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DEVELOPMENT OF AUTOMATIC FALL DETECTION DEVICE FOR OLD PEOPLE BASED ON 3-AXIS ACCELEROMETER SENSOR WITH MOBILE IOT SYSTEM

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Abstract. *Falling is one of the main risks affecting health in the elderly. Hence, in recent years, many elderly fall detection methods have been developed. The use of an automated and highly reliable fall detection system not only reduces the negative effects of falls but can also provide immediate medical assistance. One of the methods of detecting falls is by using the 3-axis accelerometer sensor, but only 1 module is used to detect falls. This method may be an error due to the inability to distinguish the falling patterns in each direction. This article presents a real-time drop detection system with two 3-axis accelerometer modules mounted to the abdomen. In this research, the different technique of both output sensors and a moving average filter will be used to detect four direction of falling: forward fall, backward fall, leftward fall and rightward fall respectively. In addition, the system was able to separate the falling and lie down patterns by means of the difference equation. The system presented will work with the smart phone through the Blynk IoT platform. The test results show that the proposed system accuracy is 100%, 95%, 100% and 97.5% for forward fall, backward fall, leftward fall and rightward fall respectively.*
Keywords: Fall detection, 3-axis accelerometer, Blynk IoT platform

1. **Introduction.** Falling is one of the major health risks of the elderly, which can cause death, illness, disability and frailty [1]. In addition to physical injuries, the fear of falling occurs among the elderly. This reduces their confidence in independent living and their participation in social activities, thereby significantly reducing their quality of life and resulting in increased frailty [2,3]. Therefore, automatic notification to caregivers after a fall is detected can be very helpful for older people by reducing the waiting time for medical assistance after a fall. That means the faster the salvage comes, the less risk the elderly will face. For example, Yazar et al. introduced vibration and passive infrared (PIR) sensors, and used winner-takes-all decision algorithm to detect falls [4]. Yu et al. developed a vision-based fall detection method by applying background subtraction to extracting the foreground human body, and information is fed into a directed acyclic graph supporting vector machine (SVM) for posture recognition so as to detect falls [5]. Nowadays, advances in technology have enabled us to help care for the elderly better, as the use of low-power devices has made it possible to design wearable monitoring devices that can be used for the elderly continuously for a long time. In addition, the Internet of Things (IoT) that works with smart phones can also be connected to a wearable device, allowing for remote surveillance [6]. There are several methods for detecting falls. One of them is computer vision based method [7]. This model will be installed in a limited space camera, and then

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will record pictures and VDO activities of the elderly. This method works effectively in indoor environments, but is difficult to use in outdoor environments due to limited camera operation. Another popular method is the installation of accelerometer sensor. The first kind of detection method is using an accelerometer. A single triaxial accelerometer can provide object's accelerations in three directions which include the influence of gravity. A coordinate will be built when the accelerometer is fixed on human's body. The influence of gravity or dynamic acceleration is available by using a low pass filter or a high pass filter [8]. Some kinds of angular movement information can also be calculated based on the relationship between acceleration components and their vector sum [9]. The second kind of detection method is based on both accelerometer and gyroscope [10]. Gyroscope can offer angular velocity, and the accelerometer could offer linear motion information [11]. As angular information can also be extracted from accelerometer measurements, a state space filter such as the Kalman filter is a commonly used technique to combine angular motion information [12]. Wang et al. [13] presented a new fall detection method based on fuzzy reasoning for an omni-directional walking training robot. However, using a single sensor may cause errors in the fall detection because the system is unable to determine the direction and nature of the fall. The basic principles of the application of 3-axis accelerometer sensors in the detection of falls are presented in Section 2.1, where this section presents the equations used to distinguish events of falls from standing. However, using a single 3-axis accelerometer sensor to detect falls may not be very accurate in the detection of falls. Therefore, in this research, two 3-axis accelerometer sensors are used for fall detection to distinguish events of falls from reclining, stooping and standing, depending on the difference in the outputs of the two sensors. In this article, a fall detection system will work together between two 3-axis accelerometer sensors, based on a new technique that relies on different outputs of the two sensors with a moving average filter. The proposed system can detect four falling directions: forward fall, backward fall, rightward fall and leftward fall, respectively. In addition, the system was able to separate the falling pattern from the lie down by the difference equation. The proposed system will work in conjunction with a smart phone past to the blynk IoT platform. This will allow real-time elderly falls tracking to be able to provide timely assistance in the event of a fall.

2. Principles and Methods.

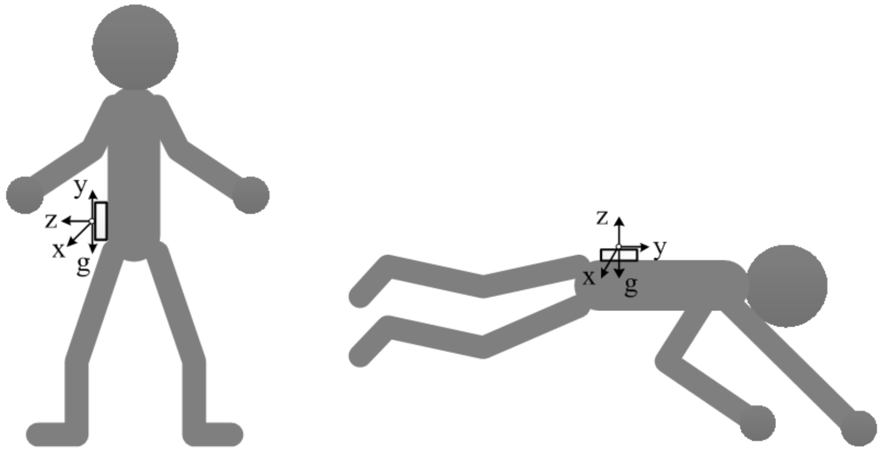
2.1. Principle of 3-axis accelerometer for fall detection.

The compact healthcare wearable devices require low power consumption and a single 3-axis accelerometer sensor could provide information, and threshold-based fall detection algorithm will be used in this system. Coordinate constructed by the accelerometer and the gravity vector is shown in Figure 1. Algorithm used in this fall detection system is based on thresholds of sum acceleration information. When a real fall happens, collision between human's body and ground will produce obvious peak value at the sum acceleration $\vec{a}$ which has magnitude as

$$|\vec{a}| = \sqrt{a_x^2 + a_y^2 + a_z^2} \tag{1}$$

where a_x, a_y, and a_z present accelerometer measurements of three axes.

The system uses the sum acceleration as the step to distinguish high intensity movements from others. After that, feature used here is an angle calculated based on acceleration measurements. The falls are calculated based on the relationship of the accelerometer and the gravity vector. However, normal movement, such as jumping or sitting, produces peak values, which means that additional sensing features are needed to separate a fall from jumping or sitting.



(a) Stand (b) Fall

Figure 1. The 3-axis accelerometer for fall detection

2.2. **Fall detection system design.** This paper proposes a fall detection system using two 3-axis accelerometer sensors attached to a wearable device and located on the abdomen as shown in Figure 2. From Figure 2, the difference of acceleration in each axis was used to determine the direction of the fall and to separate the fall from the jump, stand and lie down. The patterns of the sensors when there are various types of falls are shown in Figure 3.

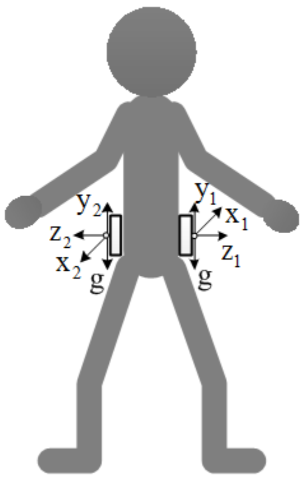


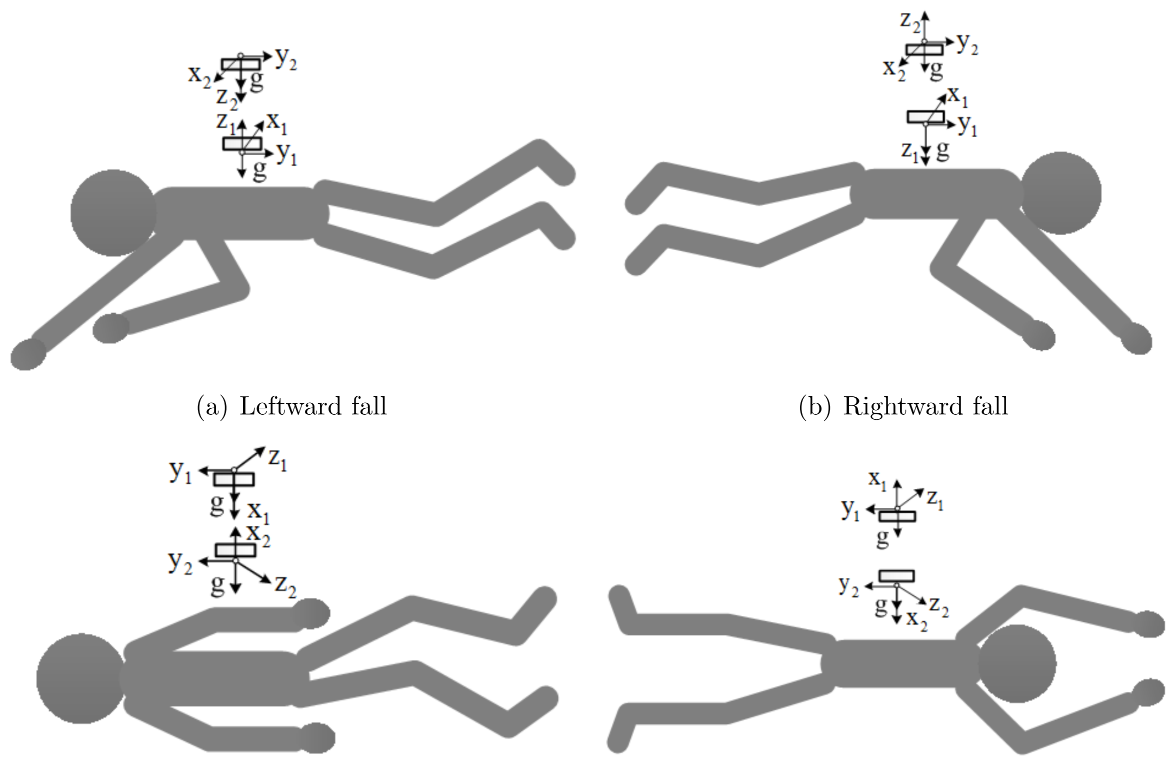
Figure 2. Fall detector with a coordinate system

From Figure 3, the direction of the fall can be described as follows: Figure 3(a) and Figure 3(b) show leftward and rightward fall. This is based on the relationship of the sensors in the z axis shown in Equation (2). Figure 3(c) and Figure 3(d) show the backward and forward fall, which relies on the sensors in the x axis shown in Equation (3).

$$\Delta a_z = a_{z2} - a_{z1} \tag{2}$$

$$\Delta a_x = a_{x2} - a_{x1} \tag{3}$$

According to Equations (2) and (3), the proposed system does not require the use of gravity vector calculations, thus simplifying the calculation of a fall detection system. In addition, the system presented provides a highly effective fall detection accuracy in detecting a fall, enabling timely fall alerts when a fall event occurs.



(a) Leftward fall (b) Rightward fall

(c) Backward fall (d) Forward fall

FIGURE 3. Fall directions and kinematic analysis of a fall

2.3. **Fall detection algorithm.** Since the output of the 3-axis accelerometer is interfered with the movement of the body, the solution to this problem in this article will be based on a method to eliminate noise using a moving average filter. The difference equation for an L-point discrete time moving average filter with input represented by the vector x and the averaged output vector y is

$$y(n) = \frac{1}{L}\left[x(n) + x(n-1) + x(n-2) + \cdots + x((n-L)+1)\right] \quad (4)$$

In addition, the proposed system used difference equation to determine the slope of the graph to separate a fall from a 45-degree forward leaning and a sit-down or lie down. Equations can be expressed as

$$w(n) - w(n-1) = \text{set point 1} \quad (5)$$

$$v(n) - v(n-1) = \text{set point 2} \quad (6)$$

where w is a vector used as a condition to indicate an elderly person is fall and v is a vector used to indicate an event of lie down. Equations (5) and (6) show a method for determining the difference of data, in other words, to find the slope of the data. The calculated values for Equations (5) and (6) are compared with the set values to distinguish reclining events from falls.

2.4. **The Blynk IoT platform for fall detection proposed system.** The system presented will display the fall result and notify the caregiver and clinician past to a remote communication system using the mobile IoT system as shown in Figure 4. From Figure 4, the wireless communication system in this research, the cc3000 wifi module is used for remote communication to connect to the blink server, which in this section allows users to see graphical monitoring at all time.

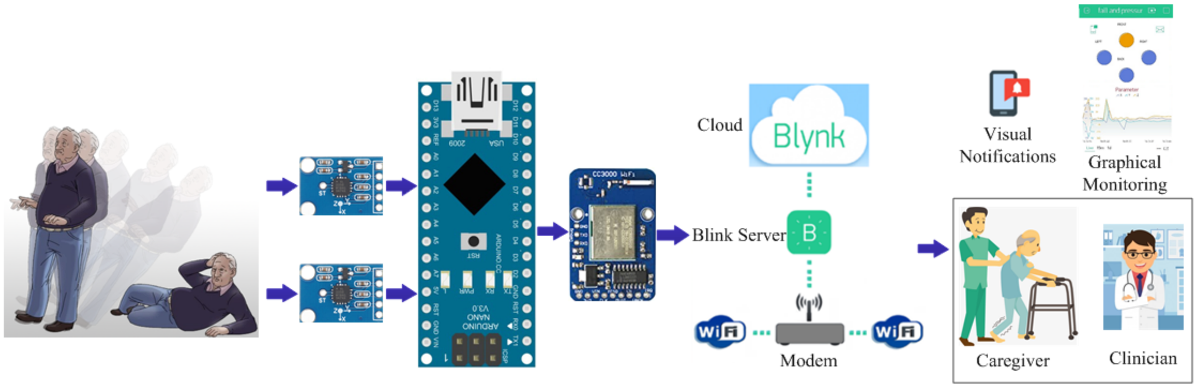
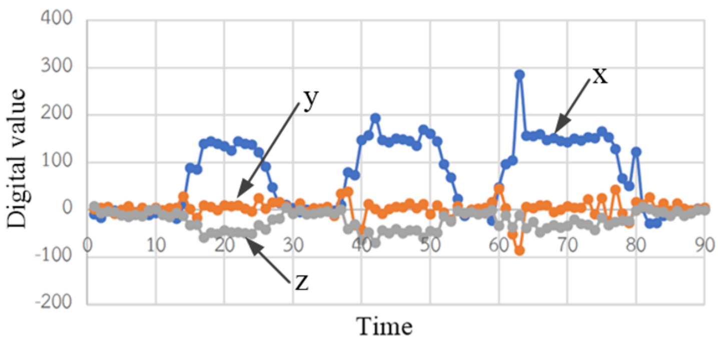


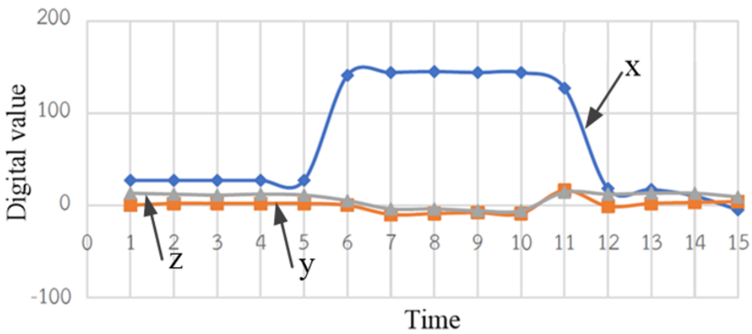
FIGURE 4. Fall detection system architecture for elderly people based on IoT

In addition, the system will provide notifications when a crash occurs through applications on the smart phone, which will enable them to help the elderly in a timely manner.

3. **Experimental Results and Discussion.** The proposed system will be tested with subject, where four types of fall events will be simulated. The proposed system test began with the installation of a fall detection kit to the volunteer's body, and then clarified the fall pattern to the volunteers to understand the fall test pattern to be tested. The test pattern will allow the volunteers to fall according to the prescribed pattern to simulate the actual fall pattern in the elderly. By testing when there is a fall, there will be a fall notification to the mobile application. The test results in the four falling patterns are shown in Figures 5 and 6. In the section of the test with subjects, 40 tests were performed for each of the fall patterns. The results are shown in Table 1. The results of the difference test between falls and tilt 45 degrees and the test results between falls

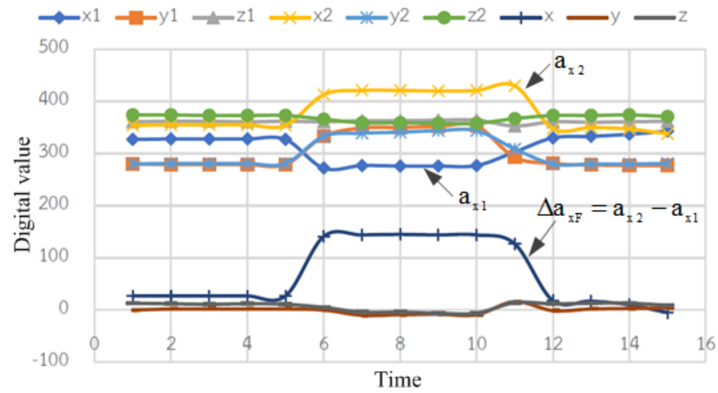


(a) Accelerometer raw data

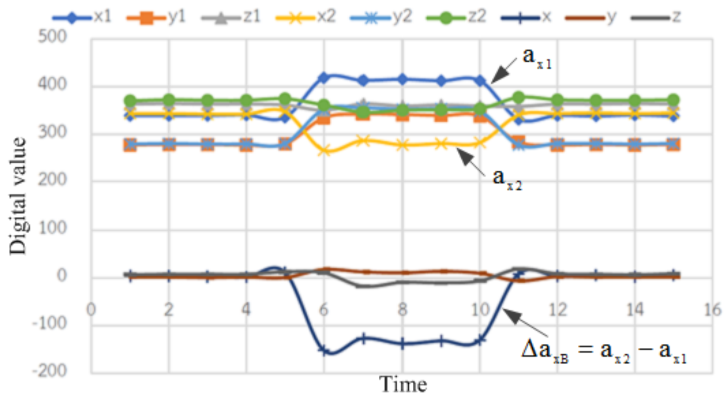


(b) Output of moving average filter

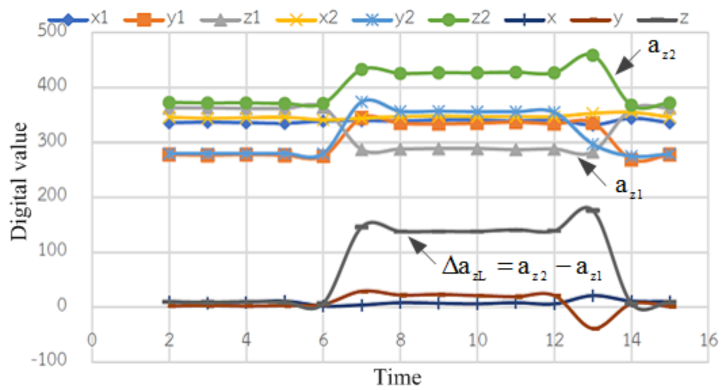
FIGURE 5. Output of the 3-axis accelerometer sensor



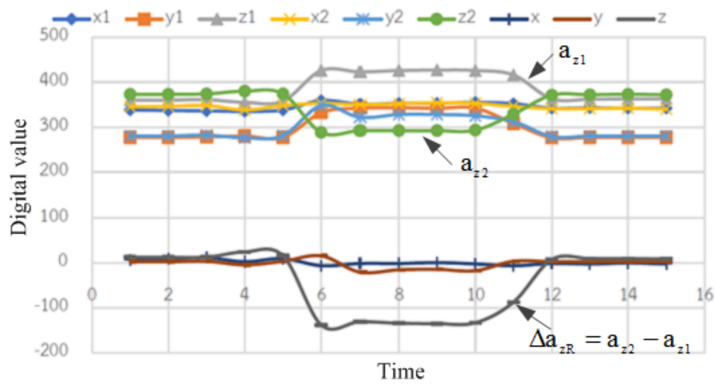
(a) Forward fall



(b) Backward fall



(c) Leftward fall

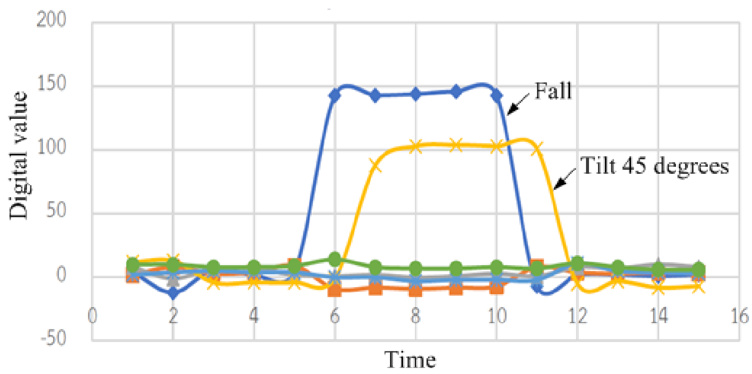


(d) Rightward fall

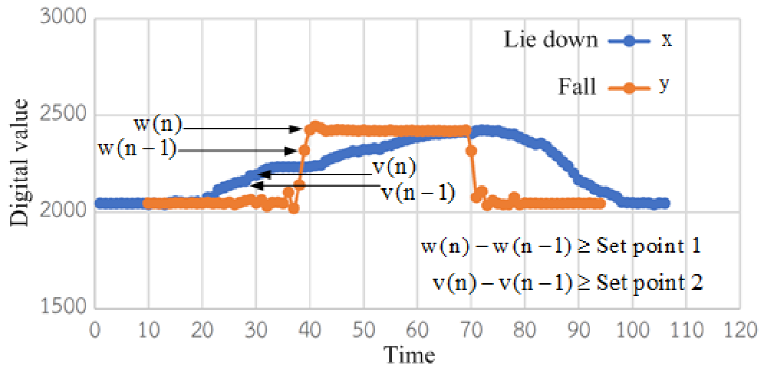
FIGURE 6. Acceleration curves of the motion type fall

Table 1. Test results for four kinds of falling

Motion type	Number of falls	Number of detected falls	Accuracy (%)
Forward fall	40	40	100
Backward fall	40	38	95
Leftward fall	40	40	100
Rightward fall	40	39	97.5



(a) Fall and tilt 45 degrees



(b) Fall and lie down

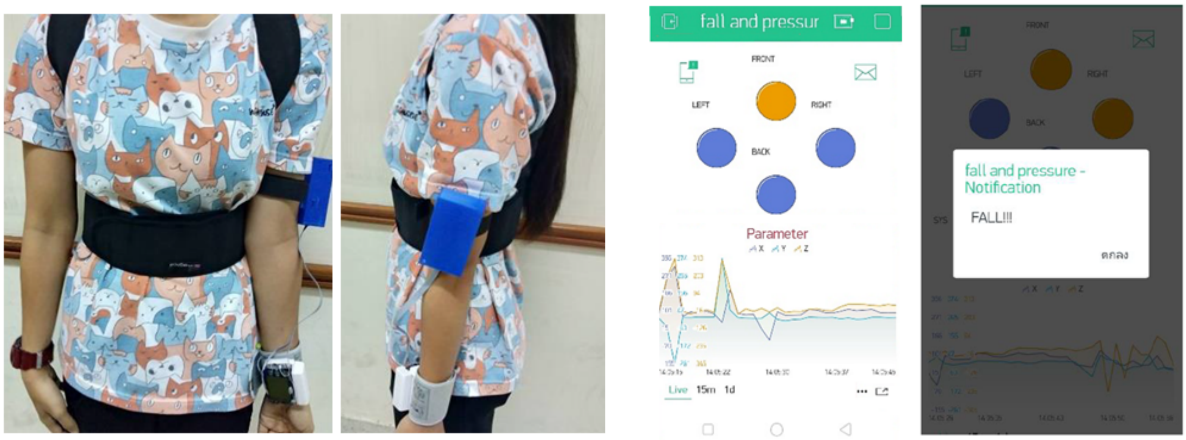
Figure 7. Comparison of falling and normal stance

and lie down are shown in Figure 7. The wearable device setup for subject and the user interface application screen are shown in Figure 8.

Figure 5 shows the test results of using the moving average filter equation. When using accelerometer raw data through the moving average filter, the output of the moving average filter will have less noise from the movement.

Figure 6 shows smooth output of sensor, and the signal is also eliminated off set according to the proposed method. Figures 6(a) and 6(b) will output in the $+\Delta a_{xF}$ direction and in the $-\Delta a_{xB}$ direction, which are used to decide which direction to forward fall and backward fall respectively. In Figures 6(c) and 6(d), output in the $+\Delta a_{zL}$ direction and in the $-\Delta a_{zR}$ direction, which are used to determine the direction of leftward fall and rightward fall respectively. In addition, the proposed system demonstrated a deciding signal pattern to distinguish between a 45-degree tilt and a fall, determined at the signal amplitude. The other is the separation effect between lie down and falling, which is determined using the slope of the signal. The test results are shown in Figure 7, when tested on subjects with a fall in each type of falling posture.

4. **Conclusions.** In this article, a fall detection system based on IoT is presented. The fall detection kit is installed on a wearable device for detecting falls of the elderly people.



(a) Attaching the wearable to the body (b) Fall detection app for user interface

FIGURE 8. The wearable fall alert device on the proposed technique

In this research, two 3-axis accelerometer sensors will be used to detect falls. In addition, the proposed system was able to classify daily activities from falls based on amplitude separation and the slope of the signal. The test results show that the proposed system accuracy is 100%, 95%, 100% and 97.5% for forward fall, backward fall, leftward fall and rightward fall respectively. After a fall is detected, if a fall event occurs, the pattern of the fall will be notified to the app on the smartphone of caregiver. The future research approach is to apply artificial intelligence to analyzing and predicting events at risk of falling among the elderly before they actually fall in order to be able to prevent falls in a timely manner.

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