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Fall detection algorithm for the elderly using acceleration sensors on the shoes

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***Abstract*— The rate of increase in the number of aging population in Korea is very rapid among OECD-member countries. And fall accident is one of the most common factors that threaten the health of the elderly. Therefore, it is needed to develop a fall detection system for the elderly. Most fall detection systems use accelerometers attached on the torso. And in various studies, it was verified that these systems have high sensitivity and high specificity. However, the elderly would feel uncomfortable when banding a sensor on the chest every day. Therefore, in this study, we attached an accelerometer on the shoes to detect fall in the elderly. This prototype system would be improved as a smaller, low-power system in the next study. Also, applying energy harvesting device to this shoe system is being developed to reduce the weight of battery.**

I. Introduction

Due to the low birth rate and the development in medical science, Korea is expected to be the most aged society among OECD countries in 2050. According to the '2010 Aging Statistics' in Korea, official figures show that the people aged 65 or more account for 11.0% of the nation but it is estimated that this number will grow up to 38.2% in 2026 [1]. With this 'silver tide' in Korea, many assisted devices and technologies have been also developed. For example, ergonomically designed canes and wheelchairs were released.

Meanwhile, falls in the elderly can result in major adverse outcomes including bruise, bone fracture, and even death. And with physical injury, fall can cause psychological damage [2]. Senior citizens who experienced fall several times feel scary about falling again and lose confidence in self-care. So, this may cause the decrease of their mobility and increase depression in elders.

There are two major types when detecting fall - environment-based method and worn device-based method. Environment-based fall detection methods use signals from bed, chair and video monitoring. Worn device-based method can tell fall from ADL (Activity of Daily Living) by analyzing the signals from belt or watch [3, 4]. Most worn device-based fall detection studies use signals from accelerometers attached on the upper body part – chest and waist. For example, A.K. Bourke[5] attempted to detect fall using signals from accelerometers fastened on the torso. In this study, we tried to detect fall with signals from accelerometers on the shoes. This would be the first trial that developed shoe-based system with accelerometer to detect fall. And this method is expected to benefit users because they don't need any additional device except putting on the shoes.

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II. Materials and Methods

A. Data acquisition set-up

As a sensing part, we attached a MMA7260Q tri-axial acceleration sensor (Motorola, Inc.) on each shoe. And with Atmel ATmega8 microcontroller, Bluetooth module was also used to transmit data in real time. In the communication environment of 10 bytes in a packet, 450 Hz sampling rate, this system can run more than 5 hours. The specification of the data acquisition module is as in the following:

- Size :50mm x 25mm x 20mm
- Weight : 40g including acceleration module and a case (100g for whole system including battery)
- Sampling rate : 225Hz
- Distance : 7m

This prototype would be developed as a smaller, low-power module in the next study.

B. Experiments

3 axis- acceleration signals were measured in three young subjects (2 young males, 1 young female, average age: 26±2). Firstly, to decide the optimal position of accelerometer in the shoe, we experimented two cases – an accelerometer on the tongue of the shoes and the heel cup of the shoes. In each case, we fastened an accelerometer on the shoe with velcro.

The fall types used in this study are the most common fall types in elderly people. Lord et al. found that 82% of falls occurred when people stood upright [6]. Elderly people also most often fall forward [7]. Lateral direction falls can cause a serious problem especially like fracture in the trochanter [8]. In addition, backward fall is also perilous because the elderly can suffer from pelvis fracture and head injury. Therefore, falls performed in this study were forward fall, backward fall,

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and lateral fall. Every Subject was required to mimick the elderly fall and repeated each fall type for 3 times. To distinguish fall from ADL, we also obtained ADL data. Because the acceleration signals from activities which accompany a lot of foot movements like running or shaking legs can be similar to the signals from falling, we composed ADL list of these kinds of activities. The ADL list is shown in the Table1.

C. Algorithm

After obtaining 3-axis accelerations, each signal was high-pass filtered using a third-order high-pass Butterworth digital filter with a cut-off frequency 1Hz. Filtered signals were summed using equation (1) :

$$A = \sqrt{A_X^2 + A_Y^2 + A_Z^2} \quad (1)$$

Then average acceleration value of each window was calculated. High amplitude of acceleration means that the movement in each foot is quick and large. And each set of acceleration data from respective foot had equal weighting, that is, weight 0.5 for each foot. Figure 1 shows the weighted acceleration values in various activities. And we can figure out that the acceleration in running or jogging is as large as the acceleration in every type of fall. Therefore, simple threshold-based algorithm which is frequently used in fall detection is not appropriate. To distinguish fall and running/jogging, if the acceleration value is higher than threshold, we marked it 'F'. If the acceleration value is lower than the threshold line, it was marked 'N'.

Then, we observed the combination of eight consecutive results. And we regarded 'NNNFNNNN', 'NNFFNNNN' and 'NFFFNNNN' as a fall. The reason that we used 3 kinds of combination is that the signals were various depending on the fall styles and subjects. The eight consecutive results from walking or jogging were different from fall. For example, 'FFNFFNFF' or 'FNFNFNFN' can be the outcome during walking or jogging because most of the acceleration values were higher than threshold.

TABLE 1
ADL(ACTIVITIES OF DAILY LIFE) LISTS

	Category	Conditions
1	Sitting on the chair	Being bumped against the table, Crossing the legs, Shaking legs, Stamping feet
2	Driving for 5 minutes	Stepping on a pedal
3	Picking up some batteries which are on the ground	Bending feet, Sitting on toes
4	Jogging for 5 minutes	Striking the ground
5	Putting on/off the shoes	Bending feet, Hitting the ground with toes
6	Going up and down the stairs	Striking the ground
7	Walking for 5 minutes	Striking the ground

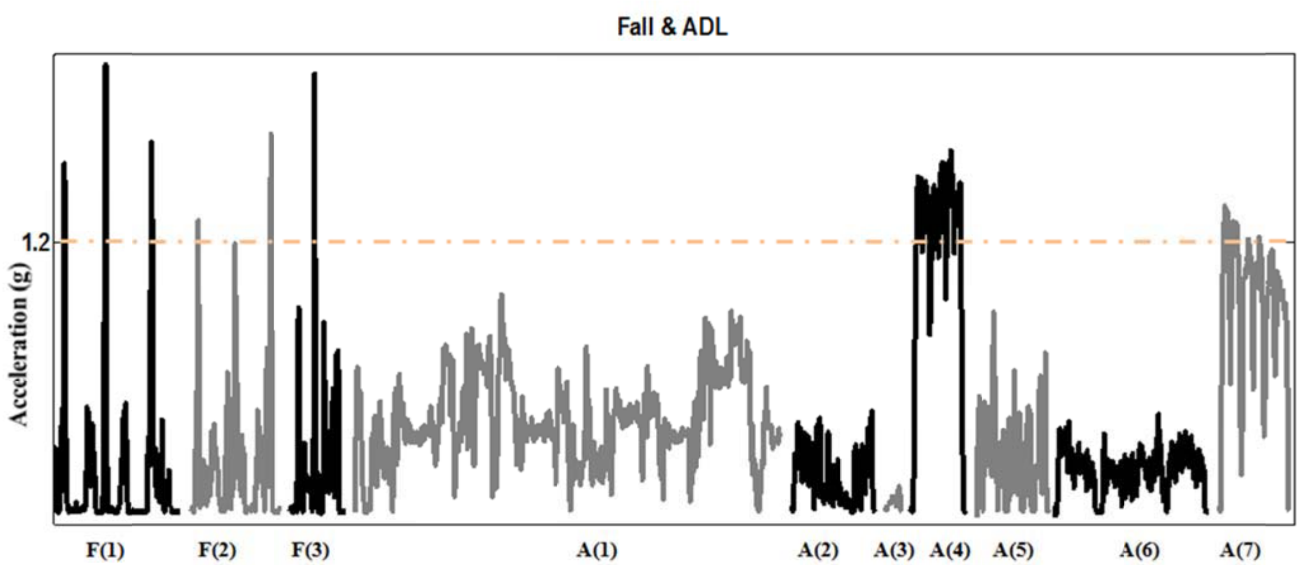


Fig.1. The acceleration values from shoes in various activities.
F(1) : forward fall, F(2) : lateral fall, F(3) : backward fall, A(1) : sitting on the chair, A(2) : driving, A(3) : picking up some batteries on the ground, A(4) : jogging, A(5) : putting on the shoes, A(6) : going up and down the stairs, A(7) : walking

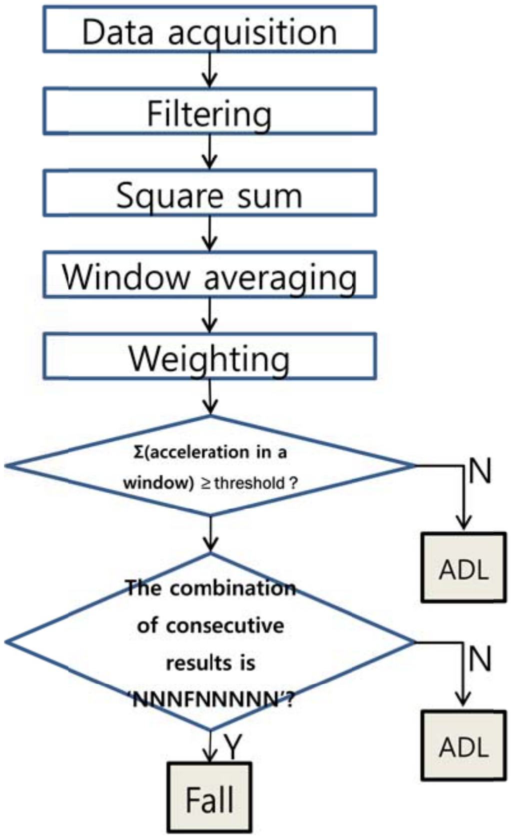


Fig. 2. Fall detection algorithm. ADL means the activity of daily life.
* 'N' means the sum of acceleration value in a window is lower than the threshold line and 'F' means the sum of acceleration value in a window is higher than the threshold value. In this study, threshold value is 1.2.

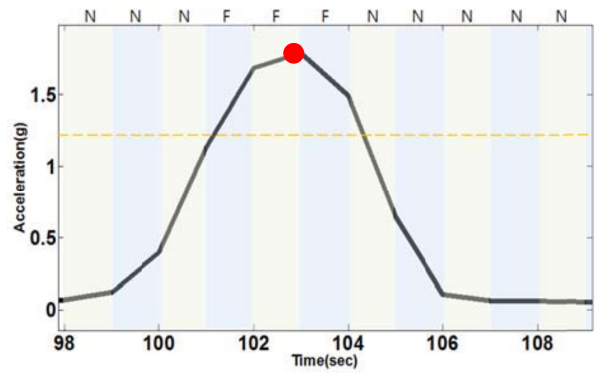
III. REULTS

A. The optimal position of accelerometer

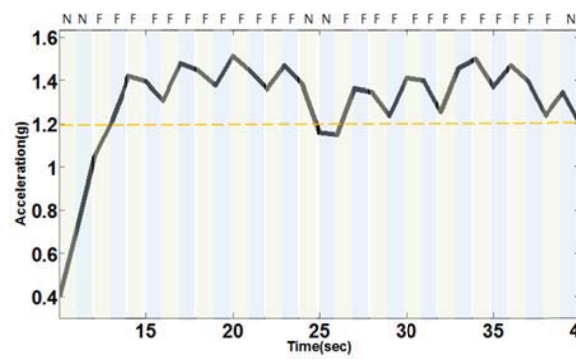
To find out the best position of sensing part on the shoes, we experimented on 2 positions. When we attached accelerometer on the tongue of the shoe, all fall types showed outstanding high acceleration values. In the case of attaching accelerometer on the heel cup of the shoes, the height of peak was high enough to be detected as a fall in forward fall and lateral fall. However, the amplitude of peak in a backward fall was a little lower than threshold. And the algorithm missed many falls in this case. Therefore, we decided to fasten the sensing part on the tongue of the shoe.

B. Algorithm performance

We calculated specificity and sensitivity to evaluate the accuracy of algorithm. In fall experiment, sensitivity means that how well the algorithm can detect it as a fall when the fall really happened. And specificity means that how well the algorithm can detect it as ADL when the subject is performing ADL like jogging, lying, and so on. In this study, sensitivity was 81.5%. Especially, this algorithm was excellent in detecting forward fall – all of the eighteen forward falls from 6 subjects were well detected. However this algorithm had a flaw that detected the end of jogging and walking as a fall in one subject.



(a) Forward fall



(b) Jogging

Fig. 3. Combination of consecutive results in forward fall(a), and jogging(b). We can find out that the combination of 'NNNFFFNNN' is found only in a fall. The red dot in the picture (a) means that the fall was detected.

IV. DISCUSSION

The result shows that this shoe-based fall detection system has relatively high sensitivity. But this algorithm had a flaw that detected the end of jogging and walking as a fall in one subject. This algorithm would be better by firmly fastening the sensing module to the shoes and adjusting the threshold value and window size.

In addition, many improvements can be applied to this prototype system. First of all, prototype module can be easily detached because it is attached to the outside of shoes. Also, some activities including putting off the shoes can be encumbered by this module. Therefore, by reducing the size of module, it can be embedded under the slipsole like 'Nike plus sensor' or 'Adidas Micoach sensor'. Secondly, because this accelerometer module needs continuous supply of electric power, battery is used in this study. However, this battery is heavier than the total weight of case and the acceleration prototype system. That is, we should solve this problem with energy harvesting. By attaching solar cell on the surface of the shoes or embedding piezo-electric element under the heel, we would be able to gain electricity to run the sensor or transmitter. Through a simple experiment performed by W.K.Lee, we could verify that it is possible to light up an LED with solar cell and piezo-electric element.

Recently, smart-phone-based fall detection method attracts many researchers. 'Mover' and 'iFall' are representatives of smart-phone-based fall detection system. These methods usually use an accelerometer in a smart-phone or pressure sensor on the insole. However, most smart-phone-based fall detection system shows low accuracy. Thus, we are supposed to develop a smart-shoes system which can transmit acceleration signals, harvest energy to detect fall and show the fall information on the smart-phone. Then, it would be possible to detect fall in outdoor activities only with shoes and a smart-phone.

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