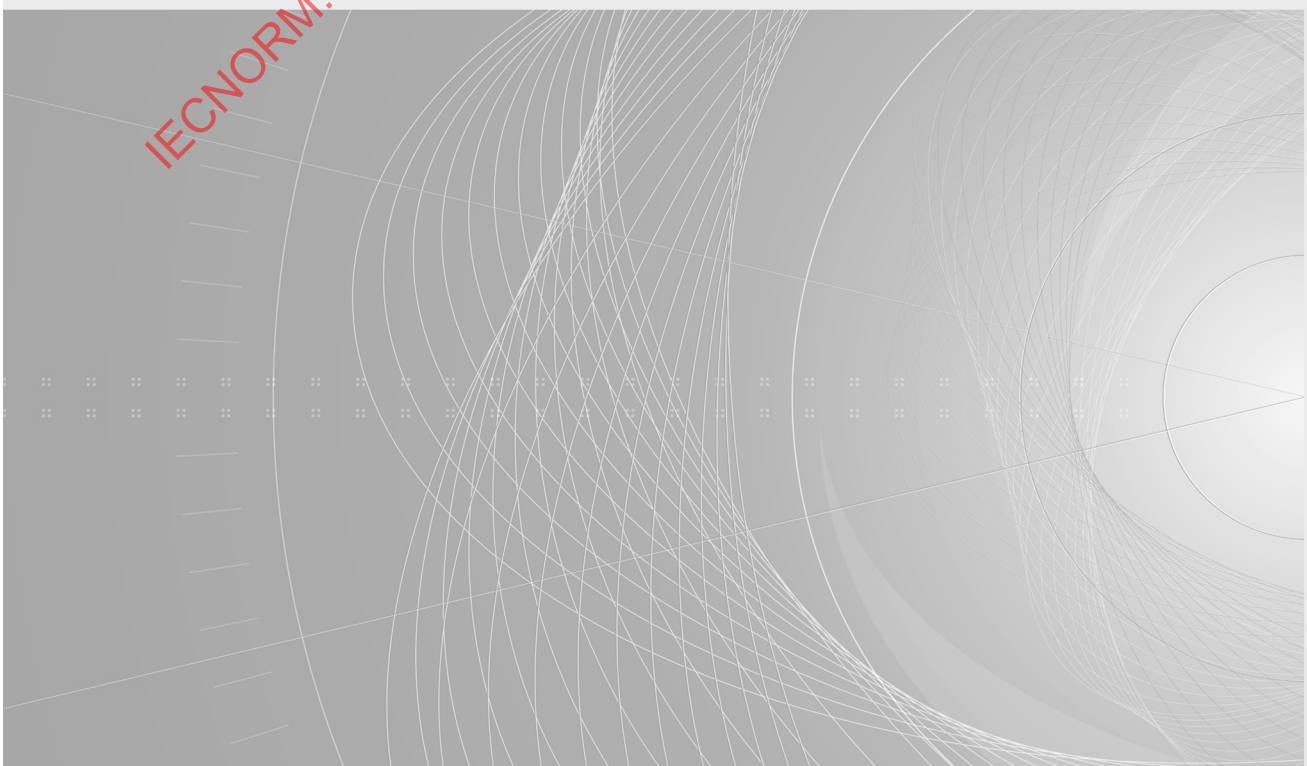
# IEC 60747-19-1

Edition 1.0 2019-11

# INTERNATIONAL STANDARD

## Semiconductor devices –
## Part 19-1: Smart sensors – Control scheme of smart sensors





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# SEMICONDUCTOR DEVICES –

# Part 19-1: Smart sensors – Control scheme of smart sensors

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The text of this International Standard is based on the following documents:

| CDV | Report on voting |
|---|---|
| 47E/642/CDV | 47E/668/RVC |

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60747 series, published under the general title *Semiconductor devices*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

# INTRODUCTION

The development of smart sensors which integrate analog-to-digital conversion and digital processing of the captured sensor signal(s) is in progress. A smart sensing unit, which comprises a smart sensor; a terminal module, to control the smart sensor and perform wireless communication; and a power supply for the smart sensor and the terminal module, can send the output data of the smart sensor wirelessly to the outside. Here, the power supply can be a plug-in power supply, a battery, an energy harvester, or their combination. A smart sensing network where a large number of smart sensing units are located in manufacturing factories, offices, and stores has been examined. With this network, environmental monitoring, sensing of operational situations of manufacturing equipment and sensing of other various events contribute to the realization of the following outcomes by analyzing the collected sensing data. Namely, energy saving, improvement in factory productivity such as operation rate, shortening of production lead time, preventive equipment maintenance, and product quality improvement can be achieved.

However, considering the three components of the smart sensing unit, namely, the smart sensor, terminal module, and power supply, standardization regarding control schemes to connect the components to each other and regarding the indication of specifications of the components has not been sufficiently established yet. This issue leads to the present situation, where the development of each component in the smart sensing unit has not proceeded efficiently.

The IEC 60747-19 series aims to address this issue. The IEC 60747-19 series comprises two parts and its structure is currently conceived as follows:

Part 19-1: Smart sensors – Control scheme of smart sensors

Part 19-2[1]: Smart sensors – Indication of specifications of smart sensors and power supplies to drive smart sensors

Part 19-1 specifies a control scheme of the smart sensor from the terminal module in the smart sensing unit. Generally, the manufacturers of sensors have incorporated into the sensors various parameters and conditions for sensing operations to fulfil various requests and needs of the users. Therefore, it has been quite difficult for the users to understand how to set the parameters and conditions adequately and master the use of sensors. This issue has been a considerable obstacle in designing the smart sensing unit and smart sensing system. The main objective of this part is to solve this obstacle for future expansion of the smart sensors and smart sensing network systems.

Part 19-2 aims to provide guidelines to specify information that is required when the smart sensing unit is newly designed. When the smart sensing unit is newly designed especially to use an autonomous power supply, the designers have to appropriately arrange the selection of the components of the unit and their usage conditions to satisfy that the power capability of the power supply successfully exceeds the total power budget to be consumed in the unit as a whole. First, information about the detailed power consumption characteristics of the smart sensors is indispensable for this achievement. Namely, information about time-axis power profiles which is not necessarily described in the datasheet of sensors is essential when intermittent sensing operations are often adopted and a careful lower power design including time-axis characteristics to allow adoption of an autonomous power supply is needed in IoT (Internet of Things) applications. Therefore, Part 19-2 discusses an indication of smart sensors' electrical characteristics of time-axis power profiles. Second, information about total power capability of the power supply to drive the unit and the smart sensor(s) is essential. This power supply as a module comprises (a) primary battery(batteries), and(or) (a) secondary battery(batteries), and(or) (an) energy harvester(s), or their combinations.



[1] Under development.

Considering the not-so-simple configuration including power management circuits as a power supply, Part 19-2 also discusses the indication of specifications of the power supply. With the establishment of appropriate indications, the three components of the smart sensing unit can be easily selected and combined from a point of view of a low-power design, when the smart sensing unit is newly designed and the overall design of the smart sensing unit itself can be facilitated.

# SEMICONDUCTOR DEVICES –

# Part 19-1: Smart sensors – Control scheme of smart sensors

## 1 Scope

This part of IEC 60747 specifies the control scheme of a sensor which is a device or a module which achieves a sensing function, data processing function and data output function, by employing a digital processing unit and a means of bidirectional communication between the sensor and an external terminal module.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

**3.1**
**smart sensor**
sensor device or sensor module which integrates analog-to-digital conversion and digital processing of the captured sensor signal(s)

**3.2**
**smart sensing unit**
unit comprising a smart sensor, a terminal module, and a power supply, which can send output data of the smart sensor to the outside

**3.3**
**terminal module**
integrated circuit device or module which is a component of a smart sensing unit, and which controls the smart sensor, receives the output data of the smart sensor, and sends the output data to the outside

**3.4**
**digital processing circuit**
integrated circuit device or a module performing digital arithmetic and(or) logic operations on digital data

**3.5**
**register**
local storage area on a digital processing circuit, which holds digital data that is being processed by the digital processing circuit

**3.6**
**operation mode**
operation type of an electronic device or module predetermined by its manufacturer, and in some cases, determined by its user

**3.7**
**sleep mode**
power-saving mode for an electronic device or module in which all unnecessary components in the device or module are shut down

**3.8**
**status information**
information regarding the current condition of an electronic device or module

**3.9**
**data ready**
type of status information, which is a piece of digital data to mark when a data preparing operation has been conducted and when data has been available in an electronic device or module

**3.10**
**error flag**
type of status information, which is a piece of digital data to mark when an error event has occurred in an electronic device or module

**3.11**
**inter-integrated circuit**
**$I^2C$**
widely used two-line digital serial communication bus

**3.12**
**serial peripheral interface**
**SPI**
widely used three-line or four-line digital serial communication bus



## 4 Construction of smart sensor's control scheme

### 4.1 General

Figure 1 provides a block diagram of the hardware configuration regarding the smart sensor's control scheme from the terminal module in the smart sensing unit. The smart sensor's control scheme utilizes registers which a digital processing circuit embedded in the smart sensor possesses. The smart sensor's control scheme is established by operations in which both the terminal module and the smart sensor mutually read and write data to the registers. Each register is of 1 byte. Table 1 provides the byte assignment of the registers in the control scheme. Here, the name, address, and content of each register are defined, and the type of each register is shown. "R/W" means that the terminal module can read and write data to the register and "R" means that the terminal module can only read data from the register. In addition, the default value of each register is defined. For mandatory register possession, 4 bytes (or 4 registers) shall be prepared in this control scheme. The maximum number of registers, including optional possession, is 256 bytes (or 256 registers) in the control scheme.

### 4.2 Assignment of the smart sensor's registers in the control scheme

The operation mode of the smart sensor is specified by writing data as in the manner determined in Table 1. That is, the two bytes of the registers with the register addresses of 0x00h and 0x01h shall be used for specifying the operation mode of the smart sensor.

When the data of "0x00h" is written to the "MODE1" register, the operation mode shall be specified to the default mode. When the data of "0x01h" is written to the "MODE1" register, the operation mode shall be specified to the sleep mode. When the data from "0x02h" to "0xFFh" is written to the "MODE1" register, the operation mode corresponding to the number of written data shall be specified. The operation contents of the default operation mode and the operation modes corresponding to the operation mode numbers are defined by the manufacturer of the smart sensor and are described in the datasheet of the smart sensor. With the corresponding numbers from "0x02h" to "0xFFh," 254 operation modes can be prepared. The 254 operation modes and the default mode result in 255 operation modes to be defined in total.

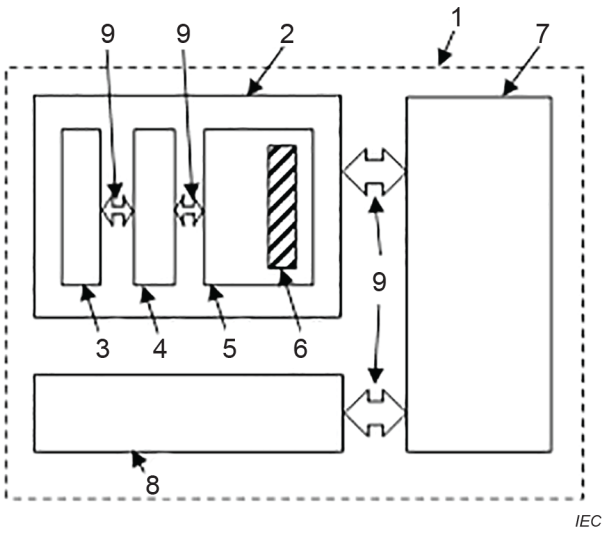
The "MODE2" register shall be prepared and may be optionally used to specify the operation modes in combination with the "MODE1" register. More than 255 operation modes become available using the "MODE2" register.

The "STATUS1" register shall be assigned to the status information of the smart sensor. The "STATUS2" register shall be assigned to the status information of the smart sensor as an option in combination with the "STATUS1" register. For example, as a status information, a data ready bit and(or) an error flag bit may be defined. The content and definition of the status information shall be defined freely by the manufacturer of the smart sensor, and its assignment is described in the datasheet of the smart sensor. The "DATA" registers with the addresses from 0x04h to 0xFFh may be assigned to the output or input data of the smart sensor. The output or input data do not contain any information about their units. The information about the units and forms of data is described in the datasheet of the smart sensor in addition to the explanation of each operation mode.

In addition, the "MODE2" register may be used to specify the parameters for an operation of the smart sensor. For example, when data processing of the filtering or judgement is performed against the acquired sensing data in a smart sensor, the parameters required for such data processing may be set using the "MODE2" register. Furthermore, although the registers assigned for the setting of the operation modes are only 2 bytes which are the "MODE1" and "MODE2" registers, the "DATA" registers may be utilized by describing this additional specification in the datasheet, in case of shortage of the available number of operation modes.

### 4.3 Operation procedure of control scheme

The basic operation procedure of the smart sensor's control scheme is explained as follows. First, the terminal module writes the operation mode number to the "MODE1" register among the registers which a digital processing circuit embedded in the smart sensor possesses. (Here, if the terminal module reads the "MODE1" register, the terminal module can confirm the previously specified number of the operation mode.) Second, the smart sensor reads data stored in the "MODE1" register and performs the operation corresponding to the read operation's mode number. Then, the smart sensor stores its output data in the "DATA" registers, as well as its status information in the "STATUS1" register. Finally, the terminal module comprehends the status information of the smart sensor by reading data stored in the "STATUS1" register and comprehends the output data of the smart sensor by reading the data stored in the "DATA" registers.




**Key**

1 smart sensing unit
2 smart sensor
3 sensor element
4 analog-to-digital converting circuit
5 digital processing circuit
6 registers
7 terminal module
8 power supply
9 electrical connections

**Figure 1 – Block diagram of hardware configuration regarding the smart sensor's control scheme from the terminal module in the smart sensing unit**

**Table 1 – Assignment of the smart sensor's registers in the smart sensor's control scheme**

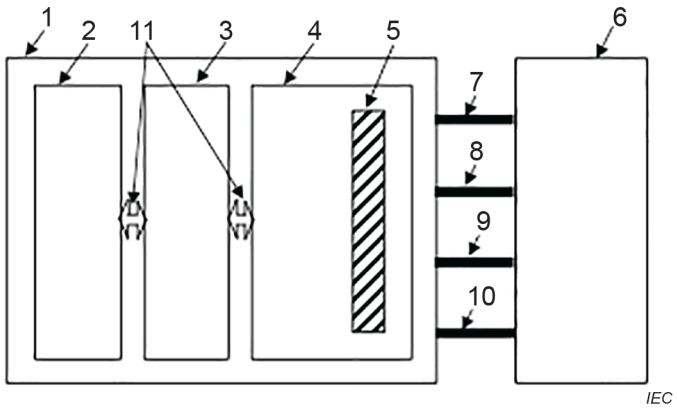
| Register name | Register address | Register type | Content of register | Mandatory/optional | | Default value |
|---|---|---|---|---|---|---|
| | | | | Register possession | Register usage | |
| MODE1 | 0x00h | R/W | 0x00h: Default mode<br>0x01h: Sleep mode<br>0x02h to 0xFFh: Operation modes of smart sensors are defined.<br>Content of this register shall be freely predetermined by sensor manufacturer and is described in the datasheet. | Mandatory | Mandatory | 0x00h<br>(0x01h may be defined.) |
| MODE2 | 0x01h | R/W | Operation modes of smart sensors are defined in combination with "MODE1".<br>Content of this register shall be freely predetermined by sensor manufacturer and is described in the datasheet. | Mandatory | Optional | 0x00h |
| STATUS1 | 0x02h | R | For sensor status information (for example, data ready and error flag).<br>Content of this register shall be freely predetermined by sensor manufacturer and is described in the datasheet. | Mandatory | Mandatory | – |
| STATUS2 | 0x03h | R | For sensor status information in combination with "STATUS1".<br>Content of this register shall be freely predetermined by sensor manufacturer and is described in the datasheet. | Mandatory | Optional | – |
| DATA | 0x04h to 0xFFh | R/W | Registers for output or input data.<br>Content of these registers shall be freely predetermined by sensor manufacturer and is described in the datasheet. | Optional | Optional | – |
| R/W: Read and write, R: Read only ("R/W" means that the user of the smart sensor can read and write the data to the register and "R" means that the user of the smart sensor can only read the data to the register.)<br>"MODE2" register may be used to specify the parameters for the operation of the smart sensor.<br>In case of shortage of an available number of operation modes, "DATA" registers may be utilized by describing this additional specification in the datasheet. | | | | | | |



A practical example of the smart sensor's control scheme is given in Annex A, and the case of a smart sensor with multiple sensors and its practical example are given in Annex B.

### 4.4 Physical connection between smart sensor and terminal module

As to the physical connection between the smart sensor and the terminal module, they shall be connected physically with a freely selected digital interface and bidirectional data communication between them. For example, $I^2C$ or SPI may be adopted for this connection. If $I^2C$ is used, the connection lines are a serial data (SDA) line, a serial clock (SCL) line, a power supply (VDD) line, and a ground (GND) line, as shown in Figure 2 and Table 2.




**Key**

1 smart sensor
2 sensor element
3 analog-to-digital converting circuit
4 digital processing circuit
5 registers
6 terminal module
7 VDD line
8 GND line
9 SDA (serial data) line
10 SCL (serial clock) line
11 electrical connections

**Figure 2 – Example of block diagram of connection lines between smart sensor and terminal module**

**Table 2 – Example of connection lines between smart sensor and terminal module**

| Connection line name | Explanation of connection lines |
|---|---|
| VDD | Power supply line |
| GND | Ground line |
| SDA | Serial data line of $I^2C$ |
| SCL | Serial clock line of $I^2C$ |



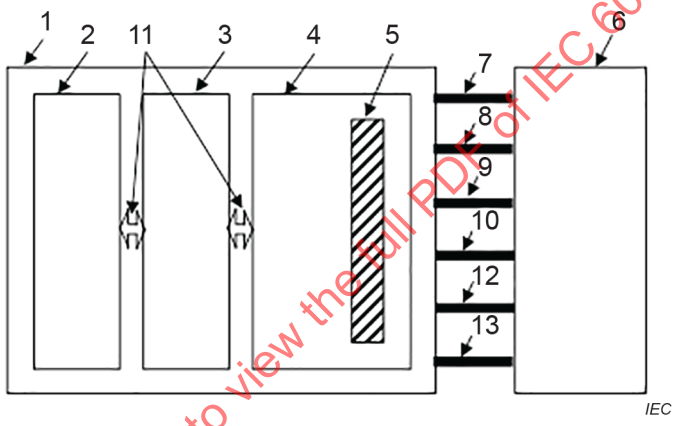
## 4.5 Optional configuration

An optional configuration in the smart sensor's control scheme, which is favorable for a low-power smart sensor is recommended. That is, the formation of interrupt lines and(or) reset lines from the terminal module to the smart sensor for hardware interrupt and reset is recommended. In case the smart sensor and terminal module perform temporarily independent operations, communications with each other are carried out via a digital serial interface such as $I^2C$ or SPI. In addition to this method, the hardware interrupt and reset can be used by forming the said interrupt and reset lines. Table 3 provides the details of the recommended optional configuration.

**Table 3 – Recommended optional configuration of connection lines between the smart sensor and terminal module**

| Name | Content |
|---|---|
| Interrupt input line | Interrupt line to interrupt from terminal module to smart sensor. Polarity and trigger type ("level" or "edge" is specified) are defined in the datasheet. |
| Interrupt output line | Interrupt line to interrupt from smart sensor to terminal module. Polarity and output type ("level" or "pulse" is specified) are defined in the datasheet. In case the output type of "level" is used, a method to turn inactive is described in the datasheet. |
| Data ready output line | The status information of "data ready" is output to this line. |
| Reset input line | Reset input line for performing compulsory reset of the smart sensor, the so-called "cold-reset." Required electrical characteristics such as polarity are described in the datasheet. |

For example, Figure 3 shows a block diagram of connection lines between a smart sensor and a terminal module in the case where I²C is used when optional interrupt input and output lines are employed.




**Key**

1 smart sensor
2 sensor element
3 analog-to-digital converting circuit
4 digital processing circuit
5 registers
6 terminal module
7 VDD line
8 GND line
9 SDA (serial data) line
10 SCL (serial clock) line
11 electrical connections
12 interrupt input line
13 interrupt output line

**Figure 3 – Example of block diagram of connection lines with optional interrupt input and output lines between smart sensor and terminal module**

### 4.6 Optional function

An optional function in the smart sensor's control scheme, which is favorable for a low-power smart sensor, is recommended as provided in Table 4.

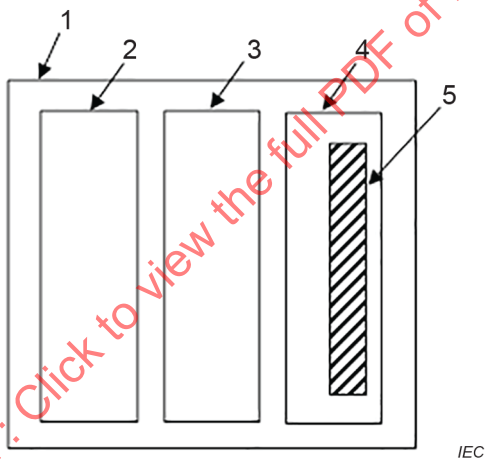
**Table 4 – Recommended optional function of smart sensor's control scheme**

| Name | Content |
|---|---|
| Power on reset | This function performs a "cold-reset" automatically whenever it detects that power is turned on. The power supply conditions where the function never fails to operate and where the function never operates are described in the datasheet. |

# Annex A
(informative)

## Practical example of smart sensor's control scheme

A practical example of the smart sensor's control scheme is shown in Annex A. Figure A.1 provides the hardware configuration of the example. An analog-to-digital converting circuit and a digital processing circuit are embedded in an accelerometer. Table A.1 provides the assignment of the smart accelerometer's registers as an example of the smart sensor's control scheme. In this example, an accelerometer suitable for vibration monitoring of rotating objects, such as industrial motors, is introduced. As shown in Table A.1, various operation modes are defined with the "MODE1" register. Focusing on utilizations with frequencies from 800 Hz to 3 200 Hz and output ranges from ±2 g to ±4 g, which are favorable for the said target application, the appropriate operation modes for the target application have been prepared in advance. Therefore, the users of the smart sensors can select and use the smart sensors appropriately without the need to perfectly understand how to use the sensors and how to set the sensors' complex parameters and conditions. Furthermore, for example, the embedded digital processing circuit in the smart accelerometer can calculate and output an acceleration composition vector composing the measured components in the three-axes direction (X, Y, and Z). This additional built-in function for realizing the required calculation becomes the so-called added value for the users.




**Key**

1 smart accelerometer
2 accelerometer
3 analog-to-digital converting circuit
4 digital processing circuit
5 registers

**Figure A.1 – Block diagram of hardware configuration of smart accelerometer as an example of smart sensors**

**Table A.1 – Practical example of assignment of smart sensor's registers in smart sensor's control scheme**

| Register name | Register address | Register type | Content of register | Default value |
|---|---|---|---|---|
| MODE1 | 0x00h | R/W | 0x00h: Default mode<br>Sampling frequency = 800 Hz<br>Cut-off frequency = 89 Hz<br>Output range = ±2 g<br>Data resolution 1LSB = 61 µg<br>0x01h: Sleep mode<br>0x02h: Sampling frequency = 800 Hz<br>Cut-off frequency = 89 Hz<br>Output range = ±4 g<br>Data resolution 1LSB = 122 µg<br>0x03h: Sampling frequency = 800 Hz<br>Cut-off frequency = 400 Hz<br>Output range = ±2 g<br>Data resolution 1LSB = 61 µg<br>0x04h: Sampling frequency = 800 Hz<br>Cut-off frequency = 400 Hz<br>Output range = ±4 g<br>Data resolution 1LSB = 122 µg<br>0x05h: Sampling frequency = 1 600 Hz<br>Cut-off frequency = 178 Hz<br>Output range = ±2 g<br>Data resolution 1LSB = 61 µg<br>0x06h: Sampling frequency = 1 600 Hz<br>Cut-off frequency = 178 Hz<br>Output range = ±4 g<br>Data resolution 1LSB = 122 µg<br>0x07h: Sampling frequency = 1 600 Hz<br>Cut-off frequency = 800 Hz<br>Output range = ±2 g<br>Data resolution 1LSB = 61 µg<br>0x08h: Sampling frequency = 1 600 Hz<br>Cut-off frequency = 800 Hz<br>Output range = ±4 g<br>Data resolution 1LSB = 122 µg<br>0x09h: Sampling frequency = 3 200 Hz<br>Cut-off frequency = 356 Hz<br>Output range = ±2 g<br>Data resolution 1LSB = 61 µg<br>0x0Ah: Sampling frequency = 3 200 Hz<br>Cut-off frequency = 356 Hz<br>Output range = ±4 g<br>Data resolution 1LSB = 122 µg<br>0x0Bh: Sampling frequency = 3 200 Hz | 0x00h |

| Register name | Register address | Register type | Content of register | Default value |
|---|---|---|---|---|
| | | | Cut-off frequency = 1 600 Hz | |
| | | | Output range = ±2 g | |
| | | | Data resolution 1LSB = 61 µg | |
| | | | 0x0Ch: Sampling frequency = 3 200 Hz | |
| | | | Cut-off frequency = 1 600 Hz | |
| | | | Output range = ±4 g | |
| | | | Data resolution 1LSB = 122 µg | |
| | | | 0x10h: Performing hot-reset operation in smart sensor. After hot-reset operation, MODE1 is set to 0x00h. | |
| MODE2 | 0x01h | R/W | Not applicable | – |
| STATUS1 | 0x02h | R | Bit0: Data ready | – |
| | | | 1 = not ready, 0 = ready | |
| | | | Bit1: Error | |
| | | | 1 = sensor does not work, 0 = operating normally | |
| STATUS2 | 0x03h | R | Not applicable | – |
| DATA | 0x04h–0x05h | R/W | Output acceleration value X-axis (16 bits) | – |
| | 0x06h–0x07h | | Output acceleration value Y-axis (16 bits) | – |
| | 0x08h–0x09h | | Output acceleration value Z-axis (16 bits) | – |
| | 0x0Ah–0x0Bh | | Output acceleration value XYZ composed (16 bits) | – |

R/W: Read and write, R: Read only ("R/W" means that the user of the smart sensor can read and write the data to the register and "R" means that the user of the smart sensor can only read the data to the register.)

g = 9,806 65 m/s$^2$

LSB: Least significant bit

# Annex B
(informative)

## Smart sensor with multiple sensors – Practical example

The case of a smart sensor with multiple sensors and its practical example are given in Annex B. Figure B.1 provides the hardware configuration of the case. Two sensor elements and the corresponding two analog-to-digital converting circuits as well as a digital processing circuit are embedded in a smart sensor. The control scheme specified in this document can be applied to such a smart sensor with multiple sensors.

For easy understanding, a practical example is shown here. Figure B.2 provides the hardware configuration of a smart sensor with a temperature sensor and a humidity sensor as an example of a smart sensor with multiple sensors. Table B.1 provides the assignment of this smart sensor's registers as an example of control schemes in the case of a smart sensor with multiple sensors. When "0x02h" is set in the MODE1 register, the smart sensor outputs a one-shot temperature sensing value. When "0x03h" is set in the MODE1 register, the smart sensor outputs a one-shot humidity sensing value. Furthermore, when "0x04h" is set in the MODE1 register, the smart sensor performs both of a one-shot temperature sensing operation with the temperature sensor and a one-shot humidity sensing operation with the humidity sensor and calculates the temperature-humidity index with the digital processing circuit using the obtained temperature value and the obtained humidity value. The smart sensor outputs the calculated temperature-humidity index value, namely, the discomfort index value. Here, regarding Status 1 register, data-ready bits and error bits are assigned to both the temperature sensor element and humidity sensor element.