嵌入式系統總整與實作

曾煜棋、吳昆儒

National Yang Ming Chiao Tung University

Last week

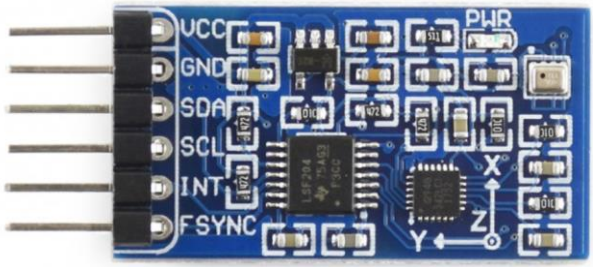
- How to use wire to connect devices?
- How to write code to read sensing data on GPIO?

LED

HC-SR04

Ultrasonic

ICM20948



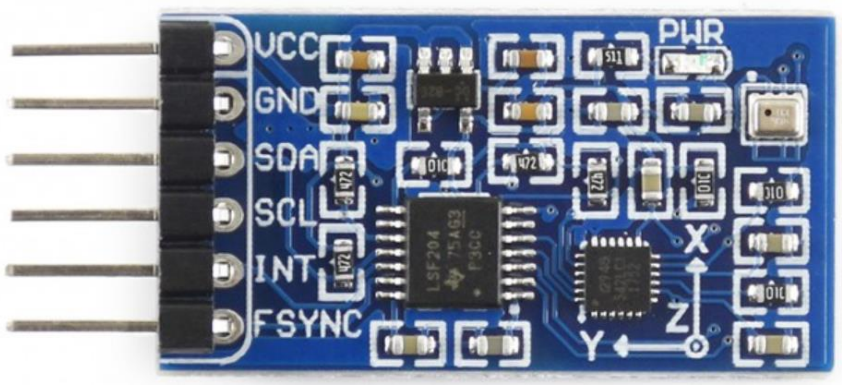
IMU
(Inertial measurement unit)

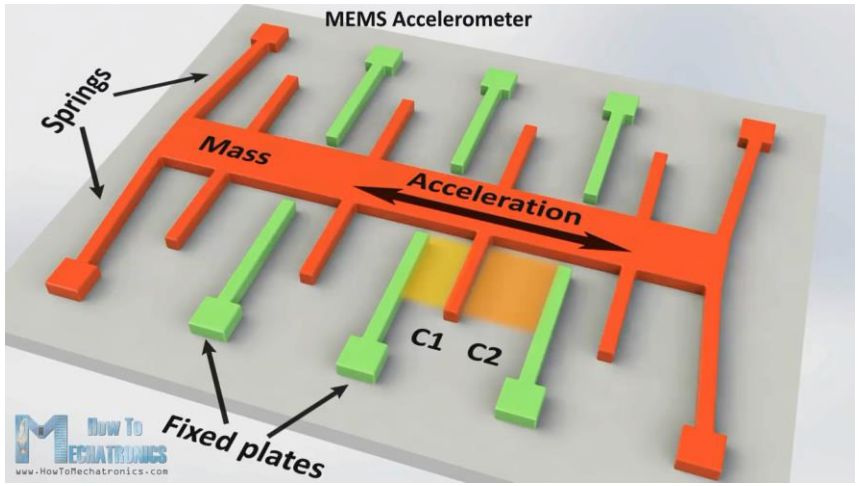
This week

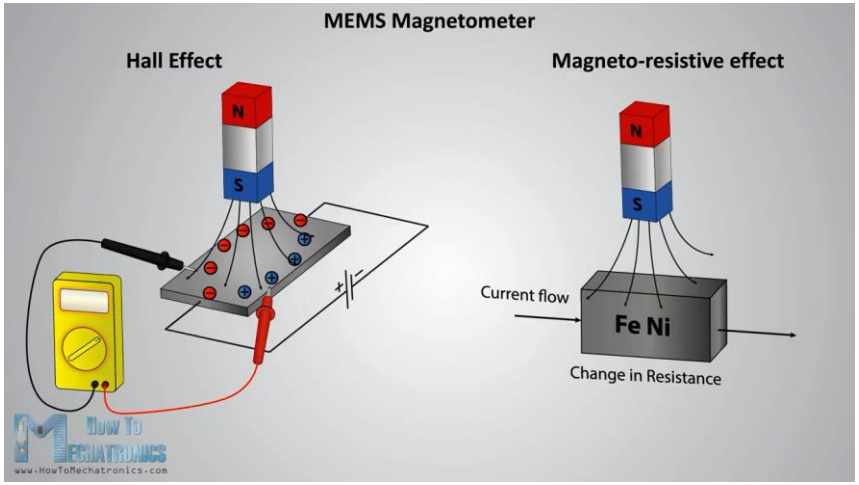
- Process sensing data
  - The information of IMU
  - Datasheet and code configuration
  - IMU applications
    - Calibration
    - Calculate distance, rotation angle and heading
    - Fall detection

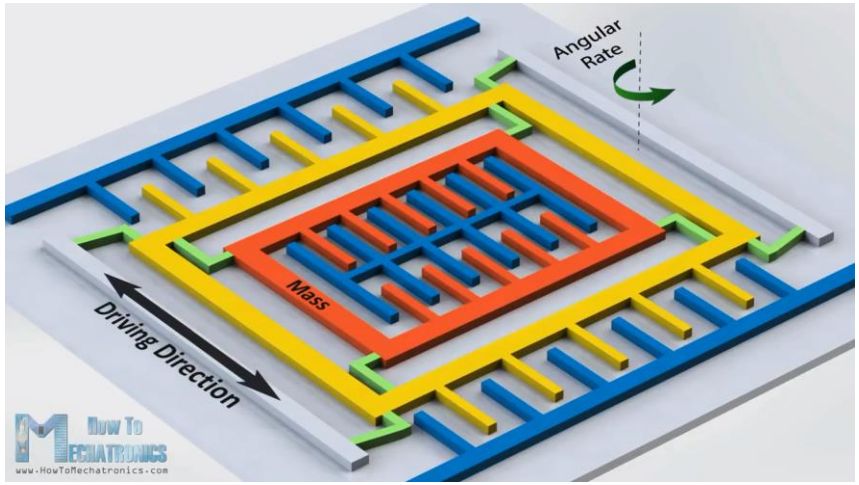
https://www.youtube.com/watch?v=eqZgxR6eRjo

How MEMS Work (Accelerometer, Gyroscope, Magnetometer)









Barometer

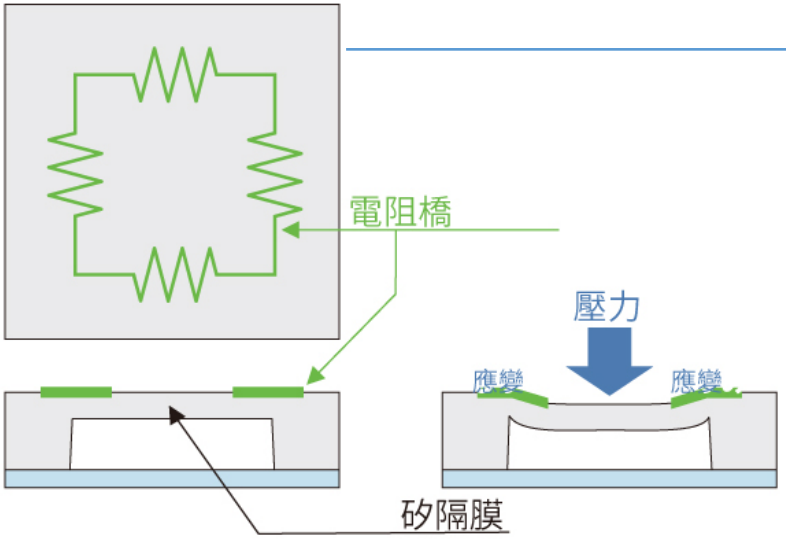
1. Altitude (BMP085)

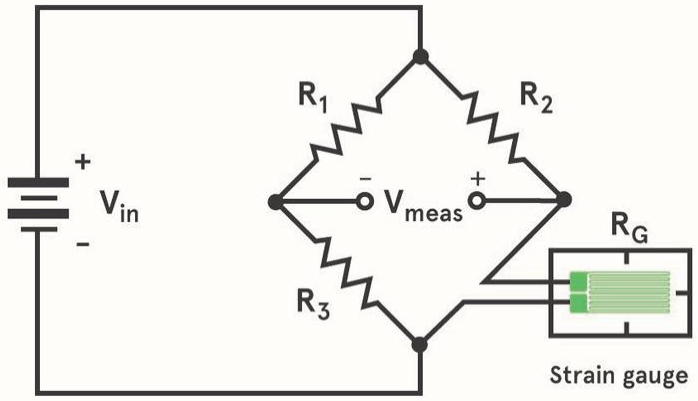
- Pressure sensing range: 300-1100 hPa
  - (9000m to -500m above sea level)
- Up to 0.03hPa / 0.25m resolution
- -40 to +85°C operational range
- +-2°C temperature accuracy
  - Temperature measurement included
- 2-pin i2c interface on chip

https://cdn-shop.adafruit.com/datasheets/BST-BMP280-DS001-11.pdf

Sensor - Barometer

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

Robert Bosch is the world market leader for pressure sensors in automotive and consumer applications. Bosch's proprietary APSM (Advanced Porous Silicon Membrane) MEMS manufacturing process is fully CMOS compatible and allows a hermetic sealing of the cavity in an all silicon process. The BMP280 is based on Bosch's proven Piezo-resistive pressure sensor technology featuring high EMC robustness, high accuracy and linearity and long term stability.

BMP280 measurement cycle

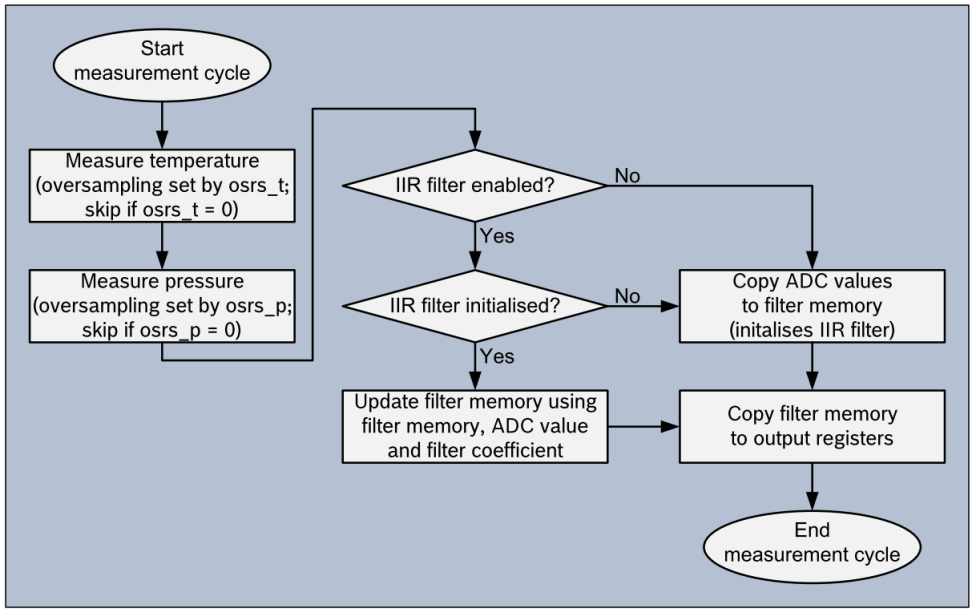


Figure 2: BMP280 measurement cycle

3.11 Output compensation

The BMP280 output consists of the ADC output values. However, each sensing element behaves differently, and actual pressure and temperature must be calculated using a set of calibration parameters. The recommended calculation in chapter 3.11.3 uses fixed point arithmetic.

Read calibration data

```
def load_calibration_params():
    # Read calibration data from EEPROM of BMP280
    calib = []
    for i in range(0x88, 0x88+24):
        calib.append(bus.read_byte_data(BMP280_ADDRESS, i))
    calib.append(bus.read_byte_data(BMP280_ADDRESS, 0xA1))
    return calib
```

Table 17: Compensation parameter storage, naming and data type

Register Address LSB / MSB	Register content	Data type
0x88 / 0x89	dig_T1	unsigned short
0x8A / 0x8B	dig_T2	signed short
0x8C / 0x8D	dig_T3	signed short
0x8E / 0x8F	dig_P1	unsigned short
0x90 / 0x91	dig_P2	signed short
0x92 / 0x93	dig_P3	signed short
0x94 / 0x95	dig_P4	signed short
0x96 / 0x97	dig_P5	signed short
0x98 / 0x99	dig_P6	signed short
0x9A / 0x9B	dig_P7	signed short
0x9C / 0x9D	dig_P8	signed short
0x9E / 0x9F	dig_P9	signed short
0xA0 / 0xA1	reserved	reserved

Read data

- Read raw data
  - Temperature
  - Pressure

```python
def read_bmp280_data():
    # Read temperature and pressure raw data from BMP280
    # Temperature
    msb = bus.read_byte_data(BMP280_ADDRESS, 0xFA)
    lsb = bus.read_byte_data(BMP280_ADDRESS, 0xFB)
    xlsb = bus.read_byte_data(BMP280_ADDRESS, 0xFC)
    adc_T = (msb << 16) | (lsb << 8) | xlsb
    adc_T >>= 4

    # Pressure
    msb = bus.read_byte_data(BMP280_ADDRESS, 0xF7)
    lsb = bus.read_byte_data(BMP280_ADDRESS, 0xF8)
    xlsb = bus.read_byte_data(BMP280_ADDRESS, 0xF9)
    adc_P = (msb << 16) | (lsb << 8) | xlsb
    adc_P >>= 4

    return adc_T, adc_P
```

Table 18: Memory map

Register Name	Address	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0	Reset state
temp_xlsb	0xFC	temp_xlsb<7:4>				0	0	0	0	0x00
temp_lsb	0xFB	temp_lsb<7:0>								0x00
temp_msb	0xFA	temp_msb<7:0>								0x80
press_xlsb	0xF9	press_xlsb<7:4>				0	0	0	0	0x00
press_lsb	0xF8	press_lsb<7:0>								0x00
press_msb	0xF7	press_msb<7:0>								0x80
config	0xF5	t_sb[2:0]			filter[2:0]				spi3w_en[0]	0x00
ctrl_meas	0xF4	osrs_t[2:0]			osrs_p[2:0]			mode[1:0]		0x00
status	0xF3					measuring[0]			im_update[0]	0x00
reset	0xE0	reset[7:0]								0x00
id	0xD0	chip_id[7:0]								0x58
calib25...calib00	0xA1…0x88	calibration data								individual

Compensation formula

3.11 Output compensation

The BMP280 output consists of the ADC output values. However, each sensing element behaves differently, and actual pressure and temperature must be calculated using a set of calibration parameters. The recommended calculation in chapter 3.11.3 uses fixed point arithmetic.

```python
def compensate_temperature(adc_T):
    # Compensation algorithm from BMP280 datasheet
    var1 = (((adc_T >> 3) - (dig_T1 << 1)) * dig_T2) >> 11
    var2 = (((((adc_T >> 4) - dig_T1) * ((adc_T >> 4) - dig_T1)) >> 12) *
    dig_T3) >> 14
    t_fine = var1 + var2
    temperature = (t_fine * 5 + 128) >> 8
    return temperature, t_fine

def compensate_pressure(adc_P, t_fine):
    # Compensation algorithm from BMP280 datasheet
    var1 = t_fine - 128000
    var2 = var1 * var1 * dig_P6
    var2 = var2 + ((var1 * dig_P5) << 17)
    var2 = var2 + (dig_P4 << 35)
    var1 = ((var1 * var1 * dig_P3) >> 8) + ((var1 * dig_P2) << 12)
    var1 = (((1 << 47) + var1) * dig_P1) >> 33

    if var1 == 0:
        return 0  # Avoid division by zero

    p = 1048576 - adc_P
    p = (((p << 31) - var2) * 3125) // var1
    var1 = (dig_P9 * (p >> 13) * (p >> 13)) >> 25
    var2 = (dig_P8 * p) >> 19

    pressure = ((p + var1 + var2) >> 8) + (dig_P7 << 4)
    return pressure
```

```c
// Returns temperature in DegC, resolution is 0.01 DegC. Output value of "
// t_fine carries fine temperature as global value
BMP280_S32_t t_fine;
BMP280_S32_t bmp280_compensate_T_int32(BMP280_S32_t adc_T)
{
    BMP280_S32_t var1, var2, T;

    var1  = ((((adc_T>>3) - ((BMP280_S32_t)dig_T1<<1))) * ((BMP280_S32_t)d
    var2  = (((((adc_T>>4) - ((BMP280_S32_t)dig_T1)) * ((adc_T>>4) - ((BMP
        ((BMP280_S32_t)dig_T3)) >> 14;
    t_fine = var1 + var2;
    T  = (t_fine * 5 + 128) >> 8;
    return T;
}

// Returns pressure in Pa as unsigned 32 bit integer. Output value of "963
BMP280_U32_t bmp280_compensate_P_int32(BMP280_S32_t adc_P)
{
    BMP280_S32_t var1, var2;
    BMP280_U32_t p;
    var1 = (((BMP280_S32_t)t_fine)>>1) - (BMP280_S32_t)64000;
    var2 = (((var1>>2) * (var1>>2)) >> 11 ) * ((BMP280_S32_t)dig_P6);
```

Results

- Run sample code:

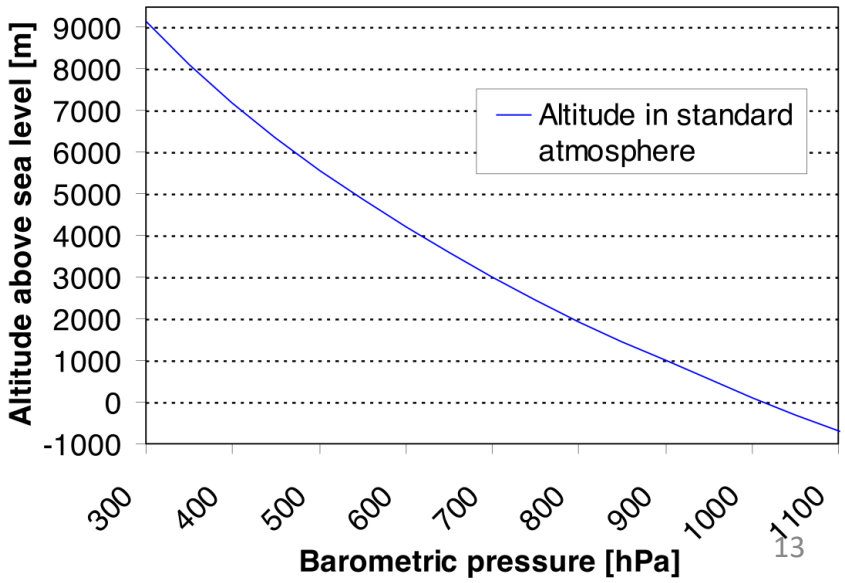
```
pi@raspberrypi:~/lab3 $ python bmp_280.py
Temperature: 23.64 C
Pressure: 835.54 hPa
Temperature: 23.64 C
Pressure: 835.54 hPa
```

```python
while True:
    # Read raw temperature and pressure data
    adc_T, adc_P = read_bmp280_data()

    # Compensate raw temperature and pressure
    temperature, t_fine = compensate_temperature(adc_T)
    pressure = compensate_pressure(adc_P, t_fine)

    print(f"Temperature: {temperature / 100.0:.2f} C")
    print(f"Pressure: {pressure / 25600.0:.2f} hPa")

    time.sleep(1)
```

Quiz 1

- Convert pressure to altitude
- Formula:
  - **altitude = (1 - (pressure_Pa / sea_level_pressure_Pa)**(1/5.255)) * 44330**
  - sea_level_pressure: 海平面的標準氣壓值
    - 通常使用 101325 Pa

$$\text{altitude} = 44330 * \left(1 - \left(\frac{p}{p_0}\right)^{\frac{1}{5.255}}\right)$$



IMU configuration

10 DOF IMU Sensor (D)

- 10 DOF:
  - 3-axis gyroscope, 3-axis accelerometer, 3-axis magnetometer, and barometric altimeter
- Chip module
  - ICM20948 (加速度+陀螺儀+AK09916磁力計), BMP280 (氣壓計)
- Accelerometer Features:
  - Measurement range (configurable): ±2, ±4, ±8, ±16g
- Gyroscope Features:
  - Measurement range (configurable): ±250, ±500, ±1000, ±2000°/sec
- Compass/Magnetometer Features:
  - Measurement range: ±4900μT
- Barometric pressure sensor Features:
  - Measurement range: 300~1100hPa (Altitude: +9000m ~ -500m)

Datasheet and code configuration

- Sample code: 10dof_imu_reading.py (from last week)
- Accelerometer
  - self.set_accelerometer_sample_rate(125)
  - self.set_accelerometer_low_pass(enabled=True, mode=5)
  - self.set_accelerometer_full_scale(16)
- Gyroscope
  - self.set_gyro_sample_rate(100)
  - self.set_gyro_low_pass(enabled=True, mode=5)
  - self.set_gyro_full_scale(250)
- Magnetometer
  - self.mag_write(AK09916_CNTL2, 0x01)

Accelerometer config

- 加速度計設定 (sample_rate)

```
ICM20948_ACCEL_SMPLRT_DIV_1 = 0x10
ICM20948_ACCEL_SMPLRT_DIV_2 = 0x11

def set_accelerometer_sample_rate(self, rate=125):
        self.bank(2)
        rate = int((1125.0 / rate) - 1) # 125Hz - 1.125 kHz / (1 + rate)
        self.write(ICM20948_ACCEL_SMPLRT_DIV_1, (rate >> 8) & 0xff)
        self.write(ICM20948_ACCEL_SMPLRT_DIV_2, rate & 0xff)
```

7	6	5	4	3	2	1	0

10.12 ACCEL_SMPLRT_DIV_2

Name: ACCEL_SMPLRT_DIV_2
Address: 17 (11h)
Type: USR2
Bank: 2
Serial IF: R/W
Reset Value: 0x00

BIT	NAME	FUNCTION
7:0	ACCEL_SMPLRT_DIV[7:0]	LSB for ACCEL sample rate div. ODR is computed as follows: 1.125 kHz/(1+ACCEL_SMPLRT_DIV[11:0])

10.11 ACCEL_SMPLRT_DIV_1

Name: ACCEL_SMPLRT_DIV_1
Address: 16 (10h)
Type: USR2
Bank: 2
Serial IF: R/W
Reset Value: 0x00

BIT	NAME	FUNCTION
7:4	-	Reserved.
3:0	ACCEL_SMPLRT_DIV[11:8]	MSB for ACCEL sample rate div.

Accelerometer config

- 加速度計設定 (full scale range)

```
ICM20948_ACCEL_CONFIG = 0x14

def set_accelerometer_full_scale(self, scale=16):
    self.bank(2)
    value = self.read(ICM20948_ACCEL_CONFIG) & 0b11111001
    value |= {2: 0b00, 4: 0b01, 8: 0b10, 16: 0b11}[scale] << 1
    self.write(ICM20948_ACCEL_CONFIG, value)
```

10.15 ACCEL_CONFIG

Name: ACCEL_CONFIG
Address: 20 (14h)
Type: USR2
Bank: 2
Serial IF: R/W
Reset Value: 0x01

7	6	5	4	3	2	1	0

BIT	NAME	FUNCTION
7:6	-	Reserved.
5:3	ACCEL_DLPFCFG[2:0]	Accelerometer low pass filter configuration as shown in Table 18.
2:1	ACCEL_FS_SEL[1:0]	Accelerometer Full Scale Select: 00: ±2g 01: ±4g 10: ±8g 11: ±16g
0	ACCEL_FCHOICE	0: Bypass accel DLPF. 1: Enable accel DLPF.

Accelerometer config

- 加速度計設定 (low pass filter): 減少輸出雜訊，提高資料穩定性

```
def set_accelerometer_low_pass(self, enabled=True, mode=5):
        self.bank(2)
        value = self.read(ICM20948_ACCEL_CONFIG) & 0b10001110
        if enabled:
            value |= 0b1
        value |= (mode & 0x07) << 3
        self.write(ICM20948_ACCEL_CONFIG, value)
```

ACCEL_FCHOICE	ACCEL_DLPFCFG	OUTPUT		
		3DB BW [HZ]	NBW [HZ]	RATE [HZ]
0	x	1209	1248	4500
1	0	246.0	265.0	1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095
1	1	246.0	265.0	1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095
1	2	111.4	136.0	1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095
1	3	50.4	68.8	1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095
1	4	23.9	34.4	1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095
1	5	11.5	17.0	1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095
1	6	5.7	8.3	1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095
1	7	473	499	1125/(1+ACCEL_SMPLRT_DIV)Hz where ACCEL_SMPLRT_DIV is 0, 1, 2,...4095

7	6	5	4	3	2	1	0

Gyroscope config

- 陀螺儀設定 (sample_rate)

ICM20948_GYRO_SMPLRT_DIV = 0x00

7	6	5	4	3	2	1	0

```
def set_gyro_sample_rate(self, rate=125):
        self.bank(2)
        rate = int((1125.0 / rate) - 1) # 125Hz - 1.125 kHz / (1 + rate)
        self.write(ICM20948_GYRO_SMPLRT_DIV, rate)
```

10.1 GYRO_SMPLRT_DIV

Name: GYRO_SMPLRT_DIV
Address: 0 (00h)
Type: USR2
Bank: 2
Serial IF: R/W
Reset Value: 0x00

BIT	NAME	FUNCTION
7:0	GYRO_SMPLRT_DIV[7:0]	Gyro sample rate divider. Divides the internal sample rate to generate the sample rate that controls sensor data output rate, FIFO sample rate, and DMP sequence rate. **NOTE:** This register is only effective when FCHOICE = 1'b1 (FCHOICE_B register bit is 1'b0), and (0 < DLPF_CFG < 7). ODR is computed as follows: 1.1 kHz/(1+GYRO_SMPLRT_DIV[7:0])

Gyroscope config

- 陀螺儀設定 (full scale range)

```
ICM20948_GYRO_CONFIG_1 = 0x01

def set_gyro_full_scale(self, scale=250):
        self.bank(2)
        value = self.read(ICM20948_GYRO_CONFIG_1) & 0b11111001
        value |= {250: 0b00, 500: 0b01, 1000: 0b10, 2000: 0b11}[scale] << 1
        self.write(ICM20948_GYRO_CONFIG_1, value)
```

10.2 GYRO_CONFIG_1

Name: GYRO_CONFIG_1
Address: 1 (01h)
Type: USR2
Bank: 2
Serial IF: R/W
Reset Value: 0x01

BIT	NAME	FUNCTION
7:6	-	Reserved.
5:3	GYRO_DLPFCFG[2:0]	Gyro low pass filter configuration as shown in Table 16.
2:1	GYRO_FS_SEL[1:0]	Gyro Full Scale Select: 00 = ±250 dps 01= ±500 dps 10 = ±1000 dps 11 = ±2000 dps
0	GYRO_FCHOICE	0 – Bypass gyro DLPF. 1 – Enable gyro DLPF.

7	6	5	4	3	2	1	0

Gyroscope config

- 陀螺儀設定 (low pass filter): 減少輸出雜訊，提高資料穩定性

```
def set_gyro_low_pass(self, enabled=True, mode=5):
    self.bank(2)
    value = self.read(ICM20948_GYRO_CONFIG_1) & 0b11000110
    if enabled:
        value |= 0b1
    value |= (mode & 0x07) << 3
    self.write(ICM20948_GYRO_CONFIG_1, value)
```

GYRO_FCHOICE	GYRO_DLPFCFG	OUTPUT		
		3DB BW [HZ]	NBW [HZ]	RATE [HZ]
0	x	12106	12316	9000
1	0	196.6	229.8	1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255
1	1	151.8	187.6	1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255
1	2	119.5	154.3	1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255
1	3	51.2	73.3	1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255
1	4	23.9	35.9	1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255
1	5	11.6	17.8	1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255
1	6	5.7	8.9	1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255
1	7	361.4	376.5	1125/(1+GYRO_SMPLRT_DIV)Hz where GYRO_SMPLRT_DIV is 0, 1, 2,...255

Table 16. Gyroscope Configuration 1

7	6	5	4	3	2	1	0

5:3 = GYRO_DLPFCFG[2:0]
2:1 = GYRO_FS_SEL[1:0]
0 = GYRO_FCHOICE

Magnetometer config

- 磁力計設定

```
def mag_write(self, reg, value):
        self.bank(3)
        self.write(ICM20948_I2C_SLV0_ADDR, AK09916_I2C_ADDR)
        self.write(ICM20948_I2C_SLV0_REG, reg)
        self.write(ICM20948_I2C_SLV0_DO, value)
        self.bank(0)
        self.trigger_mag_io()

self.mag_write(AK09916_CNTL2, 0x01)
```

13.5 CNTL2: CONTROL 2

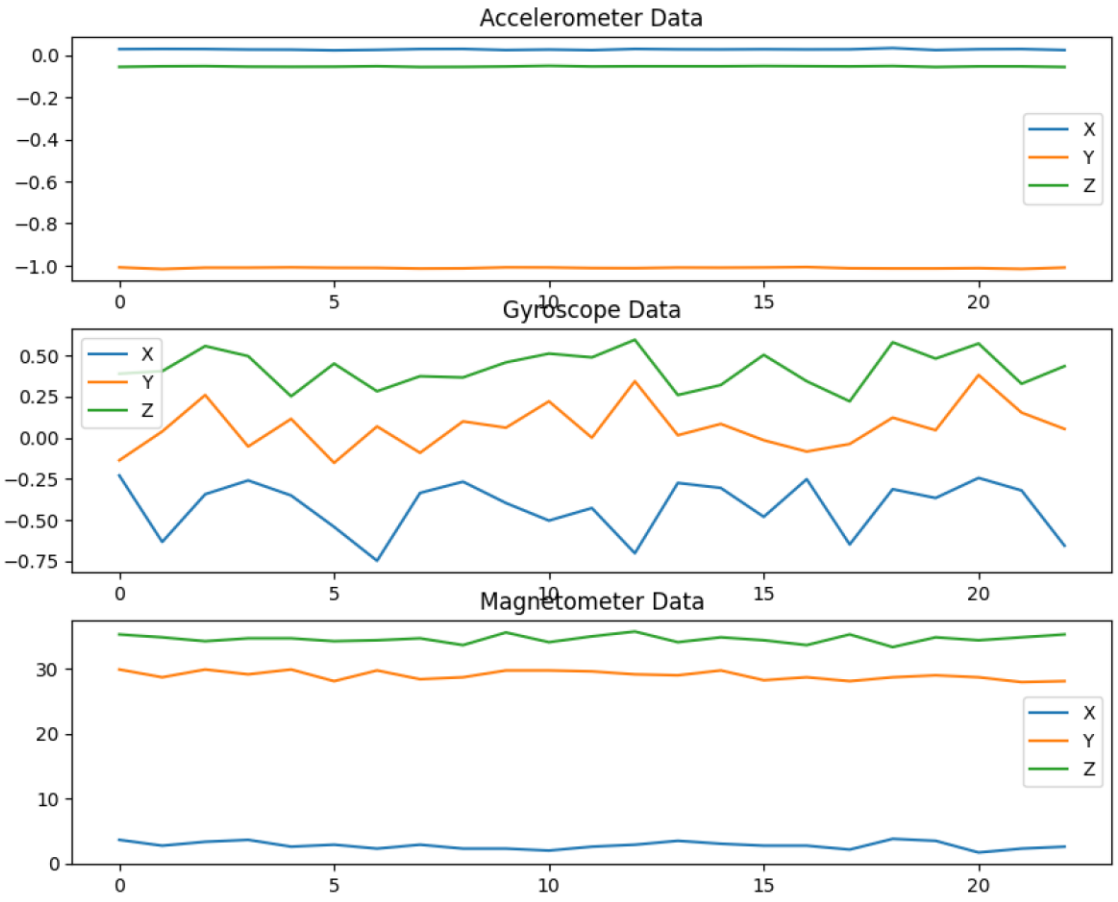
ADDR	REGISTER NAME	D7	D6	D5	D4	D3	D2	D1	D0
READ/WRITE REGISTER									
31H	CNTL2	0	0	0	MPDE4	MODE3	MODE2	MODE1	MODE0
Reset		0	0	0	0	0	0	0	0

7	6	5	4	3	2	1	0

MODE[4:0] bits: Operation mode setting
- “00000”: Power-down mode
- “00001”: Single measurement mode
- “00010”: Continuous measurement mode 1
- “00100”: Continuous measurement mode 2
- “00110”: Continuous measurement mode 3
- “01000”: Continuous measurement mode 4
- “10000”: Self-test mode

Calibration

IMU results


Accelerometer Data
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
0
5
10
15
20
X
Y
Z
Gyroscope Data
0.50
0.25
0.00
−0.25
−0.50
−0.75
0
5
10
15
20
X
Y
Z
Magnetometer Data
30
20
10
0
0
5
10
15
20
X
Y
Z

Calibration

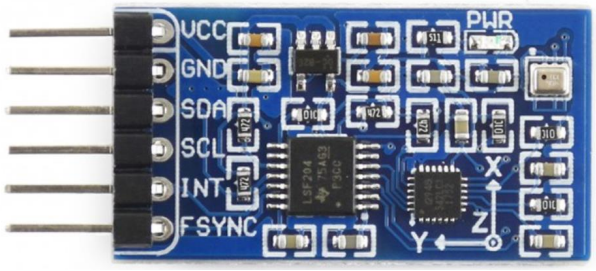
- Why calibration?
  - 靜置狀態的讀數，理論上應該是固定值
  - 但實際上會有飄動，通常稱為漂移drift錯誤 (存在offset需要修正)

- 加速度計 (Accelerometer)：
  - 一般可藉由靜置狀態的量測數值做校正（只顯示重力）。
- 陀螺儀 (Gyroscope)：
  - 在靜置狀態，通常也會有非零的讀數
- 磁力計 (Magnetometer)：
  - 受到環境磁場影響，有硬鐵和軟鐵影響，需要進行磁場校正

Accelerometer calibration

- 加速度計的output理論上在靜置時應符合：
  - 當IMU水平放置且靜止時，其測到的數值理應為：(0, 0, ±1) G

- 校正步驟：
  - 將IMU擺放在桌上，確認XYZ的方向與相應的理論值 (ex: 0, 0, +1)
  - 靜置數秒取得大量的讀數
  - 針對XYZ軸的讀數各自取平均值，再減去作為offset
  - 即: acc_x_calibrated = accel_x_raw - offset_x



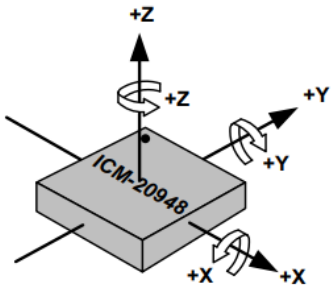
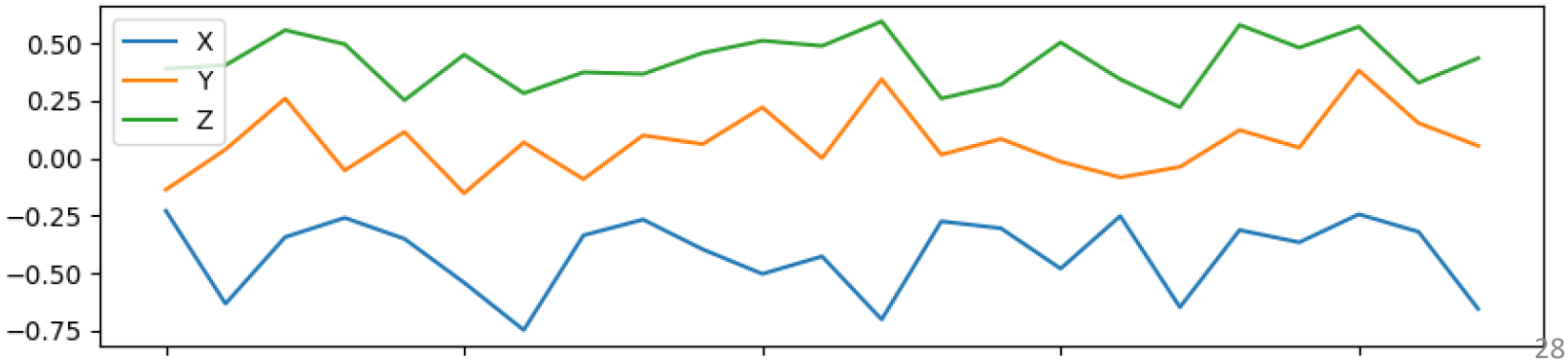


Figure 12. Orientation of Axes of Sensitivity and Polarity of Rotation

Gyroscope calibration

- 陀螺儀通常有bias（漂移），即使靜置也會有讀數

- 校正步驟：(跟上頁流程一樣)
  - 將IMU擺放在桌上，靜置數秒取得大量的讀數
  - 將XYZ的讀數取平均值當作offset
  - 量測值須扣除offset，即：gyro_x_calibrated = gyro_x_raw - offset_x



計算偏移量

- 先收集靜態資訊 (EX: 1000筆 or 記錄一分鐘)
- 偏移量(offset)
  - offset_x = average(accel_x_data); average(gyro_x_data)
  - offset_y = average(accel_y_data); average(gyro_y_data)
  - offset_z = average(accel_z_data); average(gyro_z_data)

- 程式碼:

```
acc_x_calibrated = accel_x_raw - offset_x
acc_y_calibrated = accel_y_raw - offset_y
acc_z_calibrated = accel_z_raw - offset_z

gyro_x_calibrated = gyro_x_raw - offset_x
gyro_y_calibrated = gyro_y_raw - offset_y
gyro_z_calibrated = gyro_z_raw - offset_z
```

儲存量測結果

- python 10dof_imu_reading.py >> result.txt

```
pi@raspberrypi:~/lab3 $ python 10dof_imu_reading.py
00.03    -1.01    -0.05    -0.02    00.02    00.83    02.70    29.70    35.10
00.03    -1.01    -0.05    -0.31    00.16    00.50    01.65    28.65    34.80
00.03    -1.01    -0.05    -0.35    00.01    00.54    02.70    29.40    33.30
00.03    -1.01    -0.05    -0.58    -0.08    00.45    03.45    28.20    35.85
00.03    -1.01    -0.06    -0.33    -0.05    00.35    02.25    28.95    34.05
00.03    -1.01    -0.06    -0.62    00.13    00.33    03.00    28.95    35.10
00.03    -1.01    -0.05    -0.54    00.05    00.53    02.85    28.35    34.65
```

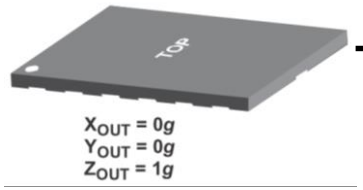
results.txt

00.03	-1.01	-0.06	-0.40	00.02	00.73	02.85	28.80	34.65
00.02	-1.01	-0.06	-0.29	00.17	00.43	02.25	28.65	35.85
00.03	-1.01	-0.06	-0.46	-0.15	00.47	02.10	29.55	34.65
00.03	-1.01	-0.06	-0.38	00.12	00.29	02.10	28.05	34.95
00.02	-1.01	-0.06	-0.29	-0.11	00.52	02.55	29.85	34.20
00.03	-1.01	-0.06	-0.25	-0.06	00.60	02.25	29.70	35.10
00.03	-1.01	-0.05	-0.44	00.02	00.44	01.80	28.80	34.95
00.03	-1.01	-0.06	-0.48	00.06	00.28	03.30	29.85	34.65
00.03	-1.01	-0.05	-0.39	00.18	00.49	02.25	28.20	34.80
00.03	-1.01	-0.06	-0.57	00.05	00.27	01.35	27.30	34.65

acc gyro mag

ACC Brief summary

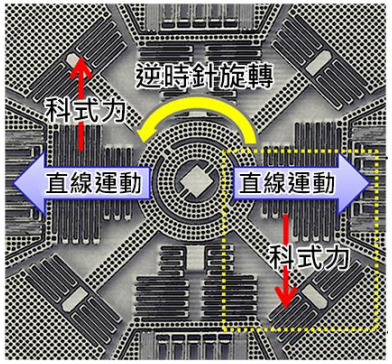
- What can we obtain from accelerometer?
  - 1. Movement along with xyz-axis
    - Unit: byte, G, or m/s^2
  - 2. Posture (Roll, Pitch)
    - Unit: Radians or Degree

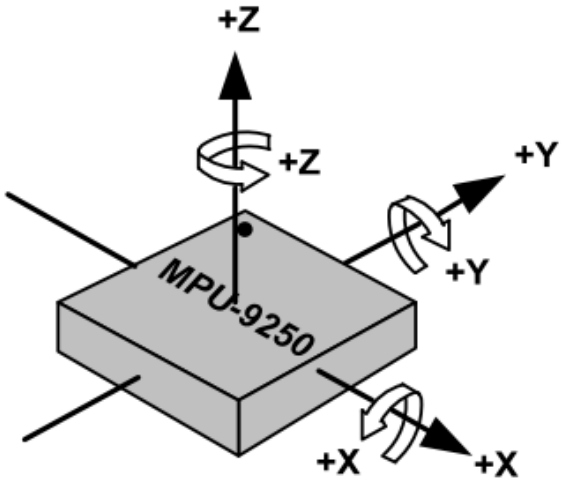


Read value → ACC data: Ax, Ay, Az (byte, G, or m/s^2) → calculation → Posture: Roll, Pitch (Radians or Degree)

Gyro 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.





Quiz 2-1

- Acceleration vs velocity vs distance

$$v = v_0 + at$$

$$s = v_0 t + \frac{1}{2} a t^2$$

- Try to calculate distance based on accelerometer
  - With calibration

```
307 if __name__ == "__main__":
308     imu = ICM20948()
309 
310     while True:
311         mx, my, mz = imu.read_magnetometer_data()
312         ax, ay, az, gx, gy, gz = imu.read_accelerometer_gyro_data()
313 
314         print(f"""
315 Accel: {ax:05.2f} {ay:05.2f} {az:05.2f}
316 Gyro:  {gx:05.2f} {gy:05.2f} {gz:05.2f}
317 Mag:   {mx:05.2f} {my:05.2f} {mz:05.2f}""")
318 
319         time.sleep(0.25)
```

Quiz 2-2

- Rotation (angular velocity) vs rotated angle

$$v = v_0 + at$$

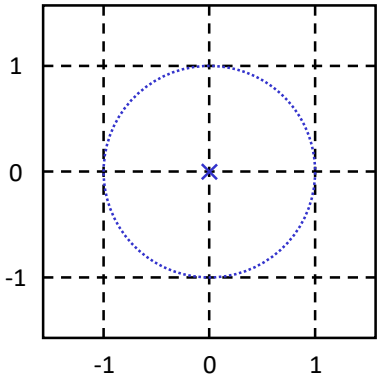
- Try to calculate rotation angle based on gyroscope
  - With calibration

```
307 if __name__ == "__main__":
308     imu = ICM20948()
309 
310     while True:
311         mx, my, mz = imu.read_magnetometer_data()
312         ax, ay, az, gx, gy, gz = imu.read_accelerometer_gyro_data()
313 
314         print(f"""
315 Accel: {ax:05.2f} {ay:05.2f} {az:05.2f}
316 Gyro:  {gx:05.2f} {gy:05.2f} {gz:05.2f}
317 Mag:   {mx:05.2f} {my:05.2f} {mz:05.2f}""")
318 
319         time.sleep(0.25)
```

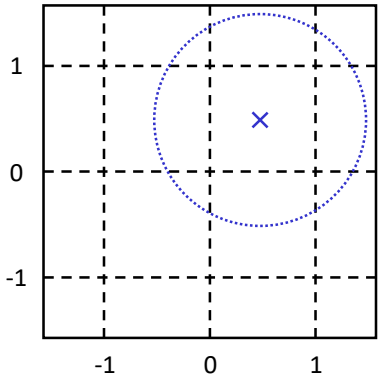
Magnetometer Calibration

- Compass distortion
  - Hard Iron (硬磁干擾: 固定強度的磁干擾物)
  - Soft Iron (軟磁干擾: 會改變強度及方向, 可扭曲磁力線的干擾物)

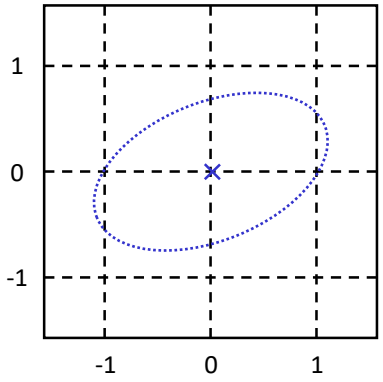
(Perfect)



No distortion

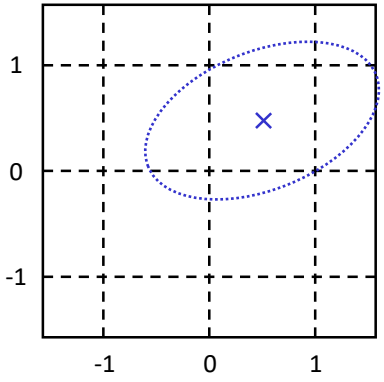


Hard Iron distortion



Soft Iron distortion

(Reality)



Soft & Hard Iron distortion

Compass Calibration


```
print "Now repeatedly rotate the hmc5883l around all three axes"

for i in range(0,100):
    x_out = read_word_2c(3)
    y_out = read_word_2c(7)
    z_out = read_word_2c(5)

    if x_out < minx:
        minx=x_out

    if y_out < miny:
        miny=y_out

    if z_out < minz:
        minz=z_out

    if x_out > maxx:
        maxx=x_out

    if y_out > maxy:
        maxy=y_out

    if z_out > maxz:
        maxz=z_out

print "x offset: ", (maxx + minx) / 2
print "y offset: ", (maxy + miny) / 2
print "z offset: ", (maxz + minz) / 2
```

執行期間, 請將磁力計朝向xyz三周轉動360度

```
x: -514 - 387, y: -577 - 0, z: -267 - 777
x: -514 - 387, y: -577 - 0, z: -267 - 777
x: -514 - 387, y: -577 - 0, z: -267 - 777
x: -514 - 387, y: -577 - 0, z: -267 - 777
x: -514 - 387, y: -577 - 0, z: -267 - 777
results:
x: min, max = -514, 387
y: min, max = -577, 0
z: min, max = -267, 777
x offset:  -64
y offset:  -289
z offset:  255
pi@raspberrypi:~/gy801$
```

```
    def __init__(self) :
        #Class Properties
        self.X = None
        self.Y = None
        self.Z = None
        self.angle = None
        self.Xoffset = 0
        self.Yoffset = 0
        self.Zoffset = 0
```

Discussion 1

- Does your magnetometer have distortion?
  - Record the raw data and plot it. (for XY, YZ, XZ)

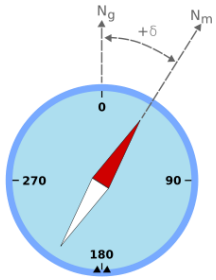
Fig source: https://makersportal.com/blog/calibration-of-a-magnetometer-with-raspberry-pi

APP: Compass

- Declination angle

-4°32’’

```
194         # Declination Angle
195         self.angle_offset = ( -1 * (4 + (32/60))) / (180 / pi)
196         # Formula: (deg + (min / 60.0)) / (180 / M_PI);
197         # ex: Hsinchu = Magnetic Declination: -4 deg, 32 min
198         # declinationAngle = ( -1 * (4 + (32/60))) / (180 / pi)
199         # http://www.magnetic-declination.com/
```



http://www.magnetic-declination.com/

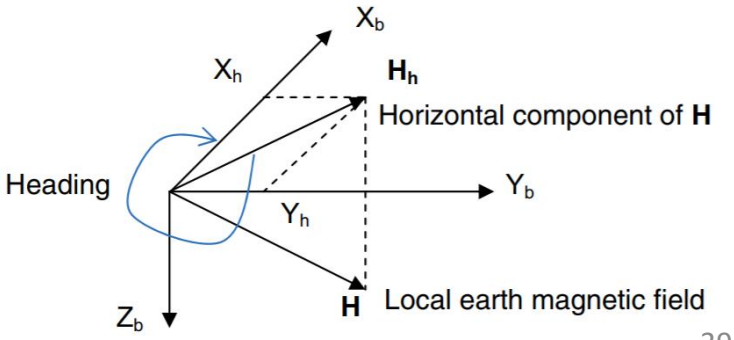
Compass code: calculate heading

```
220     def getX(self):
221         self.X = (self.read_word_2c(HMC5883L_DO_X_H, rf=0) - self.Xoffset) * self.scale
222         return self.X
223
224     def getY(self):
225         self.Y = (self.read_word_2c(HMC5883L_DO_Y_H, rf=0) - self.Yoffset) * self.scale
226         return self.Y
227
228     def getZ(self):
229         self.Z = (self.read_word_2c(HMC5883L_DO_Z_H, rf=0) - self.Zoffset) * self.scale
230         return self.Z
231
232     def getHeading(self):
233         bearing  = degrees(atan2(self.getY(), self.getX()))
234
235         if (bearing < 0):
236             bearing += 360
237         if (bearing > 360):
238             bearing -= 360
239         self.angle = bearing + self.angle_offset
240         return self.angle
```

Declination angle

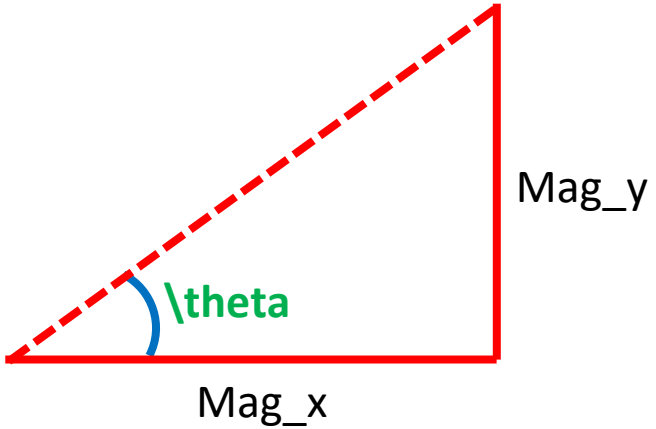
- Heading:
  - 1. measure **two orthogonal components** of the magnetic vector (**mx, my**)
  - 2. calculate the heading as the **arctangent** of their ratio

$$\operatorname{atan2}(y,x) = \begin{cases} \arctan\left(\frac{y}{x}\right) & x > 0 \\ \arctan\left(\frac{y}{x}\right) + \pi & y \geq 0, x < 0 \\ \arctan\left(\frac{y}{x}\right) - \pi & y < 0, x < 0 \\ +\frac{\pi}{2} & y > 0, x = 0 \\ -\frac{\pi}{2} & y < 0, x = 0 \\ \text{undefined} & y = 0, x = 0 \end{cases}$$



https://cdn-shop.adafruit.com/datasheets/AN203_Compass_Heading_Using_Magnetometers.pdf

Compass heading



\theta = arctan(y/x)

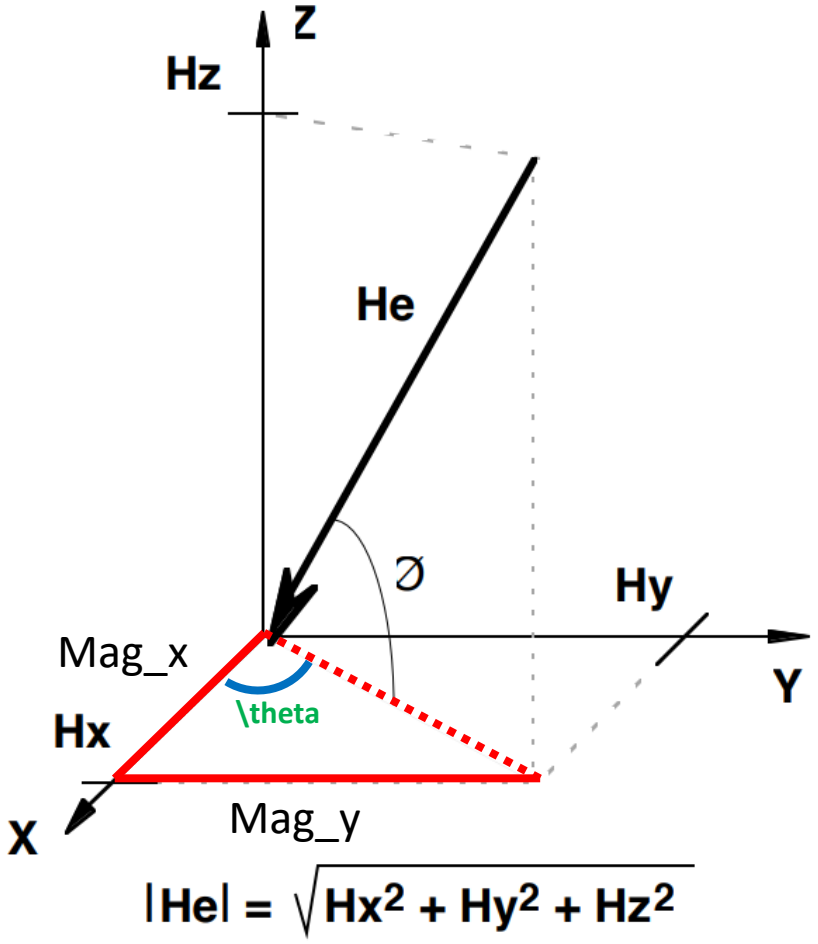


Figure 2 - Earth's Field (He) in 3 Axis

App: Fall detection

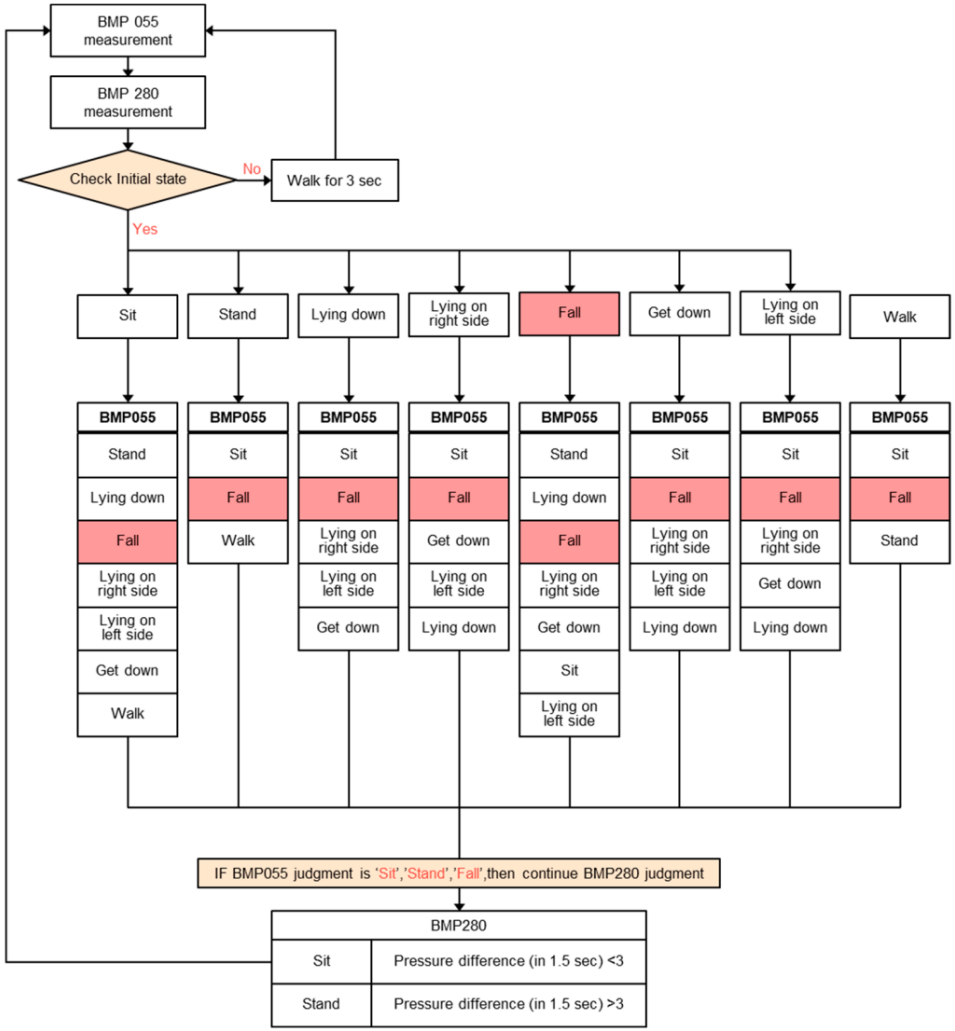
Tracking of fall detection using IMU sensor: An IoHT application
VB Semwal, A Kumar, P Nargesh, V Soni - Machine Learning, Image …, 2023 - Springer
… developed the methodology to detect the fall of a person … fall recovery capability & fall diagnosis information can be utilized to avoid the fall and to provide assistant after fall detection of …
☆ 儲存 99 引用 被引用 7 次 相關文章 全部共 2 個版本 »

Synthetic IMU datasets and protocols can simplify fall detection experiments and optimize sensor configuration
J Tang, B He, J Xu, T Tan, Z Wang… - IEEE transactions on …, 2024 - ieeexplore.ieee.org
… As per our investigation, existing IMU datasets in the field of fall detection suffer from issues such as limited data volume and inconsistent experimental paradigms. In contrast, an …
☆ 儲存 99 引用 相關文章 全部共 7 個版本

Development of LSTM Model for Fall Prediction Using IMU
V Chandramouleesvar, ME Swetha… - Advances in Science …, 2023 - Trans Tech Publ
… Existing fall detection and prediction systems focus on physiological factors such as gait, vision, cognition, and medical history of individuals. Serious injuries such as broken bones or a …
☆ 儲存 99 引用 被引用 1 次 相關文章

[HTML] TinyFallNet: a lightweight pre-impact fall detection model
B Koo, X Yu, S Lee, S Yang, D Kim, S Xiong, Y Kim - Sensors, 2023 - mdpi.com
… -classification models to preimpact fall detection using IMU and showed that additional tuning … learning models based on IMU and the development of applications based on IMU data. …
☆ 儲存 99 引用 被引用 2 次 相關文章 全部共 10 個版本 »

Fall detection paper



Paper: Fall Recognition Based on an IMU Wearable Device and Fall Verification through a Smart Speaker and the IoT

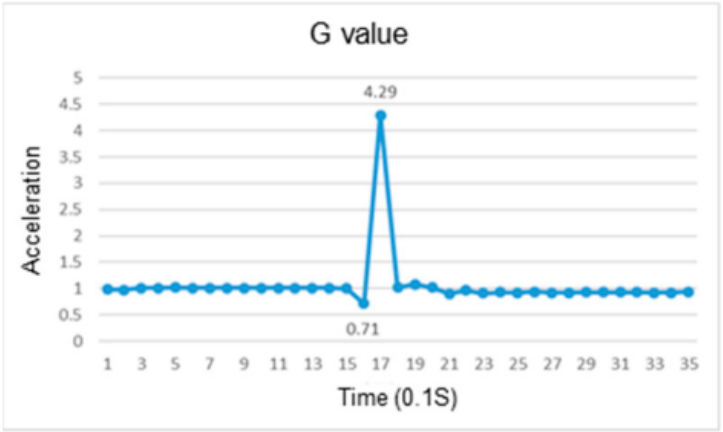
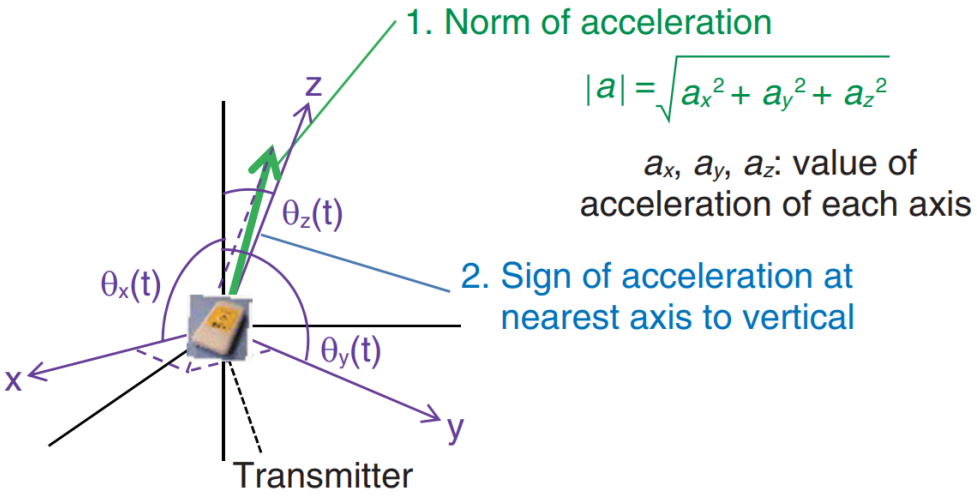


Fig. The change in the resultant force of falling backward while sitting on a chair.

Quiz 3

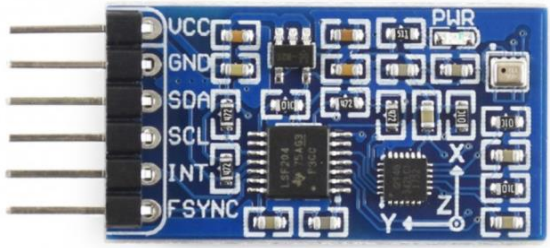
- Fall detection with notification
  - Use the total acceleration:
    - total_acc = sqrt(acc_x^2 + acc_y^2 + acc_z^2)
  - Observe the G value when falling down
  - Turn on LED if occurred



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
```

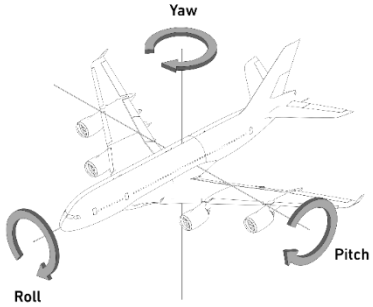
IMU summary

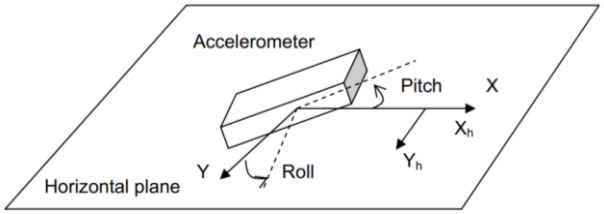


1. Accelerometer: Acceleration(加速度) -> Roll, Pitch (傾斜姿態)
2. Gyroscope: Angular velocity(角速度) -> Rotated angle (旋轉角度)
3. Magnetometer: Magnetic field(磁場) -> Heading (方位)
4. Barometer: Pressure(大氣壓力) -> Altitude (高度)

IMU information

- Roll, Pitch: Accelerometer + Gyroscope
- Heading: Magnetometer
- Altitude: Barometer





Sensor Fusion:

- Accelerometer + Gyroscope: Enhanced Rotation angle
- Accelerometer + Gyroscope + Magnetometer: Tilt-compensate compass (heading)

Summary

- Labs: process IMU data
  - The information of IMU
  - Datasheet and code configuration
  - IMU applications

- Write down the answer for discussion, upload to e-campus. Deadline (before next class): 13:10, 3/28(Fri.)
  - Discussion1: Does your magnetometer have distortion?
  - 書面問答, 請上傳到e3

- Quiz 1-3:
  - 1. Convert pressure to altitude
  - 2. Calculate distance and rotated angle
  - 3. Fall detection with notification
  - 請於課堂上完成, 找助教demo