Technical Document

How to perform BMI160 incline calibration

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1 Introduction

BMI160 is a highly integrated low power MEMS inertial measurement unit (IMU) that includes a 16-bit 3-axis accelerometer (ACC) and a 16-bit 3-axis gyroscope (GYR). Each BMI160 is factory calibrated, trimmed and tested. The ACC zero-g offsets and GYR zero-rate offsets of each BMI160 are stored in the non-volatile memory (NVM). After power up or soft reset these offset values will automatically be loaded from NVM to the image registers from 0x71 to 0x77.

However, after BMI160 is soldered on the PCB or the PCB is assembled in the final product, the offsets of BMI160 may be a little away from their trimmed values due to the mechanical stress and misalignment. Users can perform inline calibration to remove these offsets in their mass product lines by placing the PCB flat or the final product flat with BMI160 Z axis pointing to sky and X/Y axes horizontal, for example.

BMI160 has built-in two offset compensation methods for both ACC and GYR which are called fast offset compensation (FOC) and manual offset compensation (MOC).

FOC is a one-shot process to automatically generate and place new offset values into the image registers according to the predefined target values when stationary. For GYR X/Y/Z axes, the target values will be 0 degree per second (dps) when at rest. For ACC X/Y/Z axes, the target values can be, for example 0g/0g/+1g when the BMI160 is placed flat in users' mass production lines.

MOC means that users manually write new offset values into the Image registers through digital interface. For example, if a user performed his own calibration and determined the new offset values, then he can save these offset values into his MCU flash memory. In the future he can always manually load these values from his MCU flash memory and write them to BMI160 image registers.

When image registers have new offset values from FOC or MOC, users can set the gyr_off_en bit-7 and acc_off_en bit-6 in register 0x77 for the offset compensation to take effect. This means that these new offset values in the image registers will be added to the raw measurements to remove the offsets. For example, if one axis has positive offset then the corresponding image register will have negative value to cancel it. If the gyr_off_en bit-7 and acc_off_en bit-6 in register 0x77 are not set, then the new offset values in image registers will not be used for offset compensation.

Inline calibration is the process to permanently write the new offset values in those image registers which are either automatically generated by FOC or manually written by users from MOC into the NVM. This will overwrite the factory trimmed values of the BMI160. Therefore, when the BMI160 is powered on next time, these new offset values will be loaded from NVM to the image registers and used for offset compensation automatically.

This document presents both BMI160 ACC and GYR inline calibration using FOC method with sample codes included.

2 Hardware and software setup

The hardware setup is as shown in Figure 1. BMI160 shuttle board is plugged onto the application base board APP2.0. Then the APP2.0 board is connected to a PC's USB port.

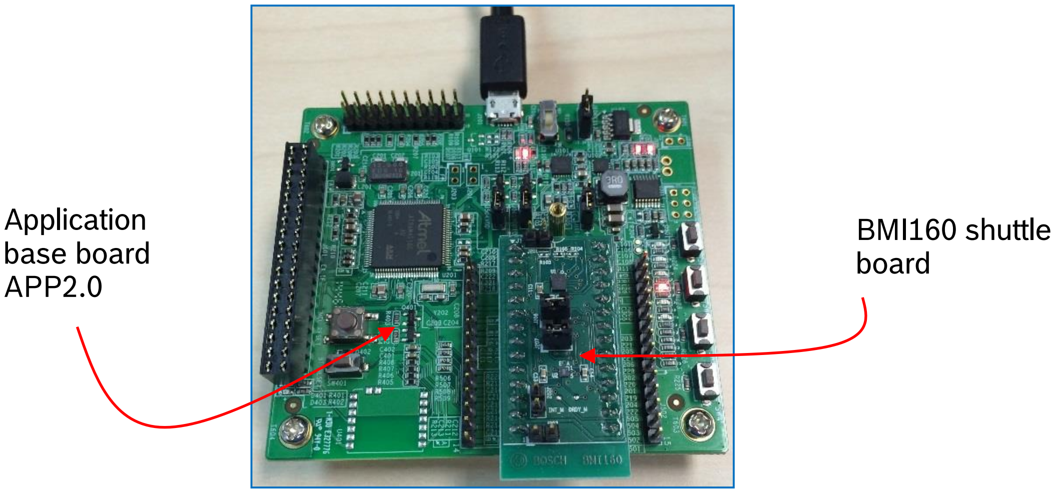

Figure 1 Hardware setup

The Windows demo software Development Desktop 2.0 (DD2.0) that is running on the PC can be used for users to configure BMI160 registers and evaluate its features.

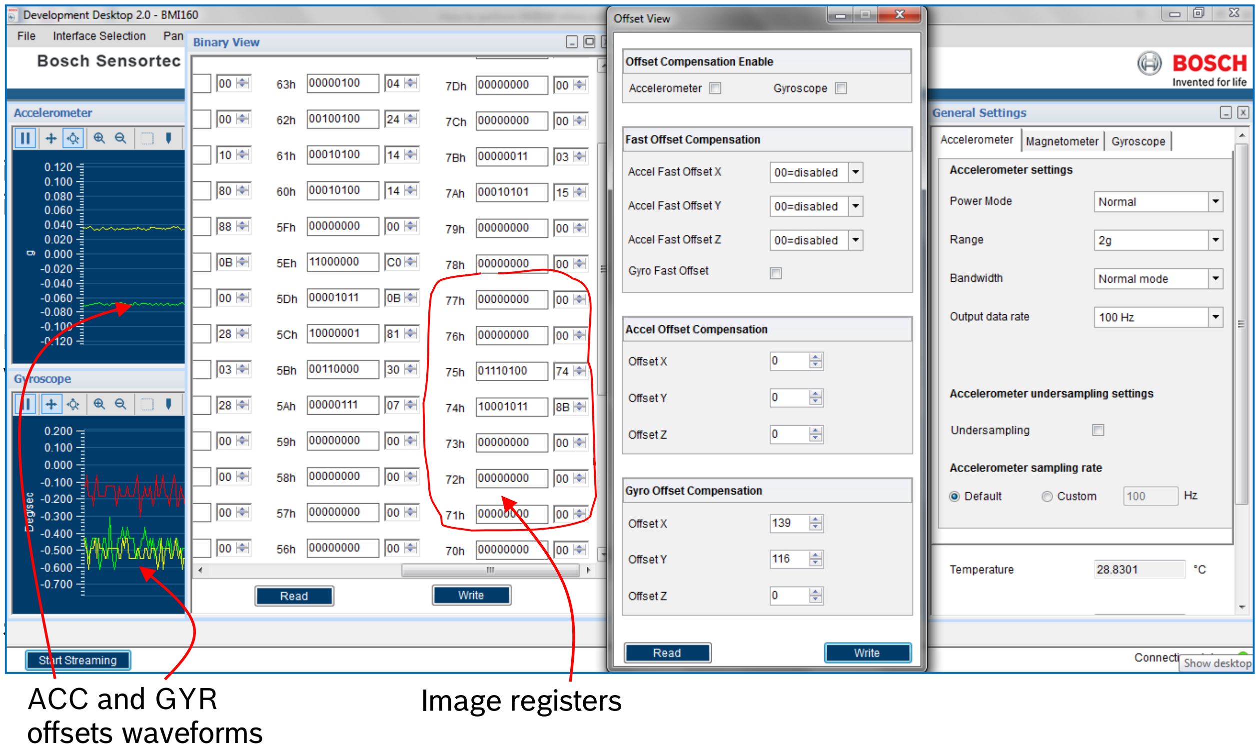

Figure 2 BMI160 ACC and GYR offsets before FOC

It can be seen in Figure 2 that after power-up, the image registers from 0x71 to 0x73 have all zero values for ACC X/Y/Z offsets, while image registers from 0x74 to 0x77 don't have all zero values for GYR X/Y/Z offsets. These non-zero values for GYR offsets are reserved for internal use and can be ignored.

It also can be seen in Figure 2 that when BMI160 is placed flat on the table stationary, the ACC and GYR offsets' waveforms are not close to 0g and 0dps due to the mechanical stress from PCB assembly. ACC_X offset (green) is about -70mg and ACC_Y offset (yellow) is about 39mg, while GYR_X offset (green) = GYR_Y offset (yellow) = -0.5dps and GYR_Z offset (red) is about -0.15dps. Please note that ACC Z axis is around +1g, it is out of the screenshot and not shown in Figure 2.

Figure 3 shows how to use the DD2.0 SW to perform both ACC and GYR FOC as an example. After FOC the new offset values for ACC and GYR are automatically placed in the image registers and both ACC and GYR offsets' waveforms are close to 0g and 0dps. For ACC Z axis the waveform will be close to +1g which is not shown in Figure 3.

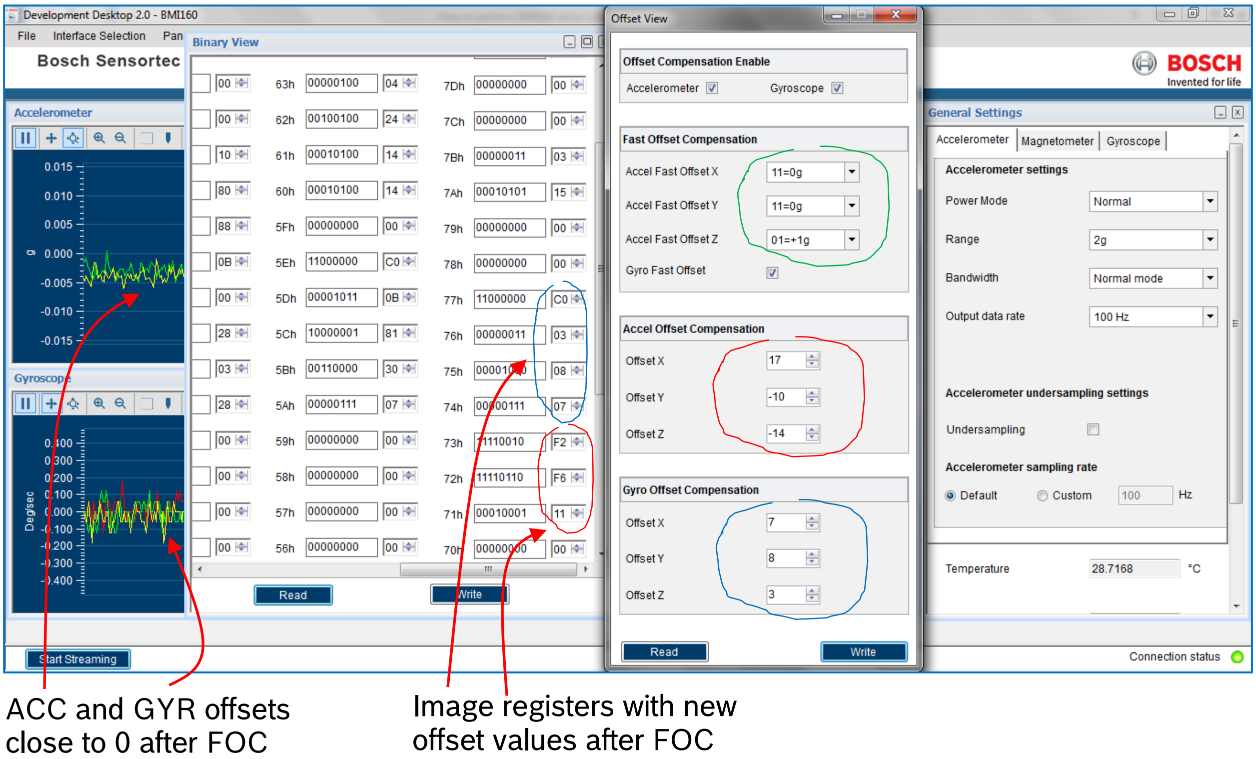

Figure 3 BMI160 ACC and GYR offsets after FOC

3 BMI160 incline calibration

BMI160 inline calibration includes two steps. The first step is to get new offset values in image registers by FOC or MOC. The second step is to write these new offset values back to NVM.

Image registers from 0x71 to 0x73 are for ACC X/Y/Z axis offset respectively with one byte each in 2's complement. Each LSB is 3.9mg regardless of full scale range. Therefore, the maximum offset compensation range is ±128LSBs * 3.9mg/LSB = ±0.5g.

Image registers from 0x74 to 0x77 are for GYR X/Y/Z axis offset respectively with 10-bit resolution in 2's complement. Each LSB is 0.061dps. Therefore, the maximum offset compensation range is ±512LSBs * 3.9mg/LSB = ±31.2dps.

For example in Figure 3, after FOC, register 0x71 (ACC_X) has the new offset value of 0x11 = 17LSBs = 17 * 3.9 = 66.3mg to cancel out -70mg offset in Figure 2. Similarly, register 0x72 (ACC_Y) has the new offset value of 0xF6 = -10LSBs = -10 * 3.9 = -39mg to cancel out the 39mg offset.

For GYR, after FOC, bit-1 and bit-0 in register 0x77 together with register 0x74 (GYR_X) has the new offset value of 0x007 = 7LSBs = 7 * 0.061 = 0.427dps to cancel out -0.5dps offset in Figure 2. Similarly, bit-3 and bit-2 in register 0x77 together with register 0x75 (GYR_Y) has the new offset value of 0x008 = 8LSBs = 8 * 0.061 = 0.488dps to cancel out -0.5dps offset. Again, bit-5 and bit-4 in register 0x77 together with register 0x76 (GYR_Z) has the new offset value of 0x003 = 3LSBs = 3 * 0.061 = 0.183dps to cancel out -0.15dps offset.

FOC for ACC and GYR can be performed at the same time or separately. Since GYR offsets need to be updated and compensated by the software, users usually only perform BMI160 ACC inline calibration in their final product. Section 3.1 shows the sample code about how to perform FOC for ACC with optional GYR. Section 3.2 presents sample code about how to write new offset values into NVM.

3.1 Sample code for FOC

The following is the pseudo code for BMI160 FOC. The product should be stationary at a certain position, for example, BMI160 ACC X = Y = 0g and Z = +1g. The code below with blue color is not needed if the user doesn't perform GYR FOC.

```
void BMI160_FOC(void)
{
    char value;                                  // variable to store register value

    // basic configurations
    Write value of 0xB6 to register 0x7E;        // soft reset BMI160 to default settings
    Delay 50ms;
    Write value of 0x11 to register 0x7E;        // set ACC to normal mode
    Delay 5ms;                                   // the max time of 3.8ms from datasheet
    Write value of 0x15 to register 0x7E;        // optional, set GYR to normal mode
    Delay 80ms;                                  // the max time of 80ms from datasheet
```

```
    // FOC configurations
    Write value of 0x3D to register 0x69;      // enable ACC FOC with target value set to X
                                               = 0g; Y = 0g and Z = +1g
    Write value of 0x7D to register 0x69;      // optional, also enable GYR FOC

    // trigger FOC
    Write value of 0x03 to register 0x7E;      // trigger FOC for both ACC and GYR
    Delay 250ms;                               // the maximum time from datasheet
    Write value of 0x00 to register 0x69;      // disable both ACC and GYR FOC

    // enable new offsets
    value = read register 0x77;                // read register 0x77
    value = value | 0x40;                      // set acc_off_en bit
    Write value to register 0x77;              // now the new zero-g offsets will take effect

    value = value | 0x80;                      // set gyr_off_en bit
    Write value to register 0x77;              // the new zero-rate offsets will take effect

}
```

The new offset values will be automatically written to image registers 0x71 for ACC_X, 0x72 for ACC_Y and 0x73 for ACC_Z axis respectively after the FOC is triggered.

3.2 Sample code for writing new offsets to NVM

After the image registers from 0x71 to 0x77 have new offset values available, the last step of BMI160 inline calibration is to write these new offset values from image registers to NVM.

The following pseudo code shows how to write the offset values to NVM.

```
void BMI160_writing_NVM(void)
{
    Write value of 0x02 to register 0x6A;      // set the nvm_prog_en bit to unlock NVM
    Write value of 0xA0 to register 0x7E;      // start writing NVM

Loop: Val = Read register 0x1B;                // read status register 0x1B to variable VAL
      If ((VAL & 0x10) == 0), then go to Loop; // NVM writing is ongoing if bit-4 nvm_rdy = 0
      Else,
          Write value of 0x00 to register 0x6A; // NVM writing is done. Lock NVM and exit
}
```

The new offset values that have been written to NVM will be automatically loaded to image registers when BMI160 is powered on next time.

4 Legal disclaimer

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5 Document history and modification

Rev. No	Chapter	Description of modification/changes	Date
1.0		Document creation	July 7th, 2015
1.1	Section 3.1	Added sample code to enable the new offsets so that they will take effect to compensate the sensor raw measurements	November 19th, 2015

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