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Wearable device for real-time monitoring of human falls

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Abstract

This paper presents a wearable micro-sensing device for monitoring human body falls. It combines micro-sensors and digital data processing technologies, such that in real-time, it can monitor the user to get immediate help by sending an emergency message to an aid station at the moment of falling. The primary feature of this system is the micro sensor, with a horizontal sensor embedded inside a smart coat. Two kinds of micro-sensors are used for the system, one is a micro-mercury switch, and the other is an optical sensor to detect if the wearer is horizontal. With the new algorithms for movement behaviors judgment, the system has the ability to collect, analyze, and transmit data by monitoring the user's body. In outdoor sports, the system sends information on body position and location, and an emergency message from the user to a specific guard in real-time.

Keywords: Wearable micro-sensing device; Monitoring human body falls; Real-time

1. Introduction

Falls are the major cause of injuries among athletes in outdoor sports. In the past 10 years, stroke, a blood vessel disease, has been the second most common cause of death, and a major cause of injury for older people. Furthermore, even if the patients have the ability to walk after recovery, there is a large possibility that they will fall again due to the injury to some of their brain neurons. According to previous studies, in-patients have the greatest probability of falling again at a convalescent hospital. Besides, automatic monitoring homecare for abnormal activities of the elderly and children at home is very important. The advantages of using the fall detection system include saving people's lives, reduce economic and medical costs, and to provide better living quality for people. Several computer vision methods have been developed to learn the activity patterns of a single person when alone [1,2]. The behavior patterns of the person being modeled are created for an automatic fall alarm system. Passive fall detection has been identified as a priority for supportive home environments

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for older people. These methods seem to provide useful cues for fall detection but not very stable. Many inexpensive, miniature accelerometer sensors can provide reliable information on mobility and objective measurement in monitoring of patients in rehabilitation [3]. Other types of sensors can also be used for real-time monitoring of balance, mobility, and falls. They have the potential in the future to stratify the risk of falls facilitating early initiation, thus avoiding further falls. The sensor of a unique monitoring system equipped with real-time automatic responsive function can be loaded in the user's clothing [4]. When the user falls down, the system will detect the position of fall and automatically sends the warning signal out. In the near end, detected signals are sent to a PDA for analysis via wireless Bluetooth (BT) technology and at the same time, signals for help stored in the speech database inside the PDA are also initiated to inform the nearby personnel for help. The user is able to send his/her information to the computer in the far end monitoring station and when the possible fall occurs, the system automatically informs the designated subject via MSM for proper crisis management. This paper outlines a new design for a potentially useful device – a wearable system for real-time monitoring of falls in high-risk individuals.

2. System structure

The primary feature of this system is a micro-sensor, with the horizontal sensor embedded inside a piece of clothing called a smart coat, as shown in Fig. 1. When a user wears this coat, the system can monitor the user 24 h a day to sense the falling moment. The smart coat is a reliable and convenient data collection system with precise data analysis and transmission functions; it includes a micro-processor, RF receiver transmitter, and micro-sensors.

The smart coat is suitable to be worn by athletes or those who have a high tendency to fall. The coat will monitor the body situation all the time, and when a fall occurs, a voice alarm is transmitted from the coat to a remote guard or nursing department for assistance.

The major components of the system are:

- sensor section,
- control board,
- PDA software.

2.1. Position of the sensors

Two kinds of micro-sensors are used for the system, one is a micro mercury switch and the other is an optical sensor to detect if the wearer is horizontal. The micro-mercury switch is less expensive and effective for tilt detection of the human body. For posture and fall detection, the micro-mercury switch net should surround the user's body. Hence, the sensors are embedded on both sides of the coat, with a total of 10 sensors on the shoulders, chest, kidney, legs, and feet.

2.2. The angle of the sensors

While the sensor is tilted, the micro-mercury switch is connected to the floating mercury ball that is formed by the high surface tension of the mercury. When the sensor is horizontal, the mercury ball will not move. When the angle of tilt is larger than 5°, the mercury ball will move to the lower position of the sensor tube by gravity causing sensor contact, as shown in Fig. 2.

The optical sensor uses the laser triangle projection method and is connected to a PSD system to measure the horizontal situation. When the testing body moves slightly, the laser spot shifts within a small area. If the testing body falls, the laser spot of the optic sensor has a large displacement. Hence the movement of the laser spot can also be used as a sensor for the system shown in Fig. 3.

2.3. Image formation using the optical sensor

Assuming an optical sensor structure as shown in Fig. 4, when the object distance is infinite, then the image distance is the focal length f, and when the object distance is u, then we can assume the image distance to be $f+x$.

Thus the diameter of the image spot d can be expressed as

$$\frac{d}{D}=\frac{x}{f+x}\cong\frac{x}{f},\qquad d=\frac{xD}{f}\cong\frac{x}{F},\qquad x=dF$$

where D is the diameter of the lens and F is the focal ratio.

From the imaging equation we can then obtain

$$\frac{1}{u}+\frac{1}{f+x}=\frac{1}{f}$$

$$\frac{1}{u}=\frac{x}{x(f+x)}$$

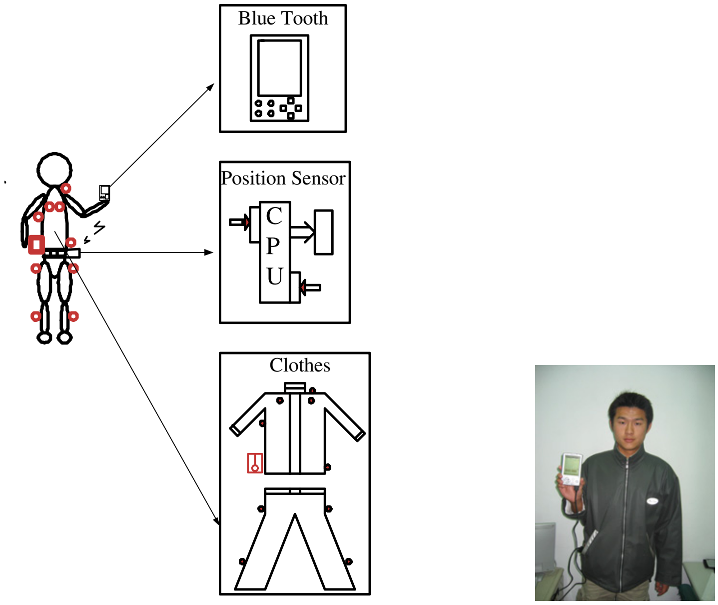

Fig. 1. System structure.

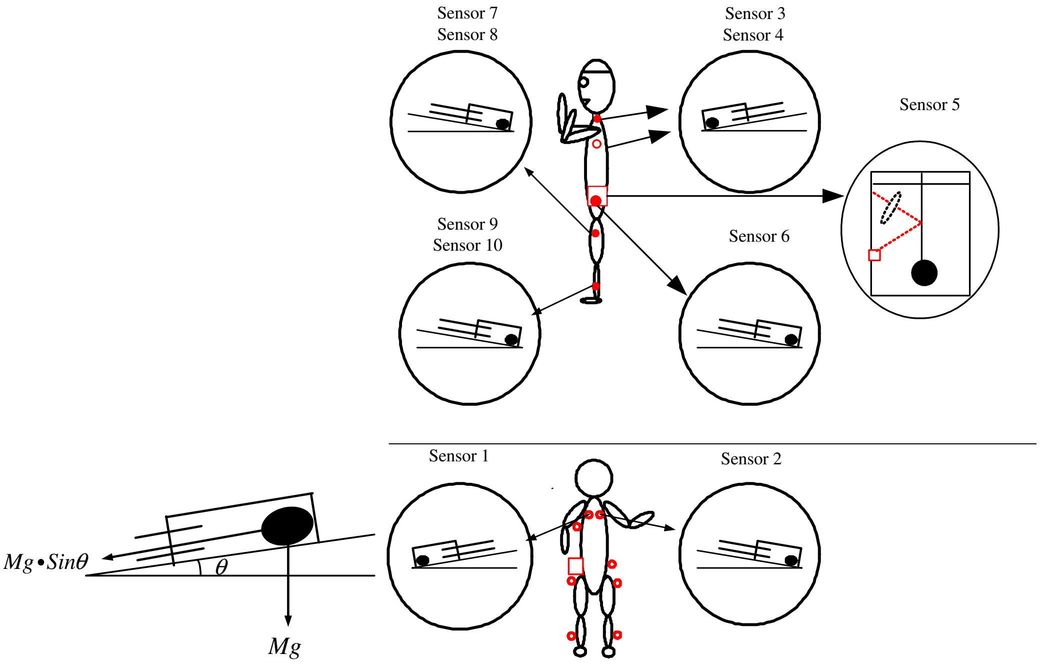

Fig. 2. The mercury ball movement inside a the switch.

then

$$u = \frac{f(f + x)}{x} = \frac{f^2}{dF}$$

when $F = 5$ and $f = 4$ mm, then the diameter of the image spot is 50 μm.

$$u = \frac{f^2}{dF} = 64 \text{ mm}$$

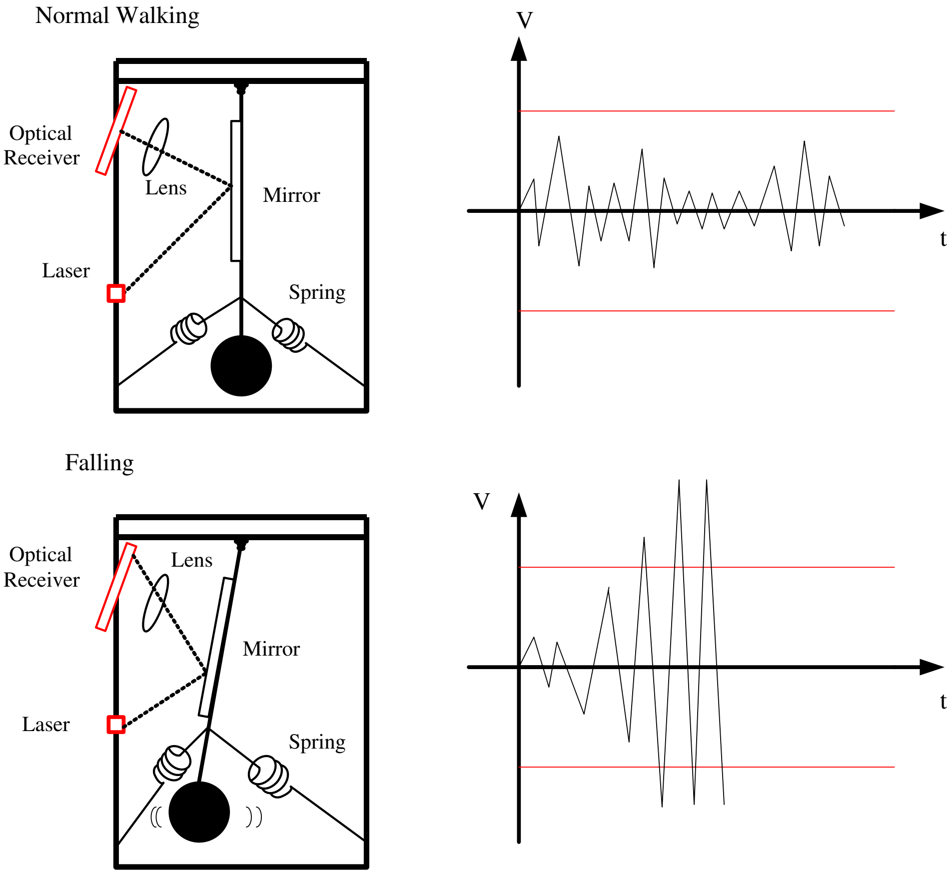

Fig. 3. The structure of the optic sensor.

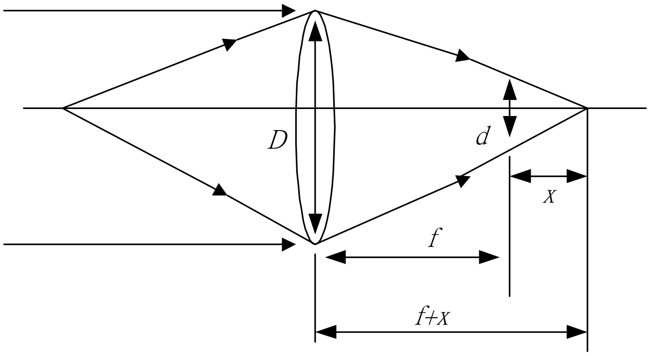

Fig. 4. The image position of a scattering type laser focus by a lens.

This indicates that when the object distance is 64 mm, then the diameter of the image spot is 50 μm. This method combines the diffraction reflection by checking the image size to make the measurement. It is relatively accurate with high tolerance for shock absorption.

2.4. Control board

The control board of the system has a microprocessor to analyze the data obtained from the sensors. The microprocessor has complete I/O capability that includes interruption, and serial transmission and receiver functions. The monitoring data after analysis is sent to the PDA of the nursing department or a security guard using Bluetooth techniques to provide real-time monitoring.

2.5. PDA software

The data collection device is a small PDA that can recognize the user's situation and make the voice alarm, record the user's body movement condition, and dial the emergency phone call to the nursing department or security guard in real-time.

2.6. System performance

The features of the system include the body balance detection device in the form of a cost embedded with many micro-sensors for monitoring the balance of the user 24 h a day. When the user falls, the device will generate a warning alarm and send a rescue message to the nursing department by radio signal. The device also records the user's body balance for health condition analysis. Over all, it combines micro-sensor and digital data processing technologies, such that in real time it monitors the user to get help immediately by sending emergency messages to the nursing station at the moment of fall [5,6].

3. Research method and experiments

A smart coat is used to monitor athletes or people with a high tendency to fall. Its 10 sensors are located at the optimum data collection points of the body, including the right shoulder, the left chest, both sides of the kidneys, both sides of the legs, and both sides of the feet. Only sensor No. 5 is an optical sensor. All the sensors are connected to the microprocessor's I/O port by tiny conducting wires as a sensor net. The I/O port of the microprocessor has been set as OFF with a high voltage level. When a user walks or exercises normally, all mercury switches are in the OFF condition. Hence, the data obtained from the switch kept high is shown in Fig. 5. When the user body is tilted, the mercury switches will turn ON. Therefore, by detecting the ON/OFF status of the mercury switches, the body movement is easily judged.

If the user faints or becomes unconscious, he or she will fall immediately, so the grabbing timing of the sensor should be set for a short enough time to ensure the system's performance, as shown in Fig. 5.

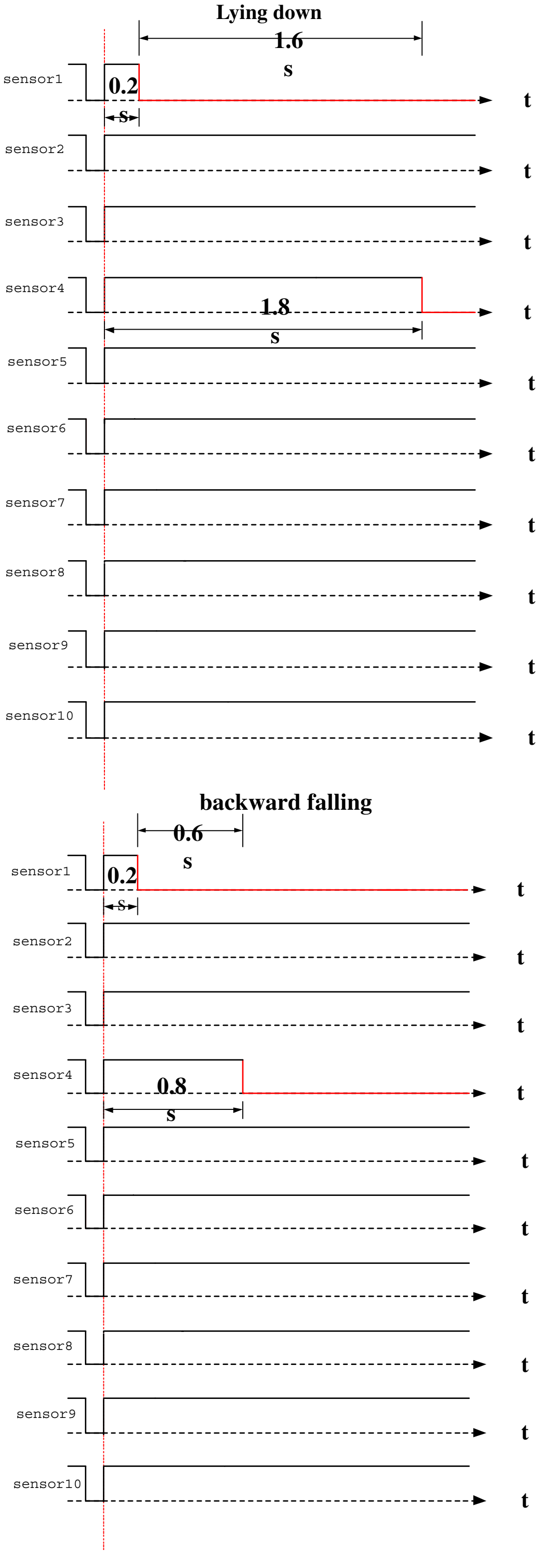

Fig. 5. Timing diagram of the sensors while body horizontal condition varies.

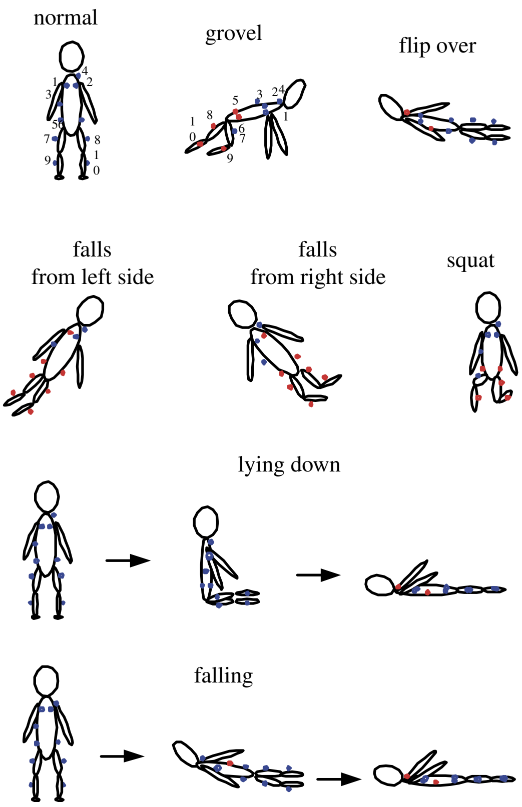

Fig. 6. The diagram of most body movement status.

Since an I/O port for the microprocessor has eight input or output pins, two I/O ports are used for 10 input sensors. Sensors 1–6 are set as the first group and connected to the first I/O port, while No. 7–10 sensors are set as the second group and connected to the second I/O port. For identification of each port and sensor, the first two bits of these two ports have been set as 01 (first group) and 00 (second group).

The second port connects only with four sensors, so bits 3 and 4 have been set as 1 (do not care). The testing signal is shown in Fig. 6. When a user stands up or walks normally, the signal obtained from the I/O port will be 011111111 and 001111111. In addition, other signals for different postures are also shown in Fig. 6. The timing diagram shows that the mercury sensor will be contacted when the angle of tilt is larger than a specific value. Therefore, the position and angle of the sensors should be adjusted and set carefully.

The algorithms for the judgment of movement behaviors are listed as follows:

Backward fall condition

$$S_5 > \theta_5, AND, \{S_1 > \theta_1, S_3 > \theta_3, S_4 > \theta_4\},$$
$$AND, \{S_4(t) - S_3(t) < 0.05(s)\}$$

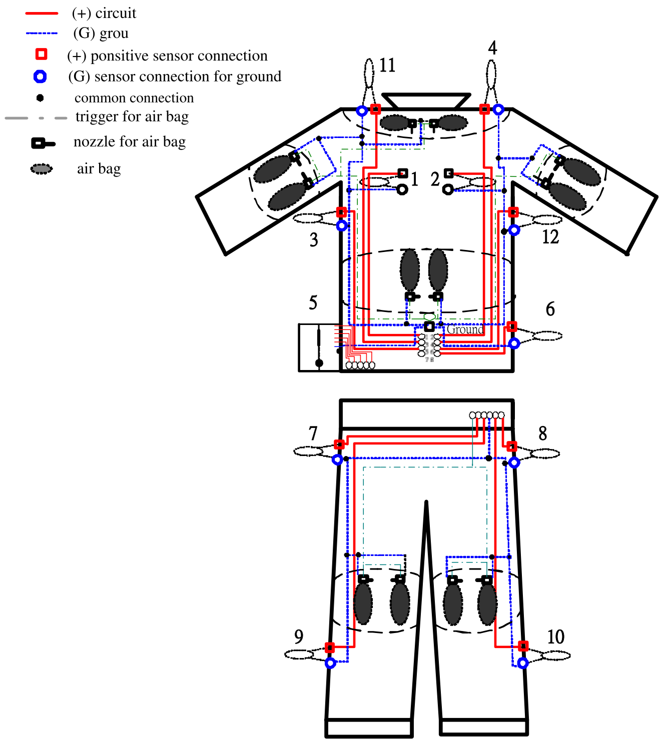

Fig. 7. The design of a smart clothes with the body protection equipments.

Lying down condition

$$S_5 > \theta_5, AND, \{S_1 > \theta_1, S_3 > \theta_3, S_4 > \theta_4\}, AND, \{S_4(t) - S_3(t) > 0.05(s)\}$$

Forward falling condition

$$S_5 > \theta_5, AND, \{S_6 > \theta_6, S_7 > \theta_7, S_8 > \theta_8, S_9 > \theta_9, S_{10} > \theta_{10}\}, AND, \{\{S_7(t) - S_6(t) < 0.1(s)\}, OR, \{S_8(t) - S_6(t) < 0.1(s)\}\}$$

Groveling condition

$$S_5 > \theta_5, AND, \{S_6 > \theta_6, S_7 > \theta_7, S_8 > \theta_8, S_9 > \theta_9, S_{10} > \theta_{10}\}, AND, \{\{S_7(t) - S_6(t) > 0.1(s)\}, OR, \{S_8(t) - S_6(t) > 0.1(s)\}\}$$

Left bending down condition

$$S_5 < \theta_5, AND, \{S_1 > \theta_1, S2 < \theta_2\}$$

Right bending down condition

$$S_5 < \theta_5, AND, \{S_1 < \theta_1, S2 > \theta_2\}$$

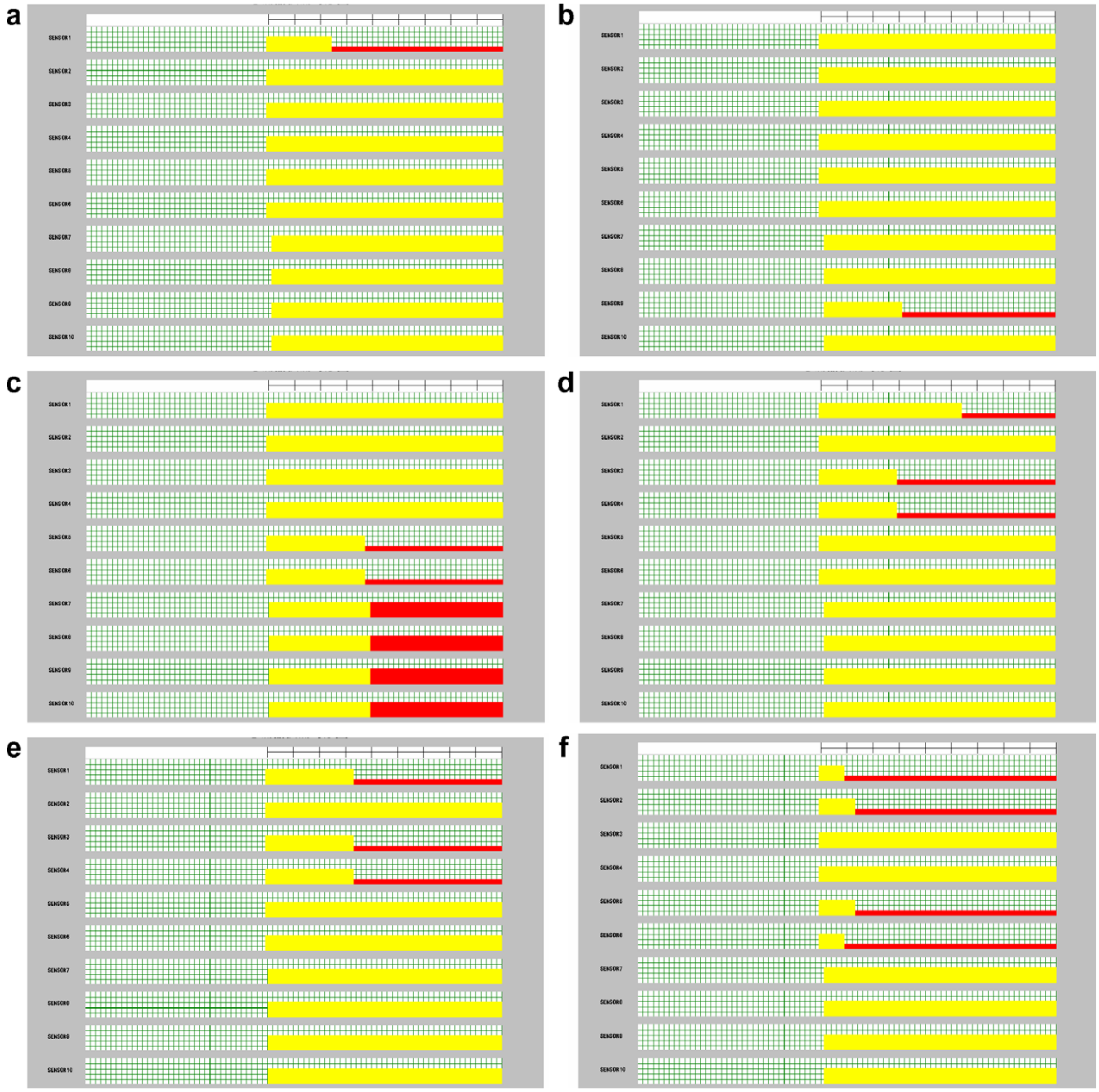

Fig. 8. Timing diagram of (a) body left tilted, (b) body right squat, (c) forward falling, (d) backward lying down, (e) backward falls and (f) body forward bending.

Squat condition

$$S_5 < \theta_5, AND, \{S_1 > \theta_1, S2 > \theta_2\},$$
$$AND, \{S_9 > \theta_9, S_{10} > \theta_{10}\}$$

Forward bending down condition

$$S_5 < \theta_5, AND, \{S_1 < \theta_1, S2 < \theta_2\},$$
$$AND, \{S_9 > \theta_9, S_{10} > \theta_{10}\}$$

where S_i is the sensor i, θ_i is the threshold limit angle of sensor i and $S_i(t)$ is the time of the sensor i between start to sensor enabled.

The control software of the microprocessor includes a parallel port for the sensor input, the interrupt data transmission and receiver, and the serial port transmission using Bluetooth techniques to the remote PDA [7,8]. The data, which the

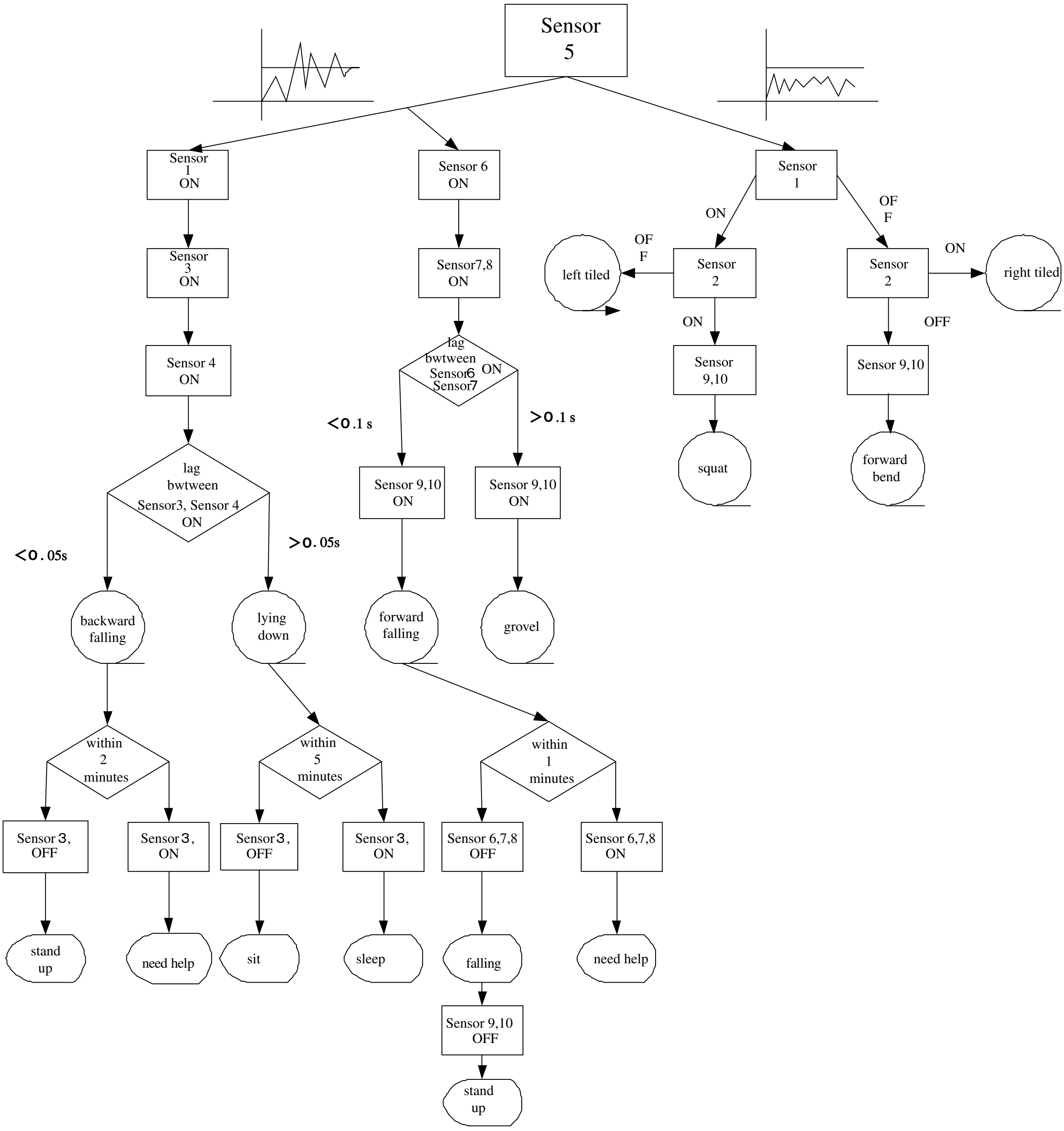

Fig. 9. Decision tree.

Table 1
Experimental results of fall detection

Behaviors judgment	Test times	Error	Reason	Accuracy (%)
Walk	50	0	N	100
Sit down	50	0	N	100
Stand up	50	0	N	100
Body left tilted	50	0	N	100
Body right squat	50	0	N	100
Sway in a small angle	50	0	N	100
Body right tilted	50	0	N	100
Forward fall	50	0	N	100
Body forward bend	50	1	The shifting of the location of sensors	98

PDA receives after analysis is transmitted in real-time by the Bluetooth interface [9]. The analysis procedure is written inside the PDA, and a posture mapping database is created for the functions of real-time monitor and alarm [10].

The control software of the PDA includes the real-time fall judgment for the user, the posture analysis, alarm generation, voice police calling, data collection and recording, as well as automatic dialing to a security guard or the nursing department. As shown in Fig. 7, the advanced design could be enhanced by combining with the body protection equipments such as the safety air bag for the protection of patients or athletes in real-time. This device could be enhanced by combining with protective equipment such as a safety air bag or water bag to further protect patients or athletes in real-time.

4. Experimental results

The comparative data of Fig. 8 shows that the conducted time is reduced when falls occur in normal cases. This characteristic is the criteria for judging when a fall has occurred.

Fig. 9 shows the decision tree of the PDA, showing the enable condition and the time record of each sensor for the judgment when a person has fallen in order to make the warning device to call for help. The experimental result of fall detection is shown in Table 1. The data shows that the discriminating rate can exceed 98% even with complicated behaviors.

5. Conclusion

This paper presents a novel device to send assistance for a patient who has fallen. The device is designed as a wearable coat, with all sensors embedded in the coat, together with a microcomputer and a RF transmitter/receiver. The coat has the ability to collect, analyze, and transmit data, so it is useful to promptly notify responsible stations when the wearer has fallen.

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