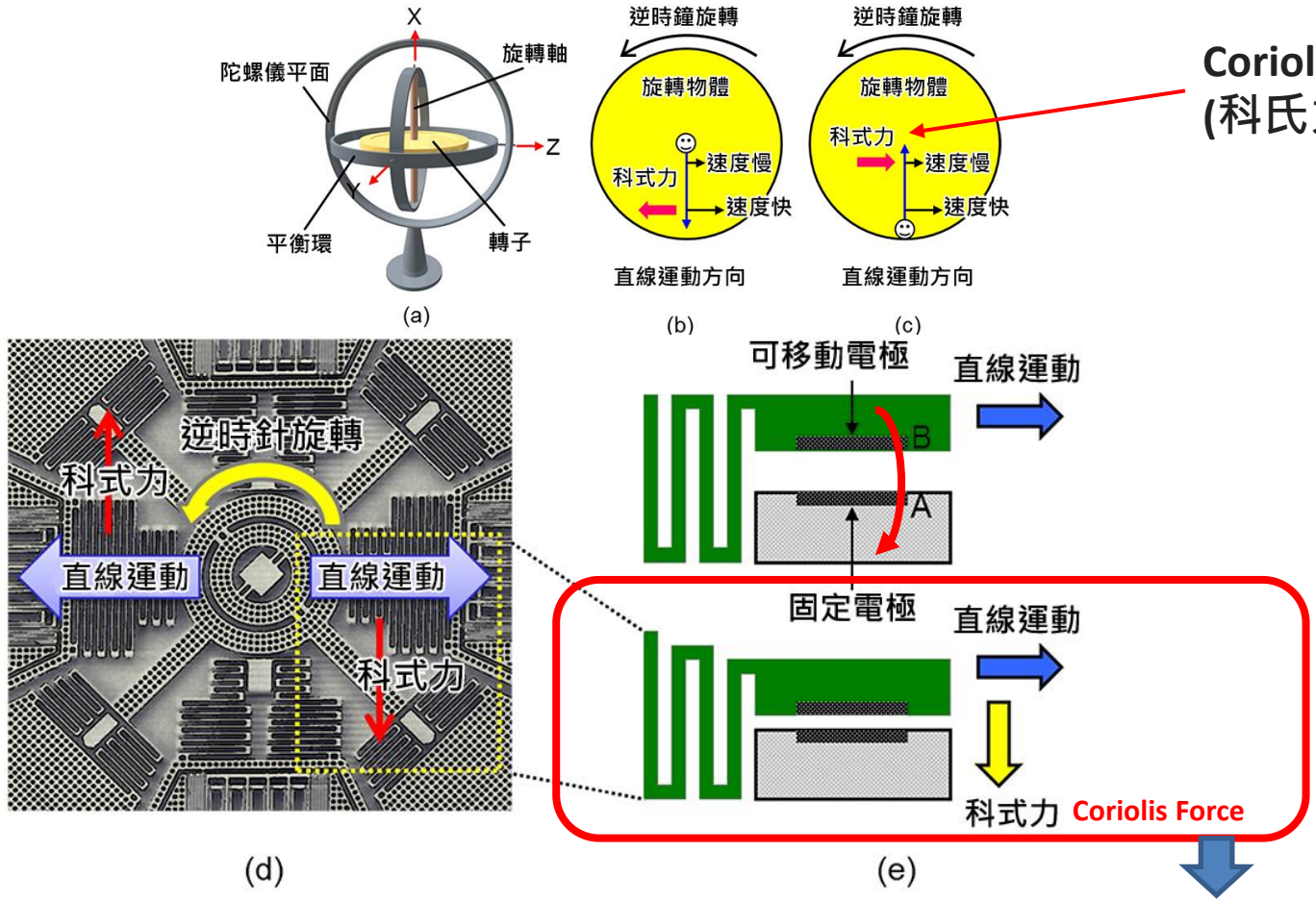
Sensor - Accelerometer



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

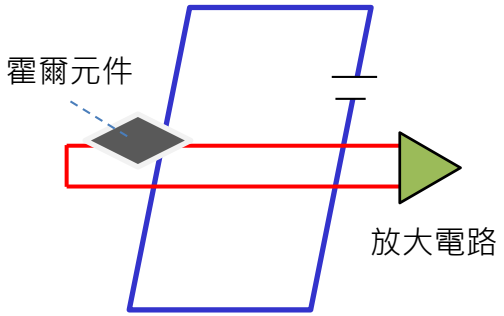
Sensor - Gyro



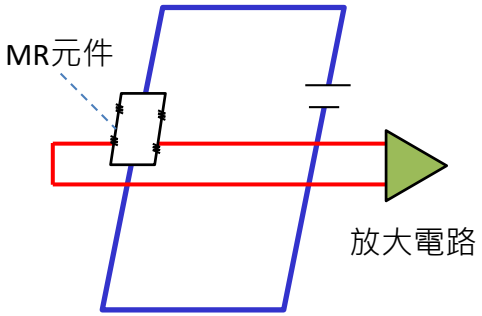
When you rotate the sensor, Coriolis Force change the distance (**capacity**).
We **use capacity to calculate Angular velocity (角速度).**

地磁感測器
https://www.rohm.com.tw/electronics-basics/sensors/sensor_what2

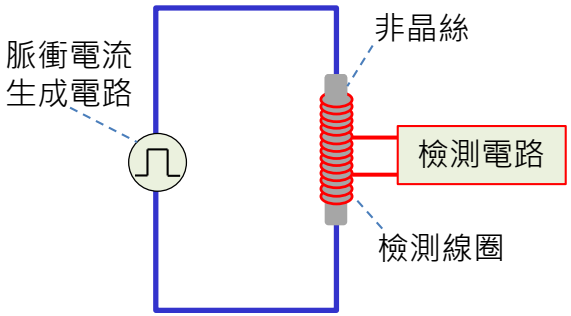
Sensor - Magnetometer



基於磁場變化
(a)電壓隨著霍爾效應發生變化



基於磁場變化
(b)MR元件的電阻發生變化



基於磁場變化
(c)利用脈衝電流檢測線圈電壓

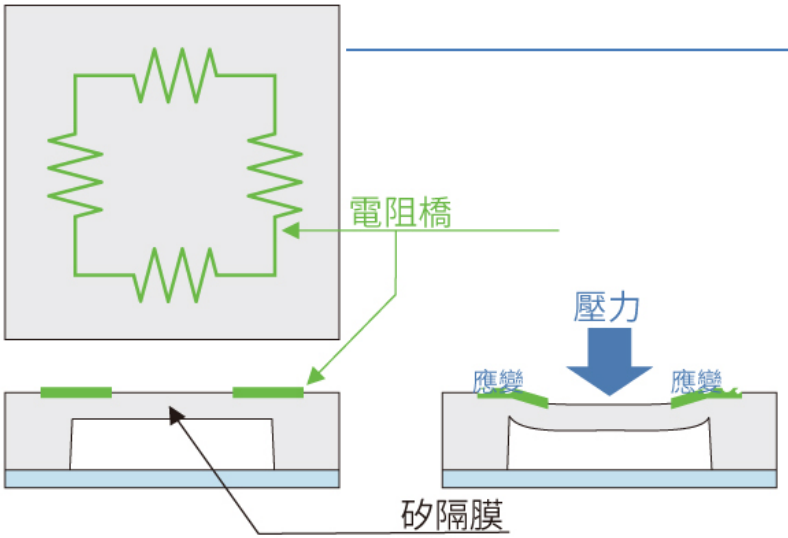
Magneto Resistance 磁阻效應感測器

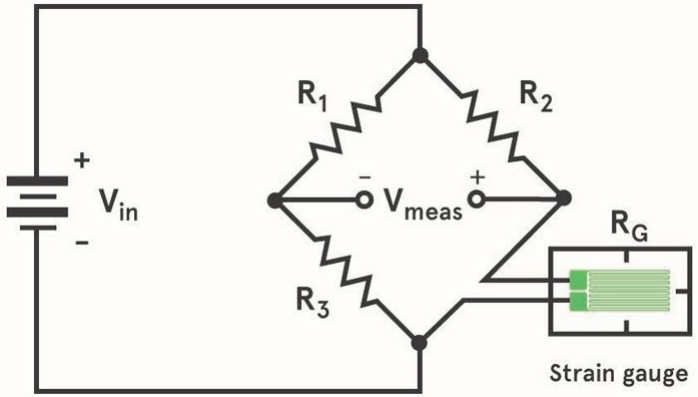
cost compassing and magnetometry. The HMC5883L includes our state-of-the-art, high-resolution HMC118X series magneto-resistive sensors plus an ASIC containing amplification, automatic degaussing strap drivers, offset cancellation, and a 12-bit ADC that enables 1° to 2° compass heading accuracy. The I^2C

壓阻式氣壓感測器
https://www.rohm.com.tw/electronics-basics/sensors/sensor_what4

Sensor - Pressure

當R3/R1 = RG/R2時，電橋平衡，檢流計無電流通過。
對於電流是否經過非常敏感，可以獲取頗精確的測量。





Wheatstone bridge

表面擴散雜質形成電阻橋電路(Wheatstone bridge)，
施加壓力產生的變形會影響電阻值，進而來計算壓力（氣壓）。

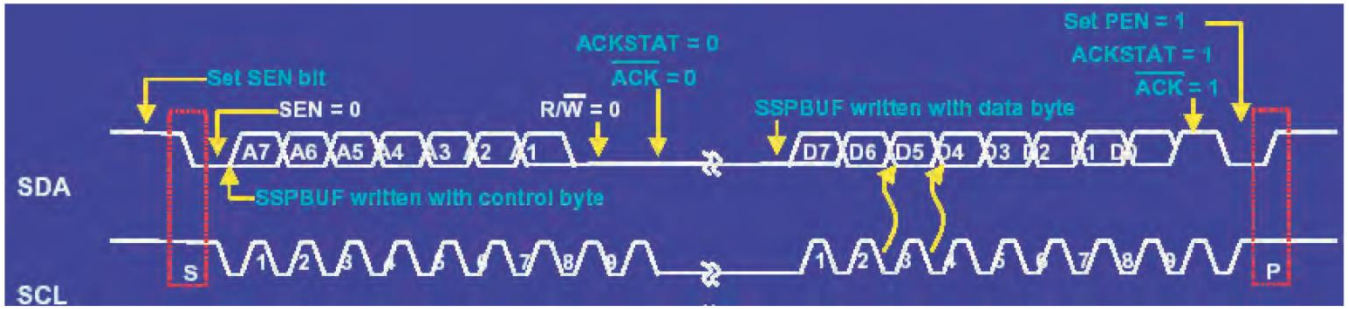
Piezo-Resistive 壓阻式感測器

The BMP085 is based on piezo-resistive technology for EMC robustness, high accuracy and linearity as well as long term stability.

這個念square喔!!

What is 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)。

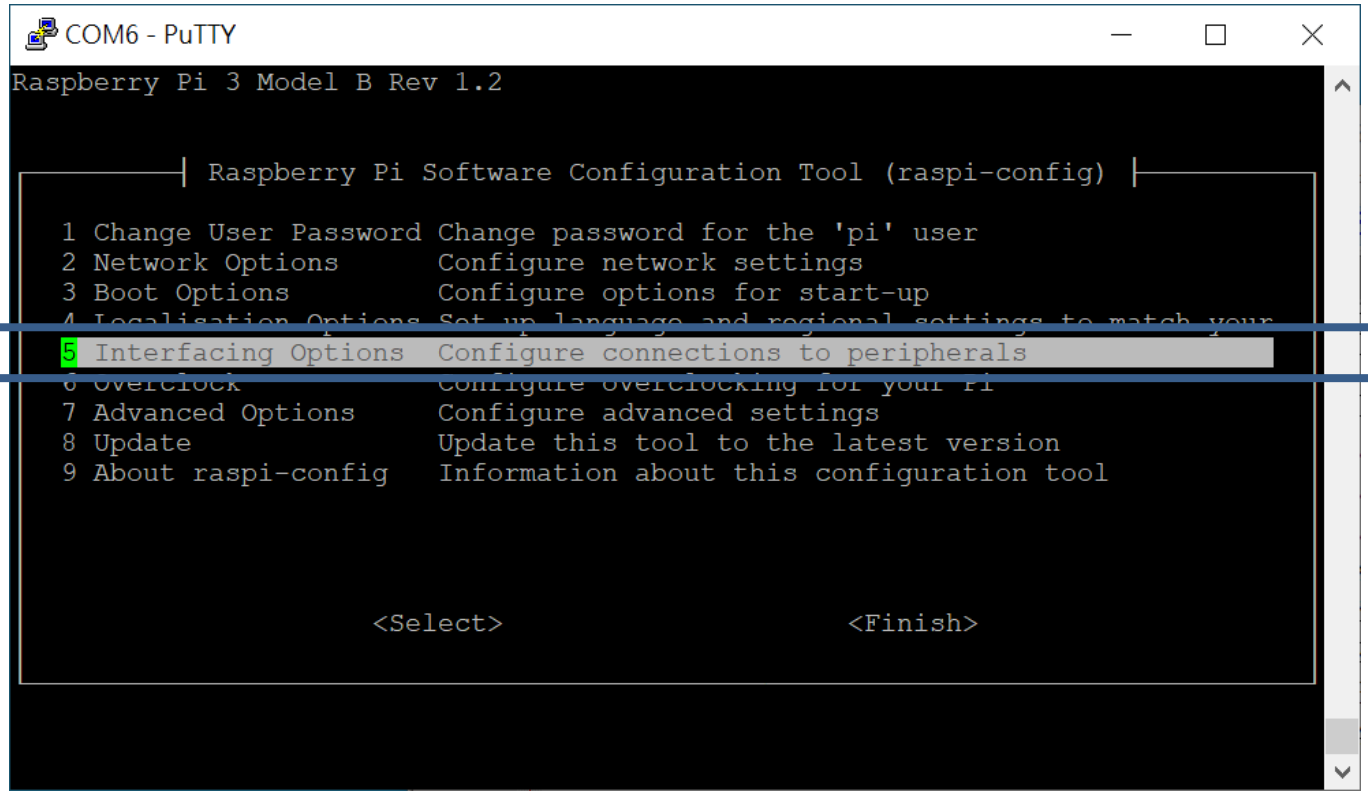


- 在傳送資料過程中共有三種類型信號，分別是：開始信號、結束信號和應答信號。
  - 開始信號：SCL為高電位時，SDA由高電位降為低電位，開始傳送資料。
  - 結束信號：SCL為高電位時，SDA由低電位升為高電位，結束傳送資料。
  - 應答信號：收到 8bit 資料後，向發送資料的IC發出特定的低電位脈衝
- 資料讀取方式：
  - 當 SCL 由低電位升為高電位時，讀取 SDA 的資料。

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

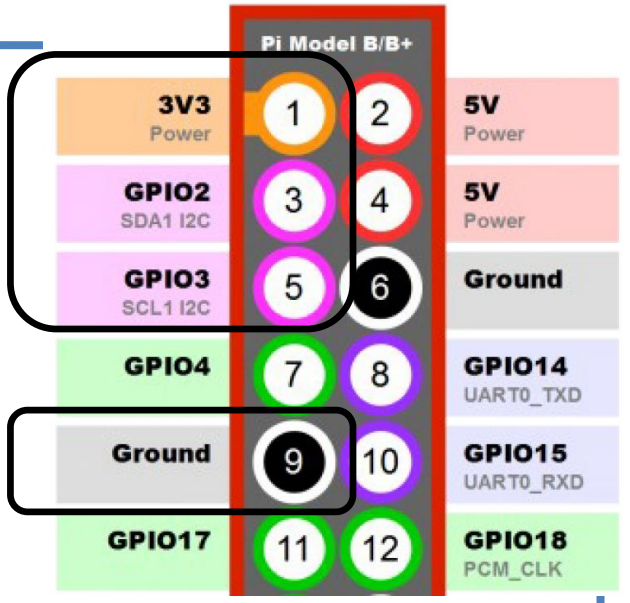
Enable I2C on Raspberry Pi

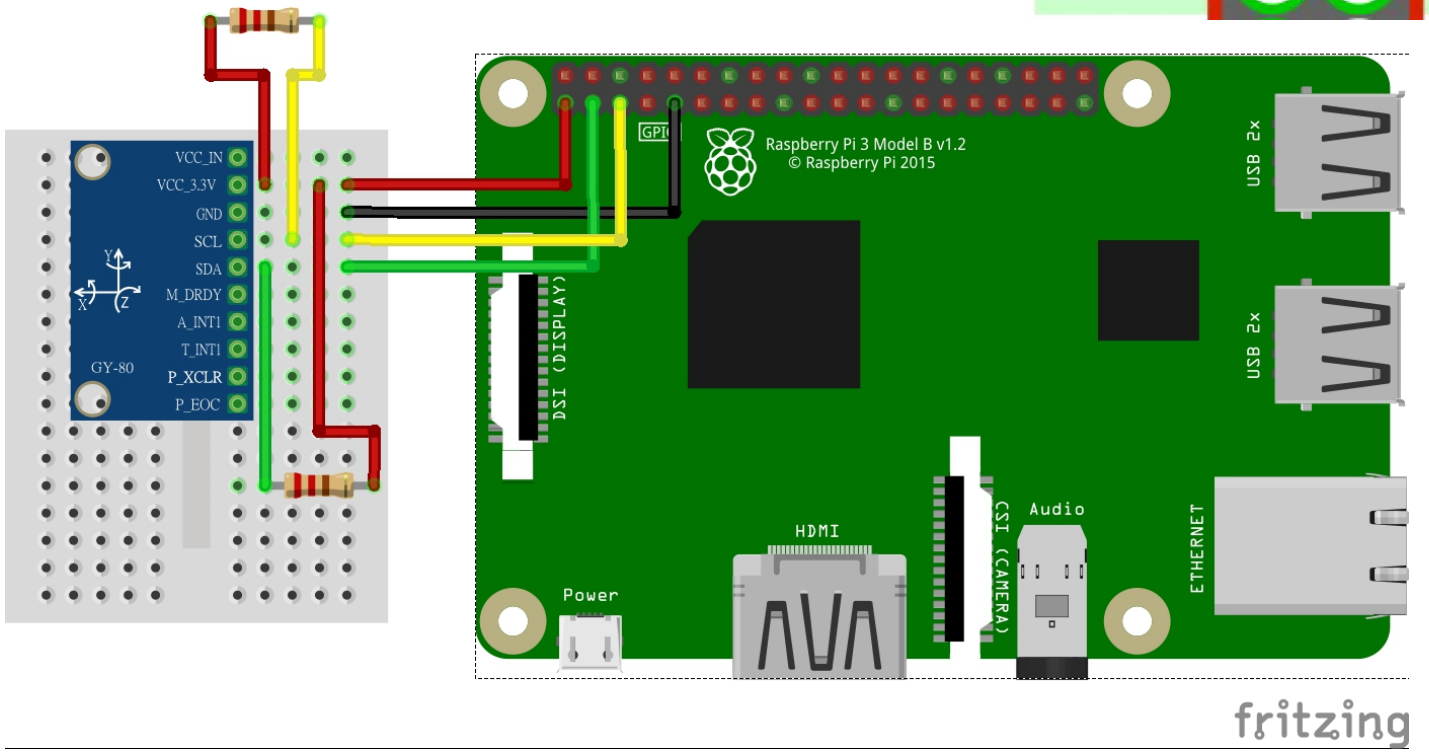
- Enter the command：**sudo raspi-config**
  - Select **5 Interfacing Options**



Connect I2C sensor

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)

Check I2C sensor

- 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
```

Check I2C sensor – part2

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

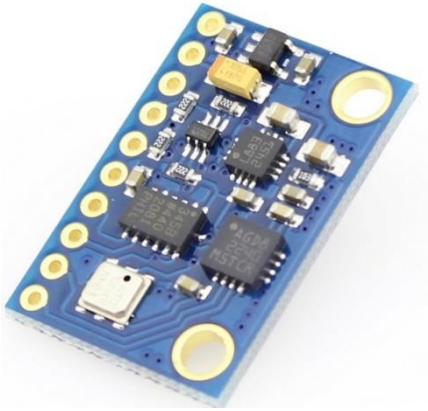
```
pi@raspberrypi:~$ ls -al /dev/*i2c*
ls: cannot access /dev/*i2c*: No such file or directory
```

  - Command 2
    - sudo i2cdetect -y 1

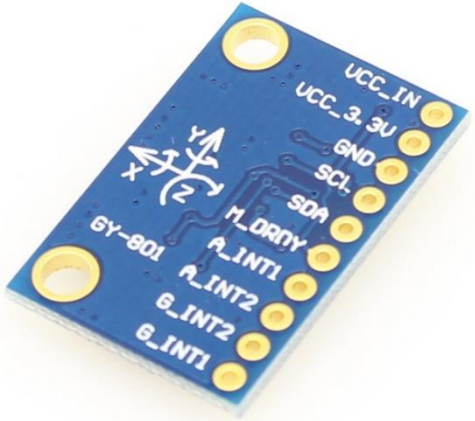
```
pi@raspberrypi:~/gy801$ sudo i2cdetect -y 1
     0  1  2  3  4  5  6  7  8  9  a  b  c  d  e  f
00:          -- -- -- -- -- -- -- -- -- -- -- -- --
10: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
20: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
30: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
40: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
50: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
60: -- -- -- -- -- -- -- -- -- -- -- -- -- -- -- --
70: -- -- -- -- -- -- -- --
```

Outline

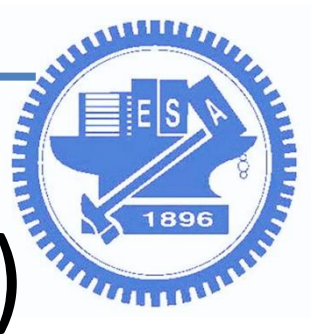
- 嵌入式應用: 人體活動偵測
  - 加速度、陀螺儀...等



- GY801 (I2C sensor)
  1. 3-axis Accelerometer, Gyroscope, magnetometer and pressure
  2. ADXL345：Accelerometer
  3. L3G4200：Gyroscope
  4. HMC5883：Magnetometer
  5. BMP085：Pressure



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



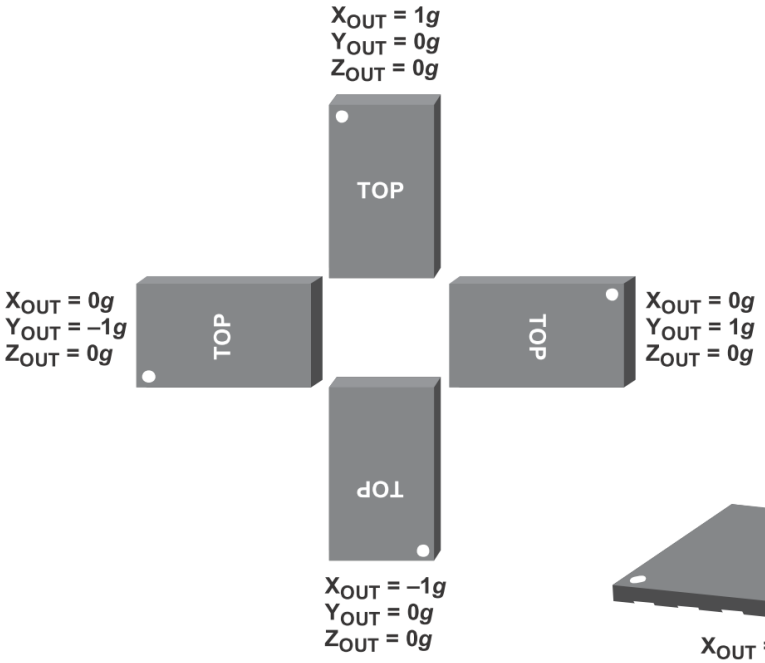
1. Accelerometer (ADXL345)

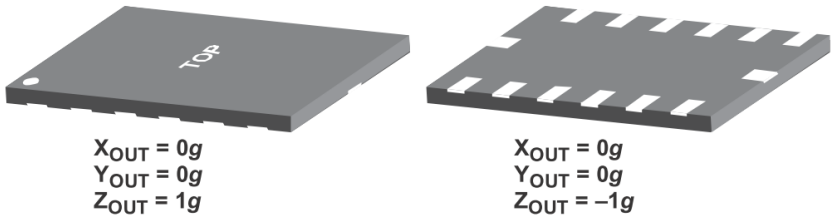
- ADXL345
  - Chipset：ADXL345
  - Power：3 ~ 5V
  - Protocol：I2C/SPI
  - Range：± 2g、± 4g、± 8g、± 16g

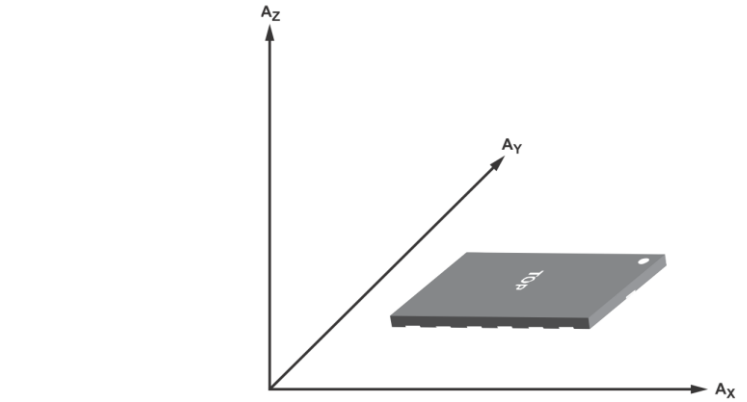
Parameter	Test Conditions	Min	Typ[1]	Max	Unit
OUTPUT RESOLUTION	Each axis				
All *g* Ranges	10-bit resolution		10		Bits
±2 *g* Range	Full resolution		10		Bits
±4 *g* Range	Full resolution		11		Bits
±8 *g* Range	Full resolution		12		Bits
±16 *g* Range	Full resolution		13		Bits
SENSITIVITY	Each axis				
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 (ADXL345)

- Output Response and Orientation





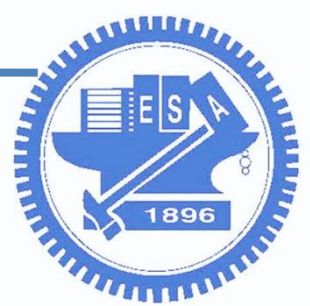


1. Accelerometer code

- Sample code results:

```
pi@raspberrypi:~/gy801$ python 1acc.py
ACC:
x = 0.498 m/s2
y = -0.306 m/s2
z = -10.343 m/s2
x = 0.051G
y = -0.031G
z = -1.055G
x = 0.000
y = -8.000
z = -270.000
```

1. Accelerometer code: **define address**




```
bus = smbus.SMBus(1); # 0 for R-Pi Rev. 1, 1 for Rev. 2

EARTH_GRAVITY_MS2     = 9.80665 # m/s2

# the following address is defined by datasheet
ADXL345_ADDRESS           =     0x53 # I2C address

ADXL345_BW_RATE           =     0x2C # Data rate and power mode control
ADXL345_POWER_CTL         =     0x2D # Power-saving features control
ADXL345_DATA_FORMAT       =     0x31 # Data format control
ADXL345_DATAX0            =     0x32
ADXL345_DATAX1            =     0x33
ADXL345_DATAY0            =     0x34
ADXL345_DATAY1            =     0x35
ADXL345_DATAZ0            =     0x36
ADXL345_DATAZ1            =     0x37
# --------------------------------

# set value
ADXL345_SCALE_MULTIPLIER= 0.00390625     # G/LSB. 1/256 = 0.00390625
ADXL345_BW_RATE_100HZ   = 0x0A           # 0A = 0000 1010
ADXL345_MEASURE         = 0x08           # 08 = 0000 1000
```

When accessing I2C sensor, we have to write code based on datasheet.

https://www.analog.com/media/en/technical-documentation/data-sheets/ADXL345.pdf

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: **read/write byte data**

```
def write_byte(self,adr, value):
    bus.write_byte_data(self.ADDRESS, adr, value)

def read_byte(self,adr):
    # read_byte_data: read one byte from "self.ADDRESS", offset "adr"
    return bus.read_byte_data(self.ADDRESS, adr)

def read_word(self,adr,rf=1):
    # rf=1 Little Endian Format, rf=0 Big Endian Format
    if (rf == 1):
        # read two byte data. ex: addr 50 and 51
        low = self.read_byte(adr)
        high = self.read_byte(adr+1)
    else:
        high = self.read_byte(adr)
        low = self.read_byte(adr+1)

    # combine "high" and "low" byte together.
    # shift "high" to left by 8 bits, then put "low"
    # like this: HHHH HHHH  LLLL LLLL
    val = (high << 8) + low

    return val

def read_word_2c(self,adr,rf=1):
    # adr = register address. ex: set "0x32", then "adr" is equal to 50
    val = self.read_word(adr,rf)

    if(val & (1 << 16 - 1)):
        return val - (1<<16)
    else:
        return val
```

Convert 16bit to 2's complement

1. Accelerometer code:
write value to specific address

```
# Register 0x2C: BW_RATE
self.write_byte(ADXL345_BW_RATE, ADXL345_BW_RATE_100HZ)
# write value= 0x0A = 0000 1010
# D3-D0: The default value is 0x0A,
# which translates to a 100 Hz output data rate.


# Register 0x2D: POWER_CTL
self.write_byte(ADXL345_POWER_CTL, ADXL345_MEASURE)
# write value: 0x08 = 0000 1000
# D3=1: set 1 for measurement mode.


# Register 0x31: DATA_FORMAT
self.write_byte(ADXL345_DATA_FORMAT, self.df_value)
# write value=0000 1000
# D3 = 1: the device is in full resolution mode,
# where the output resolution increases with the g range
# set by the range bits to maintain a 4 mg/LSB scale factor.
# D1 D0 = range. 00 = +-2g
```

1. Accelerometer code: write value to specific address

```
# Register 0x2C: BW_RATE
self.write_byte(ADXL345_BW_RATE, ADXL345_BW_RATE_100HZ)
# write value= 0x0A = 0000 1010
# D3-D0: The default value is 0x0A,
# which translates to a 100 Hz output data rate.
```

Register 0x2C—BW_RATE (Read/Write)

D7	D6	D5	D4	D3	D2	D1	D0
0	0	0	LOW_POWER	Rate			

D3D2D1D0 = 1010

LOW_POWER Bit

A setting of 0 in the LOW_POWER bit selects normal operation, and a setting of 1 selects reduced power operation, which has somewhat higher noise (see the Power Modes section for details).

Rate Bits

These bits select the device bandwidth and output data rate (see Table 7 and Table 8 for details). The default value is 0x0A, which translates to a 100 Hz output data rate. An output data rate should be selected that is appropriate for the communication protocol and frequency selected. Selecting too high of an output data rate with a low communication speed results in samples being discarded.

Output Data Rate (Hz)	Bandwidth (Hz)	Rate Code	I_{DD} (μA)
3200	1600	1111	140
1600	800	1110	90
800	400	1101	140
400	200	1100	140
200	100	1011	140
100	50	1010	140
50	25	1001	90
25	12.5	1000	60

1. Accelerometer code: write value to specific address

```
# Register 0x2D: POWER_CTL
self.write_byte(ADXL345_POWER_CTL, ADXL345_MEASURE)
# write value: 0x08 = 0000 1000
# D3=1: set 1 for measurement mode.
```

Register 0x2D—POWER_CTL (Read/Write)

D7	D6	D5	D4	D3	D2	D1	D0
0	0	Link	AUTO_SLEEP	Measure	Sleep	Wakeup	

D3 = 1

Measure Bit

A setting of 0 in the measure bit places the part into standby mode, and a setting of 1 places the part into measurement mode. The ADXL345 powers up in standby mode with minimum power consumption.

1. Accelerometer code: write value to specific address

```
# Register 0x31: DATA_FORMAT
self.write_byte(ADXL345_DATA_FORMAT, self.df_value)
# write value=0000 1000
# D3 = 1: the device is in full resolution mode,
# where the output resolution increases with the g range
# set by the range bits to maintain a 4 mg/LSB scale factor.
# D1 D0 = range. 00 = +-2g
```

Register 0x31—DATA_FORMAT (Read/Write)

D7	D6	D5	D4	D3	D2	D1	D0
SELF_TEST	SPI	INT_INVERT	0	FULL_RES	Justify	Range	

D3 = 1

D1D0 = 00

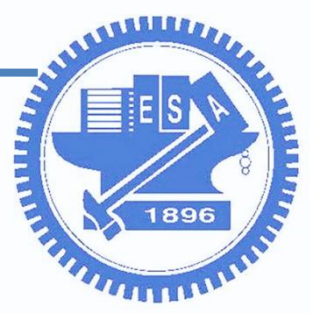
FULL_RES Bit

When this bit is set to a value of 1, the device is in full resolution mode, where the output resolution increases with the *g* range set by the range bits to maintain a 4 mg/LSB scale factor. When the FULL_RES bit is set to 0, the device is in 10-bit mode, and the range bits determine the maximum *g* range and scale factor.

Table 21. *g* Range Setting

Setting		
D1	D0	*g* Range
0	0	±2 *g*
0	1	±4 *g*
1	0	±8 *g*
1	1	±16 *g*

1. Accelerometer code: **read X/Y/Z raw data**



```
# RAW readings in LSB
# Register 0x32 to Register 0x37:
# DATAX0, DATAX1, DATAY0, DATAY1, DATAZ0, DATAZ1 (Read Only)
def getRawX(self) :
    self.Xraw = self.read_word_2c(ADXL345_DATAX0)
    return self.Xraw

def getRawY(self) :
    self.Yraw = self.read_word_2c(ADXL345_DATAY0)
    return self.Yraw

def getRawZ(self) :
    self.Zraw = self.read_word_2c(ADXL345_DATAZ0)
    return self.Zraw
```

1. Accelerometer code: **convert unit**

Parameter	Test Conditions	Min	Typ[1]	Max	Unit
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*

```
ADXL345_SCALE_MULTIPLIER= 0.00390625    # G/LSB. 1/256 = 0.00390625
self.Xcalibr = ADXL345_SCALE_MULTIPLIER

# Register 0x31: DATA_FORMAT
self.write_byte(ADXL345_DATA_FORMAT, self.df_value)
# D1 D0 = range. 00 = +-2g

# RAW readings in LSB
# Register 0x32 to Register 0x37:
# DATAX0, DATAX1, DATAY0, DATAY1, DATAZ0, DATAZ1 (Read Only)
def getRawX(self) :
    self.Xraw = self.read_word_2c(ADXL345_DATAX0)
    return self.Xraw

# G related readings in g
# This function is similar to filter. combine current value with previous one.
# plf = 1 means it only uses "current reading"
def getXg(self,plf = 1.0) :
    self.Xg = (self.getRawX() * self.Xcalibr - self.Xoffset) * plf \
    + (1.0 - plf) * self.Xg
    return self.Xg
# The offset unit is g.

# Absolute reading in m/s2
def getX(self,plf = 1.0) :
    self.X = self.getXg(plf) * EARTH_GRAVITY_MS2
    return self.X
```

SCALE_MULTIPLIER = 1/SENSITIVITY

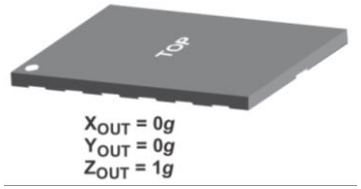
https://theccontinuum.com/2012/09/24/arduino-imu-pitch-roll-from-accelerometer/

Discussion 1

- 1. Based on the requirements, set correct value in the sample code
  - Output data rate: 100Hz
  - Range: +-2g
  - Convert LSB to G (by using SCALE_MULTIPLIER)

```
# set value
ADXL345_SCALE_MULTIPLIER= ???
ADXL345_BW_RATE_100HZ    = 0x???
ADXL345_MEASURE          = 0x???
```

- 2. Continuously measurement (infinite loop)
- 3. Calibrate your sensor (see next page)

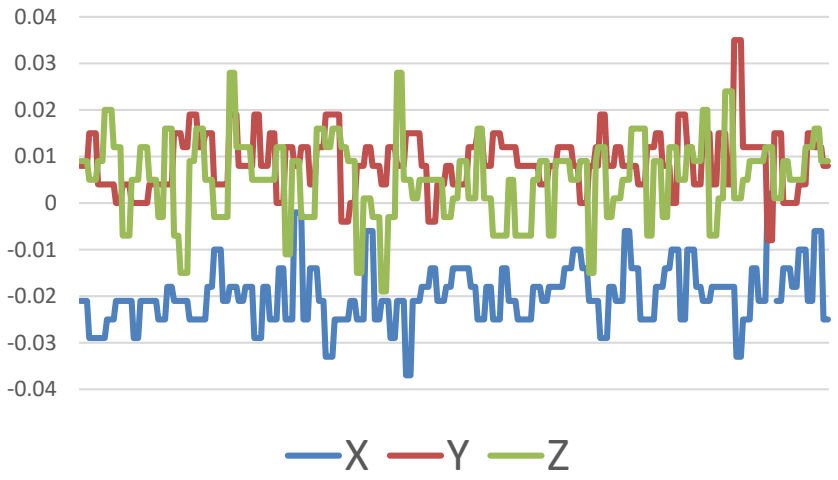


Discussion 1 (cont.)

- Theoretically: x,y,z report (0,0,1) when static
- Actually:

COM6 - PuTTY

```
pi@raspberrypi:~/gy801$ python 1accwu.py
x = -0.125 G,   y = 0.070 G,   z = 1.035 G
x = -0.125 G,   y = 0.070 G,   z = 1.035 G
x = -0.125 G,   y = 0.070 G,   z = 1.035 G
x = -0.125 G,   y = 0.062 G,   z = 1.000 G
x = -0.121 G,   y = 0.062 G,   z = 1.000 G
x = -0.121 G,   y = 0.062 G,   z = 1.000 G
x = -0.121 G,   y = 0.062 G,   z = 1.000 G
x = -0.121 G,   y = 0.074 G,   z = 1.031 G
x = -0.129 G,   y = 0.074 G,   z = 1.031 G
```



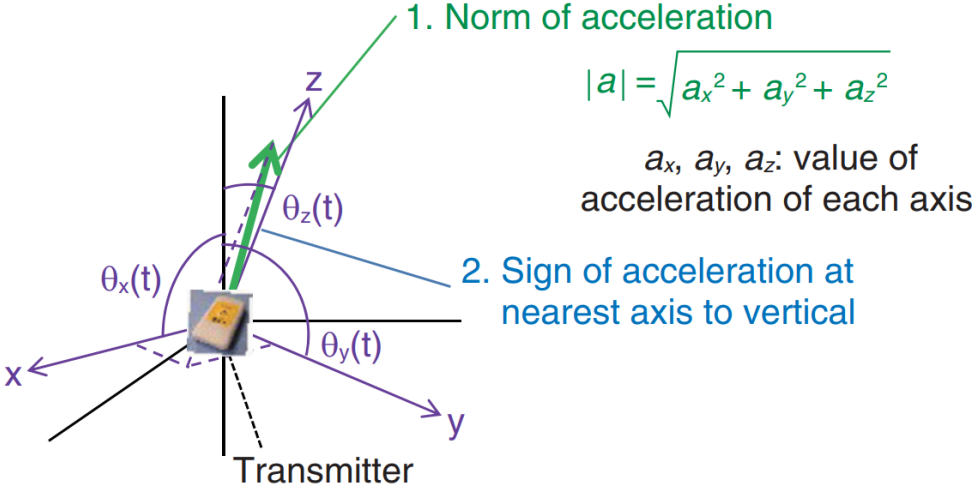
- Measure your static reading, then feedback to code

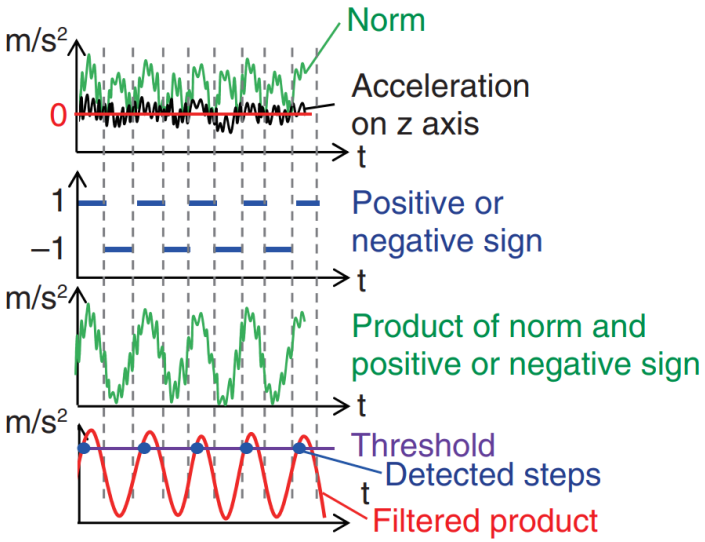
```
self.Xoffset = 0.0
self.Yoffset = 0.0
self.Zoffset = 0.0
```

Quiz 1

- Based on the result of discussion 1, calculate the norm of acceleration |a|
  - Formula:

    |a| = sqrt(x^2 + v^2 + z^2)





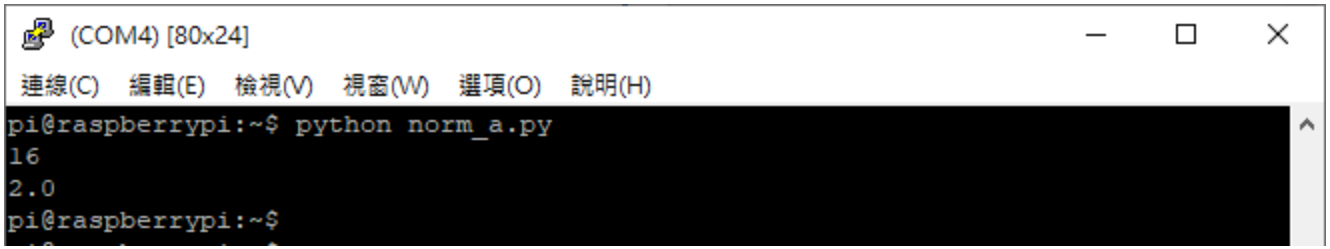
Application: step detection

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

Quiz 1

- Hint: Use python to calculate pow and sqrt

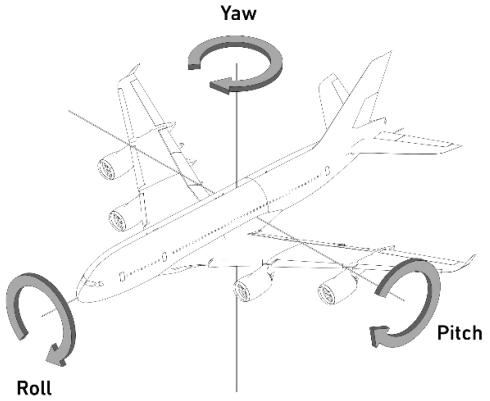
```
import numpy
x = 4

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

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

print y
print z
```



https://www.nxp.com/docs/en/application-note/AN3461.pdf
https://en.wikipedia.org/wiki/Aircraft_principal_axes

Quiz2: Roll, Pitch, Tilt

- Calculate posture:
  - Use normalized accelerometer reading G_p
  - Calculate: Roll, Pitch



(from AN3461.pdf)

Roll: $\tan \phi_{xyz} = \frac{G_{py}}{G_{pz}}$

Pitch: $\tan \theta_{xyz} = \frac{-G_{px}}{\sqrt{G_{py}^2 + G_{pz}^2}}$

Figure 3. Definition of Coordinate System and Rotation Axes

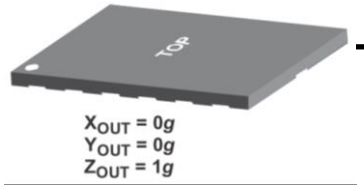
https://docs.python.org/2.7/library/math.html
https://docs.python.org/3/library/math.html

Math in Python

- Trigonometric functions
  - math.acos(x)
    - Return the arc cosine of x, in radians.
  - math.atan2(y, x)
    - Return atan(y / x), in radians. The result is between -pi and pi. The vector in the plane from the origin to point (x, y) makes this angle with the positive X axis. The point of atan2() is that the signs of both inputs are known to it, so it can compute the correct quadrant for the angle. For example, atan(1) and atan2(1, 1) are both pi/4, but atan2(-1, -1) is -3*pi/4.
- Angular conversion
  - math.degrees(x)
    - Convert angle x from radians to degrees.

Brief summary

- What can we obtain from accelerometer?
  - 1. Movement along with xyz-axis
    - Unit: byte, G, or m/s^2
  - 2. Posture (Roll, Pitch)
    - Unit: Radians or Degree



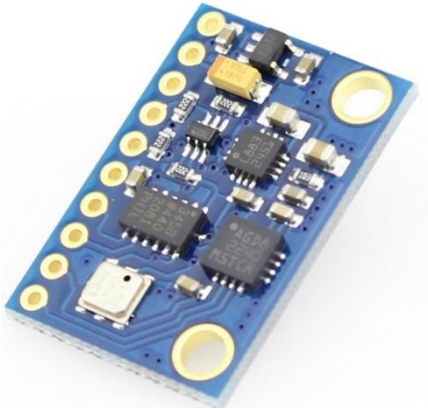
Read value → ACC data: Ax, Ay, Az (byte, G, or m/s^2)

↓ calculation

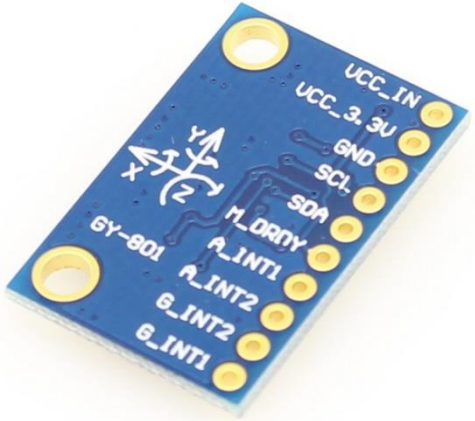
Posture: Roll, Pitch (Radians or Degree)

Outline

- 嵌入式應用: 人體活動偵測
  - 加速度、陀螺儀...等

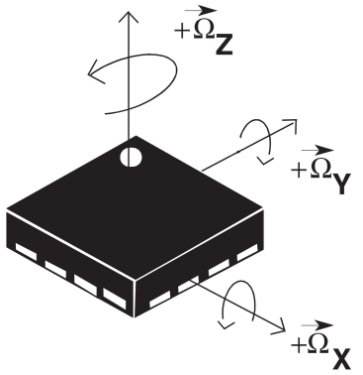


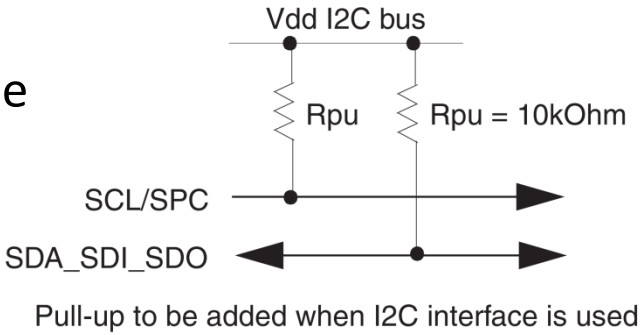
- GY801 (I2C sensor)
  1. 3-axis Accelerometer, Gyroscope, magnetometer and pressure
  2. ADXL345：Accelerometer
  3. L3G4200：Gyroscope
  4. HMC5883：Magnetometer
  5. BMP085：Pressure



2. Gyroscope (L3G4200D)

- Features
  - 3-Axis angular rate sensor
  - 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



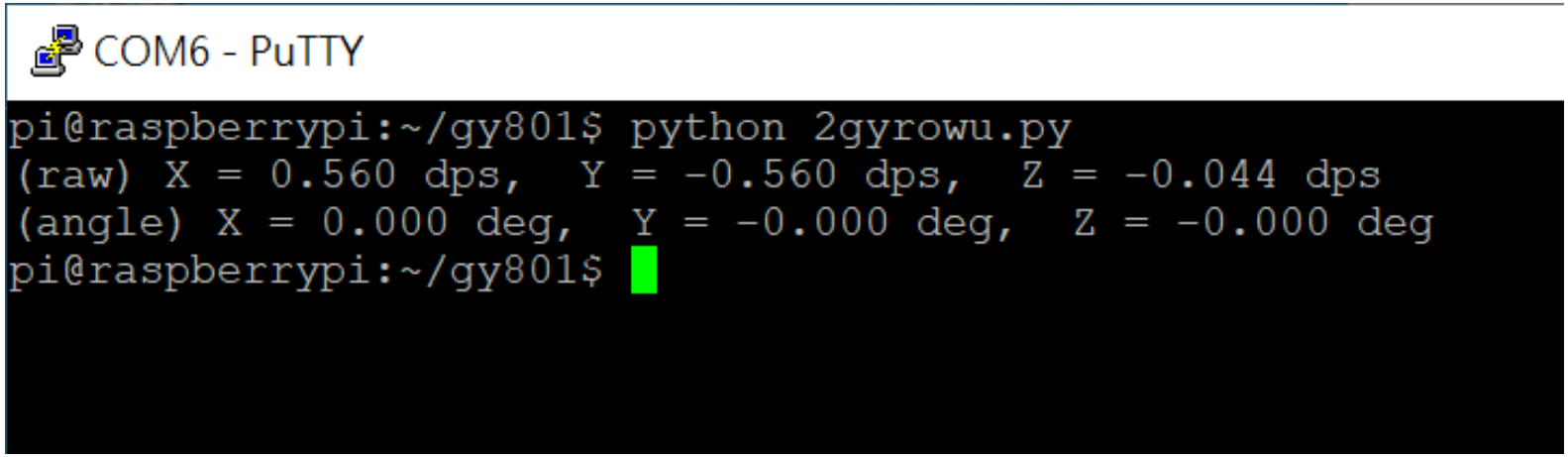


Pull-up to be added when I2C interface is used

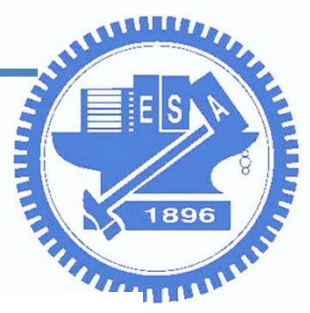
http://dlnmh9ip6v2uc.cloudfront.net/datasheets/Sensors/Gyros/3-Axis/17116.pdf
http://www.playrobot.com/gyro/284-sparkfun-tri-axis-gyro-breakout-l3g4200d.html

2. Gyroscope code

- Sample code results:



2. Gyroscope code: **define address, convert unit**



```
7   L3G4200D_ADDRESS          =    0x69
8   L3G4200D_CTRL_REG1        =    0x20 # CTRL_REG1 (20h)
9   L3G4200D_CTRL_REG4        =    0x23 # CTRL_REG4 (23h)
10  L3G4200D_OUT_X_L          =    0x28 # X-axis angular rate data.
11  L3G4200D_OUT_X_H          =    0x29 # The value is expressed as two's complement.
12  L3G4200D_OUT_Y_L          =    0x2A
13  L3G4200D_OUT_Y_H          =    0x2B
14  L3G4200D_OUT_Z_L          =    0x2C
15  L3G4200D_OUT_Z_H          =    0x2D
```

```
68          # FS=250dps, Sensitivity = 8.75 mdps/digit
69          self.gain_std = 0.00875
70
71          # 0x20: CTRL_REG1, write 0x0F = 0000 1111
72          self.write_byte(L3G4200D_CTRL_REG1, 0x0F)
73          # DR1-DR0 = 00; BW1-BW0 = 00 -> 100Hz, Cut-off=12.5
74          # PD, Zen, Yen, Xen = 1111
75
76          # 0x23: CTRL_REG4, write 0x80 = 0000 1000
77          self.write_byte(L3G4200D_CTRL_REG4, 0x80)
78          # BDU=continous update; BLE=Data LSB
79          # FS1-FS0=00 -> 250 dps
80
81          self.setCalibration()
82
83      def setCalibration(self) :
84          gyr_r = self.read_byte(L3G4200D_CTRL_REG4)
85
86          self.gain = 2 ** ( gyr_r & 48 >> 4) * self.gain_std
```

2. Gyroscope code: **write value to specific address**

```
71          # 0x20: CTRL_REG1, write 0x0F = 0000 1111
72          self.write_byte(L3G4200D_CTRL_REG1, 0x0F)
73          # DR1-DR0 = 00; BW1-BW0 = 00 -> 100Hz, Cut-off=12.5
74          # PD, Zen, Yen, Xen = 1111
```

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 code: **write value to specific address**

```
76          # 0x23: CTRL_REG4, write 0x80 = 0000 1000
77          self.write_byte(L3G4200D_CTRL_REG4, 0x80)
78          # BDU=continous update; BLE=Data LSB
79          # FS1-FS0=00 -> 250 dps
```

CTRL_REG4 (23h)

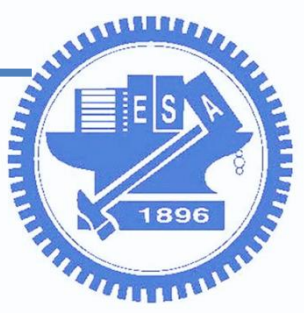
Table 30. CTRL_REG4 register

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 code: **convert raw data to degree**




```
    # read raw data
    def getRawX(self):
        self.Xraw = self.read_word_2c(L3G4200D_OUT_X_L)
        return self.Xraw

    # similar to filter. combine current value with previous one.
    # plf = 1 means it only uses "current reading"
    def getX(self,plf = 1.0):
        self.X = ( self.getRawX() * self.gain ) * plf + (1.0 - plf) * self.X
        return self.X

    # convert dps to angle. LP = loop period.
    # Degree per second * second = degree
    def getXangle(self,plf = 1.0) :
        if self.t0x is None : self.t0x = time.time()
        t1x = time.time()
        LP = t1x - self.t0x
        self.t0x = t1x
        self.Xangle = self.getX(plf) * LP
        return self.Xangle
```

Discussion 2

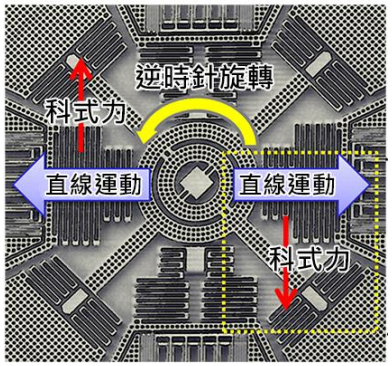
- 1. Based on the requirements, set correct value in the sample code
  - Data rate: 100Hz, cut-off = 12.5
  - Full Scale selection = 250 dps
  - Set Sensitivity for 250 dps (by using SCALE_MULTIPLIER)

```
# set value
self.gain_std = ??     # dps/digit

self.write_byte(L3G4200D_CTRL_REG1, 0x??)
self.write_byte(L3G4200D_CTRL_REG4, 0x??)
```

- 2. Continuously measurement (infinite loop)

Brief summary

- What can we obtain from gyroscope?
  - 1. rotation (angular velocity)
    - Unit: byte, DPS (Degree per Second)
  - 2. rotated angle (integral “angular velocity” to “angle”)
    - Unit: degree. You can convert it to rad.



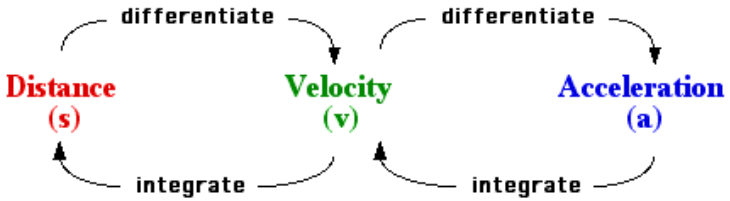
Discussion 3

- We can obtain ax/ay/az from accelerometer. How to calculate the distance?

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

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

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

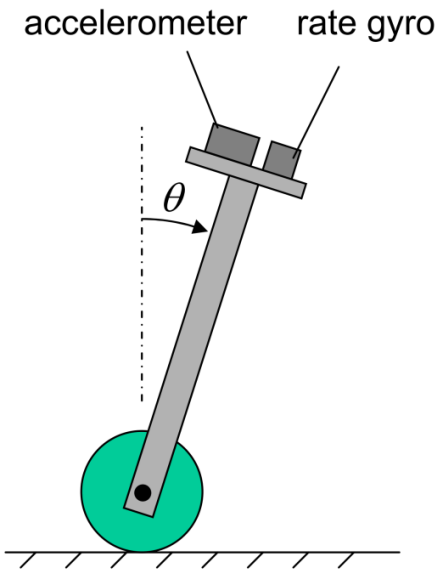



```
12      # convert dps to angle. LP = loop period.
13      # Degree per second * second = degree
14      def getXangle(self,plf = 1.0) :
15          if self.t0x is None : self.t0x = time.time()
16          t1x = time.time()
17          LP = t1x - self.t0x
18          self.t0x = t1x
19          self.Xangle = self.getX(plf) * LP
20          return self.Xangle
```

Hint: In Gyro sample code, it convert dps to angle.

Sensor fusion

- Accelerometer is good in long term.
- Gyroscope is good in short term.
  - Use Complementary filter to integrate them
  - Enhanced rotation angle

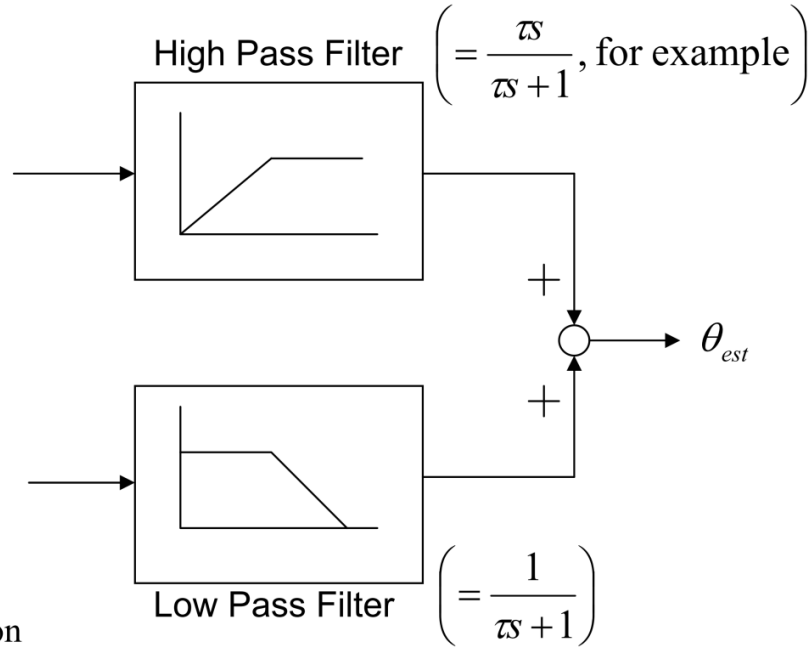


$\theta \approx \int (\text{angular rate})\, dt$

- not good in long term due to integration

$\theta \approx \sin^{-1}\left(\frac{\text{accel. output}}{g}\right)$

- only good in long term
- not proper during fast motion

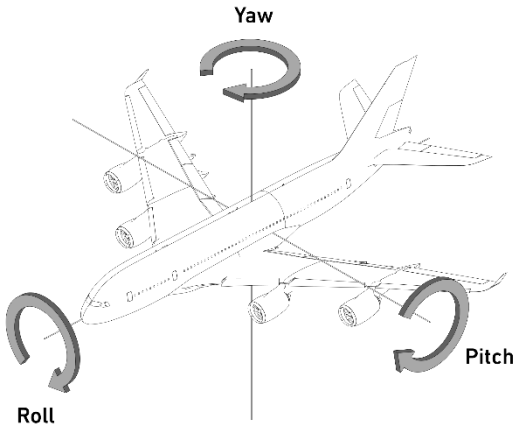


Quiz3: Sensor fusion

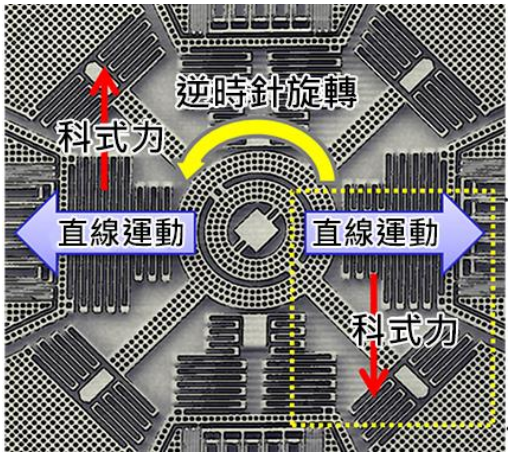
- Calculate angle based on accelerometer and gyroscope
  - Complementary filter: Enhanced rotation angle

Angle = 0.98 * (angle + gyroData * dt) + 0.02 * accData

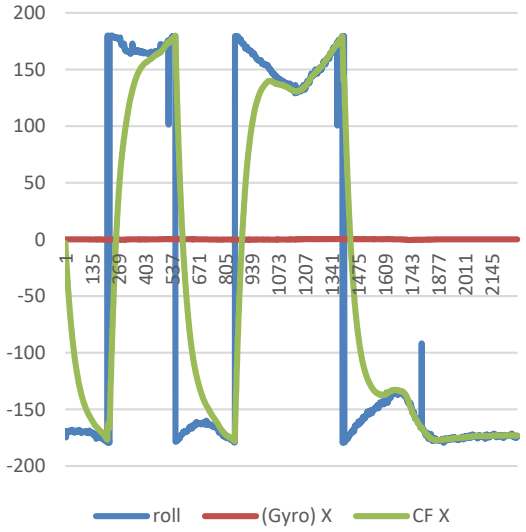
CF_Angle[t] = 0.98 * (CF_Angle[t-1] + gyroData[t] * dt) + 0.02 * accData[t]



We can get **Roll, Pitch** from accelerometer.



When rotating the sensor, we can get **Angular velocity.**



Quiz3: Sensor fusion

- Complementary filter: Enhanced rotation angle

*CF_Angle[t] = 0.98 * (CF_Angle[t-1] + gyroData[t] * dt) + 0.02 * accData[t]*
(from digikey's website)

$$\text{pitch}[t] = (\text{pitch}[t-1] + \text{Xangle}_{gyro}[t]) * 0.98 + \text{pitch}_{acc}[t] * 0.02$$

$$\text{roll}[t] = (\text{roll}[t-1] + \text{Yangle}_{gyro}[t]) * 0.98 + \text{roll}_{acc}[t] * 0.02$$

```
# convert dps to angle. LP = loop period.
# Degree per second * second = degree
def getXangle(self,plf = 1.0) :
    if self.t0x is None : self.t0x = time.time()
    t1x = time.time()
    LP = t1x - self.t0x
    self.t0x = t1x
    self.Xangle = self.getX(plf) * LP
    return self.Xangle
```

Roll: $\tan\phi_{xyz} = \frac{G_{py}}{G_{pz}}$

Pitch: $\tan\theta_{xyz} = \frac{-G_{px}}{\sqrt{G_{py}^2+G_{pz}^2}}$

Summary

- Practice Lab (accelerometer, gyroscope)
- Write down the answer for discussion
  - Discussion:
    - 1&2: Based on the requirements, set correct value in the sample code
    - 3: How to calculate distance from accelerometer
    - **(放code截圖就可以了)**
    - Deadline: Before 11:59, 4/3
- Write code for Quiz 1 - 3 (infinite loop), then demonstrate it to TAs
  - (**X/Y/Zoffset should be measured**)
  - Quiz1: Calculate the norm of acceleration |a|
  - Quiz2: Roll, Pitch, Tilt
  - Quiz3: Sensor fusion (pitch, roll with complementary filter)
    - Deadline: Before 15:10, 3/27
    - Late Demo: Before 15:10, 4/10