UM2774

User manual

Getting started with MotionAC2 2-axis accelerometer calibration library in X-CUBE-MEMS1 expansion for STM32Cube

Introduction

The MotionAC2 is a middleware library part of X-CUBE-MEMS1 software and runs on STM32. It provides real-time 2-axis accelerometer calibration through offset and scale factor coefficients used to correct accelerometer 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®-M33, ARM® Cortex®-M4 or ARM® Cortex®-M7 architecture.

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

The software comes with sample implementation running on a STEVAL-MKI209V1K MEMS inclinometer kit based on IIS2ICLX 2-axis accelerometer on a NUCLEO-F401RE, NUCLEO-L073RZ, NUCLEO-L152RE or NUCLEO-U575ZI-Q 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 MotionAC2 middleware library in X-CUBE-MEMS1 software expansion

2.1 MotionAC2 overview

The MotionAC2 library expands the functionality of the X-CUBE-MEMS1 software.

The library acquires data from the 2-axis accelerometer and calculates the offset and scale factor coefficients together with the calibration quality value. It involves aligning the system in four different orientations according to the gravity direction. The offset and scale factor coefficients are then used to compensate raw data coming from the accelerometer.

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 is described in the document.

Sample implementation is available on the STEVAL-MKI209V1K mounted on a NUCLEO-F401RE, NUCLEO-L073RZ, NUCLEO-L152RE or NUCLEO-U575ZI-Q development board.

2.2 MotionAC2 library

Technical information fully describing the functions and parameters of the MotionAC2 APIs can be found in the MotionAC2_Package.chm compiled HTML file located in the Documentation folder.

2.2.1 MotionAC2 library description

The MotionAC2 2-axis accelerometer calibration library manages data acquired from the accelerometer; it features:

- offset compensation up to 0.2 g
- scale factor compensation, in range from 0.8 to 1.2 in every direction
- update frequency from 20 to 100 Hz

Note: The maximum sample rate supported by the library is set at 1000 Hz to guarantee a good performance in terms of hardware resources and application needs. The minimum sample rate of 20 Hz is recommended to speed up calibration. By lowering the ODR, sensor calibration time will be increased.

- available for ARM Cortex M0+, Cortex-M3, Cortex-M33, Cortex-M4 and Cortex-M7 architectures
- resources requirements:
  - Cortex-M0+: 7.7 kB of code and 0.3 kB of data memory
  - Cortex-M3: 7.5 kB of code and 0.3 kB of data memory
  - Cortex-M33: 5.5 kB of code and 0.3 kB of data memory
  - Cortex-M4: 5.6 kB of code and 0.3 kB of data memory
  - Cortex-M7: 5.5 kB of code and 0.3 kB of data memory

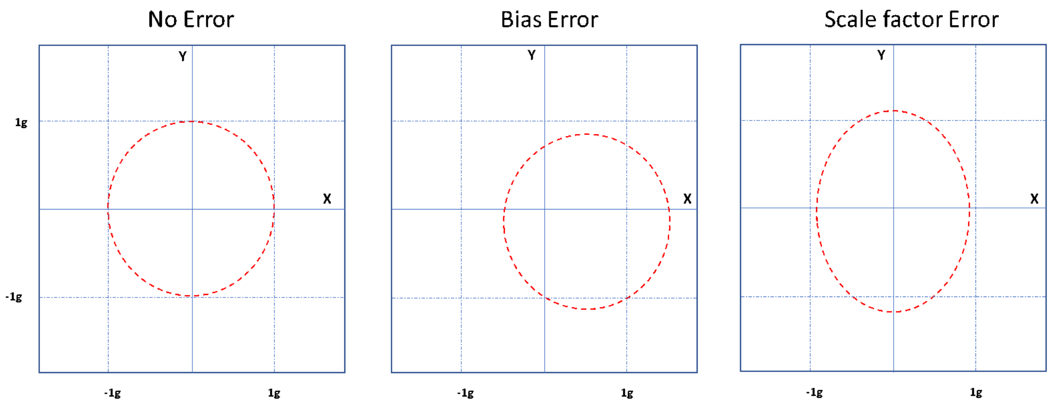
2.2.2 Accelerometer bias and scale factor

When the device is exposed to full gravity, the plot between X and Y axes can show the error in the accelerometer reading.

If the accelerometer reading is successful, the typical plot forms a circle with 1 g radius. Due to bias, the circle center can shift and the scale factor error distorts the circle, forming an ellipse.

The figure below shows the three different plots in the absence or presence of bias and scale factor error.

Figure 1. MotionAC2 accelerometer reading



MotionAC2 library automatically extracts data and exploits ellipse fitting to estimate bias and scale factor to correct accelerometer readings.

Due to bias and scale factor error, the relation between calibrated and raw accelerometer reading can be represented by:

$$X_{true} = a \cdot \left(X_{raw} - X_{off}\right) \tag{1}$$

$$Y_{true} = b \cdot \left(Y_{raw} - Y_{off}\right) \tag{2}$$

Since the total magnitude of acceleration is equal to gravity when the device is stationary:

$$X_{true}^2 + Y_{true}^2 = 1g \tag{3}$$

Rearranging the terms for X_{raw} and Y_{raw}:

$$\left(\frac{X_{raw} - X_{off}}{\left(\frac{1}{a}\right)}\right)^2 + \left(\frac{Y_{raw} - Y_{off}}{\left(\frac{1}{b}\right)}\right)^2 = 1 \tag{4}$$

Replacing 1/a and 1/b with aInv and bInv:

$$\left(\frac{X_{raw} - X_{off}}{a\text{Inv}}\right)^2 + \left(\frac{Y_{raw} - Y_{off}}{b\text{Inv}}\right)^2 = 1 \tag{5}$$

The last equation represents the ellipse equation when the library estimates all four parameters through the optimization method.

2.2.3 MotionAC2 APIs

The MotionAC2 APIs are:

- `void MotionAC2_Init(MAC2_mcu_type_t mcu_type, float *freq)`
  - performs MotionAC2 library initialization and setup of the internal mechanism
  - the CRC module in the STM32 microcontroller (in RCC peripheral clock enable register) has to be enabled before using the library
  - mcu_type - type of MCU used
  - `*freq` – the update frequency (sensor ODR)

Note: This function must be called before using the 2-axis accelerometer calibration library.

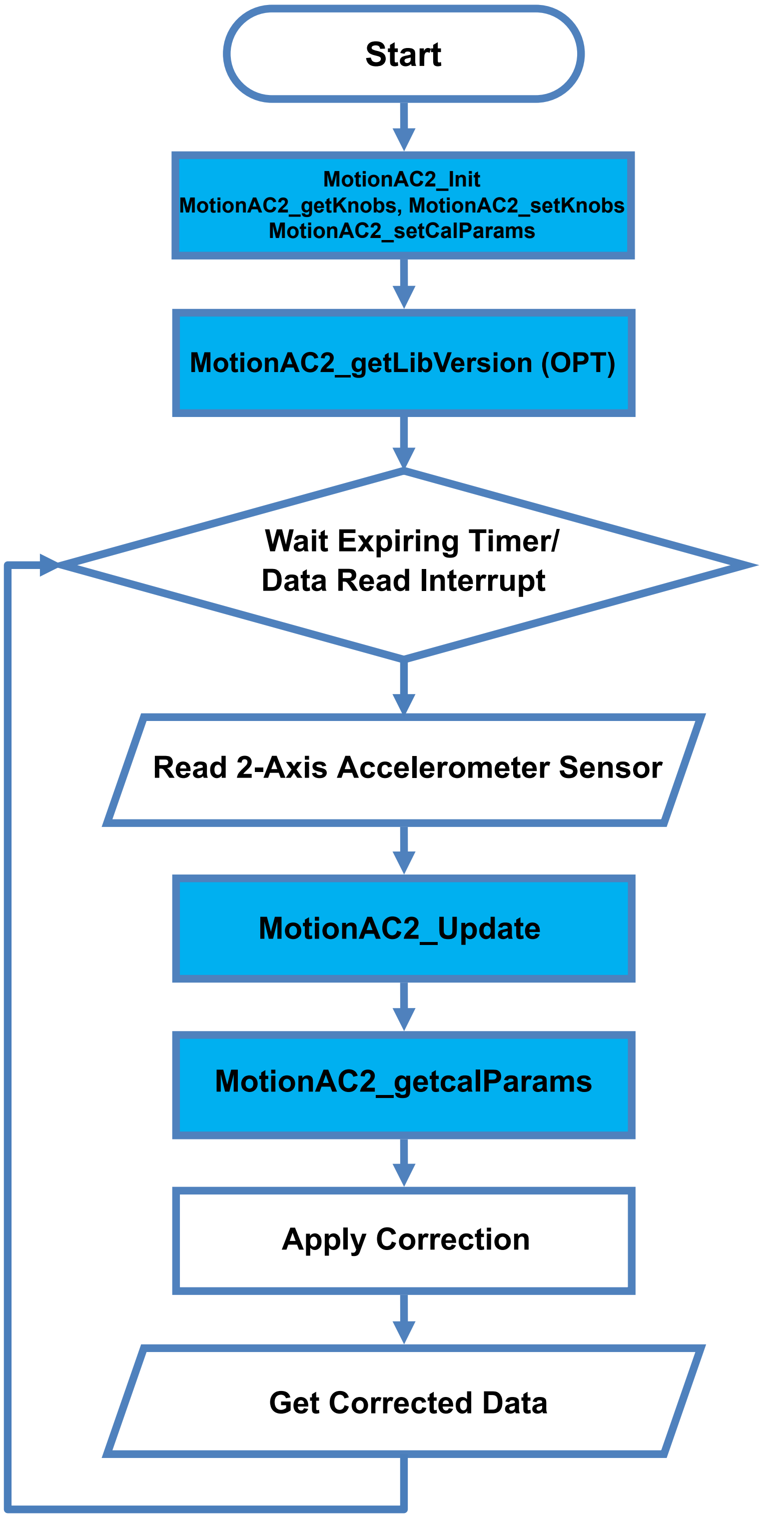
- `void MotionAC2_GetKnobs(MAC2_knobs_t *knobs)`
  - gets current knob settings
  - `*knobs` parameter is a pointer to a structure with settings
  - the parameters for the structure type `MAC2_knobs_t` are:
    - `FullScale` parameter is the accelerometer full range in the unit of g (default value is 2 g). It is recommended to set minimum 2 g to perform a successful calibration. A lower `FullScale` saturates the accelerometer signal and impacts the accuracy
    - `CalDuration_s` parameter is the expected duration of the calibration routine execution (default is 180 s). The library rejects the calibration motion if the overall motion is performed in more time than the set duration. The `CalDuration_s` is an overlapping window. The duration ensures the bias drift due to temperature does not affect the computation
    - `XlNoiseScale` parameter is the factor on noise of the accelerometer to detect the static condition to be used for calibration. It is recommended to set the value between 0.5 – 2 (default is 1); a higher value reduces the accuracy of calibration parameters. In some applications, the accelerometer noise might be higher due to vibration and requires setting a higher value. The value of `XlNoiseScale` derives from computing the variance of accelerometer data (single axis) at stationary and dividing by 5e-6 g2. Set the value with some positive margin (for example, if the computed value is around 0.8, set 0.85 or 0.9).
- `void MotionAC2_SetKnobs(MAC2_knobs_t*knobs)`
  - sets current knob settings
  - `*knobs` parameter is a pointer to a structure with settings (see `MotionAC2_GetKnobs`)
- `uint8_t MotionAC2_Update(MAC2_input_t *data_in, uint64_t timestamp_ms)`
  - executes 2-axis accelerometer calibration algorithm
  - `*data_in` parameter is a pointer to a structure with input data
  - the parameters for the structure type `MAC2_input_t` are:
    - `Acc_X` is an accelerometer X axis value in g
    - `Acc_Y` is an accelerometer Y axis value in g
  - `timestamp_ms` parameter is a timestamp of the current sample in ms
  - returns 1 in case of calibration is done with the current sample, 0 otherwise

Note: This function must be called periodically at the same interval indicated in `MotionAC2_Init`.

- `void MotionAC2_GetCalParams(MAC2_cal_params_t *cal_params)`
  - retrieves the accelerometer calibration coefficients for offset and scale factor compensation and calibration quality factor
  - `*cal_params` parameter is a pointer to a structure with calibration parameters
  - the parameters for the structure type `MAC2_cal_params_t` are:
    - `Bias[2]` is an array of the offset for each axis in g
    - `SF[2]` is the scale factor for each axis
    - `CalStatus` is the calibration status:
      - `MAC2_CAL_UNKNOWN = 0` - accuracy of calibration parameters is unknown
      - `MAC2_CAL_POOR = 1` - accuracy of calibration parameters is poor, cannot be trusted, expected accuracy ~20 deg
      - `MAC2_CAL_OK = 2` - accuracy of calibration parameters is OK, expected accuracy ~2.5 deg
      - `MAC2_CAL_GOOD = 3` - accuracy of calibration parameters is good, expected accuracy ~0.5 deg
- `void MotionAC2_SetCalParams(MAC2_cal_params_t *cal_params)`
  - sets the initial accelerometer calibration coefficients from the last run if any
  - `*cal_params` parameter is a pointer to a structure with calibration parameters
- `uint8_t MotionAC2_GetLibVersion(char *version)`
  - retrieves the library version
  - `*version` is a pointer to an array of 35 characters
  - returns the number of characters in the version string

2.2.4 API flow chart

Figure 2. MotionAC2 API logic sequence



2.2.5 Demo code

The following demonstration code reads data from accelerometer sensor and calculates compensated data.

```
[…]
#define VERSION_STR_LENG    35
#define ALGO_FREQ    100.0f

[…]

/*** Initialization ***/

char lib_version[VERSION_STR_LENG];

MAC2_knobs_t Knobs;

/* 2-Axis Accelerometer calibration API initialization function */

MotionAC2_Init(MAC2_MCU_STM32, ALGO_FREQ);

/* Optional: Get version */

MotionAC2_GetLibVersion(lib_version);

/* Optional: Adjust Knobs settings Fulls Scale = 2g, Higher noise in the system */

MotionAC2_GetKnobs(&Knobs);

Knobs.FullScale = 2.0f;
Knobs.XlNoiseScale  = 1.1f;

MotionAC2_SetKnobs(&Knobs);


[…]

/*** Using 2-axis accelerometer calibration algorithm ***/


Timer_OR_DataRate_Interrupt_Handler()

{

MAC2_input_t data_in;

MAC2_output_t data_out;

float acc_cal[2];

/* Get acceleration X/Y in g */

MEMS_Read_AccValue(&data_in.Acc_X, &data_in.Acc_Y);

/* Accelerometer calibration algorithm update */

MotionAC2_Update(&data_in);

/* Get Calibration coeficients */

MotionAC_GetCalParams(&data_out);


/* Apply correction */

acc_cal[0] = (data_in.Acc_X - data_out.Bias[0]) * data_out.SF[0];
acc_cal[1] = (data_in.Acc_Y - data_out.Bias[1]) * data_out.SF[1];
}
```

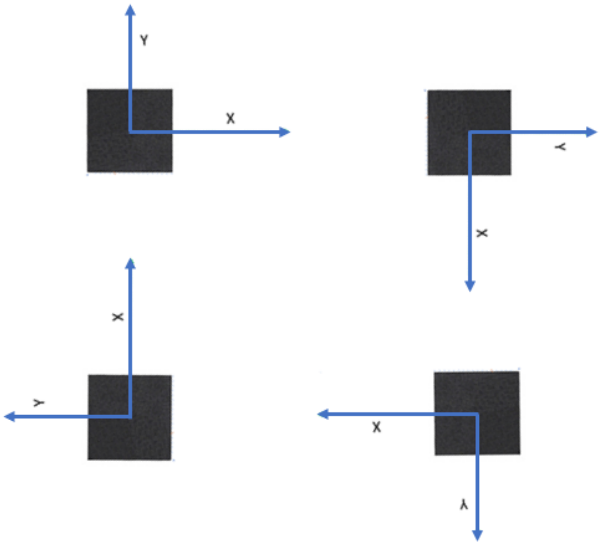
2.2.6 Calibration process

The calibration process is based on the 4-point tumble calibration of the 2-axis accelerometer sensor when exposed to Earth gravitation field. The data is collected at the stationary condition.

During calibration, the device must be placed in four different orientations at least.

Calibration can be performed by placing the device in four different directions with respect to gravity. For example, the device can be placed with ±X, ±Y.

Figure 3. Calibration motion



You can place the device in any orientation without the need of putting it in a perfect flat position but ensuring the device remains in a stationary position for at least 3 seconds before changing its orientation.

2.2.7 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		
Min	Avg	Max	Min	Avg	Max
2	2	4	15	24	1896

Table 3. Cortex-M0+, Cortex-M33 and Cortex-M7: elapsed time (µs) algorithm

Cortex-M0+ STM32L073RZ at 32 MHz			Cortex-M33 STM32U575ZI-Q at 160 MHz			Cortex-M7 STM32F767ZI at 96 MHz		
Min	Avg	Max	Min	Avg	Max	Min	Avg	Max
0	21	4000	1	1	40	4	5	130

3 Sample application

The MotionAC2 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-L073RZ, NUCLEO-L152RE or NUCLEO-U575ZI-Q development board connected to the STEVAL-MKI209V1K.

Accelerometer algorithm output data can be displayed in real-time through MEMS-Studio.

3.1 MEMS-Studio application

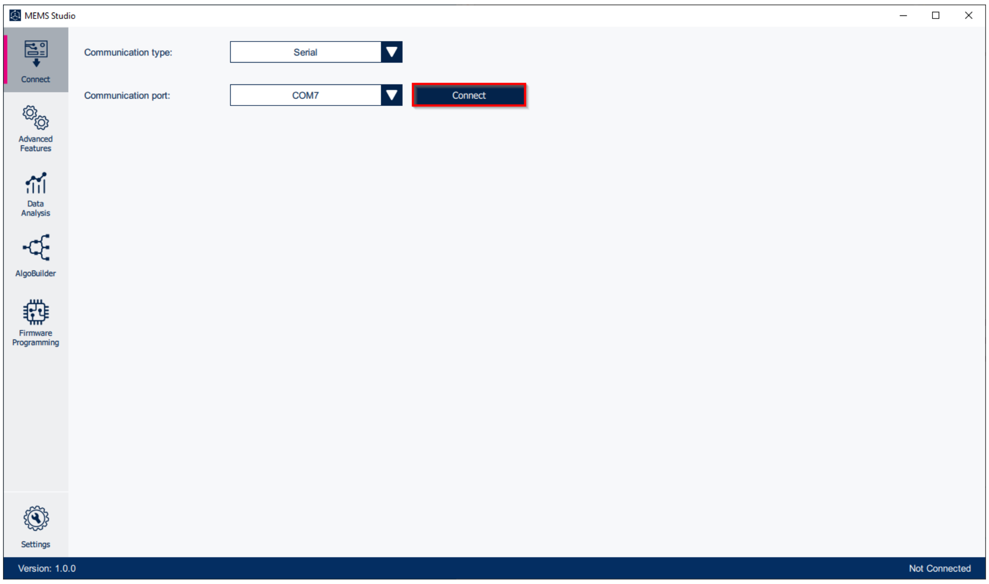
The sample application uses the MEMS-Studio GUI application, which can be downloaded from www.st.com.

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

Step 2. Launch the MEMS-Studio application to open the main application window.

If an STM32 Nucleo board with supported firmware is connected to the PC, the appropriate COM port is authomatically detected. Press [**Connect**] button to open this port.

Figure 4. MEMS-studio connect



Step 3. When connected to STM32 Nucleo board with supported firmware [**Library Evaluation**] tab is opened. To start and stop data streaming toggle the appropriate start / stop button on the outer vertical tool bar.

Figure 5. **Start**

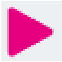
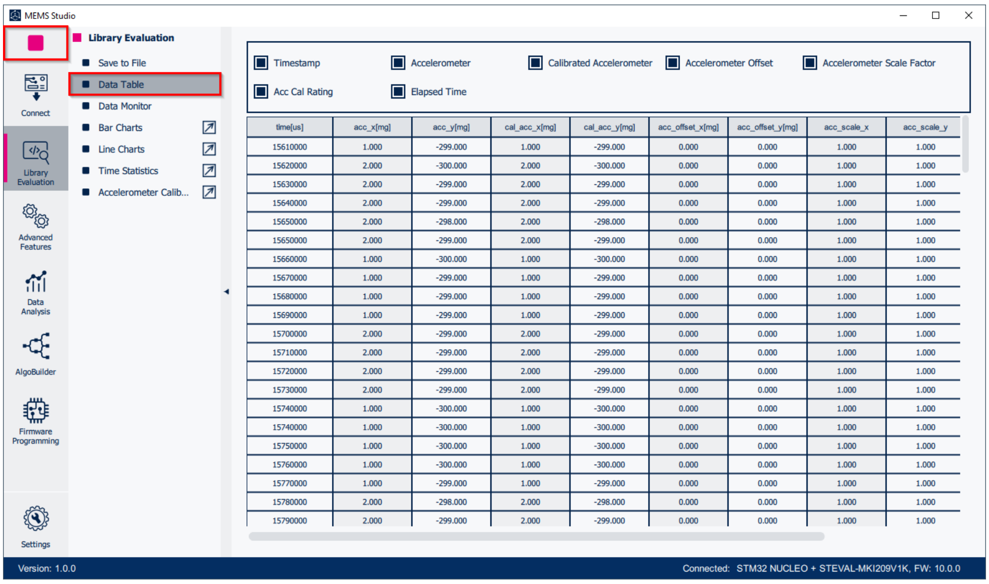


Figure 6. **Stop**

The data coming from the connected sensor can be viewed selecting the [**Data Table**] tab on the inner vertical tool bar.

Figure 7. **MEMS-Studio - Library evaluation - Data table**



Step 4. Select the [**Accelerometer Calibration**] tab on the inner vertical tool bar to open the dedicated application status view.

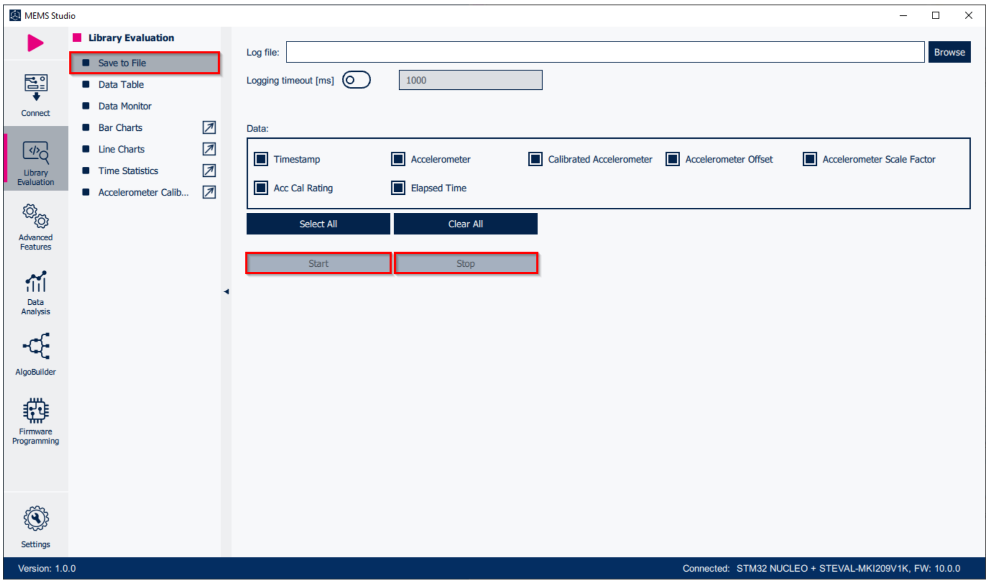
The window is split into one section with uncalibrated data, another with the calibrated data, another section with offset, scale factor and quality of calibration information and the last section with button [**Calibration Procedure**] to show instruction how to perform calibation and [**Reset Calibration**] to reset calibration values to default ones.

Figure 8. MEMS-Studio - Library Evaluation - Accelerometer Calibration

Step 5. Select the [**Save to File**] tab on the inner vertical tool bar to open the data logging configuration window.

You can select which sensor and activity data to save to log files. You can start or stop saving by clicking on the corresponding [**Start/Stop**] button.

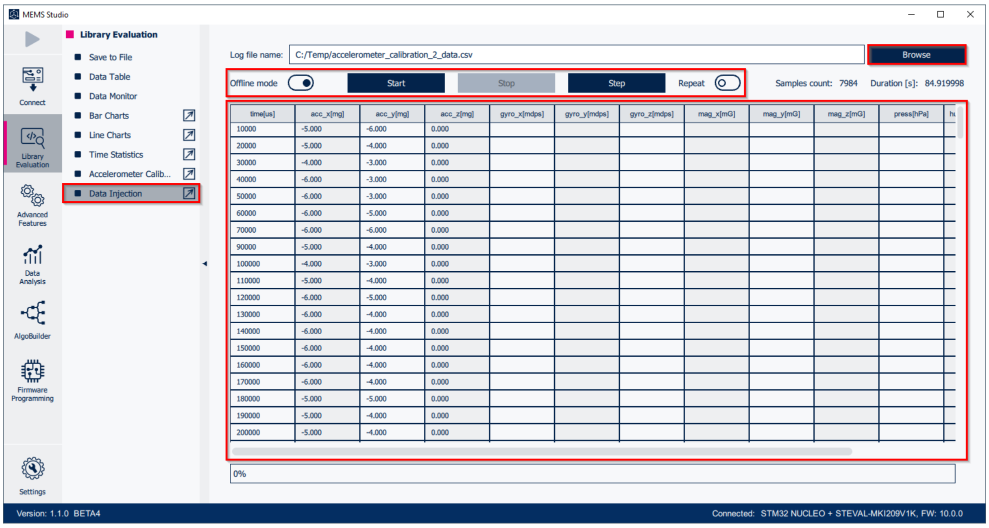
Figure 9. MEMS-Studio - Library Evaluation - Save to File



Step 6. Select the [**Data Injection**] tab on the vertical tool bar to open the wiew dedicated to process the previously captured data.

The data are processed by the MCU firmware.

Figure 10. **MEMS-Studio - Library Evaluation - Data Injection**



Step 7. Click on the [**Browse**] button to select the file with the previously captured data in CSV format.

The data will be loaded into the table in the current view.

Other buttons will become active. You can click on:

– [**Offline Mode**] button to switch the firmware offline mode on/off (mode utilizing the previously captured data).

– [**Start**]/[**Stop**]/[**Step**]/[**Repeat**] buttons to control the data the data feed from MEMS-Studio the firmware

4 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 boards (MB1136)
3. UM3233: Getting started with MEMS-Studio

Revision history

Table 4. **Document revision history**

Date	Version	Changes
08-Sep-2020	1	Initial release.
14-05-2024	2	Updated Introduction, Section 2.1: MotionAC2 overview, Section 2.2.1: MotionAC2 library description, Section 2.2.3: MotionAC2 APIs, Section 2.2.5: Demo code, Section 2.2.7: Algorithm performance and Section 3: Sample application. Replaced Unicleo-GUI application with Section 3.1: MEMS-Studio application.

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