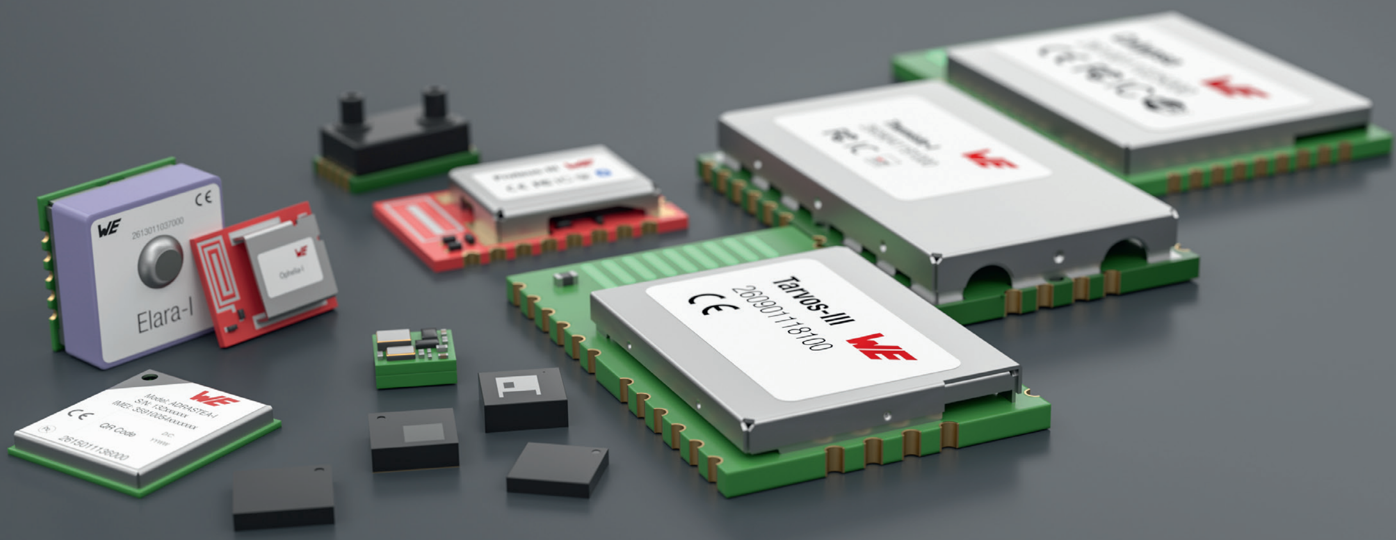

ANM002

Human fall detection with 3-axis MEMS acceleration sensor

2533020201601, 2533203301691

Version 1.1

October 21, 2024

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Revision history

App note version	Notes	Date
1.0	• Initial release of the app note	March 2020
1.1	• Updated chapter `Important notes` • Updated chapter `Legal notice`	October 2024

Abbreviations

Abbreviation	Description
FS	Full scale
I^2C	Inter integrated circuit
MEMS	Micro-electro-mechanical system
LSB	Least significant bit
ODR	Output data rate

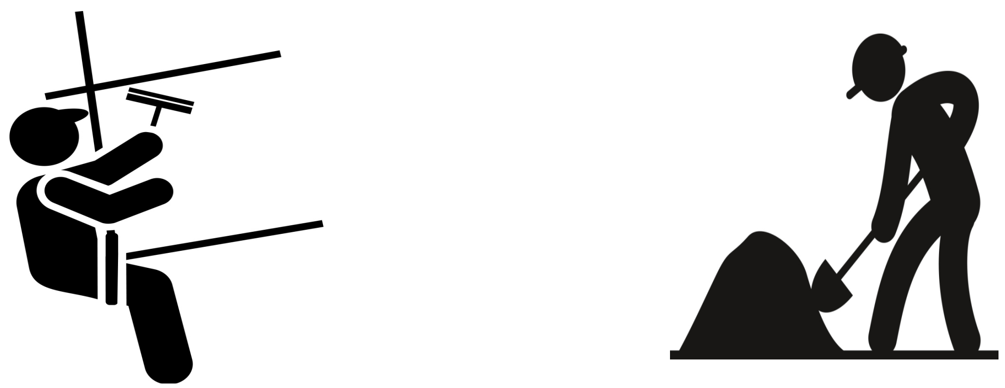
Contents

1 Introduction

Unintentional fall represents one of the major health concerns for many communities in ageing population. The evident possibility of initial injury may lead to severe consequences, if the person is not treated immediately. It is one of the biggest threats among other incidents to elderly people and also people with special assistance. It is noted that the nature of falls can be different from person to person depending on their physical conditions, weakness and balancing problem.

Figure 1: Human fall

For example, many elderly people can suffer unintentional falls due to weakness or dizziness. The major consequences are not related to the falling, but rather due to unassisted or treated with delay. To provide better living for the elderly people and those with special assistance, it is necessary to develop a monitoring system which alerts the care givers of any emergency assistance. The purpose of a monitoring system is to provide better living conditions and health care especially for the elderly people who live alone. The human monitoring system should inform the health care representatives of any emergency. Besides elderly support, there are many activities which could be beneficial with such a fall detection system especially for mountaineers, construction workers, roofers and window washers.



a) Window washer   b) Construction worker

Figure 2: Unintentional fall in the fields

There are different approaches in developing such a system to realize the detection of a fall. It could be either vision, light or motion sensor based systems. These systems are further classified as wearable and non-wearable based monitoring systems. One of the simple approach to develop a wearable based monitoring system is a motion based sensor. It requires a 3-axis acceleration sensor to monitor the fall using acceleration data. This document provides the initial idea of implementing the WSEN-ITDS 3-axis MEMS acceleration sensor to develop the fall detection system using in-built sensor features.

> **!** This document provides the initial approach to use acceleration sensor to develop fall detection systems.

> **!** The actual fall detection system could differ from person to person and further differ from applications. As the fall could be either linear, rotational or both in some cases.

2 MEMS 3-axis acceleration sensor

The WSEN-ITDS is a MEMS based 3-axis acceleration sensor with a digital communication interface. It features the measurement range of ±2g, ±4g, ±8g, ±16g in all three axes. It includes standard I^2C communication interface with a small footprint of 2mm x 2mm x 0.7mm. It has ultra-low current consumption which makes it suitable for the development of battery based fall detection systems.

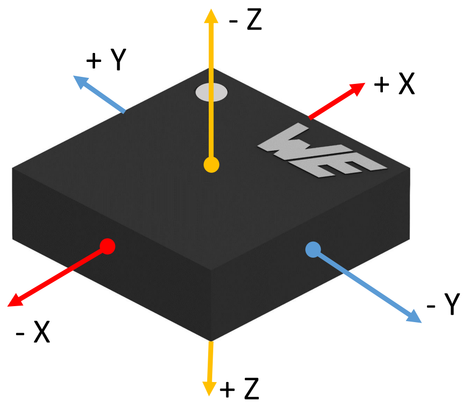


Figure 3: 3-axis MEMS acceleration sensor

The sensor includes built-in features such as free fall, wake up, tap, motion/stationary and activity/inactivity detection with two flexible interrupt pins. These features reduce the complex algorithm development effort one needs for the fall detection systems. The combination of these in-built features could detect the fall of a person which makes the WSEN-ITDS 3-axis acceleration sensor suitable for this application. The built-in features prohibit the requirement to access the acceleration data continuously from the sensor. In order to perform complex computations to realise a fall detection system. The fall detection system can be mounted to the individual as a wristband, chest belt and leg band which depends upon the type of application.

2.1 In-built sensor features

- Free fall
- Wake-up
- Tap function
- Motion and stationary
- Activity and inactivity
- 4D and 6D orientation

3 In-built sensor features for fall detection

The WSEN-ITDS 3-axis acceleration sensor includes two programmable interrupt pins INT_0 and INT_1. The interrupt pins can be enabled or disabled individually. The interrupt signals from the sensor features can be routed to these two pins. The detailed information of the interrupt pin functionality is explained in the chapter 12 of WSEN-ITDS user manual for the order code: 2533020201601. This document provides the information on how to use the in-built sensor features to develop a motion based fall detection systems.

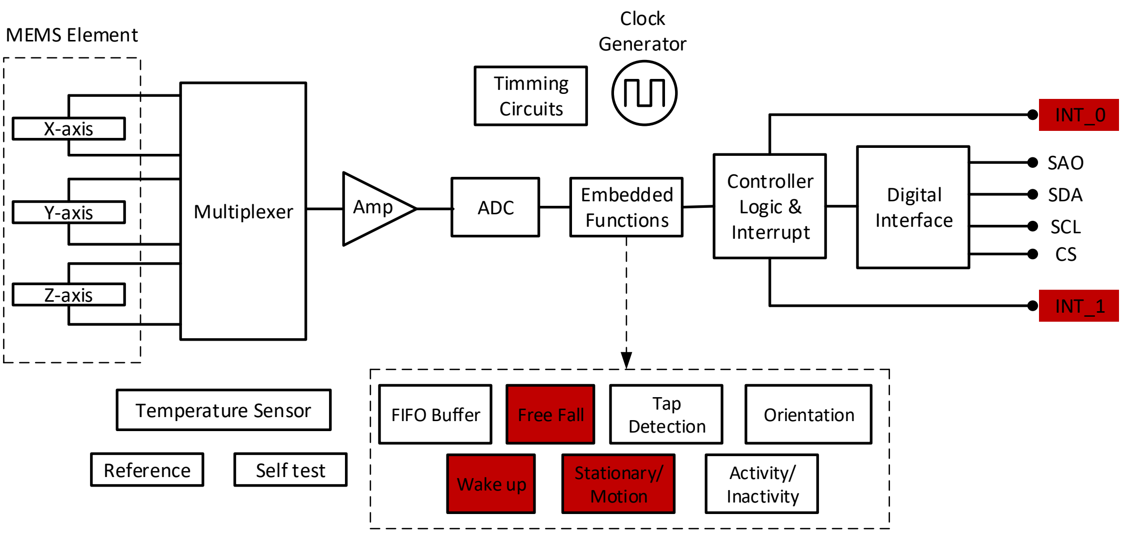


Figure 4: Sensor functional block diagram

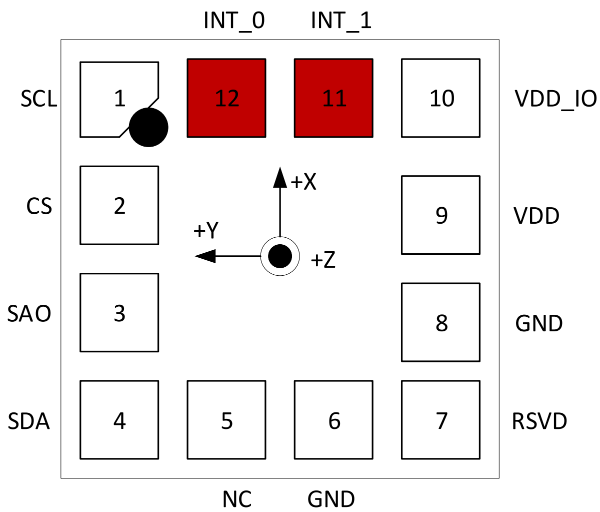


Figure 5: Sensor pinning (top view)

The fall detection can be realised using three sensor in-built features such as free fall, wake up and stationary detection feature. The combination of these sensor features help to detect when a person is falling, fell but can move and fell but cannot move. The interrupt signals from these events can be routed to INT_0 and INT_1 pins respectively. The combination of these events form the entire fall detection algorithm. It shall able to initiate the monitoring system to raise an alarm when a fall has occurred.

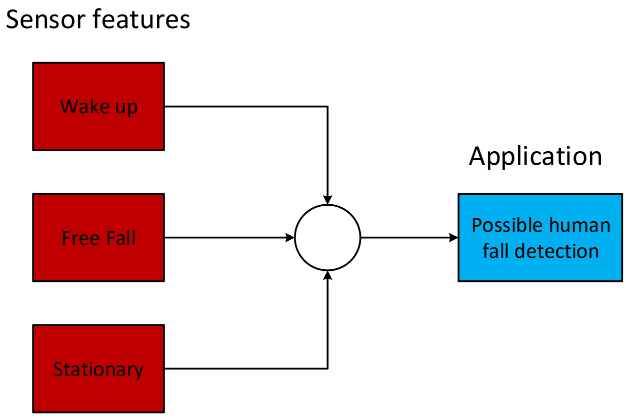


Figure 6: Combination of sensor features for the fall detection

The time interval between the free fall and stationary/wake up event will again depends upon the application. Simultaneously the duration of free fall also depends upon the application. For example, the fall duration of a window washer from few meters is higher compared to the elderly people fall duration during normal daily activity.

> The combination of in-built sensor features for the fall detection depends on the type, condition and duration of the fall.

> Please refer to the product user manual for more detailed information regarding the register mapping and description.

4 Free fall detection

The free fall detection feature describes the specific register configuration to recognize a free fall event. During free fall event the sensor acceleration value of all three axes goes to zero. It is defined by the acceleration values from three axes are small as close to zero-g to generate an interrupt.

Two parameters are necessary for the free fall detection feature which is shown in figure 7.

- Free fall duration
- Free fall threshold

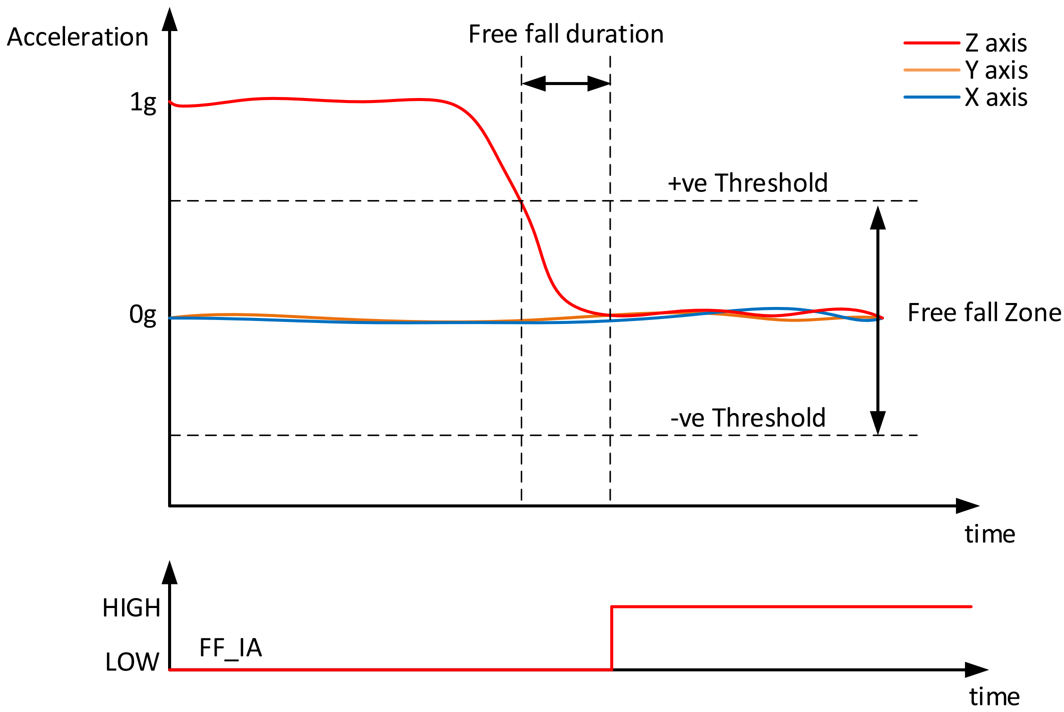


Figure 7: Free fall interrupt

The free fall interrupt is triggered when the acceleration values from all three axes is lower than the threshold value for a period of time i.e the free fall duration. The free fall interrupt signal can be routed to the interrupt pin INT_0 by enabling INT0_FF bit in the control register CTRL_4 (0x23). Simultaneously the free fall interrupt event is detected by reading the FF_IA bit in the STATUS_DETECT register (0x37).

4.1 Free fall duration

The duration of a free fall is configured by combining FF_DUR5 bit in WAKE_UP_DUR (0x35) register and FF_DUR[4:0] bits in the FREE FALL register (0x36). The free fall duration is calculated by the 1 LSB = 1*1/ODR. The table 1 refers to the free fall duration for the output date rate (ODR) of 200 Hz.

As an Example:-
FF_DUR5 = 1; FF_DUR[4:0] = 01000
FF_Duration (combining FF_FUR5 and FF_DUR[4:0]) = b101000 (Decimal value=40)
Free fall = FF_Duration*(1/ODR) = 40*(1/200) = 200 ms

FF_DU5	FF_DUR[4:0]	Free fall duration
0	00001	5 ms (1/ODR)
0	00010	10 ms (2/ODR)
0	00011	15 ms (3/ODR)
0	00100	20 ms (4/ODR)
0	00101	25 ms (5/ODR)
0	00110	30 ms (6/ODR)
0	00111	35 ms (7/ODR)
-	-	-
1	11111	315 ms (63/ODR)

Table 1: Free fall duration for ODR 200Hz

4.2 Free fall threshold

The free fall threshold value is calculated by multiplying the threshold decoding value from the FREE_FALL register (0x36) with 31.25 mg. The calculation in the table 2 shows the possible free fall threshold values.

FF_THS[2:0]	Threshold decoding (LSB)	Free fall threshold value
000	5	5 * 31.25mg = 156.25 mg
001	7	7 * 31.25mg = 218.75 mg
010	8	8 * 31.25mg = 250 mg
011	10	10 * 31.25mg = 312.5 mg
100	11	11 * 31.25mg = 343.75 mg
101	13	13 * 31.25mg = 406.25 mg
110	15	15 * 31.25mg = 468.75 mg
111	16	16 * 31.25mg = 500 mg

Table 2: Free fall threshold

4.3 Initialization of the free fall feature

The flow chart shows the initialization of free fall feature. It describes step by step register configuration to enable the free fall feature. Table 1 and Table 2 show the possibilities of the free fall duration and threshold values.

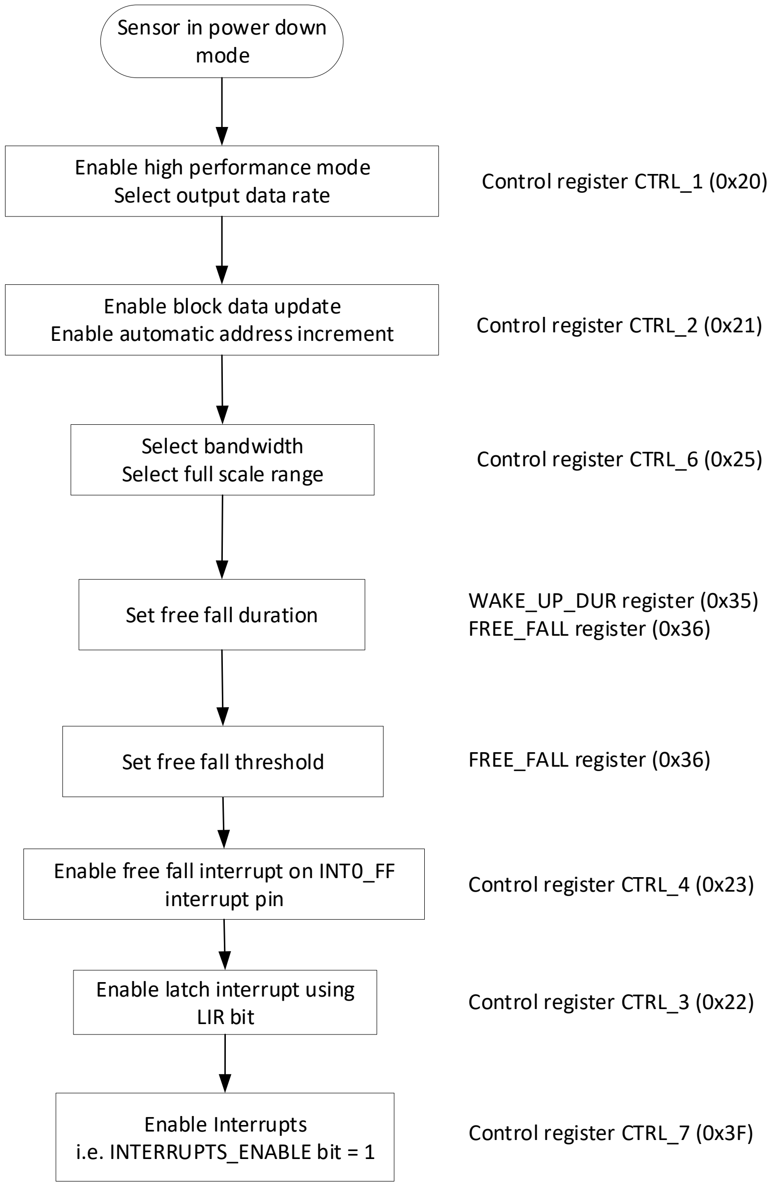


Figure 8: Initialization of the free fall detection

The reset of free fall interrupt signal depends up on the latched mode, which is enabled or disabled. It can be defined by LIR bit in the control register CTRL_3 (0x22).

4.3.1 Latched mode disabled

- If the latched mode is disabled, the interrupt signal is automatically reset when the free fall condition is not valid any more. i.e. FF_IA bit in the STATUS_DETECT (0x37) register will reset automatically.

4.3.2 Latched mode enabled

- The latched mode is enabled using LIR bit in the control register CTRL_3 (0x22) and the FF_IA interrupt signal is routed to the interrupt pin INT_0. Then the interrupt signal will not reset automatically. It will be reset by reading the content of the WAKE_UP_EVENT (0x38) or ALL_INT_EVENT (0x3B) register.
- The latched mode is enabled using LIR bit in the control register CTRL_3 (0x22) and the FF_IA interrupt signal is not routed to the interrupt pin INT_0. Then the interrupt signal will automatically reset when the free fall condition is not valid any more. i.e. FF_IA bit in the STATUS_DETECT (0x37) register reset automatically.

5 Wake up detection

The wake up interrupt signal is generated when the acceleration value exceeds a certain threshold from any one of the axes after sleep/inactive/stationary event. The wake up feature utilizes the output data to generate the interrupt either from high-pass filter output or offset output. The USR_OFF_ON_WU bit in the control register CTRL_7 (0x3F) defines the source signal for the wake up feature detection i.e. high pass filter output or offset output.

The wake up interrupt signal can be routed to INT_0 interrupt pin by enabling the INT0_WU bit in the control register CTRL_4 (0x23). The same interrupt signal can be recognised by reading the WU_IA bit in the ALL_INT_EVENT register (0x3B). X_WU, Y_WU, Z_WU bits in the WAKE_UP_EVENT register (0x38) indicates which axis has generated the wake up event.

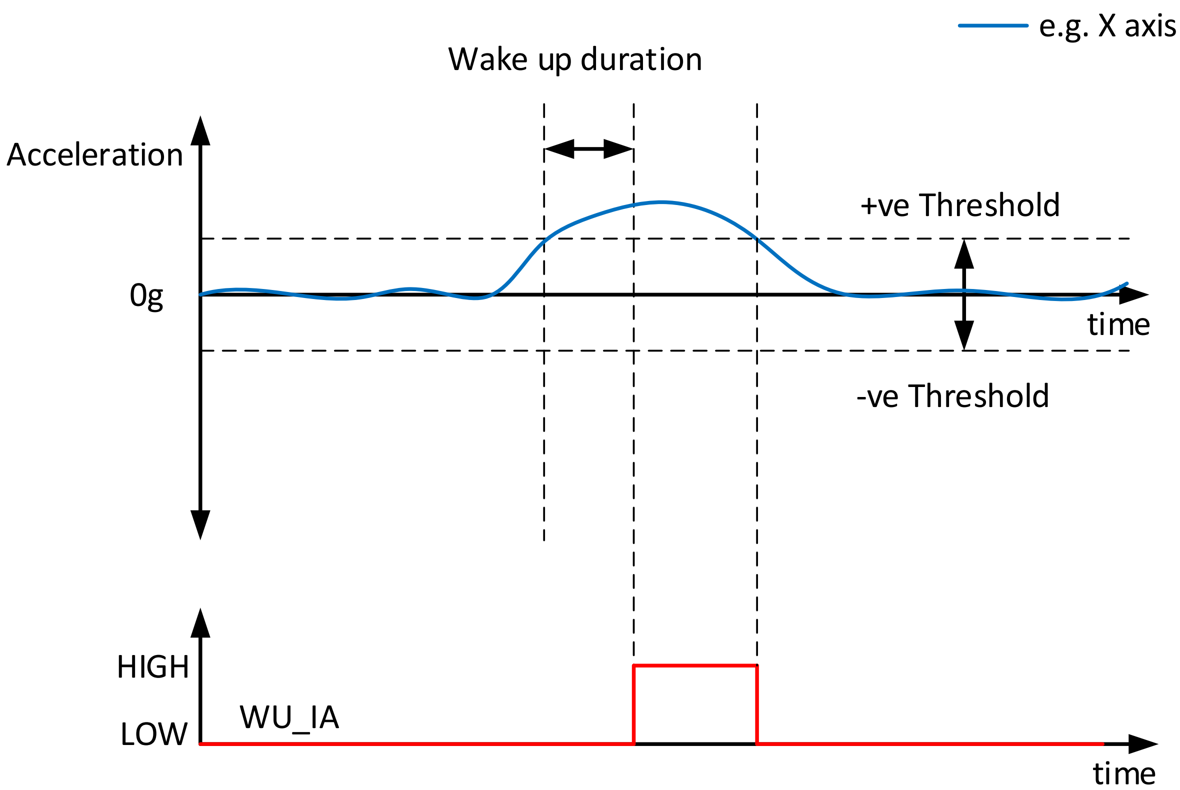


Figure 9: Wake up interrupt, e.g. X axis

The reset of wake up interrupt signal depends up on the latched mode, which is enabled or disabled. It can be defined by LIR bit in the control register CTRL_3 (0x22).

5.0.1 Latched mode disabled

- If the latched mode is disabled, the interrupt signal is automatically reset when the wake up condition is not valid any more. i.e WU_IA bit in the WAKE_UP_EVENT (0x38) register will reset automatically.

5.0.2 Latched mode enabled_wake

- The latched mode is enabled using LIR bit in the control register CTRL_3 (0x22) and the WU_IA interrupt signal is routed to the interrupt pin INT_0. Then the interrupt signal will not reset automatically. It will be reset by reading the content of the WAKE_UP_EVENT (0x38) or ALL_INT_EVENT (0x3B) register.
- The latched mode is enabled using LIR bit in the control register CTRL_3 (0x22) and the WU_IA interrupt signal is not routed to the interrupt pin INT_0. Then the interrupt signal will automatically reset when the wake up condition is not valid any more. i.e. WU_IA bit in the WAKE_UP_EVENT (0x38) register will reset automatically.

5.1 Wake up threshold

WK_THS[5:0] bits in the register WAKE_UP_DUR (0x35) defines the unsigned threshold value for the wake up feature. The threshold value is applicable to both positive and negative acceleration data. In order to realise the wake up feature at least any one of the acceleration axis value should exceed the threshold value. The threshold value is calculated by the selected full scale range which is defined in the control register CTRL_1 (0x20). The wake up threshold value is calculated by 1 LSB = FS/64. Table 3 shows the possible threshold values for full scale range of $\pm$2g.

WK_THS[5:0]	Threshold value (mg)
000001	1*(2/64) = 31.25
000010	2*(2/64) = 62.5
000011	3*(2/64) = 93.75
000100	4*(2/64) = 125
000101	5*(2/64) = 156.25
-	-
111111	63*(2/64) = 1968.75

Table 3: Wake up threshold for $\pm$2g

5.2 Wake up duration

WAKE_DUR[1:0] bits in the register WAKE_UP_DUR (0x35) defines the parameter for the minimum duration of the wake up event to be recognized. It depends on the selected ODR in the control register CTRL_1 (0x20). The wake up duration can be calculated by 1 LSB = 1*1/ODR. It is necessary to define the duration parameter to avoid a false wake up interruption event due to sudden peaks in one of the axis. Table 4 shows the possible wake up duration values for the selected ODR of 200Hz.

WAKE_DUR[1:0]	Duration (ms)
00	0
01	1*(1/200) = 5
10	2*(1/200) = 10
11	3*(1/200) = 30

Table 4: Wake up duration for ODR 200Hz

5.3 Initialization of wake up feature with high pass filter output

The flow chart shows the initialization of the wake up feature with high pass filter output data. In order to exclude the gravity vector and very low frequency disturbance during the wake up event recognition, high pass filter output should be used.

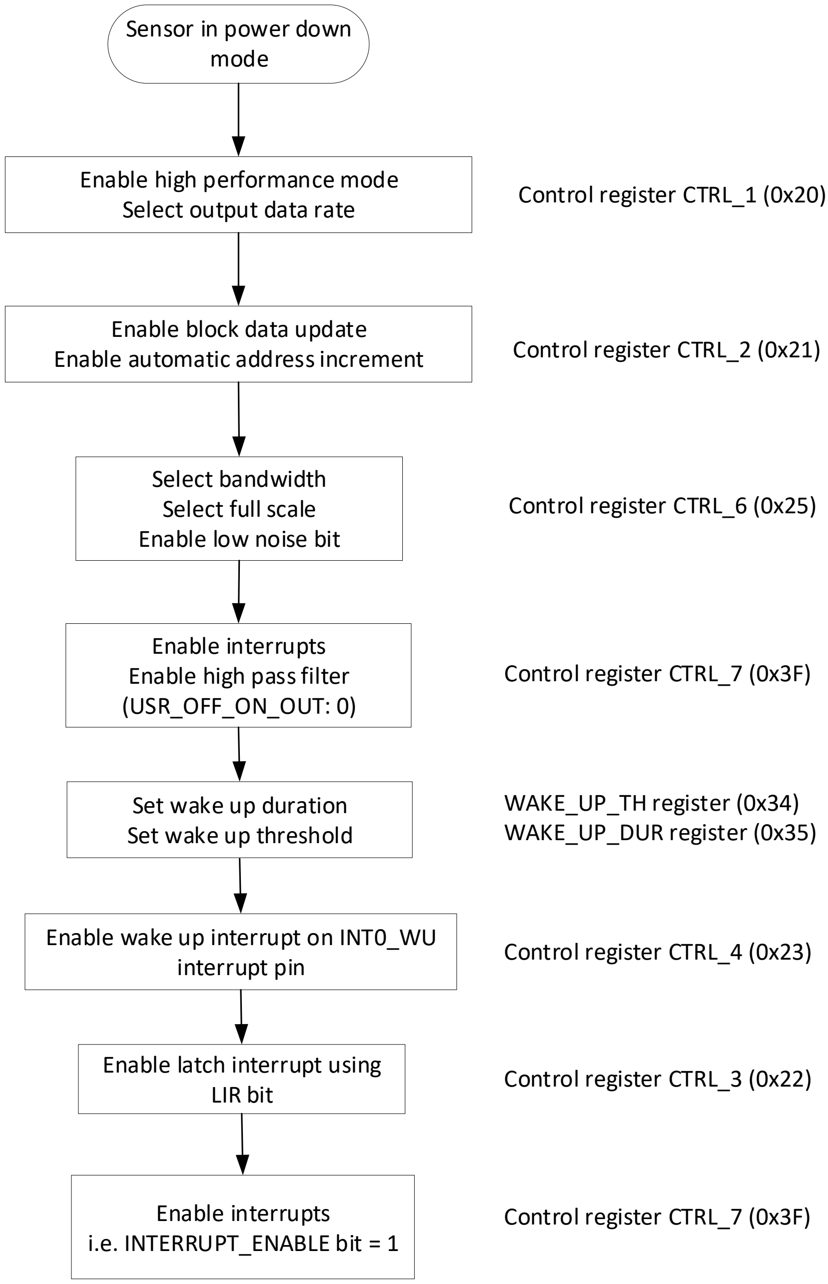


Figure 10: Initialization wake up event detection with high pass filter output

5.4 Initialization of wake up feature with offset output

The flow chart shows the initialization of the wake up feature with offset output data. The USR_OFF_W bit in the control register CTRL_7 (0x3F) defines the weight of the offset value. Writing USR_OFF_W bit to 1 gives the weight of 15.6 mg/LSB and writing 'b01000000' (decimal value: 64) to the register Z_OFS_USR (0x3E) gives the offset value 64*15.6 mg = 0.9984 g on Z axis, which is approximately 1g.

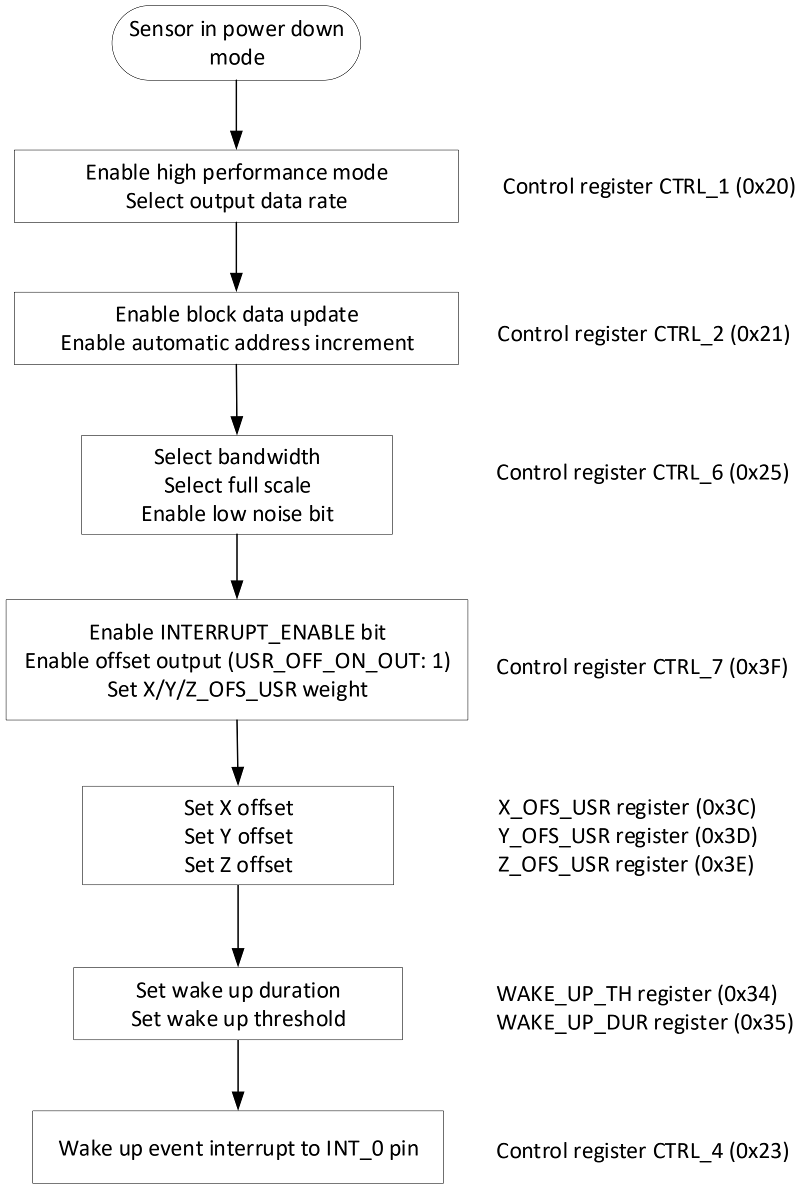


Figure 11: Initialization wake up event detection with offset output

6 Stationary detection

The stationary feature combines the both sleep and wake up detection event to realise a stationary event. There is no separate stationary interrupt signal. It can be realised by monitoring the sleep and wake up interrupt signals. The stationary feature can be enabled by writing SLEEP_ON bit to '1' in the WAKE_UP_TH (0x34) register and simultaneously writing STATIONARY bit to '1' in WAKE_UP_DUR (0x35) register. Since the stationary detection feature uses the wake up feature to generate the interrupt, the choice of output data to generate wake up detection event can be done using USR_OFF_OUT bit in the register CTRL_7 (0x3F) i.e. high-pass filter output or offset output. The wake up threshold and duration parameters can be defined as per the user application.

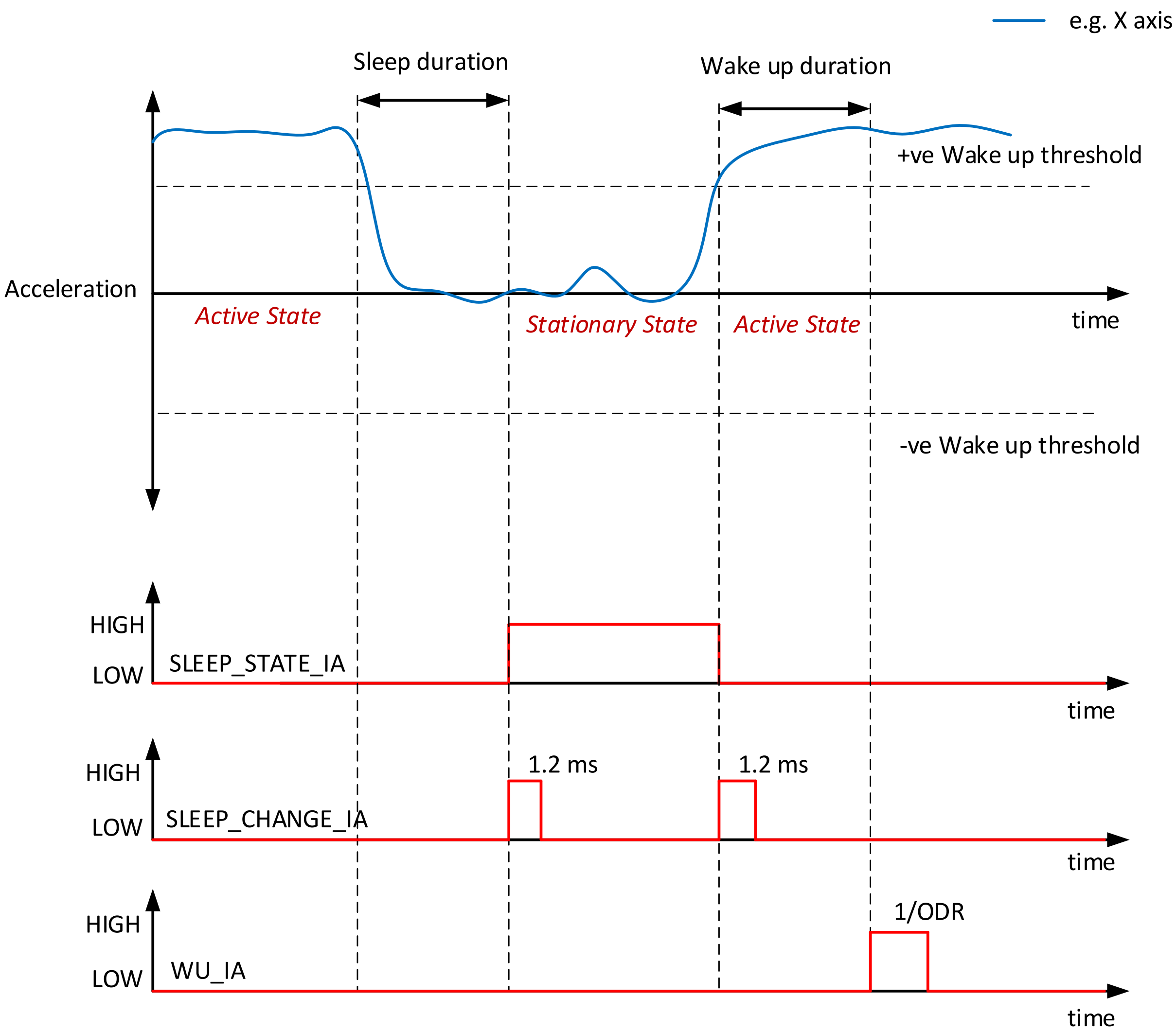


Figure 12: Stationary event detection using high pass filter data, e.g. X axis

There is no separate stationary interrupt signal. It can be defined by monitoring both the sleep and wake up interrupt signals.

6.1 Sensor in stationary state (no motion)

When a certain number of the output acceleration values from X, Y and Z axis is smaller than wake up threshold and output values remains in the range for a certain duration, then SLEEP_STATE_IA interrupt signal is generated. The threshold is defined by WK_THS bits in the WAKE_UP_TH (0x34) register. The duration is defined by SLEEP_DUR bits in the WAKE_UP_DUR (0x35) register.

The stationary event detection status is detected using SLEEP_STATE_IA bit. This interrupt signal can be routed to the INT_1 interrupt pin. Simultaneously when the sensor state changes from active to stationary or vice versa, the SLEEP_CHANGE_IA bit in the ALL_INT_SRC register is set for 1.2 ms. This status bit can also be routed to the INT_1 interrupt pin. In this case, the SLEEP_CHANGE_IA signal is not compatible with latched mode, so the LIR bit in the CTRL_3 (0x22) register should be set to 0.

6.2 Sensor in active state

When a single data from any one of the axes is higher than the defined wake up threshold and the data remains in that range for a specified duration, then WU_IA interrupt signal is generated. This interrupt signal can be routed to INT_0 interrupt pin. The duration parameter is defined by WAKE_DUR bits in the WAKE_UP_DUR (0x35) register. Simultaneously when the sensor state changes from stationary to active, the SLEEP_CHANGE_IA bit in the ALL_INT_SRC register is set again for 1.2 ms.

The duration of the WU_IA interrupt signal is 1/ODR.

6.3 Initialization of the stationary feature

The flow chart shows the initialization for the stationary feature of the sensor. This flow chart shows the step by step configuration to enable the stationary feature.

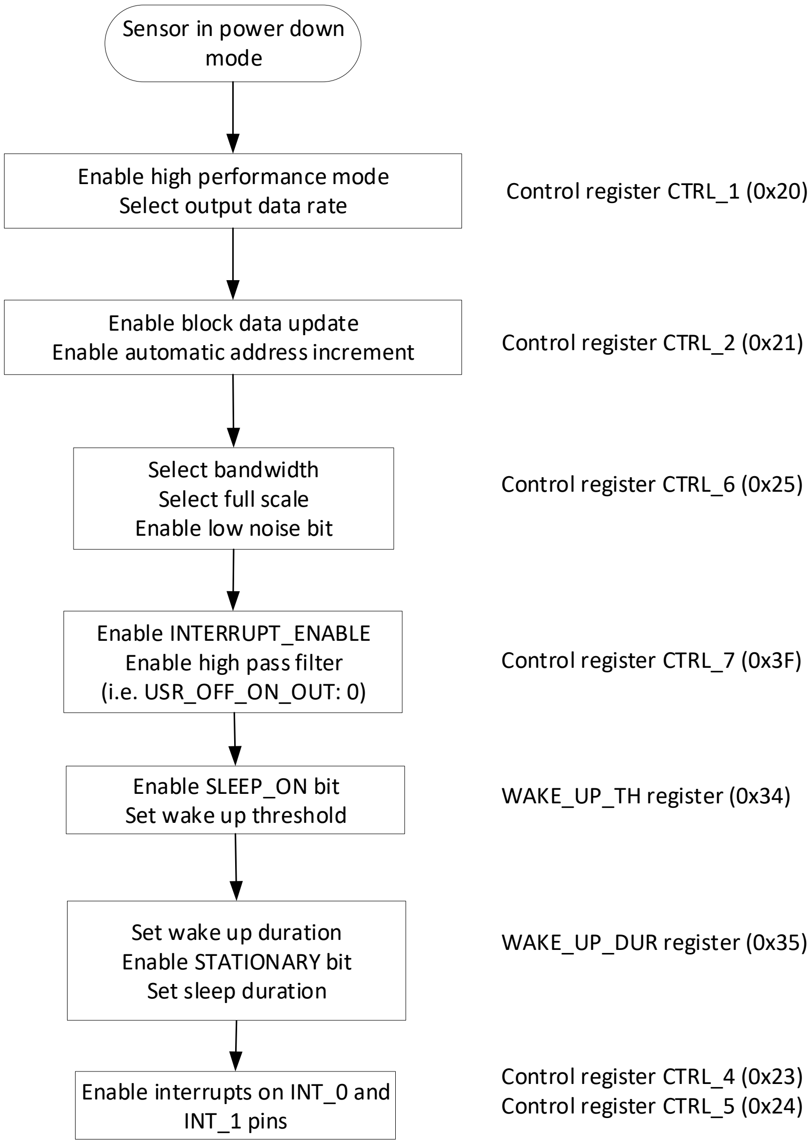


Figure 13: Stationary event detection

7 Interpretation of human fall using sensor features

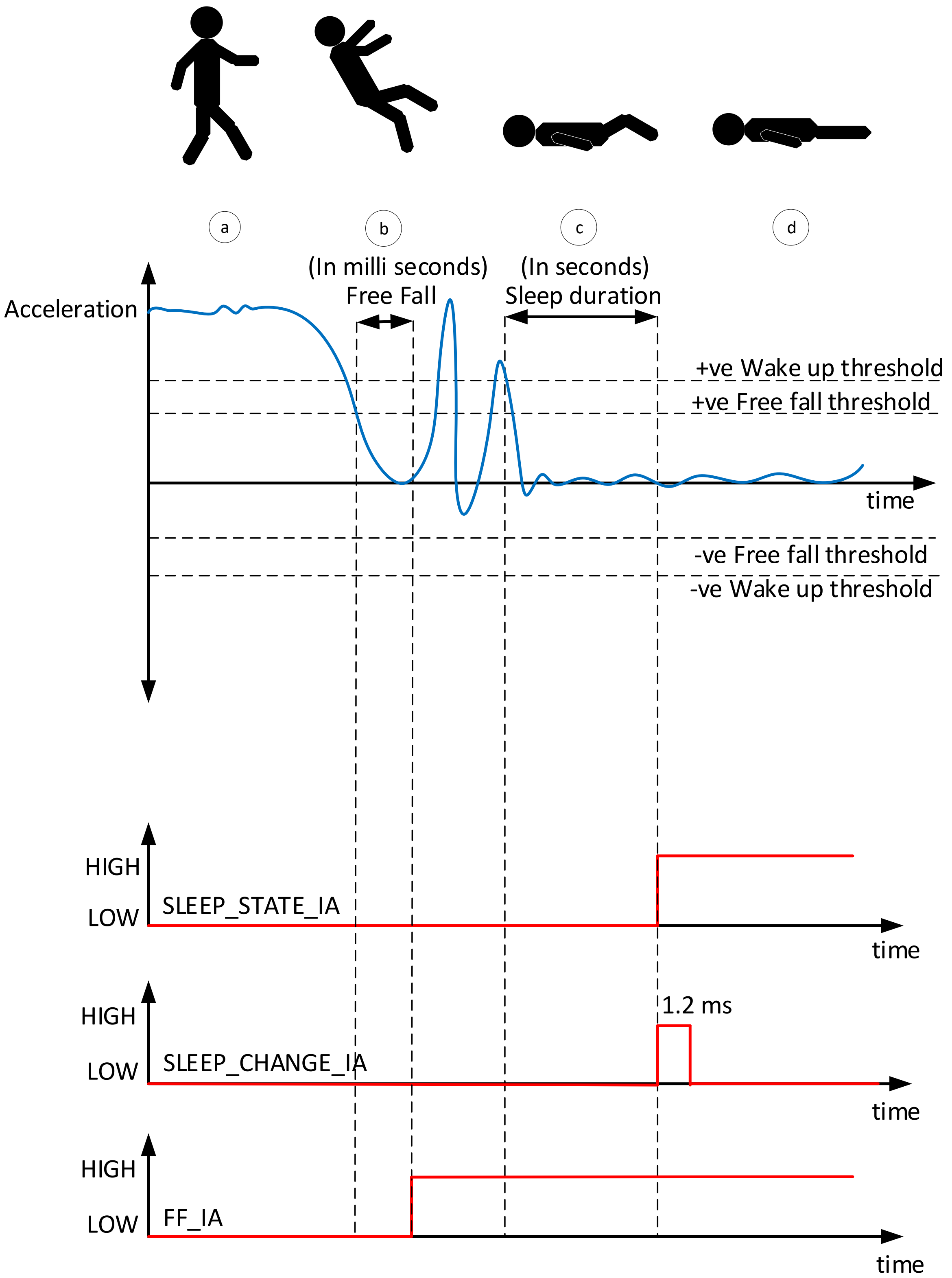


Figure 14: Stationary event detection using high pass filter data, e.g. X axis

This chapter provides the necessary information about the interpretation of human fall using free fall, wake up and sleep interrupt signals which is represented in figure **??**. In this scenario, a person fell and unable to move due to the impact of fall is been considered.

a. Before the fall, the vector sum of the acceleration values from all three axes will be close to 1g. By also monitoring the orientation of the sensor acceleration before and after the fall, additional information of the human fall event can be obtained.

b. In the free fall state, the weightlessness phenomenon will always occur at the start of a fall. With suitable free fall duration and threshold values, the fall of a person can be detected using the FF_IA interrupt signal. During the free fall, the acceleration will tend towards 0g level, but right after the free fall a strong spike of acceleration will occur due to the impact of the person falling on the floor.

c. Immediately after falling, depending upon impact of fall, the person will try to recover from the fall if the impact is not severe. When the impact of the fall is severe, the person might not be able to move immediately after the fall. The duration of this event can be configured using stationary detection feature. This duration can be assigned in terms of seconds.

d. After certain time (which is configured in stationary feature), when the person is not able to move or unconscious from the impact, SLEEP_STATE_IA interrupt and SLEEP_CHANGE_IA interrupt signal is generated. By comparing the orientation of the sensor acceleration before and after fall, the fall detection systems can be realised to generate an alarm. If the person stood up or moved within a certain time (i.e. sleep duration), the wake up interrupt signal WU_IA is generated instead of SLEEP_STATE_IA and SLEEP_CHANGE_IA interrupt signal. In this case, the fall detection system will not generate an alarm.

> **!** It is necessary to verify and check which sensor features are best suitable for the development of the fall detection systems.

8 Conclusion

The WSEN-ITDS 3-axis MEMS acceleration sensor as an ultra compact, low power and application specific featured device makes it idle for battery based human fall detection system. A new simple solution is proposed in this document for the fall detection system that takes advantage of the in-built sensor features with two individual interrupt pins. The wide range of fall detection problems in many applications like window washers, roofers, construction worker or elderly fall monitoring system can be realised using flexible in-built sensor features and the interrupt pins.

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