Detecting Aged Person's Sliding Feet from Time Series Data of Foot Pressure

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Abstract

This paper focuses on sliding feet which is one of major causes of a fall accident of aged persons and proposes a sliding feet detection system based on ordinary piezo- electric sensors, which are embedded under the carpet. Specifically, the proposed system (1) starts to extract a wave occurred from one step (composed of a time series of voltage data measured by the piezoelectric sensors), (2) transforms it to frequency components by Fast Fourier Transform (FFT), (3) extracts the characterized spectrum which includes the sliding feet feature, and finally (4) detects whether a user on the sensor slides his/her feet by comparing differences between the features of ordinary walking and that of sliding feet. In order to verify our proposal system, we conduct the human subject experiment by collecting the ordinary walking step data of two persons and the sliding feet of one aged person, and the experimental results show that the system successfully detects the users sliding feet.

Introduction

An increase the numbers of aged people living alone is a serious issue in a super aging society, Japan. This is because nobody can sense their emergency case without any notification from them. Sudden and unexpected illness or fatal injuries cause bedridden or solitary death at worst. This situation suggests that a keeping of their safety and health is one of the most important problems in Japanese society. Related to this is- sue, Tokyo Fire Department reports that 80% of emergency-transported aged people were injured by falling accidents (Tokyo Fire Department 2014). This department also reports that half of those people injured on flat floor in their home. From this fact, we focus on the main cause of the fall accident of aged people,"*sliding feet* , which is a way of walking by shuffling the feet caused by a decrease of feet muscle strength. What should be noted here is that most of aged people shuffle feet unconsciously, which makes it difficult to recognize that the time of falling accidents becomes close. Even if they walk as usual, their muscle strength gradually decreases, which increases a tendency of sliding feet.

To tackle this problem, we propose the sliding feet detection system based on the ordinary piezoelectric sensors, which are embedded under the carpet. The proposed monitoring system has the following features: (1) the system detects an users sliding feet and notifies them; and (2) the system is to be contactless and undetectable to users. This paper is organized as follows. The next section introduces the related works, and Section 3 describes our sliding feet detection system. Section 4 explains the experimental setup and Section 5 conducts the human subject experiment. The experimental results are discussed in Section 6, and our conclusion is finally given in Section 7.

Related Works

Quantification and analysis of walking, using pressure sensor have been researched in many research areas. (Yamato et al. 1994) developed a large-area pressure sensor array for recognition of persons attributes. They acquire foot pressure images and analyze them to recognize who is the walker. (Sudo et al. 1996) analyzed the characteristics of walking patterns due to sex and age, in the foot pressure images obtained by a pressure sensor array. Those researches provides effective methods and results for analyzing our walking, however, they do not aim at detecting aged persons singular walking features. Moreover, considering the floor space of Japanese typical houses, their sensors are not realistic size. The quantification of walking as a clinical application is developed by (Naito et al. 2014). They aim at preventing falling accidents of stroke hemiplegia patients and at developing small, simple and low-cost system. Therefore, their motivation is quite close to ours. The monitoring system they develop is, however, embedded inside of shoes, that is, wearable. As mentioned before, the problem we tackle is aged peoples falling accidents in the house. In summary, the previous researches have developed the mat type sensors and the wearable sensors. We are interested in the former, however, those researches are not aim at detecting aged persons singular walking, and the sensors are too big to Japanese typical houses.

Sliding Feet Detection System

Sliding feet: Assumption

To detect sliding feet of aged people, our proposed system focuses on the differences between sliding feet and ordinary walking, which is appeared in the vibration of the

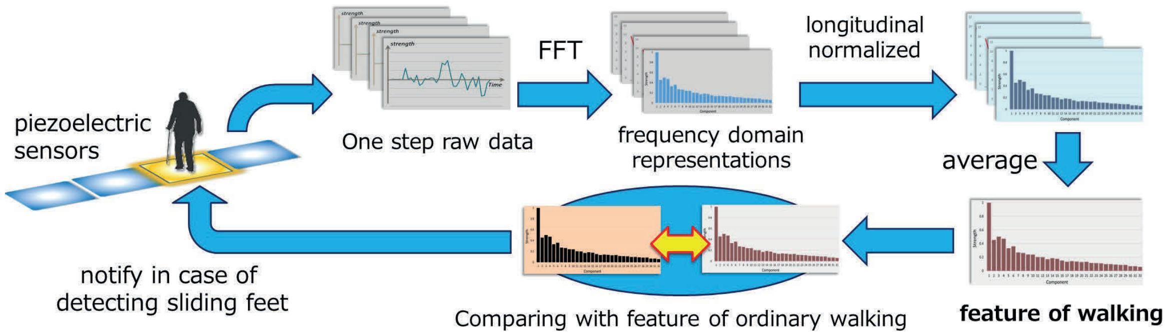

Figure 1: Overview of the sliding feet detection system (proposed)

feet strength measured by the piezoelectric sensors. Specifically, one step in ordinary walking derives a (strong) vibration wave with a long cycle as shown in Figure 2(left), while one step in "sliding feet" derives a (weak) vibration wave with many short cycles as shown in Figure 2(right). In these figure, the vertical and horizontal axes indicate the wave strength and time, respectively. The problem that we have to tackle here is to distinguish "the (strong) wave with a long cycle" and "the (weak) wave with many short cycles".

Since such waves depend on user's walking speed and his/her weight, we transforms the wave to the frequency components as the frequency domain representation by Fast Fourier Transformations (FFT) (Cooley and Tukey 1965) to extract the characterized spectrum which includes the sliding feet features.

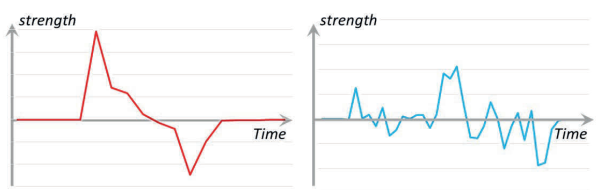

Figure 2: (left) A vibration wave of one step in ordinary walking. (right) A vibration wave of one step in sliding feet.

Overview of the proposed system

Figure 1 shows the overview of the proposed system including its processing flow. The system is consisted of some sensor panels, each of which has the piezoelectric sensors embedded under the carpet. The sliding feet detection algorithm as a core of our system is summarized as follows. The system begins to conduct the following detection processes just after a user walks through all sensor panels. In detail, the process is consisted of the following seven phases as shown in Figure 1;

Phase 1: The system extracts the vibration waves of one walking step, which can be measured in each sensor panel (*e.g.*, if the user walks the x number of the sensor panels, the sys- tem extracts the x number of the different waves). Specifically, the system sets the extraction flags during the sum of the consecutive N data of the standard deviation of the one walking step wave exceeds the threshold θ. Figure 3 shows an example of vibration wave extraction. As the same in the previous figure, the vertical and horizontal axes in Figure 3 indicate the feet strength and time, respectively;

Phase 2: To cope with the difference of users walking speed, the vibration waves of one walking step are normalized from the walking time viewpoint. Through this process, the length of waves, that is, the walkers speed is excluded from consideration. Since our system needs 2^y data ($32 = 2^5$ in our system) per wave to transform by FFT , the length of the data which constitute those extracted waves is adjusted appropriately in this phase;

Phase 3: FFT is applied to all of the waves acquired by the x number of the sensor panels to transform them to their frequency components as the frequency domain representations. Note that the representations of the waves are changed to those of their distribution ratio of each frequency components;

Phase 4: To cope with the difference of users weight, the frequency domain representations are normalized from the strength viewpoint. Through this process, the strength of waves, that is, the walkers weight is excluded from consideration;

Phase 5: All of the normalized frequency components of the waves (i.e., the x number of waves) of one walking step are averaged, which are treated as a feature of the users walking steps. An example of the feature is shown in Figure 4, where the horizontal axis indicates the frequency components while the vertical axis indicates the normalized feet strength;

Phase 6: The feature of the users walking steps is compared with that of ordinary walking steps which is calculated in advance; and

Phase 7: If some differences appear between the two features, the system detects the sliding feet and notify to users.

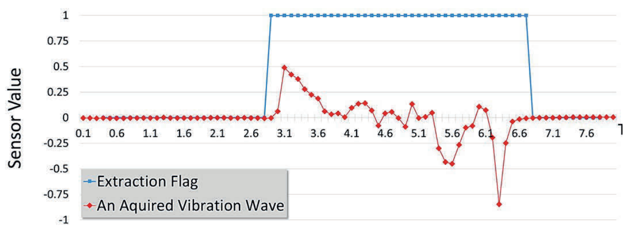

Figure 3: An example of vibration wave extraction whe each sensor value acquired every 0.1 seconds and (N, θ)=(0.02). The area where the flags are set is extracted as a sing vibration wave.

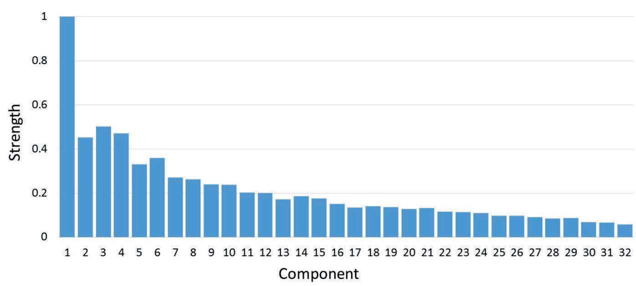

Figure 4: An example of the feature(spectrum) of one walking step. In the figure, the horizontal axis indicates the frequency components while the vertical axis is dimensionless quantity (because it is normalized in **phase 2**).

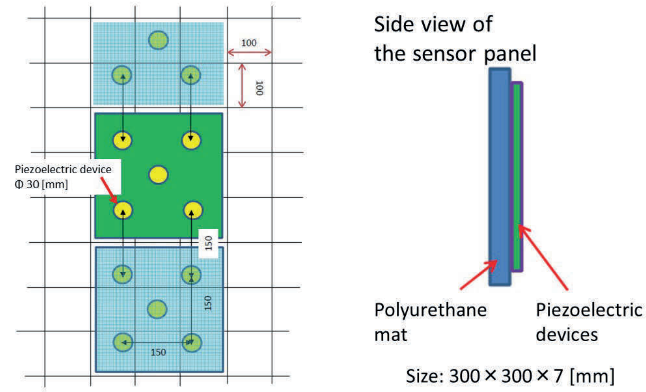

Figure 5: The details of the sensor panels.

Figure 6: The subject walks on the sensor panels.

Experimental Setup

The Sensor Settings

The proposed system is consisted of the nine sensor panels, and it measures the voltage of walking every 0.1 seconds, which value is proportional to pressure to the piezoelectric sensors. Each panel which size is 300 x 300 x 7 [mm] is composed of the polyurethane mattress and piezoelectric devices as shown in Figure 5(right), while it has piezoelectric sensors, which are embedded as shown in Figure 5 (left). Figure 6 shows the sensor panels and one of the human subjects.

Human subjects

Three human subjects (A, B, and C) participated in this experiment. The human subjects A and B are in their 30s and can walk ordinarily. The difference between human subjects A and B is the sex and weight, i.e., one subject is male with approximately 45kg weight while the other subject is female with approximately 50kg weight. The human subject C is 82 year-old aged person with approximately 40 kg weight, and she tends to slide her feet. The walking of the human subject C is compared with the ordinary walking constructed from the walking of the subjects A and B in advance.

Construction of Detection Criteria

In order to extract the feature of the one step of the ordinary walking, 10 data are collected from the human subjects A and B (*i.e.*, five data from each person). In one iteration, the human subjects pass through the sensor panels by ordinary walking, that is, they do neither run nor stop on the panels. The walking data per person acquired from 5 iterations modify into an ordinary-walking feature through **Phase 1** to **Phase 4** mentioned above.

Figure 7 shows the experimental result that compares the feature of the ordinary walking with that of the sliding feet. In this figure, the red bars indicate the average of ten features of the ordinary walking while the blue bars indicate the average of ten features of the fake sliding feet. Related to sliding feet, we construct the features of the fake sliding feet (i.e., the human subjects A and B imitate the walking of aged people). Comparing these features in Figure 7, we discovered that the feet strength (*i.e.*, the heights of the bars) of the sliding feet at each frequency component is totally higher than that of the ordinary walking. This result provides us that the sliding feet contain more waves than the ordinary walking steps. As mentioned in our assumption, the sliding feet derives the vibration wave with many short cycles like Figure 2 (right).

From this result, we define the detection criteria as follows: The system checks the frequency components 9-13 where the maximum difference between the ordinary walking and the sliding feet is appeared in a high possibility, and counts the numbers of the frequency components where the normalized feet strength of the sliding feet is larger than that of the ordinary walking, and detects the user's sliding feet when such numbers is more than one.

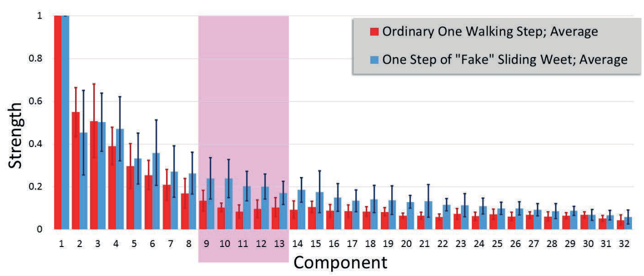

Figure 7: Comparing the feature of the ordinary walking and that of fake sliding feet. The clear differences are appeared in the colored pink area, *i.e.*, the frequency components 9-13.

Experiments

To investigate our proposed system, we conducted the human subject experiment on the human subject C who tends to slide feet. In detail, the experiments are divided in to the following different three cases which are arranged by the sensor panels. In each case, the human subject C walks five iterations as the same as the human subjects A and B. Note that the human subject C passes though on the sensor panels, that is, she does neither run nor stop on the panels.

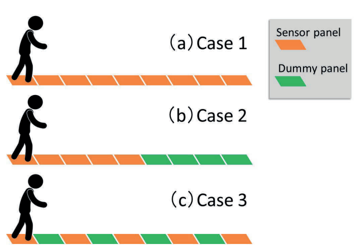

Figure 8: Illustrating of the arrangement of the sensor panels at each case.

Case 1

The nine sensor panels line up as shown in Figure 8(a).

Case 2

The four sensor panels and the five dummy panels line up as shown in Figure 8(b). Note that the sensors and the dummies are differently colored, but the subject does not know the meaning of the color of the panels.

Case 3

The five sensor panels and four dummy panels are alternately arranged to line up as shown in Figure 8(c). Note that the sensors and the dummies are differently colored, but the subject does not know the meaning of the color of the panels.

Evaluation Criteria

The system judges whether the human subject C walk in sliding feet after she has completed to pass through all panels. We evaluate the number of the correctly detection of the sliding feet judged by our system in three cases.

Results and Discussions

Table 1 shows the numbers of times that the system correctly judges. In case 1 and 2, the system perfectly detects sliding feet, however, there is a mistake in case 3. In the following subsection, we focus on the components 9-13 of the features given at each case. The colored bars in Figure 9, 10, and 11 indicate those of the features of ordinary walking step which we define in the previous section. The system detects the walker's sliding feet when such a component exists that its value is beyond that of ordinary walking step.

Table 1: Numbers of correctly detection

case 1	case 2	case 3
5	**5**	4

Case 1

Figure 9 shows the feet strength of the frequency components 9-13 of both sliding feet and ordinary walk in case 1. Focusing on the values acquired in **take 1** (described as ◯) , however, the result indicates that the human subjects walking in take 1 is close to the boundary. At the components 9, 12 and 13, those values are below the ordinary walking step. At the components 10 and 11, those values are close to the ordinary walking.

Case 2

Figure 10 shows the feet strength of the frequency components 9-13 of both sliding feet and ordinary walk in case 2. Comparing cases1 and 2, the value of the feet strength in case 2 are less dispersed than those of case 1. Focusing on the frequency components 12 and 13, the values are close to the ordinary walking, except for the**take 5**. This result indicates, at least in this case, the frequency components 12 and 13 are not effective from the viewpoint of the sliding feet detection.

Case 3

Figure 11 shows the components 9-13 of the features given in case 3. This is the only case that our system makes misjudgement in these experiments. All the values of take 5 (described as ⋄) are below to those ordinary walking step. Thus the result indicates that the system misjudges the walking taken at 5th iteration.

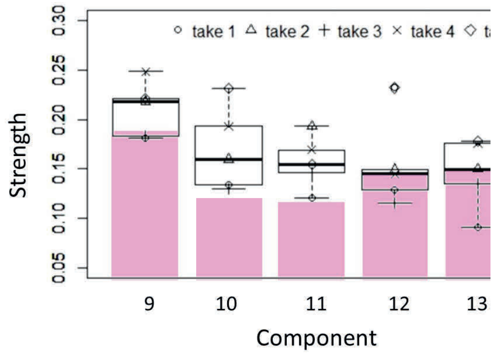

Figure 9: The values of components 9-13 in **case 1**. The colored bars are of ordinary one walking step.

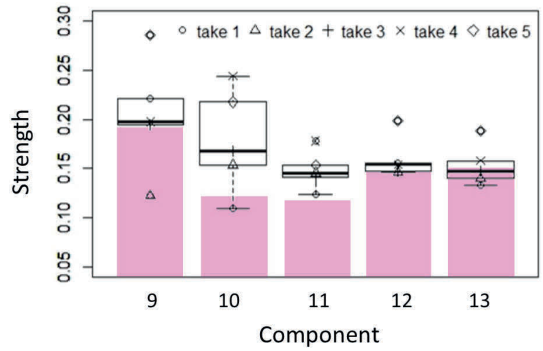

Figure 10: The values of components 9-13 in **case 2**. The colored bars are of ordinary one walking step.

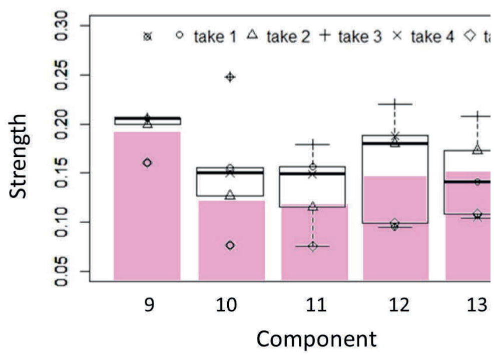

Figure 11: The values of components 9-13 in **case 3**. The colored bars are of ordinary one walking step.

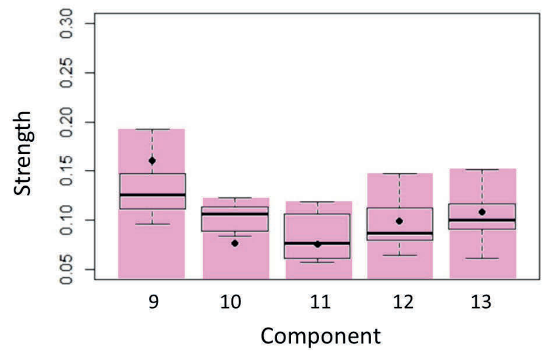

Figure 12: The values of components 9-13 of the walking in **case 3, 5th iteration** and of the ordinary walking steps. The colored bars are of ordinary one walking step.

Discussion

For more precise detection, the following question comes up, "Did the human subject C walk as the sliding feet in every case? At the **take 5** in case3, our system judges that the human subject C does not walk as sliding feet. Here, we discuss whether the decision is appropriate or not. In Figure 12, the box plots in each frequency component indicate the 10 features of the human subjects A and B, which are employed as the ordinary walking. The dots (•), on the other hand, indicates the value of walking taken at the 5th iteration of case 3 in which our system does not detects the sliding feet. Since the dots in the frequency components 11- 13 are located within the range between the upper hinge and lower hinge of the ordinary walking data, this result indicates that the feature taken at 5th iteration in case 3 is quite similar to the feature of ordinary walking. To validate this result, we checked the video of **take 5** in case 3 and found that her walking is very similar to the ordinary walking but not similar to the sliding feet. This suggests that the decision of our system is appropriate, not misjudgement at all.

Conclusion and Future Works

This paper focused on the sliding feet of aged persons and proposed the sliding feet detection system based on the ordinary piezoelectric sensors embedded under the carpet panels. Specifically, the proposed system detects the sliding feet by comparing differences between the features of the walk with those of the sliding feet. To investigate the effectiveness of the proposed system, we conducted the human subject experiments by collecting the ordinary walking step data of two persons and the sliding feet data of one aged person both of which are acquired through five iterations. The experimental results show that the system successfully detects the sliding feet of aged person. What should be noted here is that the above implications have only been obtained from data of a small number of the subjects. This suggests that further careful qualifications and justifications by increasing the number of the subjects are needed to generalize our results. Such important directions must be pursued in the near future in addition to the following future research: (1) the threshold or the detection criteria should be sophisticated by classification methods such as Learning Classifier Systems (LCS)(Holland and Reitman 1978) and Support Vector Machine (SVM) (Vapnik 1998); and (2) we should test our system on the various sensor panel arrangements except of line arrangement.

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Acknowledgments

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