A Novel Method to Minimize False Alarm Rate of Fall Detection for Wireless Sensor Networks

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Abstract. With the increasing number of elderly person and the advancement in Micro-Electro-Mechanical Systems, healthcare targeted for home use is playing an important role in our daily lives. One among three of 65-and-over aged person fall every year. Some detection related work made use of accelerometer or gyroscope only and even passive infrared or acoustic sensors, but still there were possibilities of false alarms. This paper proposed a system architecture based on wireless sensor networks to detect the falls for old and resident, among which falling can be an unpredicted and dangerous event. Additionally, we provided a method to minimize the false alarm rate of fall detection. By using this method we can detect falls did not trigger the alarm which was intervened by outside forces.

Keywords: Fall detection, heart rate, false alarm, wireless sensor networks

1 Introduction

In recent years, advances in Micro-Electro-Mechanical Systems (MEMS) technology, digital electronics, and wireless communications have enabled the development of low-cost, low-powered, multi-functional sensor nodes which are in small size and communicate in short distance [1]. Since the sensors have turned smaller, cheaper, and more intelligent, we can utilize it in many fields, such as military, health monitoring and volcanic monitoring [2].

Due to falls are among the leading cause of death for 65-and-over aged person. Although falls and daily activities are specific cases of activity classification, there was an important research focusing on fall detection and daily lives analysis [3].

Various factors were responsible for the occurrence of fall, especially in the old person. Combined effects about inside factors and circumstance surroundings should be taken into considerations, such as physiological issues, disease factors, drug response and circumstance surroundings issues. On the other hand, visual deterioration was another main factor responsible for elderly fall. Consequently, there has been a need to monitor a resident's or elderly's body status [4].

The data of fall events was supposed to be logged to study the fall and fall prevention. In the past, the events and the surrounding were recorded by asking subjects questions and documented through a self-statement. The data were inaccurate and incomplete. What's more, the cost and efficiency is unacceptable.

In this paper, we proposed a new method using accelerometer and cardiotachometer based on wireless sensor network to detect falls and minimize the false alarm rate.

2 Related Work

Numbers of research projects were undergoing in medical sensor networks as the identifying and tracking of human activities in daily lives were among the fundamental issues in an Ambient Intelligence (AmI) environment. To detect falls with good success, some of the researches tended to develop a wearable tiny sensor integrated with a tri-axial accelerometer or a gyroscope, even a possibility of a barometric air pressure sensor, but still there was a high false alarm rate which was unavailable.

Rimminen *et al.* developed a method using a floor sensor based on near-field imaging in [5], the test floor had a 9*16 resolution. 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 [6], Ling and Lin used a video-based detection to track subject movement. They found three features to identify and locate a fall event. First, a fall-down event usually occurred in a short time, period with a range of 0.4~0.8s. Second, a falling person's barycenter changed significantly and rapidly during the falling period. Third, the vertical projection histogram was also a useful feature for detecting a fall-down event. The most significant drawback of a video-based method was the sensor nodes must play a role in processing the collected images, which could have led to more power consuming and more processing cost.

Acoustic-based systems have been studied for fall detection as well [7]. Popescu *et al*. developed an acoustic-based fall detection system, which used an array of acoustic sensors. As the development of tiny sensors, it is becoming cheaper and the system is inexpensive. To further reduce the false alarm rate, this is only the first part of the complicated system. The fall detection sensors were a linear array of electret condenser placed on a pre-amplifier board. In order to capture the information of sound height, the sensors array was placed along z-axis. To preserve the users' privacy, the sound was processed on board, internally. In additional, the fall message was to send to the nurse or caregiver only. The boundedness of this method was the working hypothesis that only allowed one person in the department. The system had 100 percent sensitivity, but there still a five false detection per hour existed.

As H. Lovell *et al*. described in [8], a large percentage of fall happened at home and some of which happened at night, when the elderly person is not willing to wear monitoring devices. To detect falls occurred night, they proposed a method with wireless sensor network using passive infrared motion sensors and pressure mat force sensors. The result of this system showed that when all three types of falls occurred, the sensitivity was 59.26 percent. After aggrandizing the six scenarios into consideration, the sensitivity upgraded to 88.89 percent. When only contained unconsciousness falls, the sensitivity increases 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 are unconsciousness.

3 System Architecture and Sensor Deployment

The product will be used in residents' homes, including wireless sensor networks integrated devices. Where to place the wireless sensor network in an old person's house was a major problem, which can assure the caregiver or relatives get real-time and accuracy information.

Wireless sensor networks were now almost normalized by Zignee, but when it was used to give purpose and limited spaces, the wireless communication stack in wireless sensor network needed to be optimized. Base station with remote computer or personal digital assistant (PDA) was the access gateway between the wireless sensor network and the Internet. Through which the data of wireless sensor networks were transformed and we accessible through Internet as is shown in Figure 1.

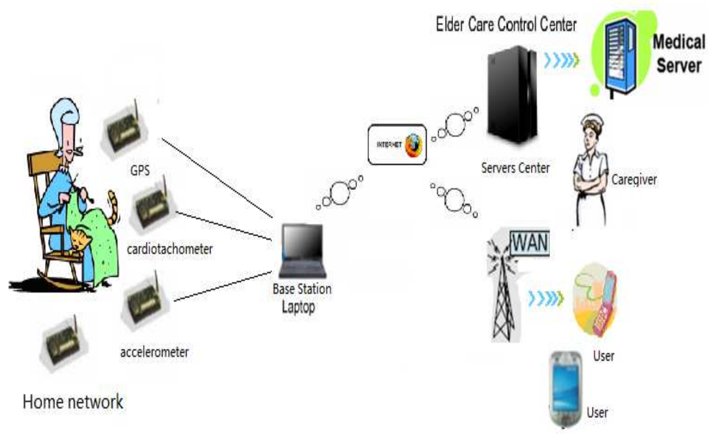

Fig 1. System architecture in wireless sensor network

Figure 1 shows the most regularly hardware configuration in the architecture of the supposed wireless sensor networks system. In the left part of the figure, accelerometer, GPS and cardiotachometer were integrated on a multi-sensor board. The board can be expended whenever we needed to test the temperature, humidity and light intensity.

As the necessity of optimizing wireless communication stack in wireless sensor network, we put many sensor nodes in one base station. Every sensor nodes can be freely seemed as master or slave.

Here to detect the acceleration and heart rate more accuracy. We divided the whole house into several clusters based on the separation of house. Each cluster has a cluster head for data collection and repeat. The sensor nodes represented accelerometer or cardiotachometer, which could be anywhere in the house. The signal of wireless acceleration or cardiotachometer sensor module can be transmitted directly to base station or through the cluster head. The radio frequency wave will go through the cluster head, when it had a problem to go directly to the base station.

4 Our Method

In order to detect falls, acceleration signals should be processed in the base station for an accuracy result. There were some limitations for local sensor nodes, such as power consumption and integration scale. The data needed to be transferred continually 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.

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

Once the integration board is loaded, acceleration of gravity force (G) all centralized in x-axial. Contrarily the G would be concentrated in y-axial or z-axial if subject fell. We can figure out the subject's posture from calculation proportions of tri-axial outputs.

The accelerometer integrated on board showed that a common fall's acceleration was at least 3 G, in more cases it was several Gs higher than the minimum value. Acceleration in activities of daily lives cannot exceed that high. Since there is some overlaps between falling and abruptly sitting down, we still need a robust method to distinguish some brutal activities from falling.

```
Initialization;
while(Network Set up)
{
    Turn sensors on;
    if(SMV over acceleration threshold)
        {
            if(Heart rate change significantly)
            {
                Call ambulance;
            }
            else
            {
                if(Tiny changes)
                {
                    Call caregivers;
                }
                else
                    Call relatives;
            }
        }
    else
        {
            if(Heart rate over threshold)
            {
                Contact caregivers;
            }
            else go to line 5;
        }
}
```

Fig 2. Pseudo code for detect falls

We collected the heart rate data through a CMP-S device. Facing with an unconscious falling, people's heart rate will have a significantly change. Once the accelerometer detected the changing rate of tri-axial surpassed the threshold, the system was supposed to screen the changes of heart rate happened in real-time. The pseudo code define the fall is described in Figure 2.

As can be seen in Figure 2, we divided the degree of emergency into three parts:

1. If the heart rate changed significantly, the system supposed the probability to be 100 percent, then it would contact with service center. The latter would call emergency center to send an ambulance to where the event happened, so that the olds can be rescued as soon as possible.

2. In case the heart rate of patient just had a tiny change or not significant (within 20 percent fluctuated), the system would supposed the probability is much higher than 0 percent, but still cannot reach 100 percent high. It would 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 was 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.

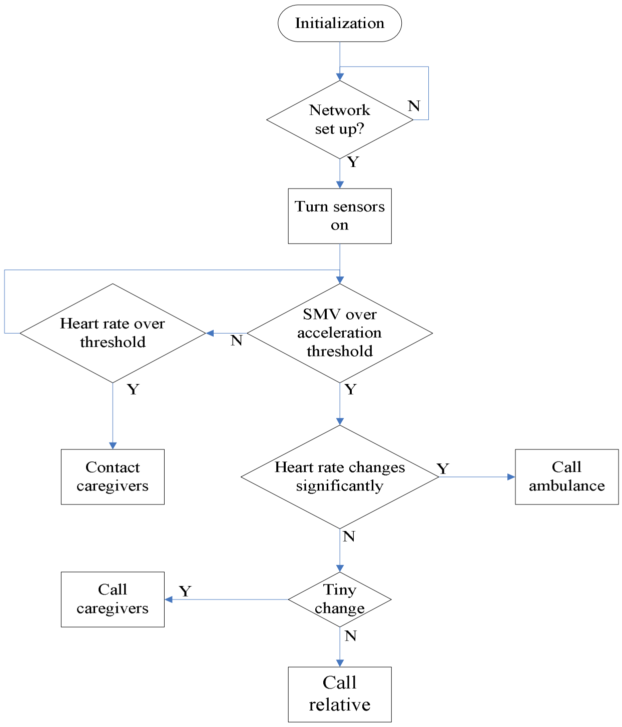

Fig 3. Flowchart of our method

Sometimes there would be some outside force slows down the speed of falls, monitoring heart rate could detect these kind of events as well. The flowchart of using heart rate threshold to minimize the false alarm rate of fall detection is given in Figure 3.

5. Performance Evaluation

The system interface is shown in Figure 4, it can record heart rate and blood oxygen level in real-time. The left vertical axis represents the blood oxygen level, the right on represents the heart rate and the horizontal axis is the time-line. We presented the whole heart rate changes during a fall. It detected heart rate every two minutes and last for one minute in order to lower power consumption. To gain the experimental data, we chose a 23 years old male. In the first recording period, we detected the subject's common heart rate which is 75/min. When an unconscious falling came, the subject's heart rate raised up to nearly 120/min as is shown in the second period. In the third recording period the peak value was even 135/min. Due to the system was a prototype, the record is not so accuracy but we can still see the significantly fluctuation during the fall.

Fig 4. Fall in real life activities

As can be seen in the figures, the subject's heart rate changed significantly when an unconscious fall occurred. When faced on the ground his heart rate rose violently to almost 80 percent than calm period. Due to the target object were olds and residents, there heart rate cannot reach that high, we can set the threshold to 15~20 percent of the common heart rate.

6 Conclusion

A fall activity recognition method with outputs from an accelerometer and cardiotachometer was presented in this paper. The system utilized wireless sensor networks integration board to reckon information. Our contribution here is twofold. First, instead of using a complicated algorithm or dumb sensors directly, we have prototyped a scenario using two simple sensors and a succinct method. Second, in order to minimize the false alarm rate of fall detection, but no missing was allowed. We balanced our method carefully so that a fall with a significant heart rate change or not will be reported accurately.

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