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Development of Novel Algorithm and Real-time Monitoring Ambulatory System Using Bluetooth Module for Fall Detection in the Elderly

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Abstract— **Novel algorithm and real-time ambulatory monitoring system for fall detection in elderly people is described. Our system is comprised of accelerometer, tilt sensor and gyroscope. For real-time monitoring, we used Bluetooth™. Accelerometer measures kinetic force, tilt sensor and gyroscope estimates body posture. Also, We suggested algorithm using signals which obtained from the system attached to the chest for fall detection. To evaluate our system and algorithm, we experimented on three people aged over 26 years. The experiment of four cases such as forward fall, backward fall, side fall and sit-stand was repeated ten times and the experiment in daily life activity was performed one time to each subject. These experiments showed that our system and algorithm could distinguish beween falling and daily life activity. Moreover, the accuracy of fall detection is 96.7%. Our system is especially adapted for long-time and real-time ambulatory monitoring of elderly people in emergency situation.**

Keywords—**Ambulatory system, fall detection, Bluetooth, accelerometer, tilt sensor, gyroscope, real-time monitoring, emergency situation.**

I. Introduction

Elderly people frequently fall. This is a serious public health problem with a substantial impact on health and healthcare costs [1], [2]. Thirty-two percent of elderly people aged over 75 years have ever fallen at least once a year, and among them, 24% have seriously injured [1], [3]. Moreover, falling can limit self-confidence and motivation of older people's independent life. Considering the increasing population of elderly people, falling will become one of the major problems to them [1], [4], [5].

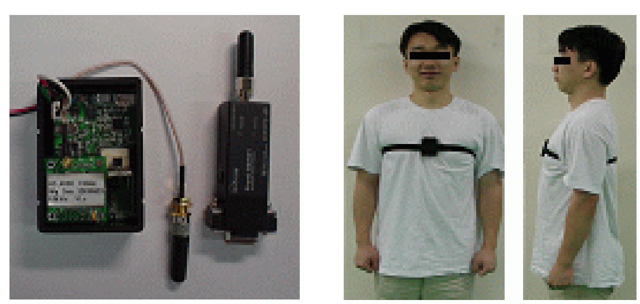
To reduce the risk of falling in elderly people's daily lives, it is important to accurately and continuously evaluate the risk of falling. Currently, the fall event is evaluated by a survey or by the posture and is evaluated using gait, independency, visibility and recognition of daily lives. However, any methods are not useful to accurately evaluate the risk of falls because of using questionnaires with their associated problems of subjectivity and limited accuracy in recall [1], [5], [6]. Therefore, previous researchers have developed a variety of systems for fall risk evaluation in elderly people and they have tried to apply the system to ambulatory system to overcome the disadvantages. Usually, the systems should be attached to two or more body segments and could not monitor elderly people at real-time. [1], [9], [10]. Because of the reasons, in case of fall detection system of gait, the systems leaded to unusual activity in daily lives of elderly people and rapid management between elderly people and a physician in emergence situation could not be performed [8], [9].

In this paper, we describe a new algorithm and real-time ambulatory monitoring system which can reduce discomfort and limitations to elderly people and manage rapidly between elderly people and a physician in emergency situation due to falling. The system is composed of accelerometer, gyroscope, tilt sensor and Bluetooth module for increasing an accuracy of fall detection and real-time monitoring. Also, the system is attached on chest for comfort. The analysis of falling was performed using our suggested algorithm. To evaluate our system and algorithm, we experimented on three people over 26 years. Each experiment was repeated ten times.

II. Methodology

A. Fall Detection System

For decreasing discomfort occurred due to sensor attachment on several body segments, we developed the fall detection system of chest attachment type (Fig. 1). The



(a) (b)

Fig. 1. Our ambulatory system for fall detection. (a) The developed system and Bluetooth module, (b) The system attached on chest with a belt.

system is composed of a real-time sensing part and a communication part. At the sensing part, we used triaxial accelerometer (Measurement Specialities, ACH-04-08-05), gyroscope (Murata, ENC-03J, ±400°/s), and tilt sensor (sharp, GP1S36). The communication part is comprised of Bluetooth™ (Initium, PromiSD10) and Microcontroller (MCU, AVR4433). Also, the communication part has been integrated with a sensing part for real-time monitoring between elderly people and a physician.

In this system, an accelerometer contains three piezoelectric sensing elements oriented in three orthogonal, linear axes. So, the accelerometer measures kinetic force at each direction when people fall. Also, Gyroscope estimates posture transition and tilt sensor detects whether people is supine or standing. Each data obtained from the sensors is transmitted to data acquisition (DAQ) program through Bluetooth Module (Fig 2). DAQ program which a physician can monitor elderly people at real-time was programmed using National Instrument Labwindow/CVI.

B. Fall Detection Algorithm

Basically, fall detection is decided by the algorithm developed using acceleration, gyroscope and tilt signal transmitted through Bluetooth module. When people fall, acceleration is rapidly changed, Tilt signal switches to ON because the tilt sensor leans over seventy degree and gyroscope produces a variety of signals along fall patterns. We developed novel algorithm using the characteristics of the signals. The algorithm was integrated with DAQ program.

The flowchart of our algorithm is summarized in Fig. 3. First, our system confirms whether tilt sensor is switched to ON. Then, buffered tilt signals in the window 1 of size 50 is averaged. If the average value is over threshold 1(α),

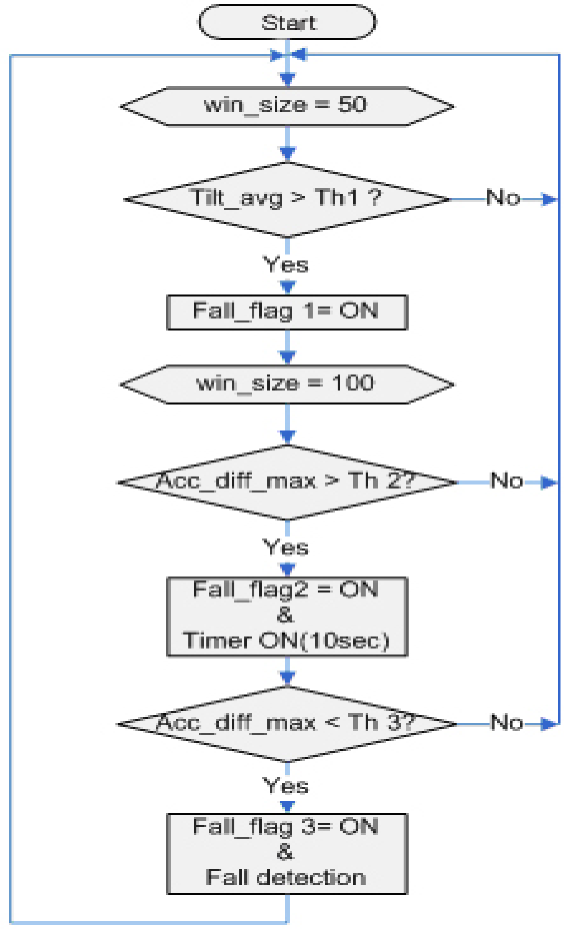


Fig. 3. Algorithm flow chart. If average value of buffered tilt signal in the window1 of size 50 is over threshold 1(α), Fall_flag1 becomes ON. After acceleration signals of each axe direction is differenced, if Maximum value among the buffered acceleration values in the window2 of size 100 is over Threshold 2(β), Fall_flag2 become ON. When Timer is expired, if the Maximum value in window2 is below Threshold 3(γ), Falling become detected.

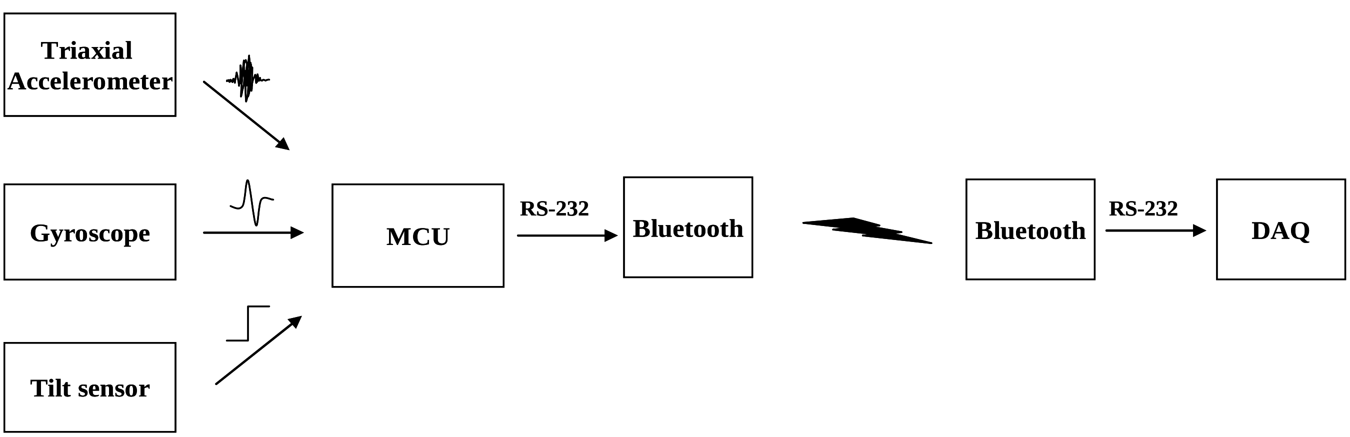


Fig. 2. Real-time monitoring system for fall detection. Traixial accelerometer measures kinetic force, gyroscope estimates posture transition, and tilt sensor switches on when people is supine. Each data obtained from the sensors is converted to digital signal by microcontroller (AVR4433), and then the signal is transmitted to DAQ through Bluetooth Module.

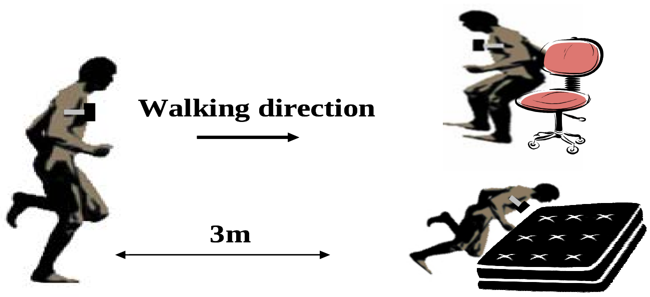


Fig. 4. Experimental setup. Each people fell on a mattress or sat on a chair after walking about three meters and walked about three meters after standing up.

Fall_flag1 becomes ON. Second, if the Fall_flag1 is ON, acceleration variations of each axis are inspected. In this phase, the acceleration difference values are buffered in the window2 of size 100. If maximum among the buffered values is over Threshold 2(β), Fall_flag 2 becomes ON and then, timer operates. Third, after 10 seconds, Timer is expired. Then, values in window 2 are confirmed again. If the Maximum is below Threshold 3(γ), Fall_flag 3 becomes ON (because people who fall do not move, there is no acceleration variation). Then, the system decides falling.

C. Experimental Setup

Three people aged over 26 years were studied to evaluate our developed system and algorithm. Actually, although we should have experimented on elderly people, we could not help studying on healthy adults because of the risk of our experiment. After the developed system was attached on people's chest, we made five cases of experiments, 1) falling forward, 2) falling backward, 3) falling aside, 4) sitting and standing and 5) daily life activity. Each experiment except for 5 was repeated ten times. The experiment during daily life activity was performed one time. Experimental setup is summarized in Fig. 4. Each people fell on a mattress or sat on a chair after walking about three meters and walked about three meters after standing up.

TABLE I

The result of fall detection in each subject. In falling forward (Forward), falling backward (backward), and falling aside (Side), we define that when fall signal switches ON is success. In Sit and Stand Daily life, when fall signal switches OFF is success. Success(S), Fail(F)

Subject	Fall Detection									
	Forward		Backward		Side		Sit and Stand		Daily life	
	S	F	S	F	S	F	S	F	S	F
1	10	0	10	0	8	2	10	0	1	0
2	10	0	10	0	9	1	10	0	1	0
3	10	0	10	0	9	1	10	0	1	0
Total	30	0	30	0	26	4	30	0	3	0
	Success: 119, Fail: 4									

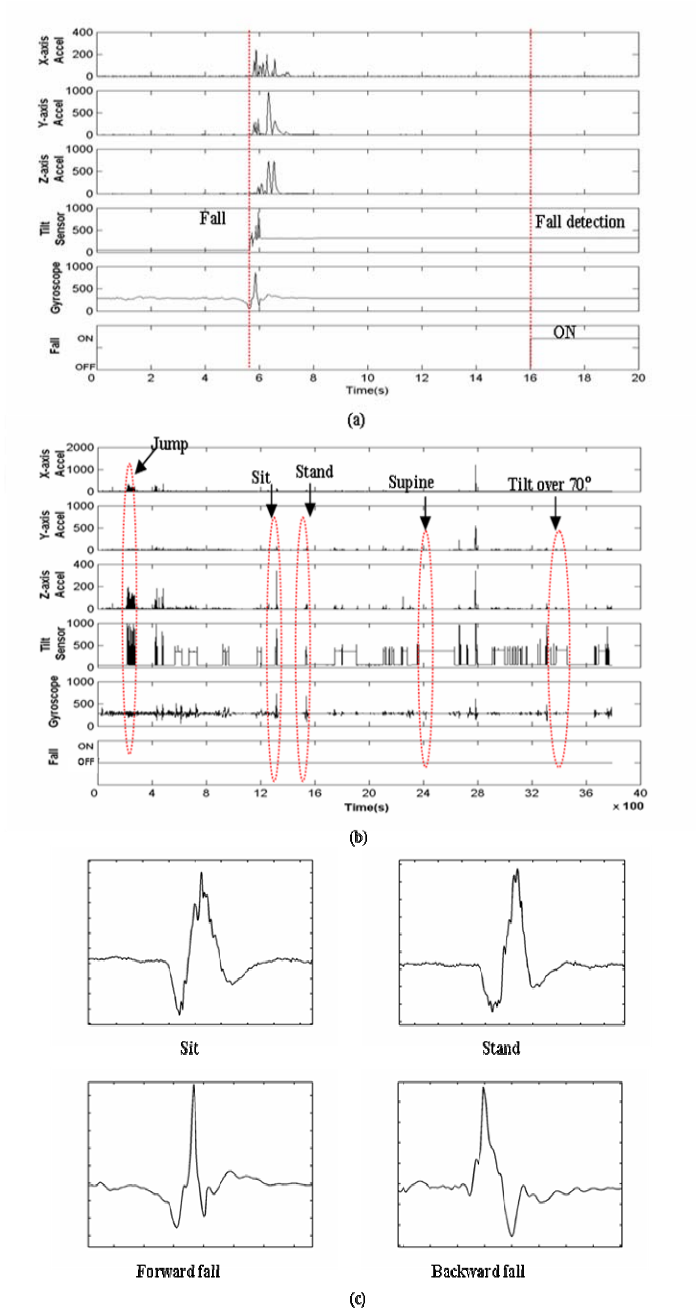


Fig. 5. Experiment result. (a) Signal patterns obtained from each sensor when people fall forward. (b) Signal patterns when people act in daily life. (c) Comparison of gyroscope signal pattern among sit, stand, forward fall and backward fall.

III. Results

We performed experiment on three people with our experimental setup. Each experiment except for a case in daily life is repeated ten times to validate accuracy, and the experiment in daily life was performed one times. Table I shows the result of our experiment. In our experiment, we defined that it is success when fall signal is switched to ON in falling forward, falling backward, and falling aside and it is success when fall signal is switched to OFF in sitting, standing, and daily life. In total 123 trials, our system succeeded in 119 times and failed 4 times. The accuracy is 96.7%.

Fig. 5(a) is the result obtained from sensors when people fall forward. During falling forward, tilt sensor switched ON. At same time, an acceleration signal exceeded threshold. And, a gyroscope signal produced the signal pattern of forward fall. After ten seconds, the system decided fall.

Fig. 5(b) shows the signal patterns obtained from each sensor during daily life activity. Theses results show that the system can differentiate other motions from fall in daily life. Especially, we can see that fall detection signal indicates OFF during that time. Also, although tilt sensor switched ON during tilting over seventy degree from vertical axis, fall was not detected since a difference value of acceleration was not over threshold.

Fig. 5(c) compares the gyroscope signal among sit, stand, forward fall and backward fall. These results show that the signal pattern of forward fall is differentiated from the pattern of backward fall and the signal pattern of sit is similar with the signal pattern of stand.

IV. Discussion and Conclusion

In this paper, a new algorithm and real-time ambulatory monitoring system for fall detection in elderly has been presented. Possible cases of experiments have been conducted to evaluate our system and algorithm. This measuring system is very simple to use, since it is based on real-time monitoring and one system attached on the chest. Therefore, the system interferes minimally with people performing their usual activities and can give a physician the real-time information of elderly people. This usefulness allows the monitoring of people in their daily environment and can let their physician know as rapid as possible in an emergency situation.

To increase accuracy, we used accelerometer, gyroscope and tilt sensor simultaneously. So, we can increase accuracy (96.7%) more than using sensors, respectively. Also, we could distinguish fall patterns when people sit, stand, fall forward and fall backward with our system [1]. Moreover, in daily life the system can differentiate the cases of supine without falling and tilt over seventy degree from the case of falling. However, in falling aside, we failed four times. Probably, it might be due to tilt sensor resolution at side direction. If we integrate another tilt sensor with our system at another side direction, we could reduce the number of fail.

In our study, we couldn't apply our system to the elderly due to the risk of experiment. Finally, it is necessary to experiment on elderly people. Therefore, after consulting with a physician, we are supposed to evaluate our system with elderly people. If our ambulatory system is applied to elderly people for fall detection, we could decrease the risk of fall in elderly people.

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