Getting started with MotionGC gyroscope calibration library in X-CUBE-MEMS1 expansion for STM32Cube

Introduction

The MotionGC is a middleware library part of X-CUBE-MEMS1 software and runs on STM32. It provides real-time gyroscope calibration through angular zero-rate level coefficients (offset) used to correct gyroscope data.

This library is intended to work with ST MEMS only.

The algorithm is provided in static library format and is designed to be used on STM32 microcontrollers based on the ARM® Cortex®-M0+, ARM® Cortex®-M3, ARM® Cortex®-M4 or ARM® Cortex®-M7 architecture.

It is built on top of STM32Cube software technology that eases portability across different STM32 microcontrollers.

The software comes with sample implementation running on X-NUCLEO-IKS01A2 or X-NUCLEO-IKS01A3 expansion board on a NUCLEO-F401RE, NUCLEO-L476RG, NUCLEO-L152RE or NUCLEO-L073RZ development board.

1 Acronyms and abbreviations

Table 1. List of acronyms

Acronym	Description
API	Application programming interface
BSP	Board support package
GUI	Graphical user interface
HAL	Hardware abstraction layer
IDE	Integrated development environment

2 MotionGC middleware library for X-CUBE-MEMS1 software expansion for STM32Cube

2.1 MotionGC overview

The MotionGC library expands the functionality of the X-CUBE-MEMS1 software.

The gyroscope sensor can have significant offset which can cause problems when using the gyroscope output data. The MotionGC library is able to minimize the offset and solve this issue.

The library acquires data from the accelerometer and gyroscope and calculates the angular zero-rate level coefficient (offset) for each axis. The angular zero-rate level coefficients are subsequently used to compensate raw data coming from gyroscope.

The library is designed for ST MEMS only. Functionality and performance when using other MEMS sensors are not analyzed and can be significantly different from what described in the document.

Sample implementation is available for X-NUCLEO-IKS01A2 and X-NUCLEO-IKS01A3 expansion boards, mounted on a NUCLEO-F401RE, NUCLEO-L476RG, NUCLEO-L152RE or NUCLEO-L073RZ development boards.

2.2 MotionGC library

Technical information fully describing the functions and parameters of the MotionGC APIs can be found in the MotionGC_Package.chm compiled HTML file located in the Documentation folder.

2.2.1 MotionGC library description

The MotionGC gyroscope calibration library manages data acquired from accelerometer and gyroscope; it features:

- the angular zero-rate level (offset) compensation
- adjustable thresholds to detect device in still state
- adjustable maximum angular zero-rate level to be compensated
- possibility to set previously saved coefficients as the initial values
- fast start-up option
- able to run with multiple sample rate from 25 Hz to 200 Hz
- resources requirements:
  – Cortex-M0+: 3.0 kB of code and 0.3 kB of data memory
  – Cortex-M3: 3.1 kB of code and 0.3 kB of data memory
  – Cortex-M4: 2.7 kB of code and 0.3 kB of data memory
  – Cortex-M7: 2.3 kB of code and 0.3 kB of data memory
- available for ARM Cortex-M0+, Cortex-M3, Cortex-M4 and Cortex-M7 architectures

2.2.2 MotionGC APIs

The MotionGC library APIs are:

- `uint8_t MotionGC_GetLibVersion(char *version)`
  – retrieves the version of the library
  – `*version` is a pointer to an array of 35 characters
  – returns the number of characters in the version string
- `void MotionGC_Initialize(float freq)`
  – performs MotionGC library initialization and setup of the internal mechanism

Note: This function must be called before using the gyroscope calibration library

  – `freq` parameter is the sampling frequency
  – the CRC module in STM32 microcontroller (in RCC peripheral clock enable register) has to be enabled before using the library

- `void MotionGC_SetKnobs(MGC_knobs_t *knobs)`
  – sets the library knobs
  – `*knobs` parameter is a pointer to a structure with settings
  – the parameters for the structure type `MGC_knobs_t` are the following:
    ◦ `AccThr` is the accelerometer threshold to detect steady state in g. The default value is 0.01 g. The input range is 0.003 to 0.05 g. For higher accuracy, set the value low; for platforms inherent vibration or noisy sensor, set the value high.
    ◦ `GyroThr` is the gyroscope threshold to detect steady state in degree per second. The default value is 0.2 dps. The input range is 0.008 to 0.4 dps. For higher accuracy, set the value low.
    ◦ `FilterConst` is the decay constant for the internal filter (from 0 to1). Setting a higher value can cause a variation in the gyro offset but allows a quick convergence. The default value is 0.002.
    ◦ `FastStart` set to 1 immediately starts computing the gyro offset and quickly converges to gyro offset. By setting the value to 1, it is possible that the initial gyro offset value is not accurate but converges over a period of time.
    ◦ `MaxGyro` is the maximum expected angular zero-rate level when still in dps. The default value is 15 dps.
    ◦ `MaxAcc` is the maximum acceleration module when still in g. The default value is 1.3 g.
- `void MotionGC_GetKnobs(MGC_knobs_t *knobs):`
  – gets the library knob setting
  – `*knobs` is a pointer to the setting structure

Note: *This function needs to be called before making changes in the settings.*

- `void MotionGC_Update(MGC_input_t *data_in, MGC_output_t *gyro_bias, int *bias_update):`
  – runs the gyroscope calibration algorithm and returns compensation parameters
  – `*data_in` parameter is a pointer to a structure with input data
  – the parameters for the structure type `MGC_input_t` are the following:
    ◦ `Acc[3]` is an array of accelerometer sensor value in g
    ◦ `Gyro[3]` is an array of gyroscope sensor value in dps
  – `*gyro_bias` parameter is a pointer to a structure with gyroscope angular zero-rate level
  – the parameters for the structure type `MGC_output_t` are the following:
    ◦ `GyroBiasX` is the actual x axis gyroscope bias value in dps
    ◦ `GyroBiasY` is the actual y axis gyroscope bias value in dps
    ◦ `GyroBiasZ` is the actual z axis gyroscope bias value in dps
  – `*bias_update` is a pointer to an integer set to 1 if the device is in stable state and the gyroscope bias is updated (0 otherwise)

Note: *This function has to be called periodically as indicated in the initialization function.*

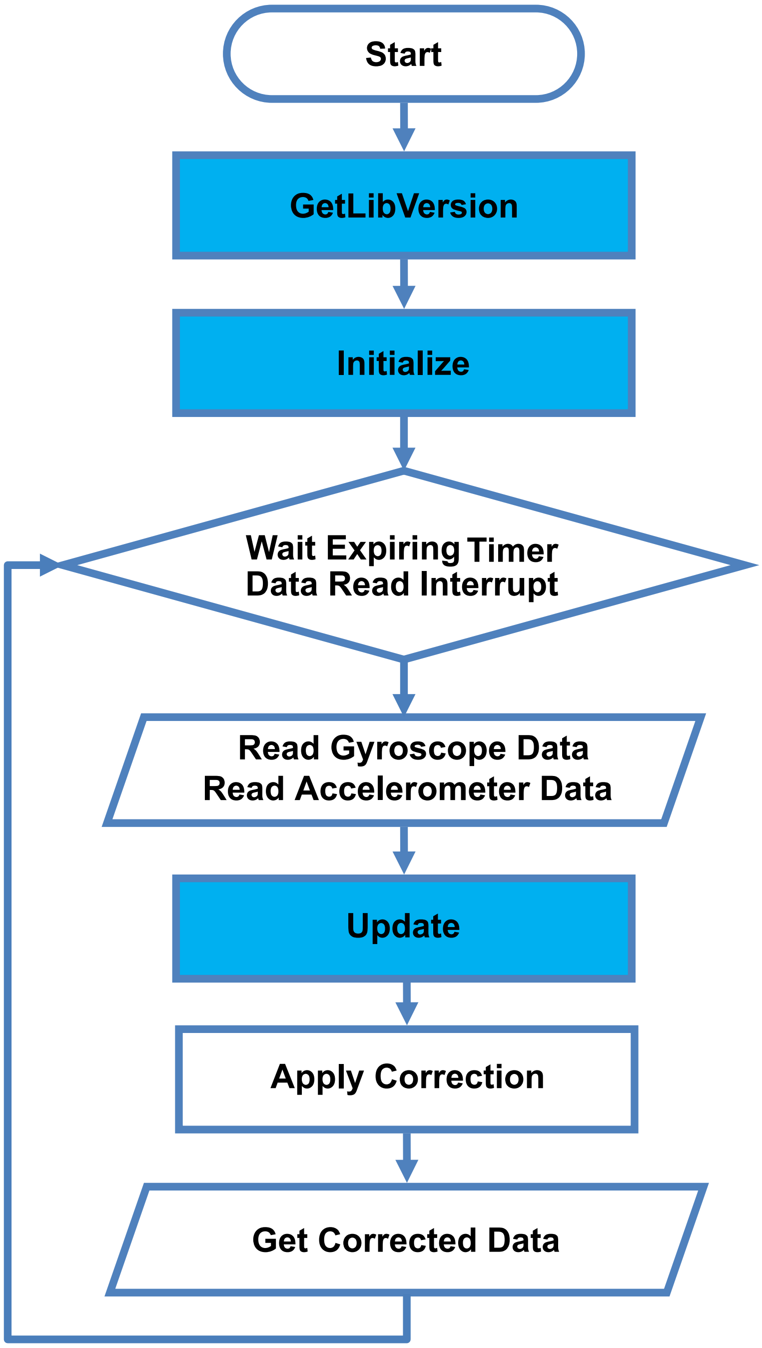
- `void MotionGC_GetCalParams(MGC_output_t *gyro_bias):`
  – retrieves the gyroscope compensation parameters
  – `*gyro_bias` parameter is a pointer to a structure with gyroscope angular zero-rate level
- `void MotionGC_SetCalParams(MGC_output_t *gyro_bias)`
  – sets the initial gyroscope compensation parameters, helping to quickly converge to the gyro offset right value
  – `*gyro_bias` parameter is a pointer to a structure with gyroscope angular zero-rate level

Note: *This function should be called just after `MotionGC_Initialize`*

- `void MotionGC_SetFrequency(float freq)`
  – applies the new sample frequency to the library without resetting
  – `freq` indicates the new sample frequency in Hertz

2.2.3 API flow chart

Figure 1. API flow chart diagram



2.2.4 Demo code

The following is an example of the demonstration code that reads data from the gyroscope sensor and from the accelerometer sensor and calculates compensated data.

```
[…]

#define VERSION_STR_LENG        35
#define SAMPLE_FREQUENCY     50.0f

[…]

/*** Initialization ***/
char lib_version[VERSION_STR_LENG];
MGC_knobs_t knobs;
MGC_output_t start_gyro_bias;
float sample_freq;

/* Gyroscope calibration API initialization function */
MotionGC_Initialize(SAMPLE_FREQUENCY);

/* Optional: Get version */
MotionGC_GetLibVersion(lib_version);

/* Optional: Get knobs settings */
MotionGC_GetKnobs(&knobs);

/* Optional: Adjust knobs settings */
knobs.AccThr = 0.008f;
knobs.GyroThr = 0.15;
MotionGC_Set_knobs(&knobs);

/* Optional: Set initial gyroscope offset */
start_gyro_bias.GyroBiasX = 0;
start_gyro_bias.GyroBiasY = 0;
start_gyro_bias.GyroBiasZ = 0;
MotionGC_SetCalParams(&start_gyro_bias);

/* Optional: Set sample frequency */
sample_freq = SAMPLE_FREQUENCY;
MotionGC_SetFrequency(sample_freq);

[…]

/*** Using gyroscope calibration algorithm ***/
Timer_OR_DataRate_Interrupt_Handler()
{
MGC_input_t data_in;
  MGC_output_t data_out;;
  int bias_update;
  float gyro_cal_x, gyro_cal_y, gyro_cal_z;

/* Get acceleration X/Y/Z in g */
  MEMS_Read_AccValue(data_in.Acc[0], data_in.Acc[1], data_in.Acc[2]);
/* Get angular rate X/Y/Z in dps */
  MEMS_Read_GyroValue(data_in.Gyro[0], data_in.Gyro[1], data_in.Gyro[2]);
/* Gyroscope calibration algorithm update */
  MotionGC_Update(&data_in, &data_out, &bias_update);
  /* Apply correction */
  gyro_cal_x = (data_in.Gyro[0] - data_out.GyroBiasX);
  gyro_cal_y = (data_in.Gyro[1] - data_out.GyroBiasY);
  gyro_cal_z = (data_in.Gyro[2] - data_out.GyroBiasZ);
}
```

2.2.5 The calibration process

The calibration process does not need any sensor motion as the offset coefficient is calculated and updated when the sensor is still.

2.2.6 Algorithm performance

Table 2. Cortex-M4 and Cortex-M3: elapsed time (µs) algorithm

Cortex-M4 STM32F401RE at 84 MHz									Cortex-M3 STM32L152RE at 32 MHz								
STM32CubeIDE 1.2.0			IAR EWARM 8.32.3			Keil µVision 5.27			STM32CubeIDE 1.2.0			IAR EWARM 8.32.3			Keil µVision 5.27		
Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
4	11	238	4	11	11	4	11	11	10	286	742	10	191	299	10	198	210

Table 3. Cortex-M0+ and Cortex-M7: elapsed time (µs) algorithm

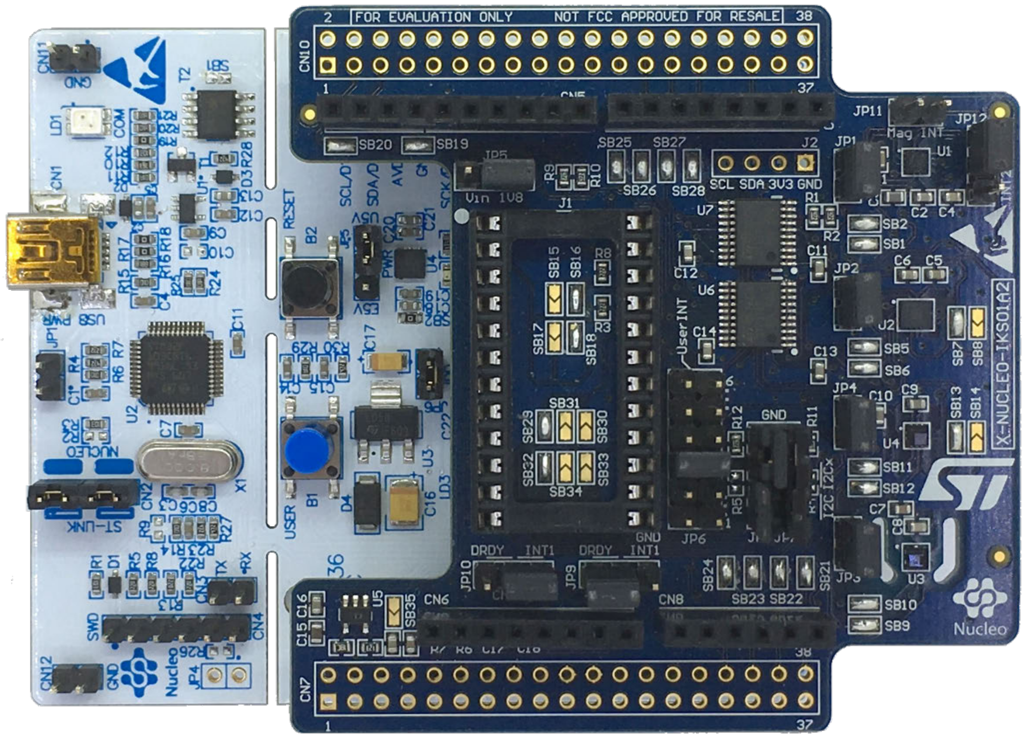
Cortex-M0+ STM32F073RZ at 32 MHz									Cortex-M7 STM32F767ZI at 96 MHz								
STM32CubeIDE 1.2.0			IAR EWARM 8.32.3			Keil µVision 5.27			STM32CubeIDE 1.2.0			IAR EWARM 8.32.3			Keil µVision 5.27		
Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
22	700	4403	22	362	711	22	355	388	4	10	11	3	8	9	3	8	9

2.3 Sample application

The MotionGC middleware can be easily manipulated to build user applications; a sample application is provided in the Application folder.

It is designed to run on a NUCLEO-F401RE, NUCLEO-L476RG, NUCLEO-L152RE or NUCLEO-L073RZ development boards connected to an X-NUCLEO-IKS01A2 or X-NUCLEO-IKS01A3 expansion board.

Figure 2. Sensor expansion board and adapter connected to an STM32 Nucleo



The gyroscope algorithm output data may be displayed in real-time through a specific GUI.

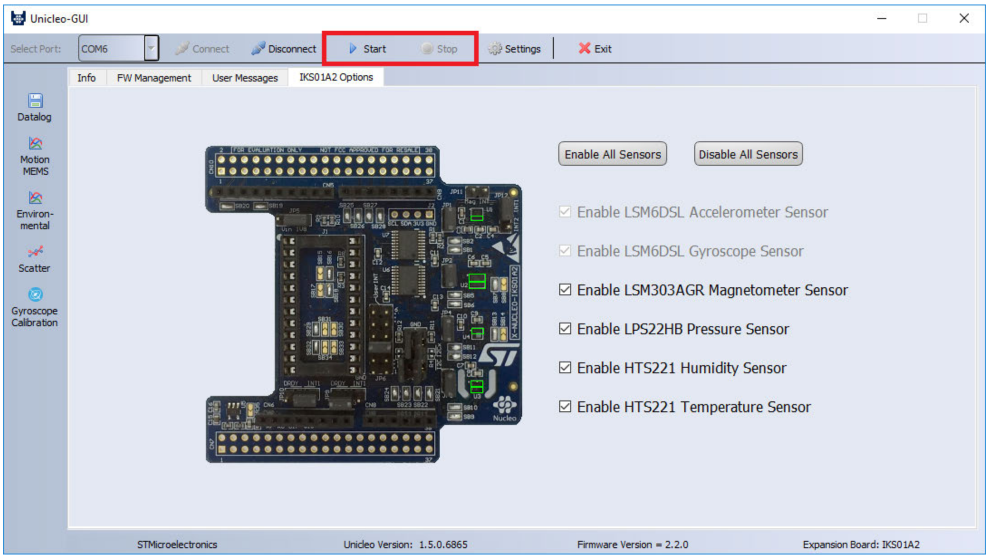
2.3.1 Unicleo-GUI application

The sample application uses the Windows Unicleo-GUI utility, which can be downloaded from www.st.com.

Step 1. Ensure that the necessary drivers are installed and the STM32 Nucleo board with the appropriate expansion board is connected to the PC.

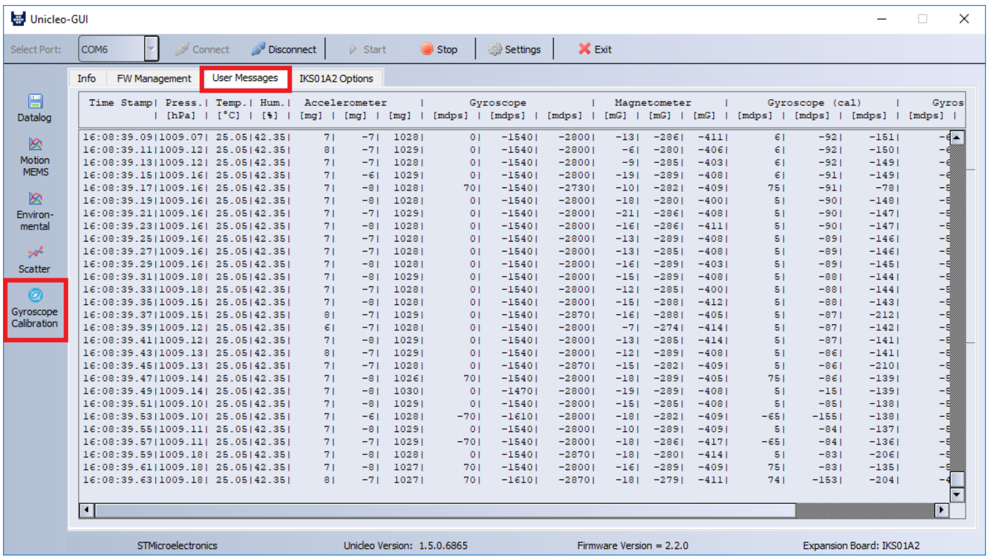
Step 2. Launch the Unicleo-GUI application to open the main application window. If an STM32 Nucleo board with the supported firmware is connected to the PC, it is automatically detected and the appropriate COM port is opened.

Figure 3. Unicleo main window



Step 3. Start and stop data streaming by using the appropriate buttons on the vertical toolbar. The data coming from the connected sensor can be viewed in the User Messages tab.

Figure 4. User Messages tab

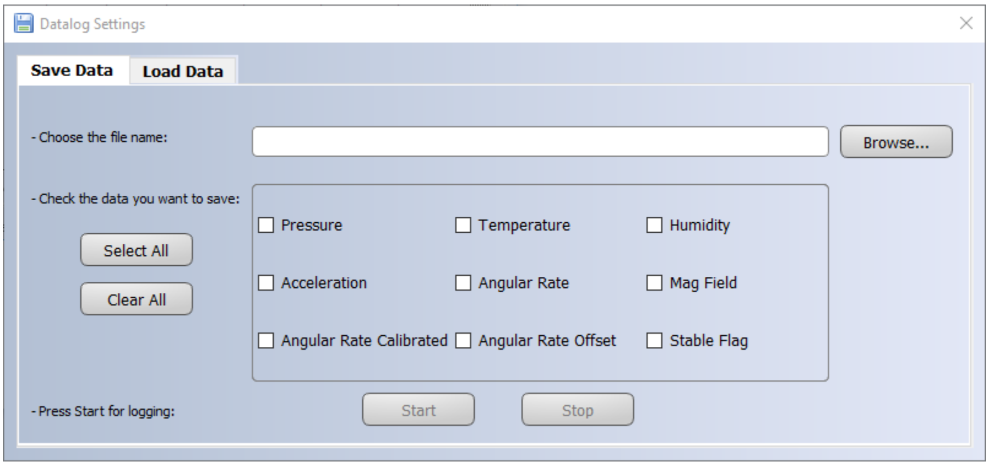


Step 4. Click on the Gyroscope Calibration icon in the vertical toolbar to open the dedicated application window. The window is split in three sections: the first one containing uncalibrated data, the second one containing calibrated data and the last one containing offset and stable flag information.

Figure 5. Gyroscope calibration window

Step 5. Click on the Datalog icon in the vertical toolbar to open the datalog configuration window: you can select the sensor and activity data to be saved in the files. You can start or stop saving by clicking on the corresponding button.

Figure 6. Datalog window



3 References

All of the following resources are freely available on www.st.com.

1. UM1859: Getting started with the X-CUBE-MEMS1 motion MEMS and environmental sensor software expansion for STM32Cube
2. UM1724: STM32 Nucleo-64 board
3. UM2128: Getting started with Unicleo-GUI for motion MEMS and environmental sensor software expansion for STM32Cube

Revision history

Table 4. **Document revision history**

Date	Version	Changes
03-Mar-2017	1	Initial release.
26-Jan-2018	2	Added references to NUCLEO-L152RE development board and Section 2.2.6 Algorithm performance.
20-Mar-2018	3	Updated Introduction and Section 2.1 MotionGC overview.
02-May-2018	4	Updated Section 2.2.1 MotionGC library description and Table 2. Cortex-M4 and Cortex-M3: elapsed time (µs) algorithm.. Added Table 3. Cortex-M0+: elapsed time (µs) algorithm. Added references to ARM Cortex-M0+ and NUCLEO-L073RZ development board.
19-Feb-2019	5	Updated Table 2. Cortex-M4 and Cortex-M3: elapsed time (µs) algorithm, Table 3. Cortex-M0+: elapsed time (µs) algorithm, Figure 2. Sensor expansion board and adapter connected to an STM32 Nucleo, Figure 3. Unicleo main window, Figure 4. User Messages tab, Figure 5. Gyroscope calibration window and Figure 6. Datalog window. Added X-NUCLEO-IKS01A3 expansion board compatibility information.
23-Mar-2020	6	Updated Introduction, Section 2.2.1 MotionGC library description and Section 2.2.6 Algorithm performance. Added ARM Cortex-M7 architecture compatibility information.

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