

A Study on Body Movement Analysis by the Foot Slip Pattern in a Fall (Suatu Kajian mengenai Analisis Pergerakan Badan melalui Pola Gelinciran Kaki sewaktu Jatuh)

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ABSTRACT

A fracture, which mostly results from a fall, is fatal for the elderly. A fall occurred when a person cannot maintain the body position. Most falls occurred when a person walks on a slippery surface or trips over an object on the ground during a gait. Most people try to avoid falls instinctively and fall when their attempt fails. As such, this study investigated the difference between two movements- a movement to avoid falls and a forward-falling movement without a fall-avoiding movement- by analyzing the body movements of the subjects. A fast-moving fall-guiding device with a pneumatic actuator was used to guide falls. The movement of the device could simulate a foot slip that may happen during daily activities. A three-axis acceleration sensor and a Bluetooth module were used to avoid disturbing the body movement during a fall as a wire sensor or a movement analysis system does.

Keywords: Body behavior; fall; fall detection; foot movement; wireless sensor

ABSTRAK

Patah, yang kebanyakannya akibat jatuh boleh membawa maut untuk warga tua. Kejatuhan ini berlaku apabila seseorang tidak dapat mengekalkan kedudukan badan. Kebanyakan kejatuhan berlaku apabila seseorang berjalan pada permukaan yang licin atau terlanggar objek sewaktu sedang berjalan. Kebanyakan orang akan cuba untuk mengelak daripada jatuh dan jatuh apabila cubaan mereka gagal. Oleh yang demikian, kajian ini mengkaji perbezaan antara dua pergerakan- untuk mengelakkan jatuh dan gerakan jatuh ke hadapan tanpa gerakan untuk mengelak kejatuhan- dengan menganalisis pergerakan badan subjek. Alat bantuan untuk mengesan pergerakan kejatuhan pantas dengan penggerak pneumatik digunakan untuk pemanduan jatuh. Pergerakan alat tersebut boleh mensimulasikan gelinciran kaki yang berlaku semasa aktiviti harian. Penderia pecutan tiga-paksi dan modul Bluetooth digunakan untuk mengelak daripada mengganggu pergerakan badan semasa kejatuhan, seperti dilakukan penderia wayar atau sistem analisis pergerakan.

Kata kunci: Jatuh; penderia tanpa wayar; pengesan kejatuhan; pergerakan kaki; perilaku badan

INTRODUCTION

A fall is defined as an act of falling or collapsing from a higher to a lower level due to a change in the body position regardless of one's intention (Tinetti & Williams 1997). A fall may especially result in a fracture in elderly people, which can cause decreased physical function and death in the elderly (Aizen et al. 2007; Heinze et al. 2007). Previous studies have reported that one of every three elderly people aged 65 years or more fall at least once a year, and half of those who have had a fall, fall again (Nevitt et al. 1989; Tinetti et al. 1988). The rate of falls increases with age and decreased in physical function (Kannus et al. 1999). Falls can occur forward, backward or on one's side. Forward falls account for the highest proportion (58%) of all falls, followed by falls on one's side (30%) and backward (12%). The body parts that are most frequently fractured according to the fall direction are the arm and the wrist due to forward falls; the shoulder or bottom, due to side falls; and the hip, due to backward falls. A hip fracture is the most fatal type of fracture in elderly people. It has been reported that 90% of hip fractures in the elderly were caused by falls (Grisso et al. 1991). About 20% of elderly people who has had a

hip fracture died within a year due to decreased in physical function caused by a long period of being bed-bound, without physical activities (Gibson et al. 1987). Even if they completed their treatment, 50% of the elderly could not have an independent lifestyle and require nursing by others (Empana et al. 2004; Wolinsky et al. 1997).

In South Korea, most falls (61.5%) occurred in housing facilities, followed by 20% on roads and 18.5% in business facilities. Ninety-five percent of falls in housing facilities occurred in the individual's home. Dangerous environmental factors such as slippery floors or stairs in houses account for 24-45% of the causes of falls in homes. 19.2% of fall patients admitted to a hospital emergency room fell due to water, ice or snow on the floor surface. In particular, water on the floor in housing facilities accounted for 20.6% of falls in housing facilities, and 74.3% of falls in the bathrooms (Chronic Disease Investigation Division 2009). In the U.S., 50% of falls occurred inside houses; 24% outside houses; and 6.5% on the roads (Schiller et al. 2007). The difference between the two countries was considered from the activity pattern of the elderly in different countries or areas. However, we noticed that most

falls among the elderly were due to a slippery surface floor or a foot or object on the ground that the elderly tripped over.

As such, this study aimed to analyze the body movement when a person falls forward due to a slippery foot or floor surface. A fall-guiding device with a pneumatic control guided various foot slips, and the following body movement was detected using a wireless sensor module.

METHODS

FALL-GUIDING DEVICE

To accurately analyze falls, fall movements should be guided according to how a person actually falls in real life. Groen et al. (2007) measured the impact force produced when a subject fell sideways with his or her knees touching the floor instead of measuring the impact force in a natural fall. Bourke et al. (2007) measured the acceleration of body movement during falls on a crash mat in young subjects only. Hsiao and Robinovitch (1997) used spring and brake for moving cart.

However, in this study, we developed a fall-guiding system in which the floor quickly moves back and forth using compressed air and cylinders to guide the fall. A safety mat was also set up on a moving cart for the subjects' safety. The cylinders were connected to the mat, which enabled fast movement by controlling the inputting and outputting of compressed air. To demonstrate various movements of the cart, the amounts of the inputted/outputted compressed air were controlled by using a solenoid valve (VX2111V-00-5D71). The solenoid valves with orifices that were 1.5 to 2.5 mm big were connected side by side as in Figure 1 to modulate the flow of air by opening/closing the individual valves. This air flow control using the individual valve opening/closing combination could create variety in the moving speed, movement duration and departing speed, and simulate an actual foot slip in daily life. The solenoid valves were two-port direct-acting valves. They were normally closed, but their orifice opened to let compressed air through when electronic communication was activated. When the maximum flow was used, the valves enabled the fall-guiding device to move with up to 2m/s speed.

ANALYSIS OF THE BODY MOVEMENT DURING A FALL

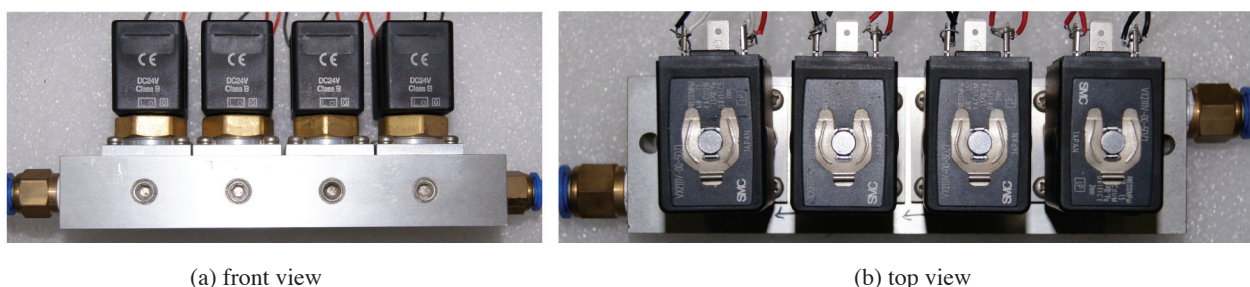
A three-axis acceleration sensor (EBIMU-9DOF, ± 8 g) was used to detect the body movement during a fall. To accurately detect the movement, the sensor was attached to the back of the subjects. Placing the sensor on the back yields better results than placing it on any other part of the body. The signals from the sensor were collected using a Bluetooth module (Parani-ESD) on a real-time basis and the LabVIEW program was used to collect data. To remove the effect of inertia by wearing additional objects, the battery and the Bluetooth module were not attached to the back with the acceleration sensor, but were connected to the sensor with a wire, as seen in Figure 2.

The test was conducted to investigate two movements: A movement that tried as hard as possible to avoid a fall despite the device's fast movement and a falling movement following the movement of the fall-guiding device. The subjects were not given any warning on the movement of the cart so that they could not predict it. They did not have a neurological disease or an abnormality in their vestibular system and had normal musculoskeletal functions. They had not participated in a study similar to this study and the study objective and all the study procedures were explained to them sufficiently before their participation in this study.

RESULT

Figure 3 shows the measurement of the cart movement after operating the valves. The decision of when to open and close the valve was made by how big the initial influx of air was needed, by means of organizing the orifices which all differed in their sizes. Here we assumed that the decrease in the influx could be regarded as friction with the ground. For this reason, we also reduce the influx either in swiftly or slowly. Figure 3 shows the possible scenarios of slips that could happen depending on the condition of the floor.

The degree of the flow decrease was considered the friction force, which could slowly or rapidly decrease the flow. The following figures show the simulated slips that could occur based on the state of the surface. Figure 3(a) shows the most common type of fall, in which the subject keeps slipping without resistance after his or her first slip. Figure 3(b) shows a fall that started with rapid slips and then suddenly stopped due to the frictional force on the



(a) front view

(b) top view

FIGURE 1. Solenoid valve for fall guiding

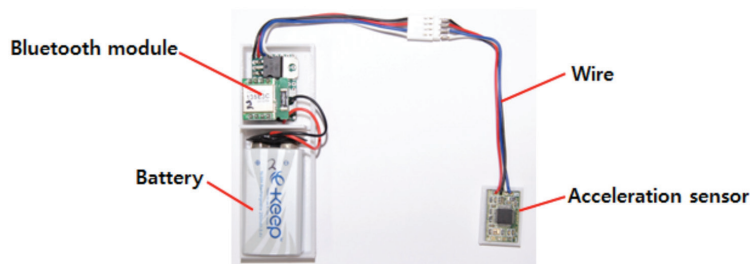


FIGURE 2. Connection of battery and sensor

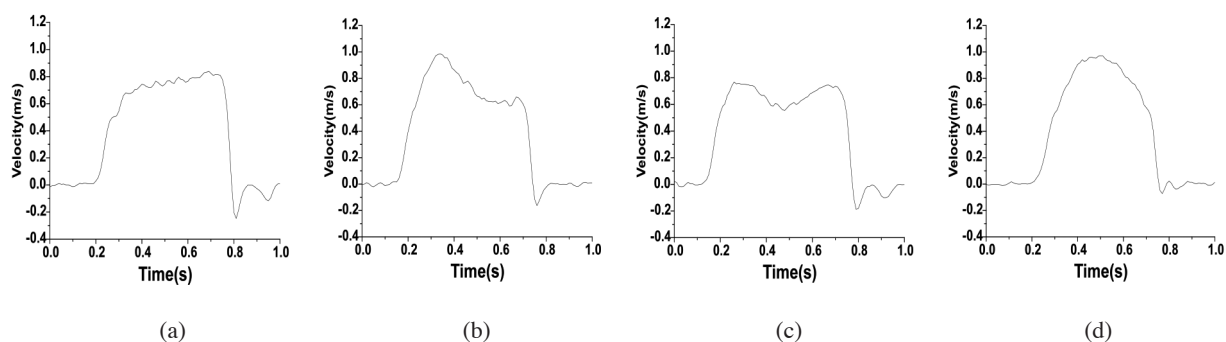


FIGURE 3. Various movements with valve control

surface. Figure 3(c) is similar to Figure 3(b), but after the sudden stop, the subject slips again. Figure 3(d) shows a type of fall characterized by slow slips and smooth stops. Figure 4 shows the acceleration of the type a which is aforementioned four types of falls shown in Figure 3. The figures show two accelerations in one graph: (a) when a subject fell when he kept moving fast until the cart stopped moving and (b) when a subject avoided a fall.

As seen in the figures, great forward acceleration was observed when the subject could not bend backward to

recover his or her balance due to fast slips of his or her feet. This result showed that a fall occurred so fast that the body cannot even regain its balance. The fall-avoiding movement showed the change in the acceleration in the up/down and forward/backward direction around 1G, which was different from the falling movement that showed up to 4G acceleration forward. This result was interpreted as that the upper body does not swing greatly when balance is recovered by the moving body parts even while the feet are moving fast. Therefore, in the case of

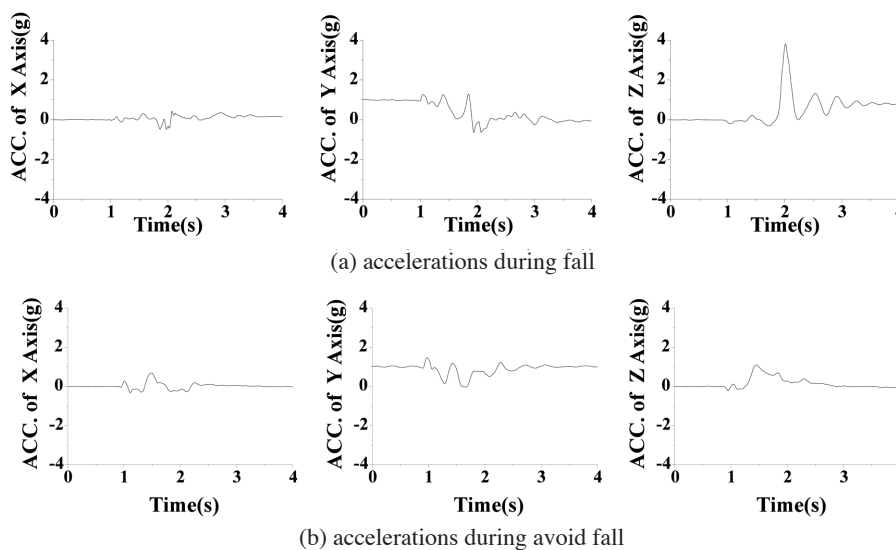


FIGURE 4. Accelerations of type a of movements of cart

fall, acceleration of forward/backward direction is the highest and acceleration of up/down direction is also high because the body contact ground in the type a.

Figure 5 shows the acceleration of fast initial movement that rapidly slows down and continuously speeds up again. When a person falls as shown in Figure 5(a), he or she has enough time to recover his or her balance as the speed increases and decreases again and the forward acceleration ends up decreasing by more than half of that before, unlike in Figure 3(a). The acceleration of the up/down movement increases as the subject is able to lift his or her upper body when he or she recovers his or her balance. Figure 5(b) shows the movement to avoid

a fall, which had a greater forward acceleration than that shown in Figure 5(a).

This increased forward acceleration was considered due to the change in the inertia during the balance recovery because it decreased rapidly from the foot slip and increased again. Also, the acceleration change in all three directions occurred at around the same time with a smaller swing of the upper body because the speed of the slip decreased and increased again.

Figure 6 shows the acceleration of the type c movement. During the fall, the speed of the slip in the early stage is relatively slow and decreases again until it is enough to maintain the balance. As a result, the forward

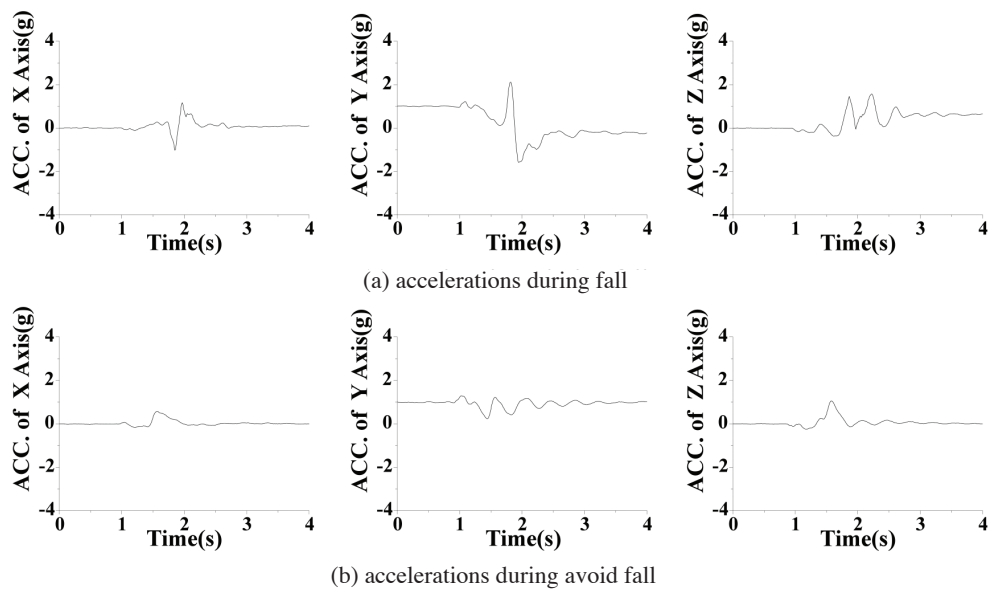


FIGURE 5. Accelerations of type b of movements of cart

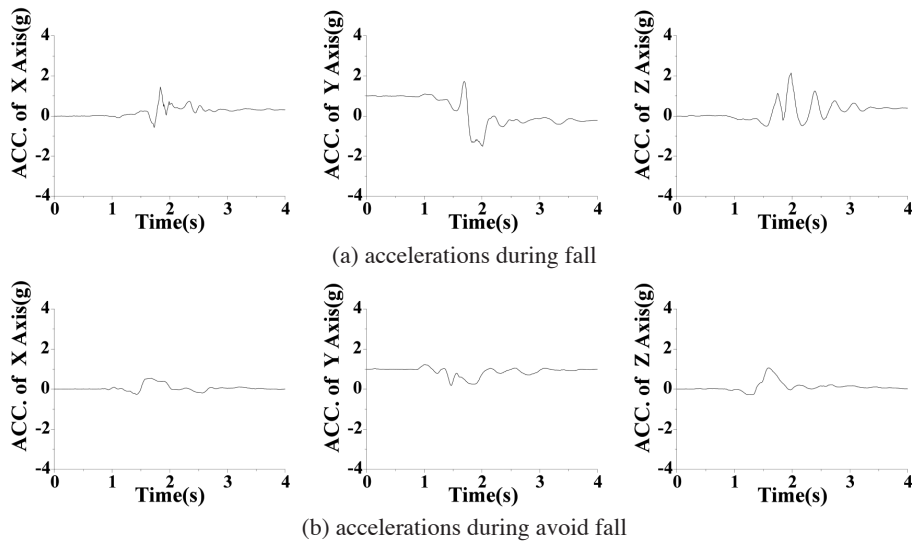


FIGURE 6. Accelerations of type c of movements of cart

acceleration does not increase greatly, as seen in Figure 5. However, the speed of the slip in the movement to avoid a fall increases, which results in a time gap between the swing directions of the upper body.

Figure 7 shows the acceleration of type d movement, which increased in the early stage and decreased again. The speed of the slip increased continuously so that the subject could not maintain his or her balance and the forward acceleration increased greatly. The fall-avoiding movement had less acceleration than the other types of movement, but the change in the slip speed was relatively low.

Table 1 shows the variations of acceleration during fall and avoid fall. During the fall, the mean variation is about 3.04 m/s^2 and during the avoid fall is about 1.13 m/s^2 . As seen in Table 1, variations during fall are much higher than that to avoid fall. It means we can distinguish between fall and non-fall by the variations of acceleration.

Consequently, the change in the forward/backward directions was greater than in the up/down direction, unlike in the other types of movement. From these graphs, we found that the body movement changes greatly depending

on the time the subject is able to recover his or her balance since his or her feet slipped, which would result in differences in the risk of a fall.

CONCLUSION AND DISCUSSION

People fall in various ways. Typically, we slip due to a slippery floor surface such as on an icy road; over an object on the floor while we are walking or running; due to a sudden change in the surface height while we are walking; and while we are climbing a hill. This study simulated the most common type of slip: a fall in which the person keeps sliding without resistance since his or her foot slipped, rapidly slips at first and then rapidly stops due to the frictional force, rapidly stops from the initial foot slip and slips again and slowly slips and smoothly stops. The movement to avoid a fall and the falling movement in each fall type were measured. The analysis results showed that the body movement differed greatly depending on the type of fall, with different acceleration rates and characteristics. However, the fall-avoiding movements showed a similar pattern, in which the subject moved his

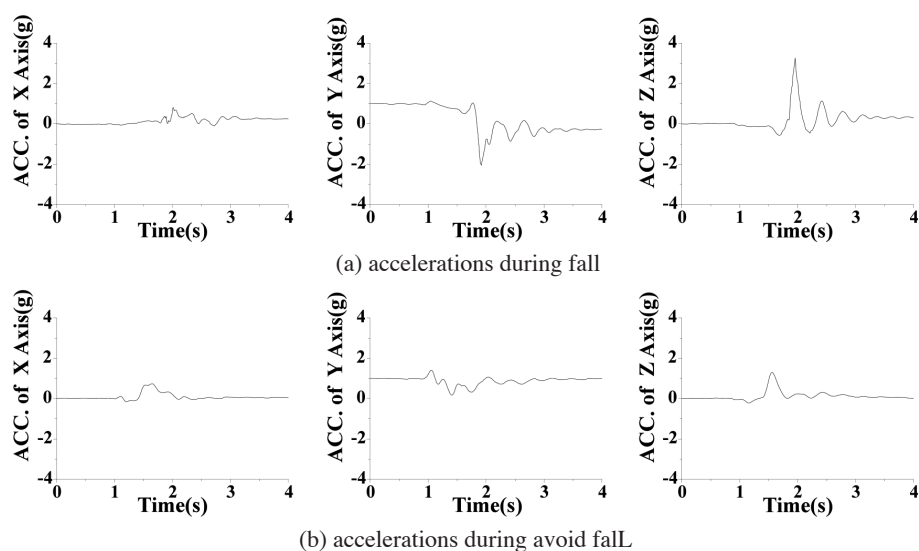


FIGURE 7. Accelerations of typed of movements of cart

TABLE 1. Variation of acceleration

Type	Forms of fall	Variation of acceleration (m/s^2)	Axis
A	Fall	3.81	Z
	Avoid Fall	1.08	Z
B	Fall	2.58	Y
	Avoid Fall	1.06	Z
C	Fall	2.51	Y
	Avoid Fall	1.06	Z
D	Fall	3.26	Z
	Avoid Fall	1.30	Z

or her upper and lower body to avoid a fall without much acceleration change. The degree of the acceleration can be an indicator of a fall, and the body movement can also be used to identify different types of slips. When these results were used to develop a fall detection system, the accuracy of fall detection can increase by reducing false alarms for a potential fall. This study investigated only the movements in forward falls. More studies on backward or side falls should be conducted. More valves with differently-sized orifices should be connected to the device to more accurately simulate slip events with more detailed time modulation. A system that can control each foot separately would lead to side and backward fall simulations that are close to the actual falls in daily activities and to more accurate analysis of falls from foot slips.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (NRF-2014R1A2A1A11053073).

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Received: 2 September 2014

Accepted: 17 August 2015