DT0105

Design tip

1-point or 3-point tumble sensor calibration

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Purpose and benefits

This design tip explains how to compute offset, gain, and cross-axis gain for a 3-axis sensor (usually an accelerometer) by performing a 1 or 3-point tumble calibration. A generalization of the algorithm is also described.

Benefits:

- Added functionality with respect to calibration provided by the MotionFX library which only provides magnetometer and gyroscope calibration and not accelerometer calibration.
- Short and essential implementation which enables easy customization and enhancement by the end-user (MotionFX is available only in binary format, not as source code)
- Easy to use on every microcontroller (MotionFX can only be run on STM32)

Scope

This design tip applies to all accelerometers, eCompass modules, and iNemo inertial IMUs from STMicroelectronics.

Specifications

Algorithm specifications:

- Input from 3-axis sensor: **[x,y,z]** data triplets for each position (minimum 4, usually 6, N using the generalized algorithm)
- Output of 1-point tumble calibration: offset for each axis (**Xofs, Yofs, Zofs**)
- Output of 3-point tumble calibration: offset for each axis (**Xofs, Yofs, Zofs**) and gain for each axis (**Xgain, Ygain, Zgain**)

Algorithm description for 1-point tumble calibration

The algorithm is described for the particular case of an accelerometer. However, it can also be used with other sensors, e.g. a magnetometer. See notes at the end of this document.

It is assumed that the sensor has nominal sensitivity equal to 1 for each axis and there is no cross-axis sensitivity. True acceleration is related to measured acceleration as follows:

$$\begin{bmatrix} \mathbf{AccX} \\ \mathbf{AccY} \\ \mathbf{AccZ} \end{bmatrix} = \begin{bmatrix} \mathbf{1} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{1} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{1} \end{bmatrix} \begin{bmatrix} \mathbf{trueAccX} \\ \mathbf{trueAccY} \\ \mathbf{trueAccZ} \end{bmatrix} + \begin{bmatrix} \mathbf{Xofs} \\ \mathbf{Yofs} \\ \mathbf{Zofs} \end{bmatrix}$$

The sensor should be oriented so that only one axis (e.g. Z = 1*g*) is stimulated while the others are orthogonal to the stimulus (e.g. X=Y=0*g*): **trueAcc = [0, 0, +1]**

Measured acceleration, derived from the equation shown at the beginning, is calculated by plugging in the values listed above for true acceleration:

1. $\mathbf{AccX = 0 + Xofs, \; Xofs = AccX}$
2. $\mathbf{AccY = 0 + Yofs, \; Yofs = AccY}$
3. $\mathbf{AccZ = 1 + Zofs, \; Zofs = AccZ\text{-}1}$

Offsets are readily available and can now be subtracted to go from measured acceleration to true acceleration.

It must be noted that if the sensitivity is not 1 as assumed, or if cross-axis sensitivities are not 0 as assumed, the computed offset will be wrong. Also if the true acceleration is not [0, 0, 1] during calibration, the computed offset will be wrong. This can happen for non-ideal sensors and imperfect alignment during calibration.

Algorithm description for 3-point tumble calibration

The algorithm is described for the particular case of an accelerometer. However, it can also be used with other sensors, e.g. a magnetometer. See notes at the end of this document.

It is assumed that the sensor has no cross-axis sensitivity. True acceleration is related to measured acceleration as follows:

$$\begin{bmatrix} \mathbf{AccX} \\ \mathbf{AccY} \\ \mathbf{AccZ} \end{bmatrix} = \begin{bmatrix} \mathbf{Xgain} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{Ygain} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{Zgain} \end{bmatrix} \begin{bmatrix} \mathbf{trueAccX} \\ \mathbf{trueAccY} \\ \mathbf{trueAccZ} \end{bmatrix} + \begin{bmatrix} \mathbf{Xofs} \\ \mathbf{Yofs} \\ \mathbf{Zofs} \end{bmatrix}$$

The sensor should be oriented so that only one axis at a time is stimulated (e.g. X, then Y, then Z) while the others are orthogonal to the stimulus.

True $\mathbf{[x,y,z]}$ acceleration for each position in a 3-point tumble calibration is as follows:

1. Gravity vector along +X axis: $\mathbf{trueAcc = [+1, \; 0, \; 0]}$
2. Gravity vector along +Y axis: $\mathbf{trueAcc = [\; 0, +1, \; 0]}$
3. Gravity vector along +Z axis: $\mathbf{trueAcc = [\; 0, \; 0, +1]}$

Measured acceleration for each position in a 3-point tumble calibration, derived from the equation shown at the beginning, is calculated by plugging in the values listed above for true acceleration:

1. $\text{AccX1} = \text{Xgain} + \text{Xofs}, \ \text{AccY1} = 0 + \text{Yofs}, \ \text{AccZ1} = 0 + \text{Zofs}$
2. $\text{AccX2} = 0 + \text{Xofs}, \ \text{AccY2} = \text{Ygain} + \text{Yofs}, \ \text{AccZ2} = 0 + \text{Zofs}$
3. $\text{AccX3} = 0 + \text{Xofs}, \ \text{AccY3} = 0 + \text{Yofs}, \ \text{AccZ3} = \text{Zgain} + \text{Zofs}$

Offsets can be taken directly from the measurements listed above or they can be computed by averaging two out of three measurements listed above. Averaging can be used to improve the quality of the final estimate.

- $\text{AccX2} + \text{AccX3} = 2\ \text{Xofs}, \ \text{Xofs} = (\text{AccX2} + \text{AccX3})/2$
- $\text{AccY1} + \text{AccY3} = 2\ \text{Yofs}, \ \text{Yofs} = (\text{AccY1} + \text{AccY3})/2$
- $\text{AccZ1} + \text{AccZ2} = 2\ \text{Zofs}, \ \text{Zofs} = (\text{AccZ1} + \text{AccZ2})/2$

Once offsets are computed, gains can be computed as follows:

- $\text{Xgain} = \text{AccX1} - \text{Xofs}$
- $\text{Ygain} = \text{AccY2} - \text{Yofs}$
- $\text{Zgain} = \text{AccZ3} - \text{Zofs}$

Now offsets can be subtracted, and multiplication by inverse gains can be done to go from measured acceleration to true acceleration.

Notes

Applications to other sensors:

- While it may be easy to exploit the known gravity vector to <u>impose</u> the desired true reference on the accelerometer, it may not be possible to achieve perfect accuracy when switching from one position to another during the 3-point tumble calibration
- An alternative way to perform the calibration is to use a gold reference sensor which has the same orientation of the sensor to be calibrated, so that the desired true reference can be <u>measured</u> and checked.
- Special equipment, arrangements or procedures may be needed to impose or measure the desired true reference on other sensors such as magnetometers or gyroscopes
- For the case of the magnetometer: Helmholtz coils can be used to impose the desired true reference; alternatively, the Earth's magnetic field vector can be used together with a gold reference sensor.

- For the case of the gyroscope: a single-axis turn table or a step-motor spin table can be used to impose the desired true reference; alternatively a gold reference sensor can be used as previously described.

Other algorithms: *6-point tumble calibration*, discussed in Design Tip DT0053, can be used to estimate offsets, gains and cross-axis gains. In the same Design Tip, a generalization is also presented for *N-point tumble calibration*.

Support material

Related design support material
BlueMicrosystem1, Bluetooth low energy and sensors software expansion for STM32Cube
Open.MEMS, MotionFX, Real-time motion-sensor data fusion software expansion for STM32Cube
Documentation
Application note, AN4508, Parameters and calibration of a low-*g* 3-axis accelerometer
Application note, AN4615, Fusion and compass calibration APIs for the STM32 Nucleo with the X-NUCLEO-IKS01A1 sensors expansion board
Design Tip, DT0053, 6-point tumble sensor calibration

Revision history

Date	Version	Changes
28-Aug-2018	1	Initial release