A Novel Fall Activity Recognition Method for Wireless Sensor Networks

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Abstract

Healthcare targeted for home activity is playing an important role in our daily lives as the number of elderly person is increasing sharply. Researches pointed out that one third of 65-and-over aged person fall per-year. Some detection related work made use of accelerometers or gyroscopes, some use passive infrared or acoustic sensors. But there were some false alarms. Falls can be an unpredicted and dangerous event. A system based on wireless sensor networks to detect the falls for old and resident was proposed in this paper. We provided a method to minimize the false alarm rate of fall detection as well. Besides, we can detect falls that did not trigger the alarm which was intervened by outside forces.

Keywords: Fall detection, heart rate, wireless sensor networks

1. Introduction

For the last 10 years due to the well advanced technology in Micro-Electro-Mechanical Systems (MEMS) technology, digital electronics, and wireless communications low-cost, low-powered, multi-functional sensor nodes have been developed for short distance communications [1]. We could utilize it in many fields such as military, health monitoring and volcanic monitoring, since the sensors have turned smaller, cheaper, and more intelligent [2].

According to the study by Kinsella and Phillips, in the next 20 years, the population of the 65-and-over aged in the developed countries will approach 20 percent of their population [3]. In 2000 the percentage elderly in major parts of Latin America and almost all of Africa and Asia was below 7.5 percent. In contrast, Western Europe was already above 15 percent, with Italy on top at 18.4 percent (UN 2009), while in Japan the percentage was 17.2. The percentage of 65-and -over in the United States in 2000 was 12.4, while in Africa it was 3.3. In 2050, Japan was expected to have 37.8 percent of the population 65-and-over (UN 2009, Medium Variant), while in Italy the percentage of 65-and-over was then expected to be 33.3. In contrast, the percentage 65-and-over in the United States in 2050 was expected to be equal to 21.6, while in Africa it would be 7.1 [4]. Among elderly, falling can be an unpredictably and dangerous event. Hornbrook et al. estimated that one among three 65-and-over aged person falls every year [5]. Falling was the leading cause of injury-induced death in the elderly [6]. In 2003, the global number of death caused by fall events was about 391 thousand and the year over 70 took approximately 40 percent places [7]. Various factors were responsible for the occurrence of fall, especially in the older people. For the older people, fall

was mainly caused by physical aging and visual aging.

Noury, et al., [8] figured out that the cost of health care could be greatly reduced by fast detection and delivering signals to the specified target for immediate relief, potentially. Due to the big population of old people, it was impossible to have sufficient caregivers for all of them. However, thanks to the development of wireless sensors and low-power sensor nodes, we can now approach the problem through a brand-new method, as we will discuss in section II.

In order to detect falls, the data of fall events was supposed to be logged. In the old days, the events and the surrounding were recording by asking subjects questions and documented through a self-statement [9]. However, the collected data were inaccurate and incomplete, while the associated cost was massive and the efficiency was unacceptable. In this paper, we propose a new method for fall detection by using accelerometer and cardiotachometer based on wireless sensor network.

Organization of the paper: The main content of this paper is constructed in 6 sections as follows: Section 2 gives an overview about most fall detection method. Section 3 describes the system architecture and sensor deployment. Section 4 describes our method. Section 5 discusses the performance of our method. Section 6 concludes our work and future work.

2. Related Work

Numbers of research projects are undergoing in medical sensor networks. Identifying and tracking human activities in daily lives were among the fundamental issues in an Ambient Intelligence (AmI) environment. To detect falls successfully, some of the researches tended to develop a wearable sensor board integrated with a tri-axial accelerometer or a gyroscope, even a possibility of a barometric air pressure sensor.

Relying solely on the accelerometer to distinguish a fall from activities of daily lives (ADL) was not an accurate solution [10]. In addition, it is necessary to have a high sample rate to distinguish falls from ADL, otherwise it will be difficult to distinguish a fall from an abruptly sitting down [11]. As figured in [12], Rimminen et al. developed a method using a floor sensor based on near-field imaging, the test floor had a 9×16 resolution. The postural of the subject used the Bayesian filtering, instead of the features being classified directly, since the features contained noises from surrounding and had a significant over-lap between falls and activities of daily lives. The process of the detection is as followed: near-floor imaging detection, data association (Greedy assignment method), tracking (Kalman filter), feature extraction (Number of observations, Longest dimension, Sum of magnitudes), pose estimation (Markov chain state model, Bayesian filtering). The sensitivity was 90.7 percent and the specificity was 90.6 percent. But the correct classification of onto knees falls was only 20 percent.

In [13], Ling and Lin used a video-based detection to track subject movement. They found three features to identify and locate a fall event of elderly person. First, a fall-down event usually occurs in a short time, period with a range of 0.4~0.8s. Second, a falling person's barycenter changes significantly and rapidly during the falling period. Third, the vertical projection histogram is also a useful feature for detecting a fall-down event, due to it also changes significantly during the falling period. The main proposed method contains two steps, compressed-domain object extraction and fall detection. Apart from matching the three features of identification and location, there are also three parameters that used to detect the fall as well, (1) the rate of barycenter's change; (2) gradient of the maximum of vertical projection histogram; (3) duration of the event. The introduced noises from surroundings

interferes the system and resulted in the false alarms. The most significant drawback of a video-based method is that the sensor nodes would lead to more expensive processor. Because the sensor nodes play an essential role in processing the collected images and high power consuming.

Acoustic-based systems have been also studied for fall detection applications [14]. Popescu et al. developed an acoustic-based fall detection system, which used an array of acoustic sensors. The system is now cheaper to be implemented due to the cost reduction of small sensors. The fall detection sensors are linear arrays of electret condenser placed on a pre-amplifier board. In order to capture the information of sound height, the sensors array was placed in the z-axis. To keep the users' privacy, the sound will be processed on board, internally. In additionally, the fall signal will be sent to the nurse or caregiver. The limitation of this method is that only one person was allowed in the department. The system has 100 percent sensitivity, but there still a five false detection per hour exists.

As H. Lovell, et al., described in [15], a large percentage of fall happened at home and some of which happened at night, when the old people is not willing to wear monitor devices. To detect falls which occur at night, they proposed a method with wireless sensor network using passive infrared motion sensors and pressure mat force sensors. According to their theory, distinguishing between different scenarios can help to improve the accuracy of fall detection. The scenarios can be classified as follows: enter and leave room, out of bed and dresses to leave room, in bed / wake up and have a drink and back to sleep, sit on toilet then leave bathroom, bedroom to bathroom and back to bed (fall in corridor), bedroom to bathroom and back to bedroom (fall in bathroom). They also classified falls into three types: (1) fall with unconsciousness; (2) fall with failure to recover; (3) fall with successful recover. The result of this system shows that when it comes to all three types of falls, the sensitivity was 59.26 percent. After aggrandizing the six scenarios into consideration, the sensitivity upgraded to 88.89 percent. When only containing falls where unconsciousness occurs, the sensitivity increased to 100%. On the other hand, passive infrared motion sensors and pressure mat force sensors were not as available as to daily life and we cannot assure all the falls were unconsciousness.

In [16], Degen, et al., proposed another method by using activities detection. The senor would firstly detect a high velocity towards the ground as the first condition. In the following three second an impact needs to be detected. After impact, the activity was observed for 60 seconds, if there were no records of activities for at least 40 seconds, an alarm would be activated. The results were positive in the way that there were no false alarms given, but still disappointing in a large percentage of backwards and sideways falls were not alarmed.

All the results above are summarized in Table 1.

Main Contributions: The main contributions in this paper can be summarized as follows: (1) a full scale wireless sensor network based fall detection system is figured and evaluated; (2) a method intended to minimizing the false alarm rate of fall detection is proposed and tested.

**Table 1. Falls Detection Performance and Characteristic**

Method	Sensitivity (%)	Characteristic
PIR & PM I	59.26	All scenarios included
Acoustic-based	70.00	Somewhat expected on which falls occur
PIR & PM II	88.89	All scenarios except fall with successful recovery
Video-based	90.00	Significant challenges to process
Wearable sensors	97.50	Someone may see it inconvenient
PIR & PM III	100.0	Only ADL and falls with unconsciousness

3. System Model

Our product will be set up in elders' houses, including wireless sensor networks integrated devices. However, in order to assure the caregiver or relatives get real-time and accuracy information, where to place the wireless sensor network is a challenging.

Modern wireless sensor network has been highly normalized by ZigBee, but cannot handle specific tasks constrained environment efficiently. In order to do so, the wireless communication stack in wireless sensor network needs to be optimized.

Base station with remote computer or personal digital assistant (PDA) is the access gateway between the wireless sensor network and the Internet, through which the data of wireless sensor networks is transformed and is accessible through Internet as is figured in Figure 1. It shows the commonly applied hardware configuration of the wireless sensor networks system. Accelerometer, GPS and cardiotachometer are integrated on a multi-sensor board on the left side of the graph. The board can be expanded whenever the temperature, humidity and light intensity or other parameters needs to be tested.
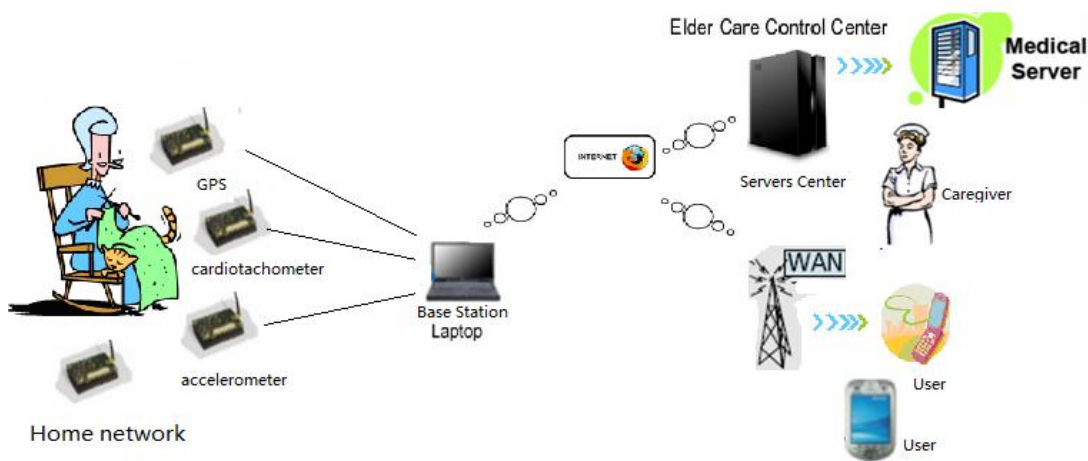

Figure 1. System Architecture in Wireless Sensor Network

In order to optimize wireless communication stack in wireless sensor networks, many sensor nodes need to be put in one base station. Every sensor nodes can be freely seemed as master or slave.
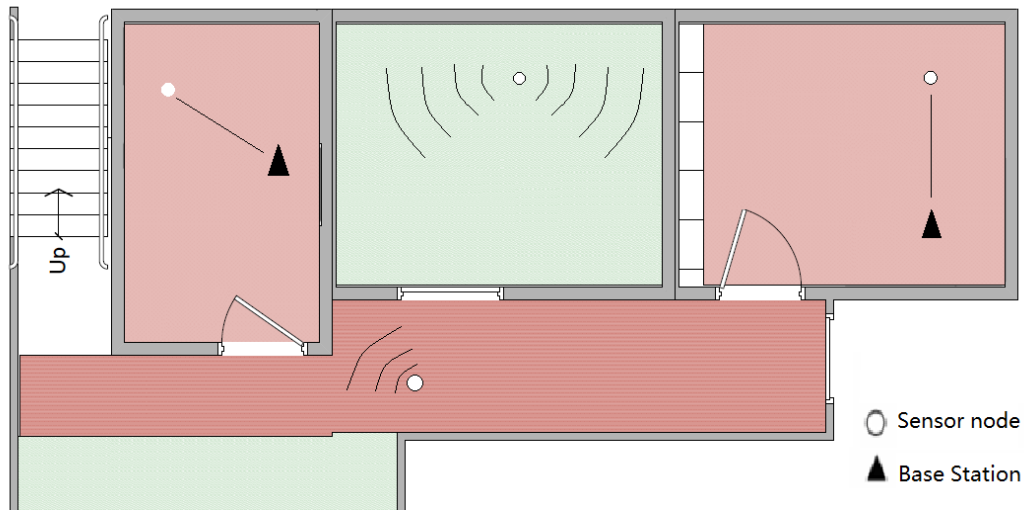
Figure 2. Sensor and Base Station Deployment

Because sensors on board are powered by two AA batteries, the generated radio frequency wave is sometimes too weak to pass through the reinforced concrete wall. Because of that the reinforced concrete wall can cause the wireless signal's exhaustion and reflection. The base station therefore usually cannot receive the signal generated by RF-transmitter from the room next door like shown in Figure 2.
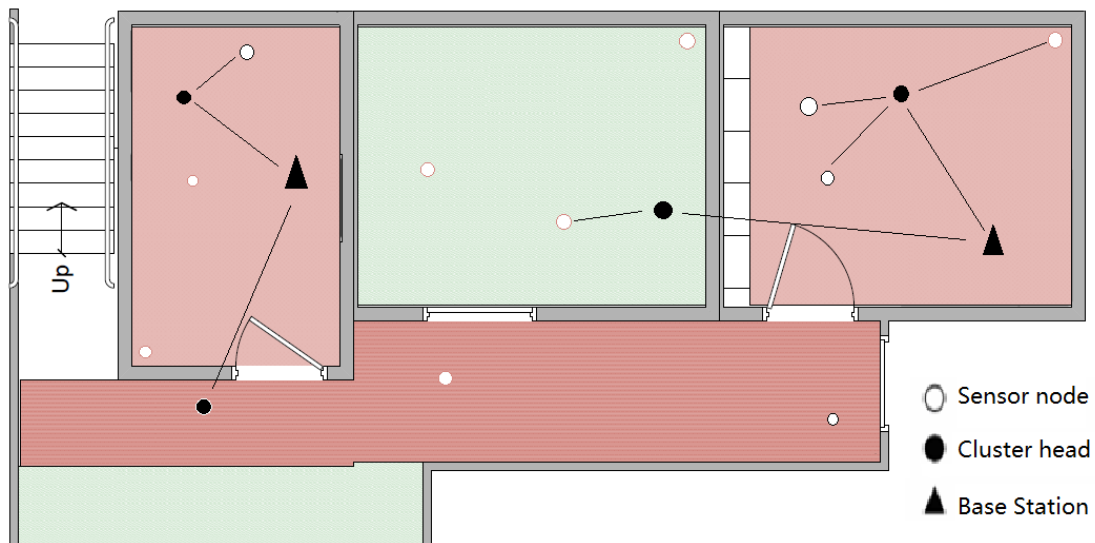
Figure 3. Sensor, Cluster and Base Station Deployment

To detect the acceleration and heart rate more accuracy, we divided the whole house into several clusters based on the room locations. Each cluster has a cluster head for data collection and repeat. The sensor nodes represented accelerometer or cardio tachometer,

which could be located anywhere in the house. The signal from wireless accelerometer or cardio tachometer sensor module can be transmitted directly to base station or through the cluster head. The radio frequency wave passes through the cluster head, when it encounters problems of connecting to the base station directly. Figure 3 indicates how the sensors deploy in the patient's home.

The most important part of this system is the accelerometer. In this paper a tri-axis digital output low voltage linear accelerometer product by STMicroelectrnics is recommended. It contains a sensing element and an IC interface which is able to take the signals from the sensing element and generate the measured acceleration signals to the surrounding environment. The sensing element which detects the accelerating motion of fall and is manufactured by using dedicated process developed by ST to produce inertial sensors and actuators in silicon. The IC interface is uses complementary metal-oxide-semiconductor (CMOS) process which follows high level of integration to design a dedicated circuit which is factory trimmed to provide a better match the sensing element characteristics. The sensor has a user selectable full scale of ±2g, ±6g and it is capable of measuring acceleration over a bandwidth of 640 Hz for all axes. The device may be configured to generate an inertial wake-up/free-fall interrupt signal when a programmable acceleration threshold is crossed at least in one of the three axes. LIS3LV02DQ belongs to a family of products suitable for a variety of applications: Free-Fall detection, Motion activated functions in portable terminals, Antitheft-systems and Inertial navigation, Gaming and Virtual Reality input devices, Vibration Monitoring and Compensation.

The direction of the detectable acceleration is as shown in Figure 4.
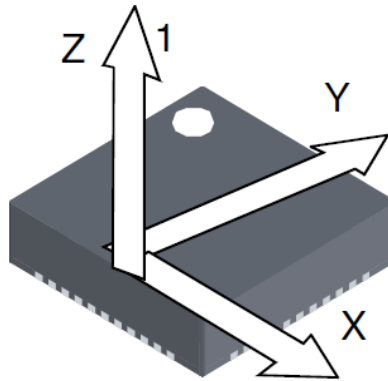
Figure 4. Direction of the Detectable Acceleration

4. Our Algorithm

In the following part we will discuss a method with heart rate monitoring to minimize the false alarm rate of fall detection.

Although methods base on neural network have an excellent performance in falls detection, but it turns out to be unrealistic when facing practical applications. As the aim of the proposed system is only to distinguish falls with activities of daily lives, there was no need to use such complicated algorithms. On the other hand, resource of devices is very expensive in practical applications. Due to the complexity of real-time system, highly complicated methods like wavelet analysis and frequency analysis can be hardly achieved. The neural network system is therefore not suitable for such application also because of its high cost of production, high power consumption, high complex rate and low real-time rate

cannot match the original starting point of this system.

An accident is defined as an unforeseen and unplanned event or circumstance, often with lack of intention or necessity. It usually implies a generally negative outcome which may have been avoided or prevented had circumstances leading up to the accident been recognized, and acted upon, prior to its occurrence. For the old people, the possible consequence of an accidental fall would be losing abilities of moving their bodies or even their consciousness which will lead to a fluctuating of heart rate.

In order to detect falls, acceleration signals can be processed in the base station for an accuracy result, because of the limitation of local sensor node, such as power consumption and integration scale, etc. The data is required to be transferred continually and simultaneously to the base station through the established system architecture.

Signal magnitude vector is defined as formula (1). Acc_x , Acc_y and Acc_z is on behalf of outputs of x-axial, y-axial and z-axial, respectively.

$$SMV = \sqrt{Acc_x^2 + Acc_y^2 + Acc_z^2} \tag{1}$$

If we only want an answer in binary in order to match the digital circuit, we can substract SMV with a constant as formula (2). The constant is the threshold of fall detection.

$$ALARM = \sqrt{Acc_x^2 + Acc_y^2 + Acc_z^2} - C \tag{2}$$

Since we cannot predict which direction the falls would happen, it is inappropriate to use only one output of an axial. The advantage of this formula is that it is sensible to all kinds of falls. Once fall happens, ALARM would exceed the critical value of particular threshold which is adjustable.

As shown in Figure 5, once the integration board is loaded, acceleration of gravity force (G) lay in the x direction.
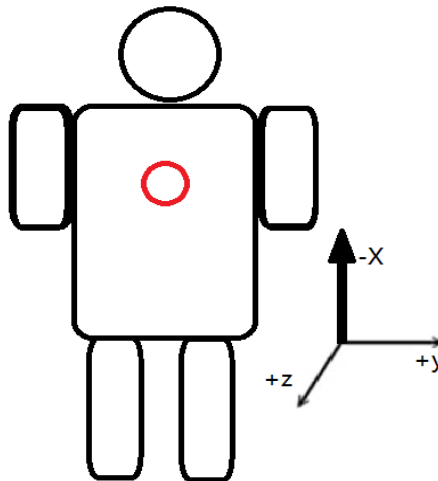
Figure 5. Tri-axial Accelerometer's Original State

Contrarily the gravity force will be concentrated in y-axial or z-axial if the subject falls as is shown in Figure 6. The subject's posture can be determined from calculating the proportions of the outputs in three directions.
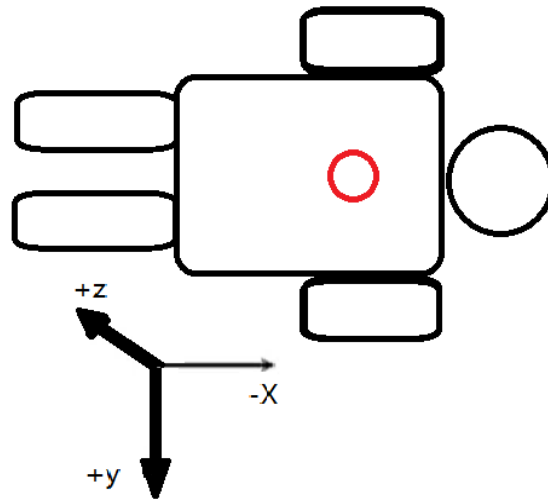
Figure 6. Tri-axial Accelerometer's Fallen State

The accelerometer that was integrated on board shows that a common fall's acceleration was equal vent at least 3 G, in most cases it was several times higher than the minimum value. When the proposed system is applied for old people, the fall detection can be very accurate since the small experienced acceleration in old people's daily activities which excludes intensive running and jumping can be clearly distinguished from the fall. Only one exception is the abruptly sit down which requires a more robust method for the distinguishing.

The heart rate data was collected through a CMP-S device, which could not only detect the subjects' heart rate but also his/her blood oxygen level. When a fall occurred, the breath of the subject will speed up. It can cause the density of free oxygen to change the density of blood oxygen. The change is not significant, but still can be a method to detect if there is an emergency happened. It concluded that when experiencing an unconscious falling, people's heart rate would change significantly. Once the accelerometer detects the changing rate of tri-axial which is over threshold, the system will display heart rate fluctuation over time domain.

We can classify emergency case into three levels:

1. If the heart rate changes significantly, the system supposed the probability to be 100 percent. It will contact the service center immediately. The service center would then call emergency center to send an ambulance to the place where the event happened, so that the injured people will receive medical support as soon as possible.

2. The heart rate of patient have only small change (within 10% fluctuated), the system would suppose the probability is much higher than 0 percent, but still cannot reach 100 percent high. It will contact the caregiver or relatives, but if all these actions failed, the service center would have to send an ambulance to check if the caretaker really falls.

3. If the heart rate is exactly the same as what it was like before the alarm, the system would assume the alarming to be a false positive. But in case falls indeed happened, we still need to make a phone call to the patient's relatives so that a personal verification could be made before everything is too late.

Sometimes there could be some outside force slows down the speed of falls, monitoring heart rate could detect these kind of events as well. For example, when an acute myocardial infarction happened, the patient might hang on the desk or the wall to get an outside force that

the acceleration cannot be detected. The flowchart of using heart rate threshold minimizing the false alarm rate of fall detection scheme is given in Figure 7.
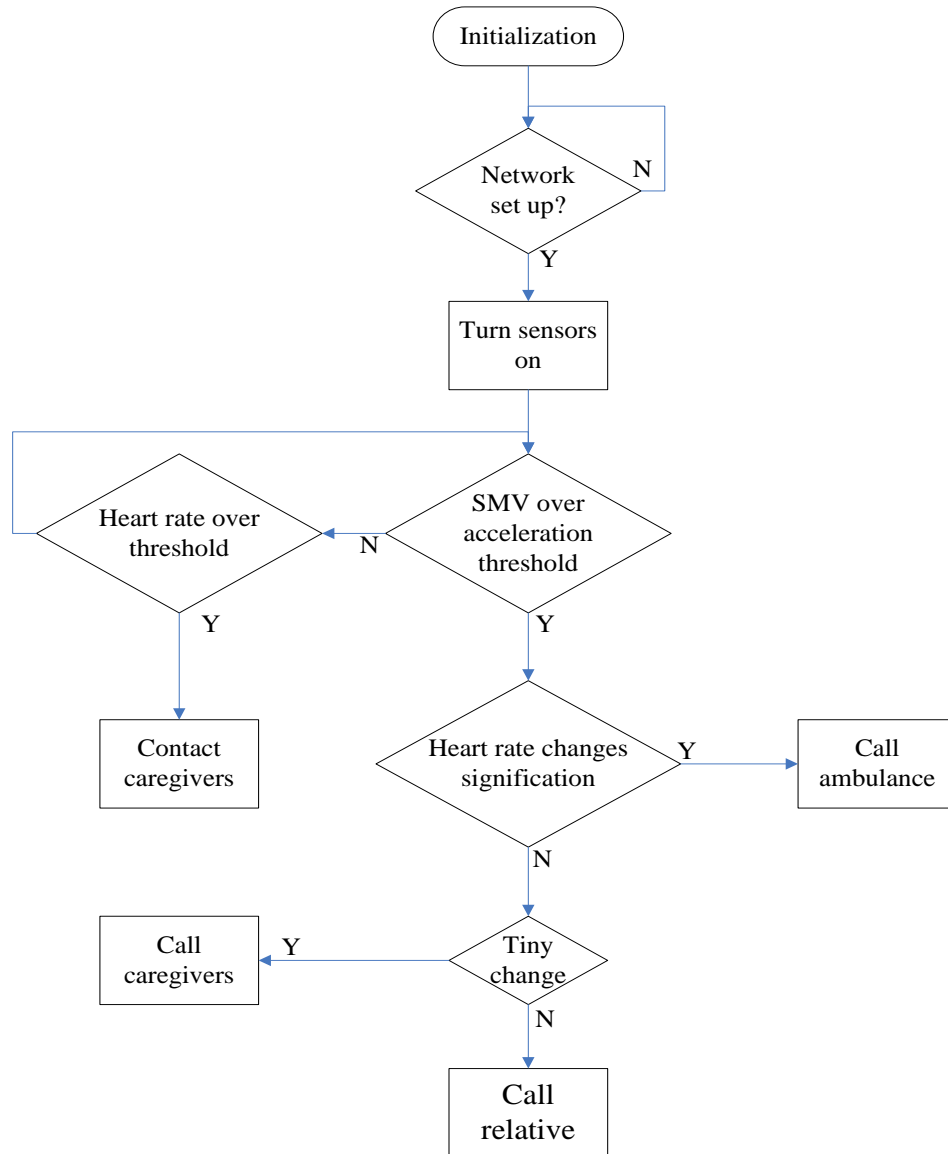
**Figure 7. Flowchart of Our Method**

5. Performance Evaluation

The interface of heart rate detecting system can be shown in Figure 8. The system can monitor four patients' heart rate and blood oxygen level at a same time. In each part of it, left vertical axis represents the blood oxygen level and the right represents the heart rate and the horizontal axis is the time-line. The red number in the top-right shows the current blood oxygen level and the yellow number in the right-bottom shows the heart in real-time.
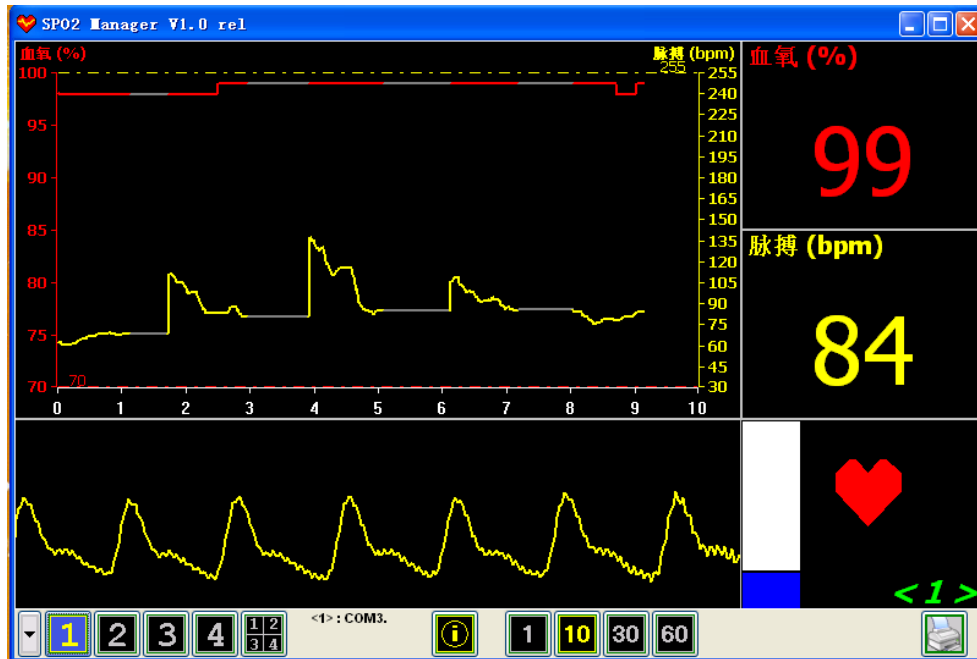
Figure 8. System Interface of Heart Rate Monitoring

By substituting the tri-axial acceleration values which detected by accelerometer into equation (1) and set the threshold to 3G, we tested how heart rate will change when an unconscious fall happened.
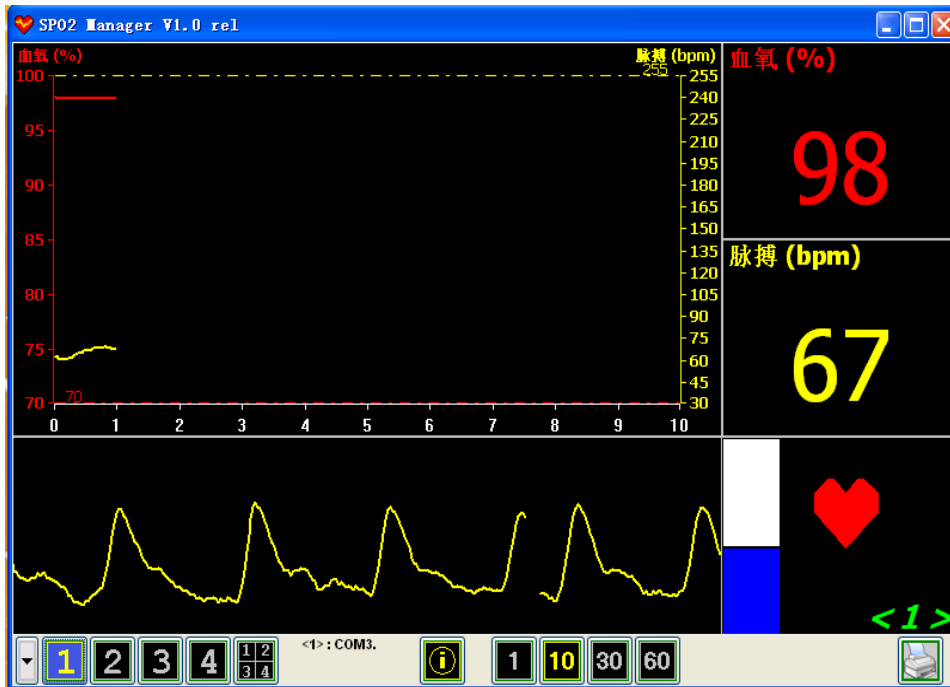
(a) The original state of the detection system

(b) The whole change of heart rate during a fall

Figure 9. Fall in Real Life Activities

To lower power consumption, the heart system receives heart rate impulse every minute. According to Figure 9 (a), the frequency of the subject's normal heart was 67/min. When an unconscious fall occurred his heart rate speeded up to nearly 135/min, and his blood oxygen level upgraded by 1 percent. With time passed, his heart rate dropped down to about 80/min as is shown in Figure 9 (b). From the phenomenon we can point out that the frequency of the subject's heart rate has changed significantly when an unconscious fall occurred. When faced on the ground his heart rate rose violently to almost 60 percent compare to that of the calm period. For elderly people, because their heart rate is generally at a low level, the threshold of their heart rate can be set to 15~20 percent of the common rate.

6. Conclusions

A fall activity recognition method utilizing a wireless sensor network integration board with outputs from a cardiotachometer was proposed in this paper. This work built on accelerometer sensor and heart rate detector has collected the most informative features against the misunderstanding of falls and activities of daily life. Instead of using complicated methods and less sensitive sensors directly, a prototype scenario with two simple sensors and a succinct method has been applied. The system was tested under a laboratory condition with samples chosen from volunteers.

The proposed approach has the potential of achieving the goal of taking care of the elderly and disabled people. It has the potential to drive away from the laboratory testing into real life applications at the care centers. In order to comply with humans' needs and be able to cope with more real-time contextual information in the attentive home, the future work on wireless sensor technologies should focus on overcoming multiple daily lives activities with a higher degree of complexity on human gait system.

Acknowledgements

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