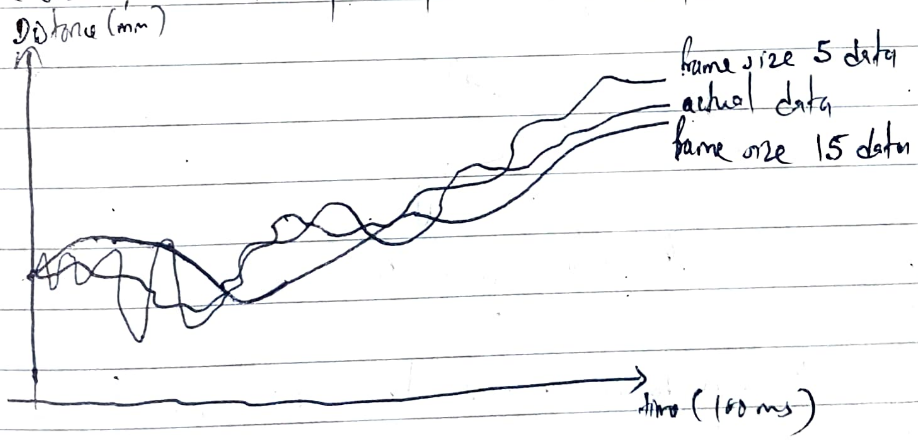
Filters ~ an implementation either in software or hardware to reduce noise or unwanted response from a system's input. (@ Robu)

→ Filters for Rangefinders → Rolling average (Moving Average), Kalman filter, Standard Deviation, Median Filters, Distance filter??

* Moving Average: ~smooths out the irregularity occurring in data
  main types → Simple Moving Average (SMA) → Cumulative Moving Average (CMA)
  ↳ Exponential Moving Average (EMA)
  ↳ Weighted Moving Average (WMA)

→ time series constructed by taking averages of several sequential values of another time series.
→ type of mathematical convolution
→ finite impulse response filter / low pass filter
→ typical for 1D signal model ??

* Algorithm:
  → select frame size (no. of elements in an array i.e. no. of data to be averaged)
  less the frame size, more responsive the output is, bigger the frame size, less ~~less exp.~~ responsive the output is.

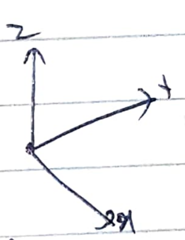


→ save the values in an array and average them
→ take next input as the last element move the other elements down the array.
→ output average and continue the last step.

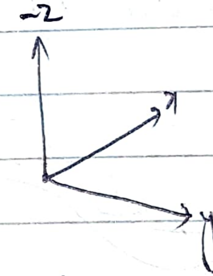
MPU 9250 :

- → motion tracking device.
- → 3-axis gyroscope / 3-axis accelerometer / 3-axis magnetometer
- → two dies in a single package → 1 die has gyro & accelerometer
  - → 1 die has magnetometer (AK8963)
- → Thus, 9-dof sensor (10-dof if barometer is added to auxiliary I2C bus.
- → 3 16-bit ADCs for each outputs ~ total 9 ADCs of 16 bits
- → Gyro range : ±250, ±500, ±1000, ±2000 dps
- → Acc. range : ±2g, ±4g, ±8g and ±16g
- → Mag range : ±4800 μT
- → inbuilt digital filters with 1% drift from (-40° to 85°C)
- → embedded temp. sensor
- → support both I2C & SPI interfaces
- → I2C at 400 KHz & SPI at 1MHz {(1-20) MHz available}

Note : typically, motion processing algorithms should be run at a higher rate; often around 200Hz in order to provide accurate results with low latency. This is required even if the application updates at a much lower rate



Orientation for Accl. & gyro



Orientation for magnetometer

* Selection of gyro scale: → should be able to handle the rotational speed of micromouse
  → (Rpm of motors is 650 rpm)

Scale 1: ±250 dps ⇒ $\frac{250}{360} \times 60 = 41.6$ rpm

2: ±500 dps $\frac{500}{360} \times 60 = 83.3$ rpm

Scale 8: ± 1000 dps $= \frac{1000}{360} \times 60 = 166.4$ rpm

± 2000 dps $= \frac{2000}{360} \times 60 = 332.8$ rpm ✓

Rotational speed of the micromouse bot: 100~300 rpm (limit तक)

* selection of accl. range: should be able to handle the acceleration the robot is moving with (force associated with acceleration)

Scale 1 : $\pm 2g$ = bot experiencing 2 times the force of gravity.
Scale 2 : $\pm 4g$: " " 4 " " " " "
Scale 3 : $\pm 8g$: " " 8 " " " " "
Scale 4 : $\pm 16g$: " " 16 " " " " " ✓

* Post data calculations: (after reading raw data):
→ raw data is simply the o/p of 16 bit ADCs of the corresponding sensors.
→ for accelerometer: sensitivity is defined in LSB/g.

$\pm 2g$	16384 LSB/g
$\pm 4g$	8192 LSB/g
$\pm 8g$	4096 LSB/g
$\pm 16g$	2048 LSB/g

So, real data in gs is: raw_data / (LSB/g);

Ex: for $\pm 16g$: raw_data / 2048; ⇒ gs

: suppose raw_data = 12,000;

value in g = 12,000 / 2048 = 5.85 g

Note: Trade-off between sensitivity and range; optimum use is to select lowest possible scales for each sensor

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For gyro: value in degrees per second = raw_data / (LSB/dps)

± 250 dps	131
± 500 dps	65.5
± 1000 dps	32.8
± 2000 dps	16.4

Example: Select scale 4: ±2000 dps: suppose raw data is 32,000

value in dps = 32000 / 16.4
= 1951.21 dps

* Degrees per second to degrees

o/p $f(t) = \frac{dx^\circ}{ds}$ = output of sensor data in dps

Integrating: $\int f(t) \times ds = \int dx^\circ$
$\Rightarrow x^\circ = \int f(t) \times ds$
= integration of sensor data with net time

Code: degrees = value in dps × time of refresh

* for better results: $\frac{1}{\text{Time of refresh}} \geq 250$ Hz

time of refresh $\geq \frac{1}{250}$ = 4×10^{-3} seconds = 4000 µs = 4 ms

from above example: degrees = 1951.21 / 250
= 7.80°

or degrees = 1951.21 * 4×10^{-3}
= 7.80°

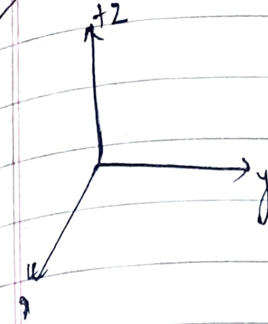
for integration:

~~new_degrees = previous degrees * 4×10^{-3} + previous degrees;~~
~~previous_degree = degrees;~~

new_degrees = new_degrees + prev_degrees * 4×10^{-3};

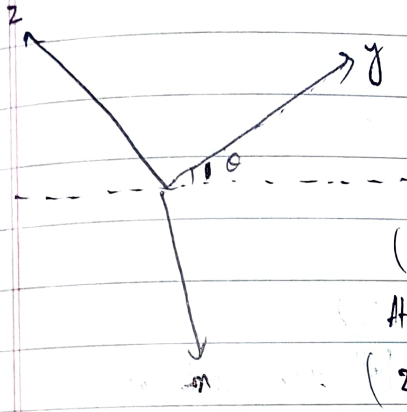
→ gyro accumulates error with time (integral error)
→ needs to be solved before use (solved by using reference of accelerometer)
② (roll, pitch, yaw same calculations)

(*) Accelerometer calculations:



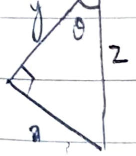
↑ reading (in g) ≃ 1g
↓ gravity

As in our previous example: for ±16g : raw_data = 2048
(z) value in g's = raw_data / 2048 = 1g



(z) value in g's depends upon θ.
At θ = 45°, raw_data = 1024
(z) value in g = raw_data / 2048 = 0.5g

Using pythagoras Theorem; $h^2 = p^2 + b^2$
Here, $h^2 = (1024)^2$



$z^2 = x^2 + y^2$

Also, $\tan\theta = \frac{p}{b} = \frac{x}{y}$ ⇒ $\tan 45° = \frac{x}{y}$ ⇒ $x = y$

&; $h^2 = x^2 + y^2$
$1024^2 = 2x^2$
$x = 724.07 = y$

$\therefore \theta = \tan^{-1}\frac{x}{y} = \sin^{-1}\frac{x}{z} = \cos^{-1}\frac{y}{z}$

*(for a moving body; the acceleration should be normalized; ??)

total_acceleration(a) = $\sqrt{x^2 + y^2 + z^2}$ where x = value at x-axis in g

y = " " y-axis " g

z = " " z-axis " g

for, pitch = $\sin^{-1}\left(\frac{y}{a}\right)$ (in radians)

for roll; $\sin^{-1}\left(\frac{x}{a}\right)$ (in radians)

(~use complementary filter to compensate gyro drift:)

~~* (AK8963) magnetometer~~

⇒ calibration for post raw-data (raw, pitch, calculate गरे पछि angle compensate गर्दै

AK8963 Magnetometer: (separate die inside MPU9250)

→ 3 axis electronic compass with high sensitive hall sensor technology

→ Built-in ADC ⇒ 14/16 bit selectable data output for each axis

Sensitivity: 0.6 μT / LSB (14 bit)

0.15 μT / LSB (16 bit)

→ DRDY access for measurement ready

→ Magnetic sensor overflow ~~read~~ monitor function

→ Built-in oscillator for internal clock source

→ Self test function with built-in internal magnetic source

→ Measurement range ± 4900 μT

* Operation Modes ⇒ (7) modes → Power-down Mode (0000)
  → Single Measurement Mode (0001)
  → Continuous Measurement Mode 1 (0010).
  → Continuous Measurement Mode 2 ~~(0011)~~ (0110)
  → External trigger measurement mode (0100)
  → Self-test Mode (1000)
  → Fuse ROM access mode (1111)

CNTL1 register [3:0] bits configures the modes.

* Single Measurement Mode : → measured for 1 times and data is output
  → goes to power down mode automatically after measurement ended

* Continuous Measurement Mode 1 : → sensor is measured in 8Hz periodically
  → doesn't go back to power down mode automatically

* Continuous Measurement Mode 2 : → sensor is measured periodically in 100Hz

* External trigger Mode : → sensor is measure for one time by ext trigger
  → waits for next trigger to read the sensor

* Fuse ROM access Mode : → factory calibrated values are stored ~~here~~ in fuse ROM of the device
  → to access the fuse ROM, this mode is used
  → needs manual transition to power down mode

* (After mode selection, wait 100ms for sensor to stabilize)

* AK8963 has the limitation for measurement range that the sum of absolute values of each axis should be smaller than 4912uT

  i.e $|X| + |Y| + |Z| \leq 4912\,\mu T$

* when magnetic field exceed beyond this, the data is not correct. (overflow)

during overflow HOFL bit is 1, returns to 0 when next measurement starts

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⇒ Output of Magnetometer ⇒ the output of ADC of Magneto...
for 14° bit selection; (scale of 0.6 μT/LSB)

	Max. value : 1FFE (Hex)	8190 (Decimal)	4912 μT
	Min. value : 8E002 (Hex)	-8190 (Decimal)	-4912 μT
Unit :	0001	1	0.6 μT

for 16° bit selection

	Sensor raw-data Hex	Decimal	Calculated mag. field (μT)
Max	7FF8	32760	4912
Min	8008	-32760	-4912
Unit:	0001	1	0.15 μT

CNTL1 register Bit [4] has selection bit for 14 or 16 bit O/P.
Bit [4] ⇒ 1 = 16 bit O/P
⇒ 0 = 14 bit O/P

* Calibration of Magnetometer:

1. → Offset calibration of raw data
2. → Environmental Calibration (soft iron & hard iron)
3. → Magnetic declination off at that place
4. → bank angle and elevation calibration

(1) Offset calibration :→ read data from FUSE ROMs
→ perform sensitivity adjustment

registers → 10H (ASAX) → mag. sensor X-axis sensitivity adjustment
11H (ASAY) → " " Y-axis " "
12H (ASAZ) → " " Z-axis " "

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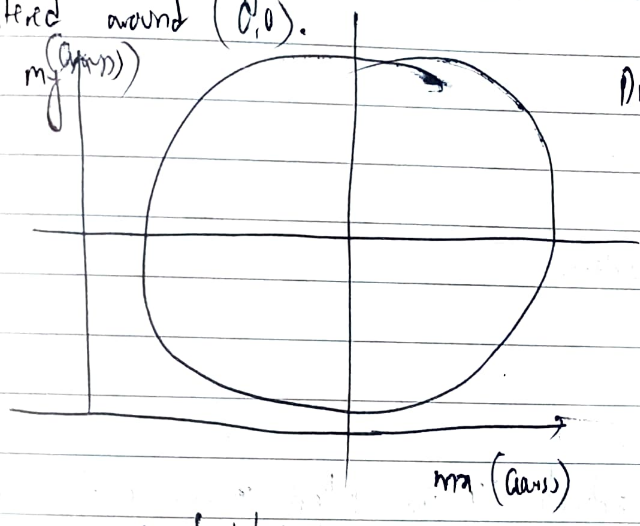
$$Magnetic\_value = H_{raw\_data} \times \left(\frac{(ASA - 128) \times 0.5}{128} + 1 \right)$$

(c) Environmental effect calibration → for soft iron and hard iron in the affinity
→ 8 shape movement for 3D calibration
→ Simple rotation about yaw for 2D calibration

reference: https://www.nxp.com/en/application-note/AN4246.pdf

→ If no distorting fields are present (absence of soft & hard iron), a rotating magnetometer through a minimum of 360° and plotting the result data as y axis vs. x axis will result in a circle centered around (0,0).



Distortion free magnetic data

→ But presence of hard/soft iron produces perturbation of the circle as a simple offset from (0,0) in case of hard iron and deform the circle in case of soft iron.

Note: Soft iron : distorts the shape of the circle
Hard iron : shifts the circle beyond origin (0,0).

This calibration is for only at that specific time and surrounding. The values will change for change in surrounding metallic substances

* Hard-iron distortion : → produced by materials that exhibit a constant additive field to the earth's magnetic field, thereby generating a constant additive value to the o/p of each of the magnetometer axes.

→ compensated by determining the x and y offsets and then applying these constants directly to the raw data

→ sensor should be rotated minimum of 360°

$$\alpha = \frac{(x_{max} + x_{min})}{2} \quad , \quad \beta = \frac{(y_{max} + y_{min})}{2}$$

α = X axis offset

β = Y axis offset

x_{max} = max. x value

x_{min} = min. x value

y_{max} = max. y value

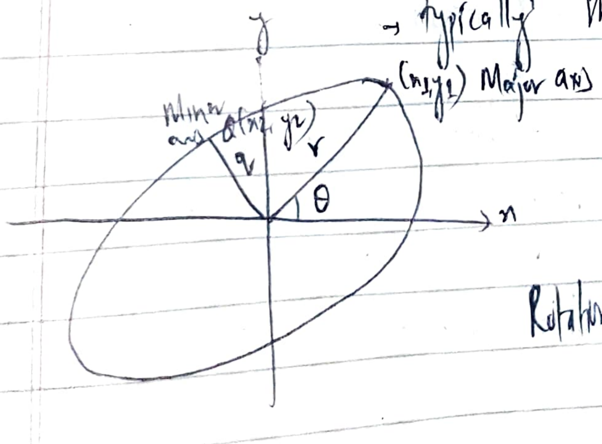
y_{min} = min y value

→ subtract α & β from raw data

* Soft-iron calibration : → materials like iron, nickel causes soft iron distortion

→ needs more complicated procedure to calibrate and computation is a bit resource heavy

→ typically the distortion created is ellipsoid



Here, $r = \sqrt{x_1^2 + y_1^2}$

$\theta = \sin^{-1}\left(\frac{y_1}{r}\right)$

$$\text{Rotation matrix } (R) = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$$

$v_x = R v_x$

$v_y = R v_y$

After rotation, the major axis of the ellipse will be aligned with the reference frame X-axis and the minor axis will align with the Y-axis.

To transform this rotated ellipse into a proper circle, the scale factor σ is determined using the eq^n: $\sigma = \frac{q}{r} = \frac{\text{minor axis}}{\text{major axis}}$

Then each magnetometer x-axis value is divided by σ to obtain the desired circle.

Once the scaling is completed, a final rotation must be made to rotate the data back to their original position, thus compensating for soft-iron distortion.

Here, $R^{-1} = \begin{bmatrix} \cos(-\theta) & \sin(-\theta) \\ -\sin(-\theta) & \cos(-\theta) \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$

$V_1 = R^{-1} v_x$

$V_2 = R^{-1} v_y$

Algorithm for soft iron calibration (work-around)

$\alpha' = \frac{x_{max} - x_{min}}{2}$, $\beta' = \frac{y_{max} - y_{min}}{2}$, $\gamma = \frac{z_{max} - z_{min}}{2}$

$\text{Average} = \frac{\alpha' + \beta'}{2}$ or $\text{Average} = \frac{\alpha' + \beta' + \gamma}{3}$

$\text{offset}_x = \text{average} / \alpha'$

$\text{offset}_y = \text{average} / \beta'$

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(3) Magnetic declination:

latitude: 27° 40' 9.4" N
longitude: 85° 19' 52.3" E

Magnetic Declination: +0° 35'
Magnetic Inclination: 43° 34'
Magnetic field strength: 48523.5 nT

Without tilt compensation

(1) Heading = $\tan^{-1}(y/x)$. (in radians) $\left(* \frac{180}{\pi}\right)$ to degrees

Tilt compensation:

(2) $y = y \times \cos(roll) - z \times \sin(roll)$

$x = x \times \cos(pitch) + y \times \sin(roll) \times \sin(pitch) + z \times \cos(roll) \times \sin(pitch)$

Heading = $\tan^{-1}(-y/x)$ (in radians)