V-Sensor Calibration Manual

Last Updated on 03/05/2015

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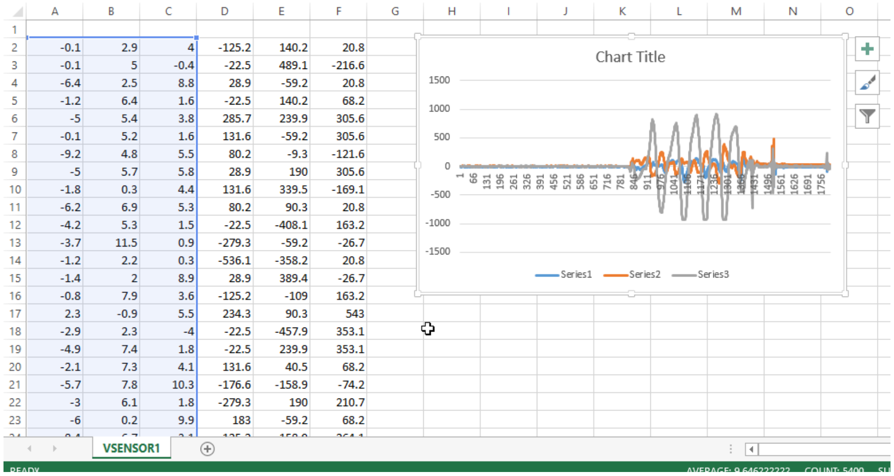
1. Background Information

Vsensor is a 3 axis accelerometer based on poly silicon MEMS technology which provides accurate realtime 3 axis acceleration information that is written to a micro SD card.

A sample dataset written to SD card which can be directly open up using Excel:-



	A	B	C	D	E	F
1						
2	-0.1	2.9	4	-125.2	140.2	20.8
3	-0.1	5	-0.4	-22.5	489.1	-216.6
4	-6.4	2.5	8.8	28.9	-59.2	20.8
5	-1.2	6.4	1.6	-22.5	140.2	68.2
6	-5	5.4	3.8	285.7	239.9	305.6
7	-0.1	5.2	1.6	131.6	-59.2	305.6
8	-9.2	4.8	5.5	80.2	-9.3	-121.6
9	-5	5.7	5.8	28.9	190	305.6
10	-1.8	0.3	4.4	131.6	339.5	-169.1
11	-6.2	6.9	5.3	80.2	90.3	20.8
12	-4.2	5.3	1.5	-22.5	-408.1	163.2
13	-3.7	11.5	0.9	-279.3	-59.2	-26.7
14	-1.2	2.2	0.3	-536.1	-358.2	20.8
15	-1.4	2	8.9	28.9	389.4	-26.7
16	-0.8	7.9	3.6	-125.2	-109	163.2
17	2.3	-0.9	5.5	234.3	90.3	543
18	-2.9	2.3	-4	-22.5	-457.9	353.1
19	-4.9	7.4	1.8	-22.5	239.9	353.1
20	-2.1	7.3	4.1	131.6	40.5	68.2
21	-5.7	7.8	10.3	-176.6	-158.9	-74.2
22	-3	6.1	1.8	-279.3	190	210.7
23	-6	0.2	9.9	183	-59.2	68.2

The arrangement of data columns are x1 y1 z1 x2 y2 z2. **All values are in milli G forces.**

X1 Y1 Z1 can be selectable 2G or 16G range (the lower the range, the higher the accuracy i.e. less noise).

X2 Y2 Z2 is fixed as 100G range only.

Both X1 Y1 Z1 and X2 Y2 Z2 are read from the sensors and written to micro SD card at the same time.

You can readily plot the vibration curves in excel.

2. Disclaimer

- V-Sensor has been certified type tested in the laboratory under JJG 233-2008 (equivalent to ISO 16063-21-2003).
- The calibration methods stipulated in this document is inline with ISO 16063-16 except that the calibration twist angle was set to 180 degrees instead of 30 degrees in order to obtain maximum convenience without using special angular holder equipment.

3. Preparation

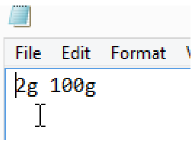
Make sure the V-Sensor surfaces on all 4 faces are smooth and flat before continuing. Use sandpaper if necessary.

4. Basic Usage

Changing the accelerometer range

You can change the range by changing the values inside RANGE.txt inside the micro D card.

For example, if you want to select the 16G sensor, change 2g to 16g.



Note that 100g is fixed and you cannot change this.

Note that every time you change the sensor range without deleting the CALIBRATION.txt will result in rapid blinking of 2 LEDs in the device during start up. This indicates that the calibration values in CALIBRATION.txt are wrong and will be set to default values automatically.

Removing gravitational offset and open up a new Excel file

Press the button once to remove gravitational offset from the data and at the same time open up a new Excel file for data reading.

The Excel file naming convention is:-

VSENSORx.xls

Where x is the number which increments from 1 every time you press the button.

Since Excel 2003 files (xls) have maximum limit of 60,000 lines, the Excel file will increment every time it overflows:-

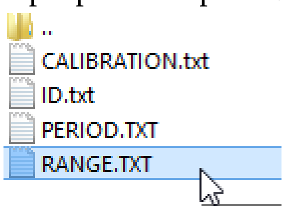
VSENSORx_k.xls

Where x is the number which increments from 1 every time the xls file overflows.

5. Prior to Calibration

Check the accuracy of the sensor and whether it requires calibration or not. Refer to section 5 of this manual.

6. Automatic Calibration

1. Let's calibrate the 2G & 100G sensors in the device
    a. Open up RANGE.txt in the micro SD card using Windows Explorer in your laptop or computer. If the file does not exist, then create the text file.
    

    b. Make sure the following text is inside the RANGE.txt:-
    2g 100g

    If not, then edit the text file and save.
    Turn on the sensor and wait until the LED starts blink periodically every second (which means the 2g reading has been written to permanent flash memory).

2. Format the microSD card by either:-
    a. Holding on the button for 4 seconds and waiting for the LEDs to double blink. Open the microSD card to check all files have been removed.
    b. Alternatively format via Windows formatting function.

3. Remove microSD card from device. When you turn on the device, you should see both LEDs turn on and stay on.

4. Place the device on a flat surface (90 degrees relative to gravity) – it is recommended to check this alignment using a bubble rule/meter.

5. Press and hold the button for > 7 seconds until one red LED blinks rapidly (see Figure 1 & Figure 2).

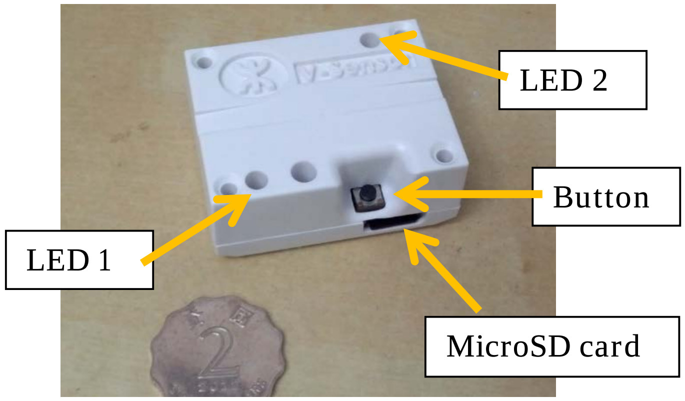


Figure 1 Hardware overview

6. Calibrate Z axis
    a. Immediately place the device flat on the table and the calibration will begin.
    b. Wait until both LEDs blink slowly to indicate that it has finished.
    c. Then flip over the device upside down and wait until one LED blinks rapidly again (see Figure 3).

7. Repeat the above steps to calibrate each of X and Y axis (the sequence/order is not important as the sensor can detect which axis and side you are calibrating).

8. After the above process is complete, the LED will no longer blink rapidly and all LEDs will be off. However if the LED keeps blinking rapidly, this indicates that the calibration had failed due to values exceeding limits -> make sure the table surface is flat then redo the whole calibration process starting from step 4 (i.e. no need to hold on the button again).

Figure 2 To calibration Z axis, hold button until one LED is blinking rapidly then place sensor flat on table

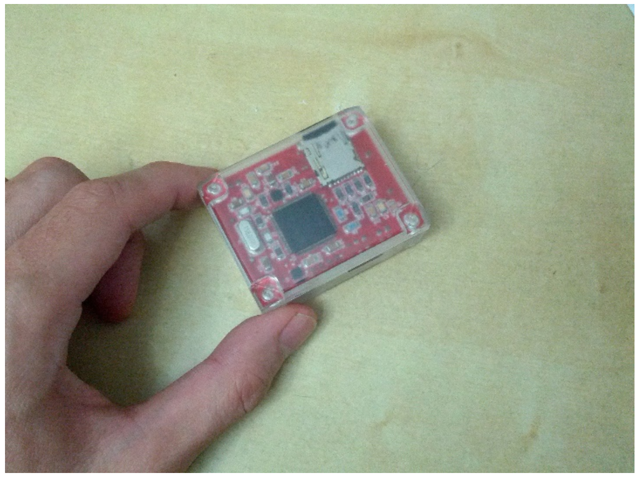
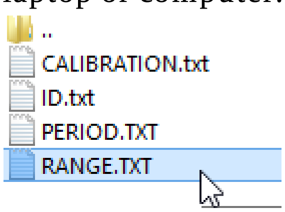


Figure 3 Wait until LED turns from rapid blinking to slow blinking then flip sensor upside down like above and wait until LED turns from rapid blinking to slow blinking then repeat the process for X and Y axis

9. If everything is complete, we need to calibrate the 16G sensor.
    a. Open up RANGE.txt in the micro SD card using Windows Explorer in your laptop or computer. If the file does not exist, then create the text file.



    b. Make sure the following text is inside the RANGE.txt:-
    16g 100g
10. Repeat steps 4 to 6 to calibrate the 16G sensor
11. Note that all calibration values will be stored in permanent storage flash memory in the CPU.
12. Note that every time you delete CALIBRATION.txt in the micro SD card, the calibration values from flash memory will be automatically loaded into the micro SD card.

7. Checking the Calibration Accuracy

Using your computer/laptop, change the text in RANGE.txt to “2g 100g”.

Insert the micro SD card in the device and turn it on.

When one LED starts blinking this means it is reading values from the sensors and writing to micro SD.

Press the button once to remove gravitational offset from the data and at the same time open up a new Excel file for data reading.

You can either:-

a) Rotate the device to measure the gravitational pull (see example in Figure 4)
    - Note you should get 1000mG when the device is placed 90 degrees.

      Note the 1000mG reading may be out by +/- 100mG due to magnification of even the slightest angle of misalignment at ~90 degrees tilt but you will not see this in real life measurements as the sensor would not be tilted > 20 degrees.
      i.e. if sensor is titled at 90 degrees from gravity with misalignment of around 5 degrees: -
      tolerance = 1000mg x sin(5) = 87 mg variation
      i.e. you will get 1087 mG reading instead of 1000mG

    - Note you should get 2000mG (precisely) when the device is placed 180 degrees (i.e. flipped) – the value is double the 1000mG gravity reading because we zeroed out gravity before (zero gravity is equivalent to placing the device at 0 degrees).

      Note the value of 2000mG should be a precise value as there will be little variation when the sensor is flipped.
      i.e. if sensor is aligned perfectly with gravity direction:-
      reading = 1000xsin(90) = 1000mg
      if sensor is misaligned with gravity by 5 degrees:-
      reading = 1000xsin(85) = 996mg which is very close to 1000mG

    - Note that when you rotate the device, two of the axis will pick up zero mG, 1000mG @ 90 degrees or 2000mG @ 180 degrees while one of the axis may pick up erroneous data due to gravity effect on an imperfectly tilted sensor.

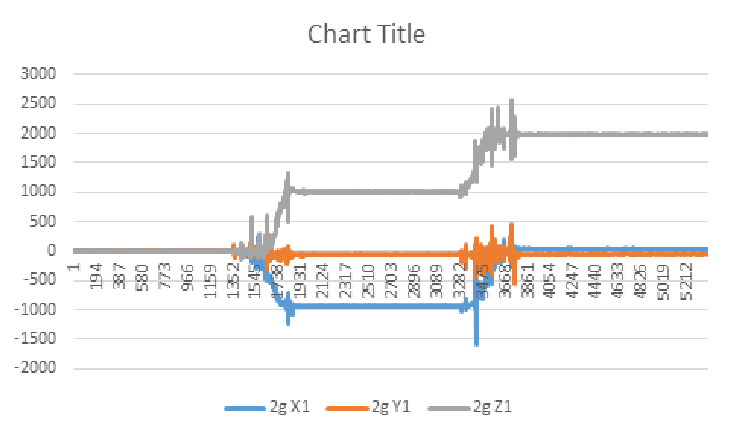
b) Shake the sensor and compare the 16g with 100g and 2g with 100g in built sensors (see example in Figure 5)

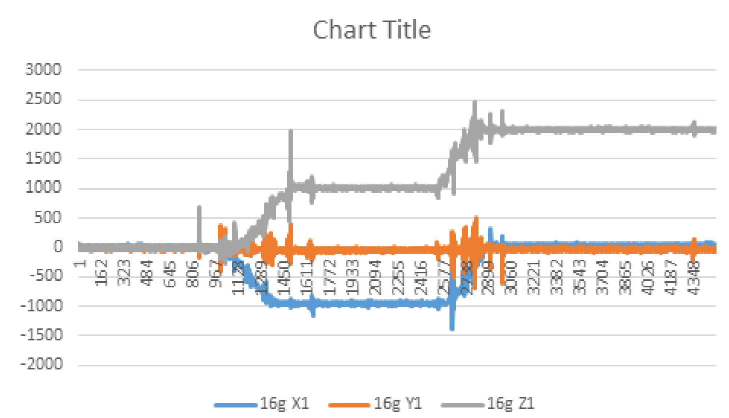
c) Place the sensor on a calibrated vibrating jig (to test with varying frequency response)

- Test the sensor to ISO 16063-21:2003 in which the sensor would be subjected to 160Hz vibration at multiple points within the G force range of the sensor then compared with the applied load of the calibrated jig.
- Note you can change the data read frequency of the device by editing PERIOD.txt (note the maximum achievable period is 2ms or 500Hz).

If there are any observed deviances in accuracy, the calibration values in CALIBRATION.txt may be changed manually as in section 5 of this manual.

Using your computer/laptop, change the text in RANGE.txt to “16g 100g” then repeat the process as above.





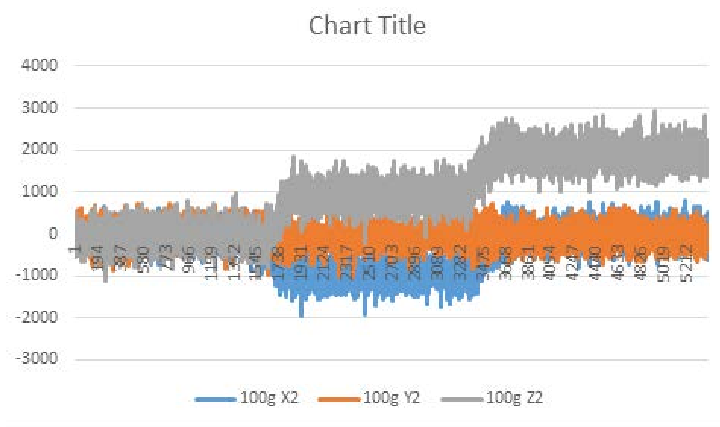


Figure 4 Expected results from device rotated 0 degrees -> 90 degrees -> 180 degrees around the y axis; Noted: The spikes at the transient are due to rough handling of the rotating sensor

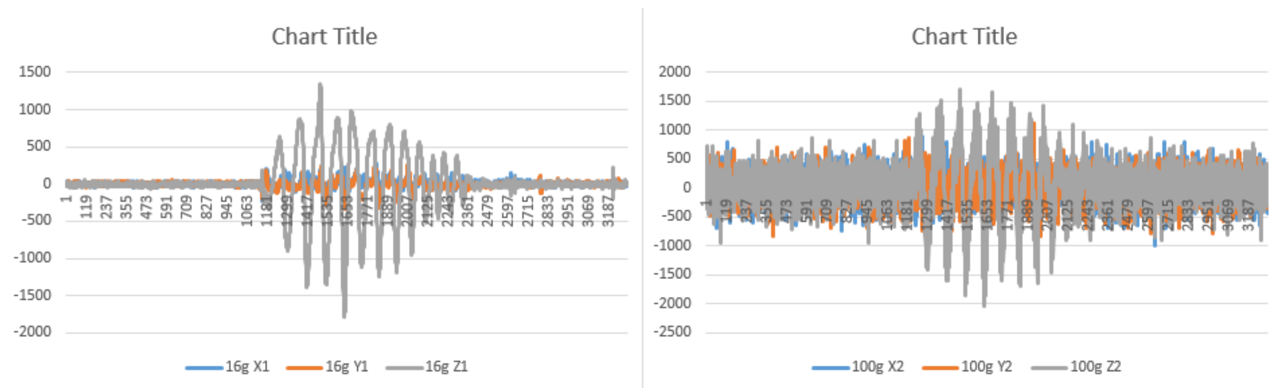


Figure 5 Expected results from device shaking in 16g 100g mode. You can compare both sensor values at the same time. Note that the 100G sensor values (picture to the right) has noise range of +/-1000mG at the worst case so nominal vibration shall be taken instead of peak vibration

8. Manual Adjustment of Calibration Values

1. Using your laptop/computer, delete CALIBRATION.txt from the micro SD card. Set the range from RANGE.txt to 2g 100g
2. Place micro SD card into device.
3. Wait until one LED is blinking every 1 second to indicate it is ready.
4. Press the button once to generate calibration file CALIBRATION.txt

5. Take the micro SD card out, open the text file, you will see values like this:-

Offset X1   Offset Y1   Offset Z1   Offset X2   Offset Y2   Offset Z2

On the same line:-

Sensitivity X1   Sensitivity Y1   Sensitivity Z1   Sensitivity X2   Sensitivity Y2   Sensitivity Z2

Where X1/Y1/Z1 corresponds to the 2G or 16G sensor depending on selection in RANGE.txt

Where X2/Y2/Z2 corresponds to the 100G sensor.

The calibration values are Sensitivity X, Y, Z which follows the equation:-

*vibration data output = sensitivity * sensor_raw_data*

In other words, the final value is a multiple of sensitivity.

6. If needed, you can change the sensitivity values manually using your laptop/computer for Sensitivity X, Y, Z then switch off the device then on again to load the new values into the device.

7. Using your laptop/computer, backup CALIBRATION.txt for future use.

8. Set the range from RANGE.txt to 16g 100g, delete CALIBRATION.txt and repeat the process as above starting from step 2.

Appendix I – Device Characteristics

Parameter	Design Rating	Comment
Max sampling frequency	1000Hz / 1ms	
Recommended sampling frequency	333Hz / 3ms	Period of 3ms; this provides optimized data collection size and sampling resolution and usually suitable for a wide range of applications
Nominal noise for 2G range	+/-7 mG	
Peak noise for 2G range worst case)	+/- 20 mG	
Nominal noise for 16G range	+/-40 mG	
Peak noise for 16G range worst case)	+/- 60 mG	
Nominal noise for 100G range	+/-500 mG	
Peak noise for 100G range worst case)	+/- 1000 mG	
Bandwidth for 2G or 16G sensor	1600Hz	Also depends on the sampling frequency you set in PERIOD.txt
Bandwidth for 100G sensor	1000Hz	Also depends on the sampling frequency you set in PERIOD.txt

The noise floor is measured at 25 degrees C but does not change much through time.

Appendix II – Calibration Algorithm

Description

The device can be set to auto calibration mode (see sections per above) which takes 100 samples per axis and determines the sensor sensitivity relative to gravity. Stipulated below is the 30 degree tilt angle calibration methodology.

Definitions and Methodology

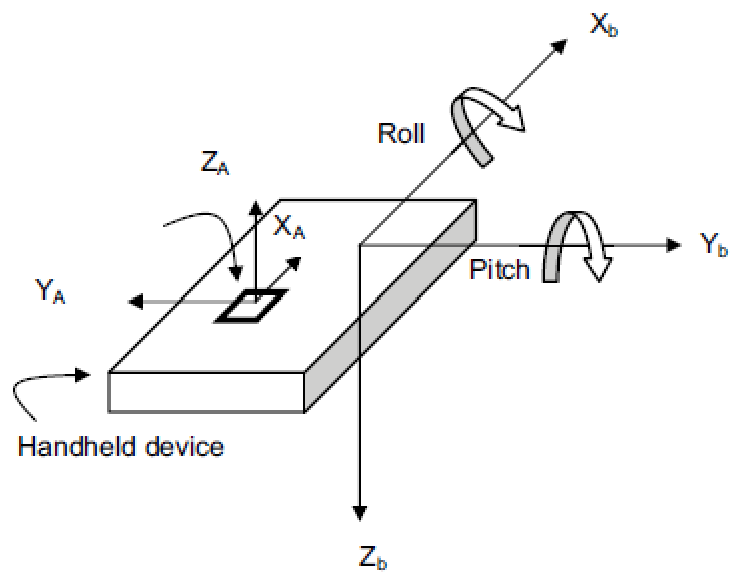


Figure 1 - Definitions

X_b, Y_b and Z_b are the device body axes with a forward-right-down configuration.

X_A, Y_A and Z_A are the accelerometer sensing axes, respectively. Note that the sign of Y_A and Z_A from the sensor measurements need to be reversed to have the sensing axes in the same direction as the device body axes.

Pitch and roll angles are referenced to the local horizontal plane, which is perpendicular to the Earth's gravity.

Pitch (alpha) is defined as the angle between the X_b axis and the horizontal plane. Assume that the pitch angle resolution is 0.1°, then it goes from 0° to +179.9° when rotating around the Y_b axis with the X_b axis moving upwards from a flat level, and then keeps

moving from a vertical position (+90°) back to a flat level again. The pitch angle goes from 0° to -180° when the X_b axis is moving downwards from a flat level, and then keeps moving from a vertical position (-90°) back to a flat level again. For example, in *Figure 2*, Y_b is fixed, X_b is rotating from Pitch = 0° to +30°, +90°, +150° and +179.9° for a positive direction.

Roll (Beta) is defined as the angle between the Y_b axis and the horizontal plane. Assume that the roll angle resolution is 0.1°, then it goes from 0° to +179.9° when rotating around the X_b axis with the Y_b axis moving downwards from a flat level, and then keeps moving from a vertical position (+90°) back to a flat level again. The roll angle goes from 0° to -180° when the Y_b axis is moving upwards from a flat level, and then keeps moving from a vertical position (-90°) back to a flat level again. For example, in *Figure 3*, X_b is fixed, Y_b is rotating from roll = 0° to +30°, +90°, +150° and +179.9° for a positive direction.

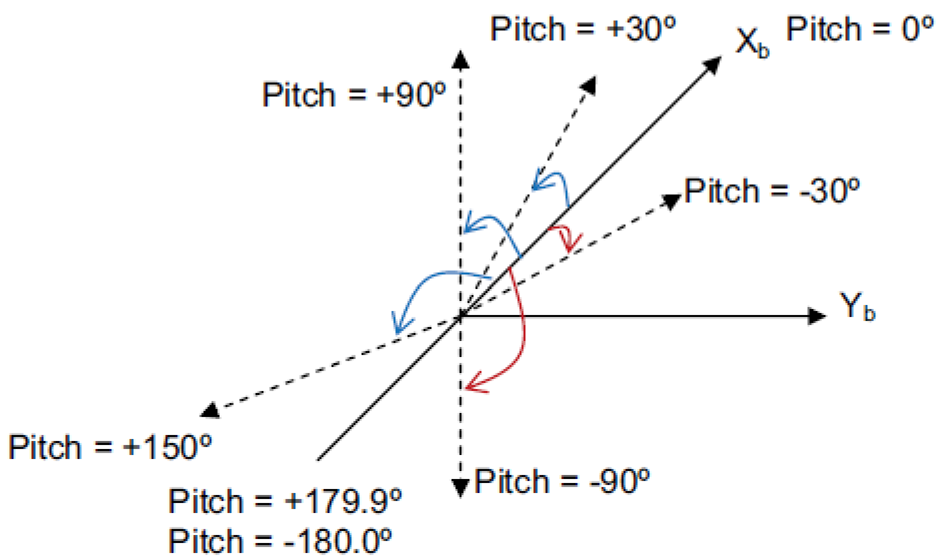


Figure 2. Pitch definition

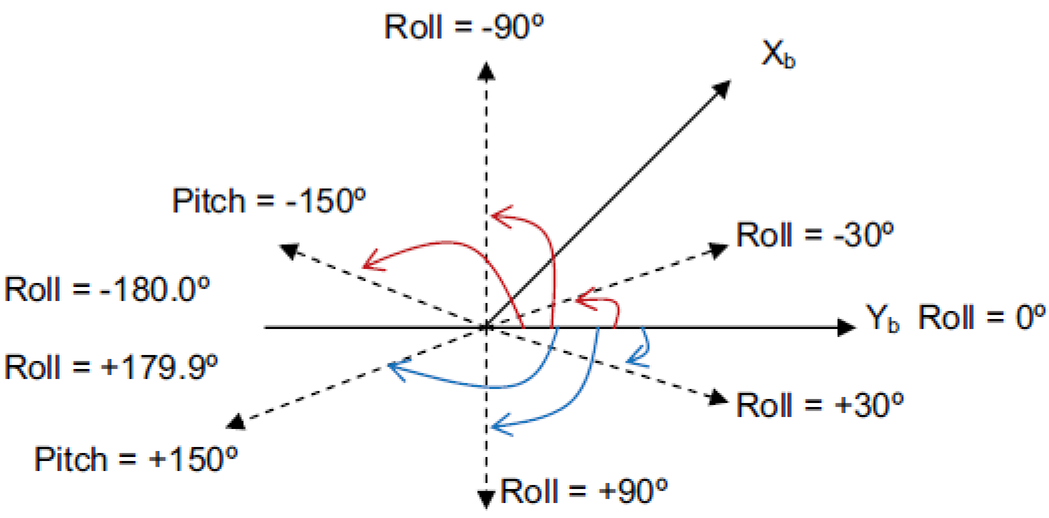


Figure 3. Roll definition

Assume A_x, Ay, A_z is the accelerometer raw measurement in the format of LSBs. *Table 1* shows the sign definition of the raw sensor data at 6 stationary positions with respect to the known Earth gravity vector. For example, in *Figure* 1, X_b and Y_b are level and Z_b is pointing down. Therefore, A_x = Ay = 0, A_z = +1 g.

Table 1. Sign definition of sensor raw measurements

Stationary position	**Accelerometer (signed integer)**		
	Ax	**Ay**	**Az**
Z_b down	0	0	+1 **g**
Z_b up	0	0	-1 **g**
Y_b down	0	+1 **g**	0
Y_b Up	0	-1 **g**	0
X_b down	+1 **g**	0	0
X_b up	-1 **g**	0	0

The relationship between the normalized A_{x1}, A_{y1} and A_{z1} and the accelerometer raw measurements A_x, A_y and A_z can be expressed as,

Equation 1

$$\begin{bmatrix} A_{x1} \\ A_{y1} \\ A_{z1} \end{bmatrix} = [A\_m]_{3x3} \begin{bmatrix} 1/A\_SC_x & 0 & 0 \\ 0 & 1/A\_SC_y & 0 \\ 0 & 0 & 1/A\_SC_z \end{bmatrix} \cdot \begin{bmatrix} A_x - A\_OS_x \\ A_y - A\_OS_y \\ A_z - A\_OS_z \end{bmatrix}$$
$$= \begin{bmatrix} ACC_{11} & ACC_{12} & ACC_{13} \\ ACC_{21} & ACC_{22} & ACC_{23} \\ ACC_{31} & ACC_{32} & ACC_{33} \end{bmatrix} \cdot \begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix} + \begin{bmatrix} ACC_{10} \\ ACC_{20} \\ ACC_{30} \end{bmatrix}$$

where [A_m] is the 3 x 3 misalignment matrix between the accelerometer sensing axes and the device body axes, A_SC_i (i = x, y, z) is the sensitivity (or scale factor) and A_OS_i is the zero-g level (or offset).

The goal of accelerometer calibration is to determine 12 parameters from ACC_{10} to ACC_{33}, so that with any given raw measurements at arbitrary positions, the normalized values A_{x1}, A_{y1} and A_{z1} can be obtained, resulting in:

Equation 2

$$|A| = \sqrt{A_{x1}^2 + A_{y1}^2 + A_{z1}^2} = 1$$

Calibration can be performed at 6 stationary positions as shown in *Table 1.* Collect 5 to 10 seconds of accelerometer raw data with ODR = 100 Hz (or as appropriate) at each position with known A_{x1}, A_{y1} and A_{z1}. Then apply the least square method or equivalent to obtain the 12 accelerometer calibration parameters.