SHM-H Board

High-Sensitivity Accelerometer Sensor Board

Datasheet and User's Guide

Overview

Developed as part of the Illinois Structural Health Monitoring Project, the SHM-H sensor board is designed to interface with the Imote2 smart sensor platform. This high-sensitivity sensor board is an extension of the SHM-A board. A high-quality and low-noise accelerometer (SD1221L-002) and low-noise circuitry has been used in this sensor board to enable the measurement of low-level ambient acceleration. The sensor board provides a single axis of high-sensitivity acceleration as well as two axes of general purpose acceleration and temperature/humidity measurements.

Features

- One high-sensitivity accelerometer axis (z axis)
- Slide switches for selection of vertical & horizontal measurement with a high-sensitivity accelerometer
- Two general-purpose accelerometer axes (x & y axes)
- Temperature and relative humidity sensors
- User-selectable sampling rates and cut-off frequencies
- Customizable digital filters
- Open-source software available for operation with the Imote2

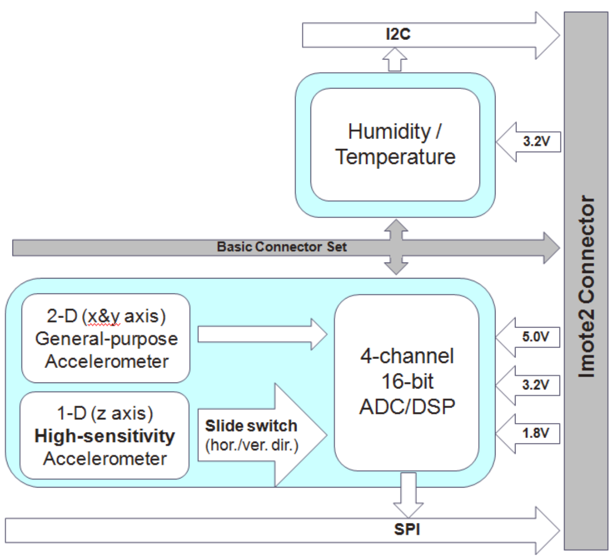

Figure 1. SHM-H sensor board: perspective (left), top (middle), and bottom (right).

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1 Block diagram and pin descriptions

1.1 Block diagram

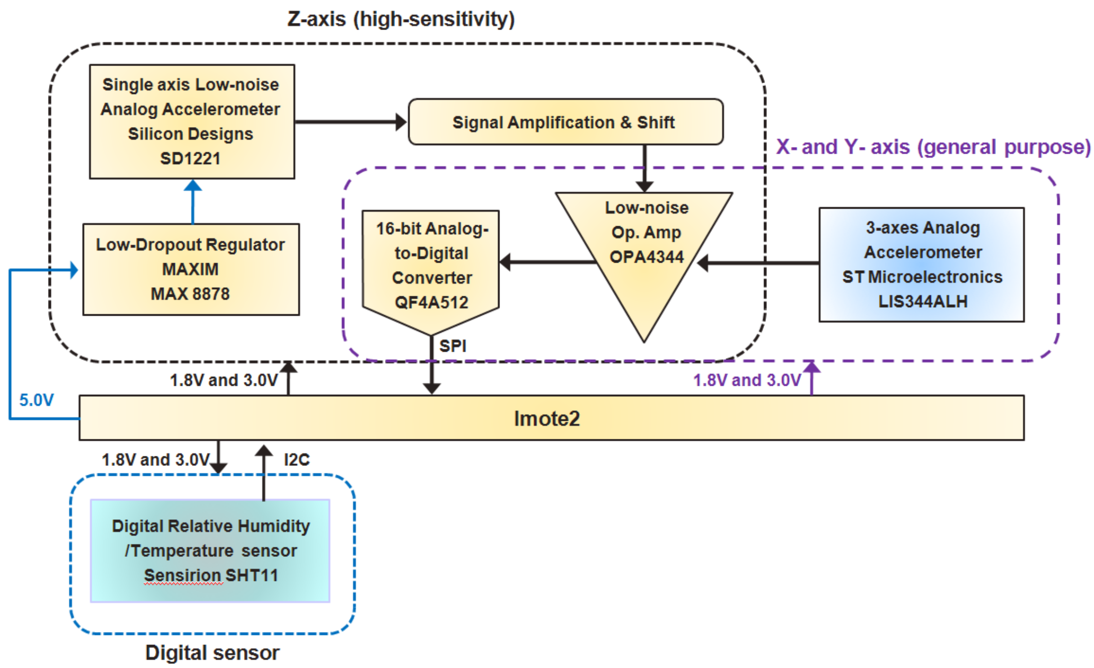

Figure 2. SHM-H block diagram

1.2 Pin descriptions

The SHM-H board connects to the Imote2 via two connectors located on the bottom of the board. In addition, the SHM-H board provides two connectors on the top of the board to allow the stacking of additional boards to interface with both the SHM-H board and the Imote2. Figure 3 gives the dimensions of the SHM-H sensor board, indicates the location of the connectors on both the top and bottom of the board, and shows the acceleration measurement directions. The pin descriptions are given in Tables 1 and 2.

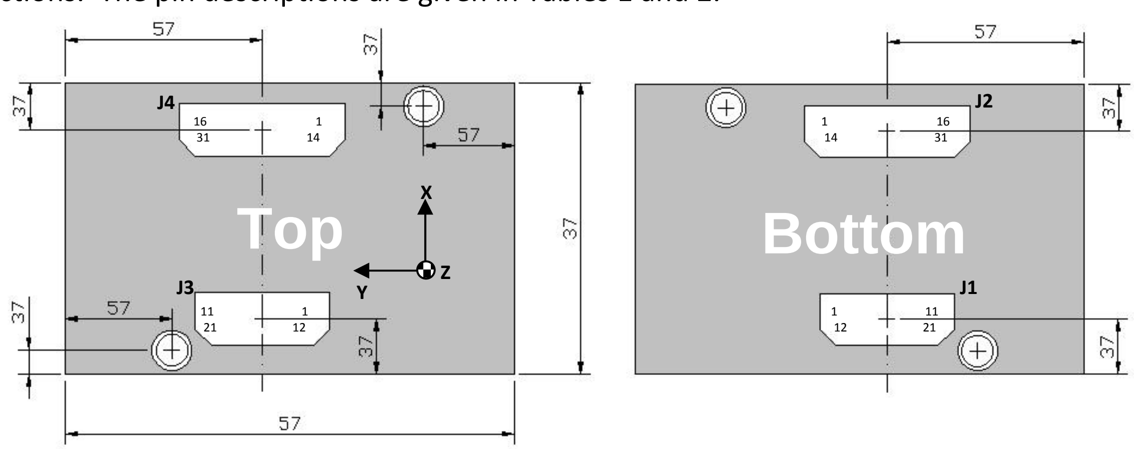

Figure 3. SHM-H dimensions (all dimensions in mm).

Table 1. Imote2/SHM-H 31-pin connector (J2 and J4) pin descriptions.

Pins	Group	Imote2 Description	SHM-H Functionality
1	UART1	Serial port communication or General Purpose I/O	none
2			none
3			SHT11 (Temp. and Hum.) data[1]
4			SHT11 (Temp. and Hum.) clock[1]
5-8	UART2	Serial port communication or General Purpose I/O	none
9	GND	Ground	GND
10	SPI2	SSPCLK2– SPI Clock	none
11		SSPFRM2 – Chip Select	none
12		SSPTxD2 – SPI Serial Data Input	none
13		SSPRxD2 – SPI Serial Data Output	none
14	GPIO94	General purpose I/O	none
15,16	Reserved	Reserved	none
17	I^2C	SCL – I^2C Serial Clock	none
18		SDA – I^2C Serial Data	none
19	SPI1	SSPCLK1– SPI Clock	QF4A512 (ADC) SPI Clock
20		SSPFRM1 – Chip Select	QF4A512 (ADC) Chip Select
21		SSPTxD1 – SPI Serial Data Input	QF4A512 (ADC) Serial Data Output
22		SSPRxD1 – SPI Serial Data Output	QF4A512 (ADC) Serial Data Input
23	GPIO10	General Purpose I/O	QF4A512 (ADC) Data Ready Interrupt
24	GND	Ground	GND
25	SDIO	MMCLK	none
26		MMCMD	none
27		MMD0	none
28		MMD1	none
29		MMD2	none
30		MMD3	none
31	GPIO93	General Purpose I/O	QF4A512 (ADC) Chip Reset

[1]The humidity and temperature sensor cannot be accessed when the Imtoe2 is connected to the debug board (IIB2400) since it uses the same pins as the one of the two serial ports used by the debug board.

Table 2. Imote2/SHM-H 21-pin connector (J1 and J3) pin descriptions.

Pins	Group	Imote2 Description	SHM-H Functionality
1-2	VBAT	Drives power to processor (3.2 – 4.7V input)	none
3	GND	Ground	GND
4	PMIC_TBAT	PMIC battery temperature input	none
5	Power	5.0V (USBH)	5.0V supply
6-9	Reserved	Reserved	none
10		Available for expansion	none
11			none
12	Power	1.8V (programmable 1.8 – 3.3V)	1.8V supply
13		3V (programmable 1.8 – 3.3V)	3.2V supply
14	Reserved	Reserved	none
15	ALARM	Alarm input to PMIC	Connected to VRTC (18)[1]
16	RESET	Reset – manual reset	none
17	GND	Ground	GND
18	VRTC	Imote2 processor powered indicator - high if on or asleep	Connected to Alarm (15)[1]
19	nCHARGE_EN	Battery select (primary or rechargable)	none
20	STDUart	STD_RxD – Debugging with BLUSH	none
21		STD_TxD – Debugging with BLUSH	none

[1]VRTC is connected to the PMIC Alarm if R10 is populated. This connection causes the Imote2 to power on if a USB plug power source is inserted or the Imote2 is connected to a powered battery board without the need to press the reset button.

2 Mechanical and electrical specifications

2.1 Mechanical characteristics

Table 3. Acceleration characteristics @ V_{SB} = 5.0V (for SD1221) & 3.2V (for LIS344ALH), T = 25°C unless otherwise noted.

Axis	Parameter	Min	Typ.	Max.	Units
z-axis: high-sensitivity	Acceleration Range		±0.2 (1±0.2)[1]		g
	Least significant bit (LSB)	0.0143	0.0148	0.0154	mg
	Sensitivity	65000	67500	70000	LSB/g
	Zero-g offset	13000	14000	15000	LSB
	Temperature sensitivity[2]	-0.025		0.025	%/°C
	Zero-g change vs. temperature[2]		0.4	1.2	mg/°C
	RMS Noise level[3]	0.04	0.05	0.06	mg
	Maximum Frequency[2]		400		Hz
x & y axes: general purpose	Acceleration Range[4]		±2		g
	Least significant bit (LSB)	0.133	0.143	0.152	mg
	Sensitivity	6600	7000	7500	LSB/g
	Zero-g offset	13300	14000	14600	LSB
	Temperature sensitivity[5]	-0.08		0.02	%/°C
	Zero-g change vs. temperature[5]		-1.25		mg/°C
	RMS Noise level[3]	0.2	0.3	0.7	mg
	Maximum Frequency[4,6]	1158	1448	1736	Hz

[1]( ) value is for vertical measurement.
[2]According to Silicon Designs SD1221L-002 Datasheet: http://www.silicondesigns.com/pdfs/1221.pdf.
[3]RMS noise at 20Hz bandwidth.
[4]According to STMicroelectronics LIS344ALH Datasheet: http://www.st.com/stonline/products/literature/ds/14337/lis344alh.htm.
[5]Before on-board temperature correction.
[6]This is represents the maximum analog frequency prior to digital filtering that results from 1nF capacitors on the output of the accelerometer.

Table 4. Temperature / Humidity sensor characteristics

Parameter	Min	Typ.	Max.	Units
Temperature Range[1]	-40		123.8	°C
Temperature Resolution[1]	0.04	0.01	0.01	°C
Temperature Accuracy[1]		±0.4		°C
Temperature Response Time[1]	5		10	s
Humidity Range[1]	0		100	%RH
Humidity Resolution[1]	0.4	0.05	0.05	%RH
Humidity Accuracy[1]		±3.0		%RH
Humidity Response Time[1]		3		s

[1]From the Sensirion SHT11 – Digital Humidity Sensor Datasheet: http://www.sensirion.com/en/pdf/product_information/Datasheet-humidity-sensor-SHT1x.pdf. Not all characteristics were specifically tested on the SHM-H board.

3 Typical performance characteristics and comparisons

The following plots are intended to give typical performance characteristics of the sensor board. Unless otherwise noted, the boards were tested at ~25°C with V_{SB} = 5.0V (for SD1221) & 3.2V (for LIS344ALH).

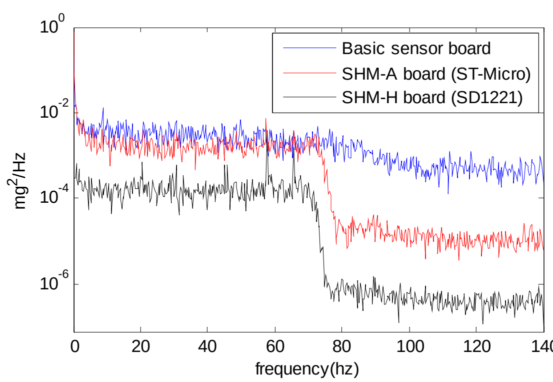

Figure 4. Noise characteristic comparisons (Static still test)

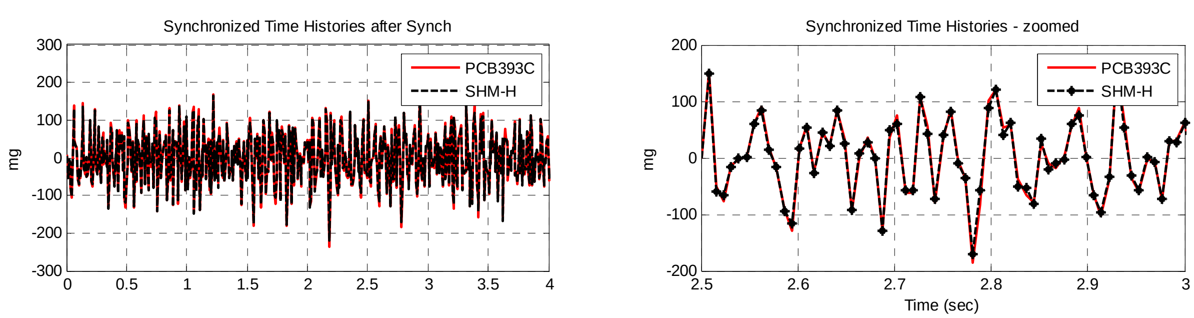

Figure 5. Time history comparison with conventional wired accelerometer (Shaking table test)

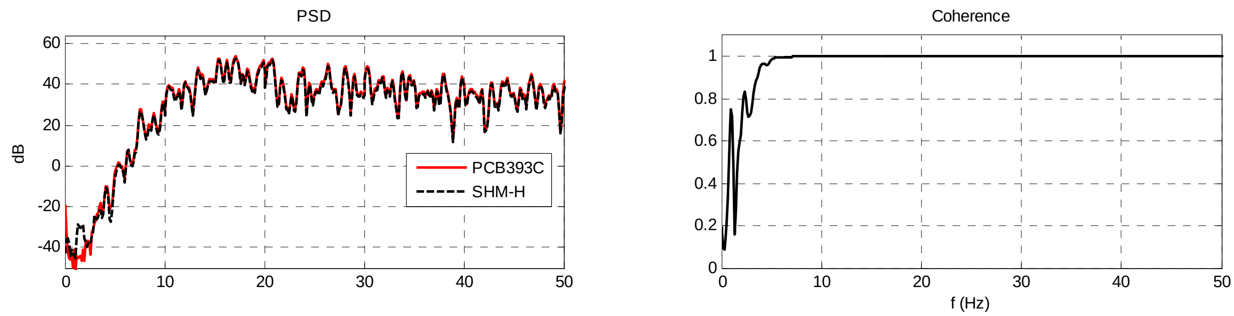

Figure 6. Frequency domain comparison with conventional wired accelerometer (Shaking table test)

4 Directional switch for horizontal and vertical axis measurement

The low-noise accelerometer SD1221 included in SHM-H board has a DC offset value that differs when for the vertical- and horizontal-axis measurements. To accommodate these different DC-offset values, two different Op-amp circuits are required for the signal amplification of each directional measurement. Since the SD1221 is capable of only single-axis measurement, the SHM-H board includes directional switches for the selection of the vertical- or horizontal-axis measurement. Figure 7 shows the directional switches located on the top and bottom side of the SHM-H board.

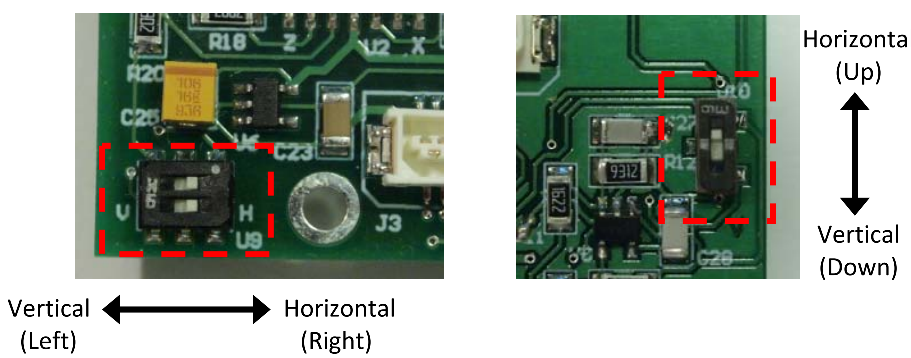

Figure 7. Directional switches: top side (left) and bottom side (right)

- To measure vertical acceleration (ranging 0.8g ~ 1.2g) using the high-sensitivity capability of the SHM-H board, the actuator of the switch on top side should be in the “Left” position and the actuator of the bottom switch should be in the “Down” position. It should be noted that the top side of the SHM-H board should be upward direction for the vertical acceleration measurement.
- To measure horizontal acceleration (ranging -0.2g ~ 0.2g), the actuator of top switch should be in the “Right” position and the actuator of bottom switch should be in the “Up” position.

5 Temperature compensation

A capacitive type sensor is susceptible to mean value drift of the signal due to the temperature change inside the sensor. The SD1221 accelerometer also experiences this drift effect. Usually it is not required to consider this issue when measuring relatively short periods of data. However, long data records will exhibit drifts. The SD1221 accelerometer provides a temperature-dependant current source output; which is useful for the estimation of the temperature change inside the sensor. The temperature-dependent current output is connected to the 4th channel of the QF4A512 ADC in the SHM-H board after converting to voltage signal and is utilized for the temperature compensation. The temperature effect is automatically corrected in the SHM-H board driver; i.e. the temperature compensated acceleration measurement is available with SHM-H board. Figure 8 shows the typical time history of a constant acceleration signal measured by the SHM-H board and comparison of before- and after temperature correction. For the temperature correction in SHM-H board, the smoothed temperature data is de-trended not to add unnecessary noise.

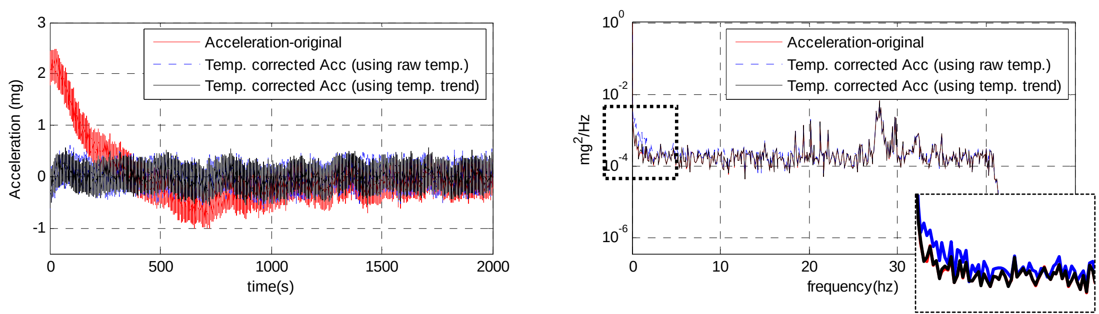

Figure 8. Time history (left) and power spectral density (right) of temperature corrected acceleration

By default, the temperature correction function in the SHM-H sensor board driver is disabled. Because the sensitivity of temperature dependent signal is different from board to board, this would result in potential error if default setting is used. To activate this function, little update of SHM-H board driver is required.

5.1 SHM-H board driver update for temperature correction

The relation between the temperature signal and the mean value drift of the acceleration signal is shown in Figure 9 (left). Using linear regression, the mean value temperature sensitivity (slope of the regression line) of the z-axis high-sensitivity acceleration signal can be estimated, and the scaled- and soothed temperature signal is used for the temperature correction.

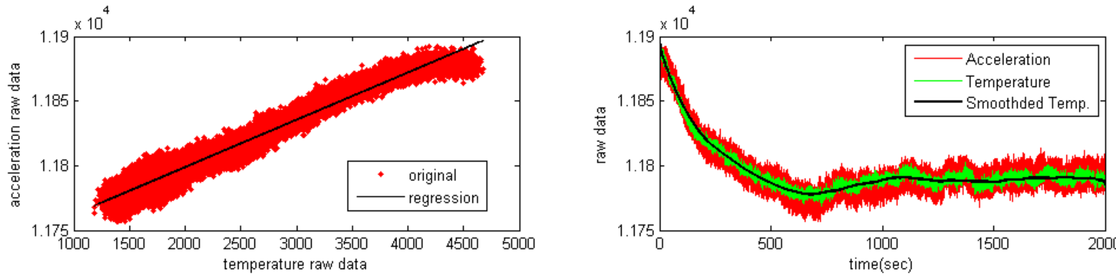

Figure 9. Relation between mean-value drift in acceleration signal and inside temperature: (left) linear relation between the acceleration & the internal temperature, (right) scaled- and scaled-smoothed temperature signal.

- First, measure the high-sensitivity acceleration (3rd channel data) and the temperature data (4th channel data) using `RemoteFlashSensing`. The same parameters that will be used for actual measurements will give better results.
- Then, find the mean value temperature sensitivity (scale factor) using the linear regression. *MATLAB* users can use below simple code to find the scale factor.

```
ch4 = data(:,4);            % Temperature data
ch3 = data(:,3);            % z-axis high-sensitivity acceleration data
X = [ones(size(ch3)) ch3];
a = X\ch4;                  % a(2): scale factor
```

- Open the `sensorboard.h` file (`shm/sensorboards/SHM_H/sensorboard.h`), and change the z-axis temperature sensitivity constant (3rd one) as shown in Figure 10. First two constants are for the x- and y-axis general purpose acceleration measurements. More information of these two constants can be found at Advanced Users Guide of SHM-A board: http://shm.cs.uiuc.edu/files/ISM400_AdvancedUsersGuide.pdf

```
const sensor_scaling_t *channelDataScaling[TOTAL_SENSOR_CHANNELS] = {
    &accelChannelScaling,
    &accelChannelScaling,
    &accelChannelScaling,
    &accelChannelScaling,
    &tempChannelScaling,
    &accelChannelScaling
};

// First two constants are for x- and y-axis (general purpose acceleration measurement)
// The 3rd constant is for the z-axis high-sensitivity acceleration measurement
const float tempSens[] = {0.03, 0.02, -0.40844};

#endif /* _SENSORBOARD_H */
```

Figure 10. Registration of temperature sensitivity constants in `sensorboard.h`

- Each time these constants are changed in `sensorboard.h`, the sampling application (eg. RemoteSensing) should be recompiled and reinstalled on each corresponding leaf nodes

6 Software

The software required to operate the SHM-H board interfaced with the Imote2 is open-source and can be found at http://shm.cs.uiuc.edu/software.html. This software includes drivers for the QF4A512, the temperature and humidity sensor and the light sensor as well as a wide range of application software for acquiring data locally and remotely.

6.1 Driver

After installing the Illinois Structural Health Monitoring Project (ISMHP) Services Toolsuite, the driver for the SHM-H sensor board can be found in the shm/sensorboards/SHM_H directory. Included in this directory are the main driver for the QF4A512 (ADC) as well as driver for the SHT11 (temperature and humidity) component. Basically, those are same drivers as SHM-A board is using. A difference is the onboard temperature correction method in main driver. The SHM-H board uses the 4th channel data of QF4A512, which is connected to the temperature dependent current output of SD1221, for the onboard temperature correction, while SHM-A board utilizes the temperature data from SHT11 sensor. Table 5 describes the contents of each file.

Table 5. SHM-H driver files.

Component	File	Description
QF4A512 - Accelerometer and external input ADC	AccelSensorM.nc	Module and configuration file for QF4A512 operation.
	AccelSensorC.nc	
	AccelSensor.h	Defines constants associated with QF4A512 operation.
	filters.h	Defines configuration files and filter delays to be loaded for QF4A512 operation.
SHT11 – Temperature and Humidity Sensor	TempHumSensorM.nc	Module and configuration file for temperature and humidity sensor operation.
	TempHumSensorC.nc	
	TempHumSensor.h	Defines constants and numerical relationships for temperature and humidity sensor.
	hardware.h	Defines SHT11 I2C parameters.
SHM-H – whole board operation	SensorboardM.nc	Module and configuration file for SHM-H board management including channel setup, memory allocation for sensed data and temperature correction.
	SensorboardC.nc	
	sensorboard.h	Defines constants for SHM-H board including temperature correction factors.

6.2 Channel configuration file

The channel configuration file specifies the number of active channels as well as the sampling rate, analog gain, and digital filter characteristics for each channel. There are four default configuration files included in the SHM-H sensor board driver in the ISHMP Services Toolsuite. Table 6 gives the parameters for each of these files.

Table 6. Default SHM-H configuration parameters.

Sampling Rate (Hz)	Cut-off Frequency (Hz)	Gain	Active Channels	Latency (points)	File Name
10	4	1	1,2,3	80	filter3ch_fs10Hz_fc4Hz.h
50	20	1	1,2,3	89	filter3ch_fs50Hz_fc20Hz.h
100	40	1	1,2,3	78	filter3ch_fs100Hz_fc40Hz.h
280	70	1	1,2,3	94	filter3ch_fs280Hz_fc70Hz.h

Please refer to “SHM-A Sensor Board: Advanced User’s Guide” for instructions on creating new configuration files.

6.3 Application software

The application software in the ISHMP Services Toolsuite allows the acquisition of data from the SHM-H sensor board. Please see the associated documentation for further instructions on the use of the application software.

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