SAFLOOR: Smart Fall Detection System for the Elderly

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***Abstract*—The main reason for hospital admission of elderly people worldwide is falls. The longer one has to stay on the floor due to inability to get up after falling, the more severe the injury can become. Existing fall detection devices that need to be worn on the body is not very useful because the elderly simply forget or do not want to wear them. From this, we have created a fall detection system named "SaFloor" - a soft mat with force sensors embedded inside. SaFloor can be placed in fall-prone areas, such as by the bedside, bathroom, at the bottom of stairs, etc. It can distinguish between a real fall and other impacts such as walking and dropped objects, and send out a notification to a family member or a care giver via Line message when a fall is detected. The experiment consisting of 14 participants with different weights and heights shows that SaFloor has a successful fall detection rate of 88%.**

***Index Terms*—force sensor, Internet of things, fall detection**

I. Introduction

The second leading cause of accidental death worldwide is falls. People aged above 65 are the ones who suffer the greatest number of the fetal fall, and one third of them experience falls at least once a year. [1]. In Thailand, many elders experience accidental falls where the statistic for females is 21.5% which is more often than males (14.4%). According to [2], places where the most falls happens are bathroom (71.4%), bedside (22.9%), walking (20%) and moving (22.9%) respectively. The situation worsens for elders who live alone where there is no one around to notice the accident. Most family are not able to reach their love ones in time which leads to loss of life or severe injury [3]. It can be seen that falls are a major cause of hospital admission in the elderly.

Fall detection systems are devices and systems whose function is to notify whenever a fall occurs. The system can be composed of various sensors such as accelerometers, force sensors, algorithms to distinguish real falls from false alarm such as normal walking or dropping objects on the floor. Fall detection system could also utilize a camera and integrates with smart phones. In this work we focus on the use of force sensors and algorithm to reliably detect fall while keeping false alarm to a minimum. The motivation for this approach is the make the system low cost and preserve privacy by not using a camera.

The proposed smart fall detection system's benefits are reducing the phobia of falls by the elderly as well as the anxiety of people who must leave their elderly alone in the house. The other important objective is that this fall detection system should lower the time the elderly has to remain on the floor before help arrives. Time is critical because it is also what determines the severity of a fall accident. Most elders who had fallen down are not able to get up, and this can result in pressure sores, dehydration or even hypothermia [4]. As a result many fall detection technology has been proposed ranging from smart phone built-in accelerometer, wearable accelerometer devices, accelerometer-attached to the body, and cameras. Nonetheless, many of them still face problems regarding privacy, inconvenience and irritation. Wearable devices are sometimes not effective due to the fact that the elders do not always wear them because of many reasons such as forgetting, irritation and the insecure feelings, rendering such devices completely useless. Smartphone based accelerometers faces the same problem as external sensors because only 20% of elders keep their smartphone by their sides all the time [5]. On the other hand, using image processing and camera can provide better fall detection, but the elders themselves are not comfortable with it. Many of them feels like someone have violated their privacy and that they are being watched from the camera.

The aim of "SaFloor" is to be a more convenient fall detection system. The idea is to insert force sensors under a soft flooring mat. With this technique, not only a fall event can be detected, but by using a soft floor the impact of the fall itself can be reduced. Under the mat, many sensors are inserted to provide better detection and the ability to distinguish between common movement such as walking, dropped objects and a real fall. At the same time we keep the number of sensors to a minimum to keep the cost of the system low. SaFloor aims to be a reliable and affordable fall detection system available to all.

II. Related Works

Fall is a leading cause of accident and major reason of hospital admission worldwide. Many countries are now confronting the problematic issues of falls in the elderly [6]. In Thailand, more than 10% of Thai elders have experienced falls at least once a year. Females fell more often than males. Around 65% falls outside their house mostly during the daytime [7]. Besides from the physical injury, the psychological trauma seems to be even harder to healed and remain with a patient long after the physical injuries have healed [8]. Another consequent issue caused by falls is that as people become more considerate regarding falls, the money spent on the elder's care increases [9]. In Thailand, the money many people spent on taking care of their elderly relatives is a large portion of their income. This does not include the payment that they have to pay if there is an actual fall event happened. The cost associated with fractures resulting from fall is about 12,000 baht each time in Thailand. When comparing to the average family income which is only around 7,000 baht, economic consequences of the falls is significant in Thai society, which is unfortunate since many falls can be prevented. In order to limit and prevent falls, the elderly themselves should change and improve their health performance and behavior by avoiding the causes of falls. Arranging living environment to remove risk of falls is the most effective way to avoid falls [10]. However, no matter how much one is careful, accident can happen, which is why fall detection systems are needed.

A. Fall Detection System Using Wearable Device

The work by [11] was the first in using accelerometer for detecting fall. In the study, body orientation changes from upright to laying after a large negative acceleration was concerned as a fall. The accelerometers together with the previous mentioned two conditions are used in the fall detection algorithm. A device worn on the wrist detects of the following conditions for considering if a fall has occurred. Firstly, high velocity toward the ground need to be detected, then an impact within 3 seconds. After the impact, activity of the person will be observed for 60 second. If inactivity is recorded at least for 40 seconds, an alarm will be activated. From this, if the user does not clear the alarm within a certain amount of time, a fall is considered to have occurred. However, this technology could not detect a large percentage of backwards and sideways falls [12]. As an example, the Tunstall fall detector shown in Fig. 1, is a commercially available example of this kind of fall detection system. This fall detector use s detection algorithm based on two stages. There is the sleep state that will be woken up when a strong impact is detected. The wearer's orientation will be estimated by the second sensor, and if the wearer is in a laying down state for longer than a set time period, an alarm will be raised. As shown in Fig. 2. Various locations around the body were considered for placement of the sensor and the waist was found to be the optimum location for reliably detecting falls.

As mentioned, devices which has to be worn on the body is not effective because many elders just forget to wear them. There we designed SaFloor to be a soft mat which can be placed anywhere that a fall is likely to occur such as bedside or in the bathroom. It only has to be setup once and does not require any effort by the elderly themselves to be used.

Fig. 1. The Tunstall fall detector [13].

III. METHOLOGY

A. System Architecture

The system consist of five major parts. Starting with the biggest hardware component, the SaFloor itself will receive the force that come from anything acting on it such as human being or object. Force sensors under the mat will be activated when there is a person or object on the mat, the output of each sensor will be read by a micro controller (MCU). After obtaining the data, MCU will send it into a server where the fall detection algorithm runs. The server also hosts a database that save the data for further uses. The fall detection algorithm works by detecting adjacent sensors whose output is above a certain threshold, which is set when there is nothing on the SaFloor mat, a fall is detected when the threshold is exceed for many consecutive readings of the sensors. When a fall is detected, notification will be delivered to the user(s) via notification part. The system architecture is shown in Fig. 3

B. The Pressure Sensor

Two yoga mats of the same size are used. The size of both are 61 centimeter width and 86.5 heights. Two yoga mats are stacked together, so that there is one piece of the SaFloor mat is 61x86.5 centimeter and become thicker as well as softer than using a single yoga mat. The number of sensors is 24, placed between the two yoga mats. Each sensor is 6x6 centimeter. The force sensors consists of a sheet of velostat - a material whose resistance changes in response to a force applied perpendicular to its surface [14], sandwiched between two sheets of copper as shown in Fig. 4. By putting this sensor in series electrically with a resistor of known value, where the total voltage across the whole circuit is 5V, applied force will cause the voltage going into the MCU to fall between 0-5V, which is the common operating range of many MCU's analog to digital converter (ADC). For a 10 bit ADC, the maximum voltage of 5 V corresponds to the digital value of 1023.

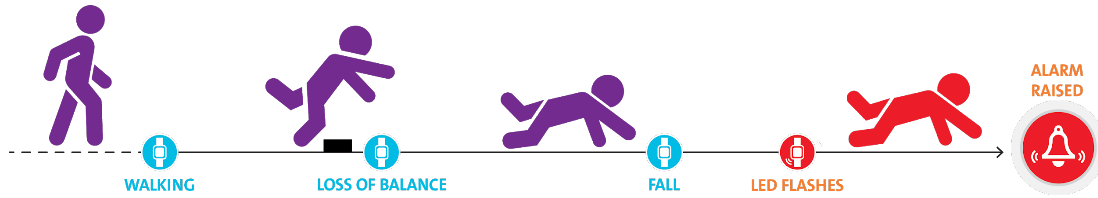

Fig. 2. Algorithm of the Tunstall fall detector[1].

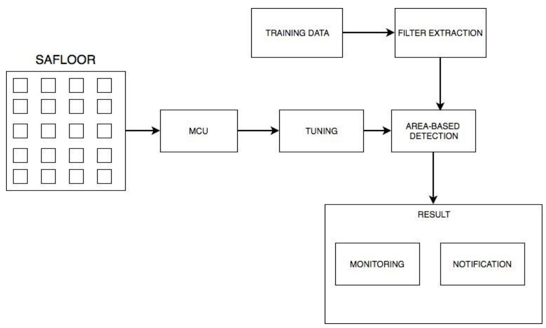

Fig. 3. System Architecture of SaFloor.

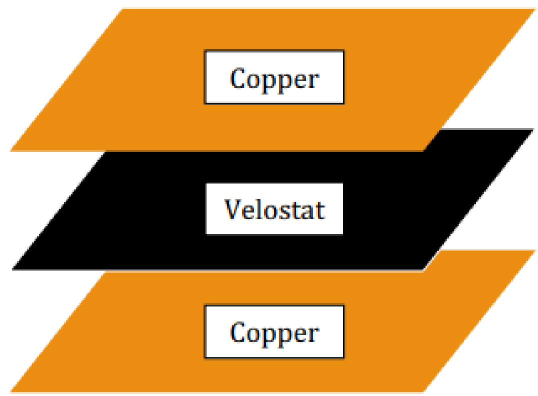

Fig. 4. Sensor Materials

TABLE I
VELOSTAT EXPERIMENT

Number of Velostat Tape(s)	Voltage Value
1	700 - 900
2	500 - 700
3	300 - 500

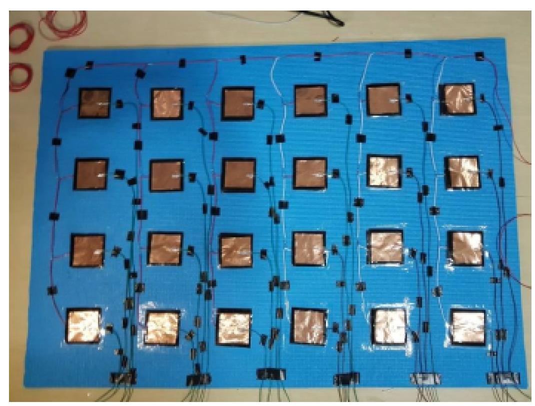

Fig. 5. Installation of sensors on the yoga mat.

However, the resistance value of one layer of velostat is too low, there is very low amount of voltage drop across the sensor, which cause the range of measurable force to become too small, i.e., when no force is applied, the voltage output is almost 5V. This leaves a very small range of voltage left for when a force is actually applied. To solve this problem, we perform an experiment to check how many layer of velostat tapes we need for each sensor, so that there can be enough voltage drop across the sensor to allow for big enough measurement range. After the experiment, we found that 3 layers of velostat per sensor is the best since the voltage value from this one is low enough to perceive a wider range of force. The (digital) voltage value of when 3 layers of velostat tapes is used and force is applied is between 300-500, while the values when 2 and 1 velostat layers is used is between 500-700 and 700- 900 respectively. The experiment result is shown in Table I. Furthermore, a completed SaFloor mat can be seen in Fig. 5. We used 10k ohm resistor to go in series with the sensor, which was found to be the best value to use with 3 velostats sensors. The force sensors are attached between the two yoga mats and the signal are read through an Arudino board [15] with a MUX shield from Spark Fun Electronics.

[1]http://www.tunstallhealthcare.com.au/solutions/fallspendant

C. Distinguishing Falls from Normal Walking

In order to detect falls, first a baseline value for each sensor must be established, since each sensor's response characteristic is a little different from all the other due to the variation in constructing them, as well as the variation in the resistance value of the resistors. A total of 5 output values from each sensor is recorded with the mat empty, and the average of those 5 values for each sensor is used as its baseline value. When a sensor is loaded, i.e., there is an object on the mat, the output value of each sensor is categorized into 3 levels: green is when the sensor's output fall between its baseline up to baseline + 100, blue is baseline + 101 up to baseline + 150, and finally red is for any value over baseline + 150. The sensors are read from every 0.5 seconds. An example of

Fig. 6. Sensors output pattern corresponding to a fall.

the sensors output pattern is shown in Fig. 6, where the black numbers underneath indicate the pattern are obtained from 10 consecutive readings of the sensors output.

From experimentation we observed that a fall coincide with large patches of red areas, therefore we devise a simple rule to detect a fall: if there is any patch of red-valued output that consists of six or more adjacent sensors (diagonal is also considered adjacent), and this patches remains for 5 or more consecutive reading in any given 10 consecutive sensor reading, a fall is considered to have been detected.

IV. Experimental Design and Results

A. Experiment Set-up

The experiment involved 14 participants, 7 men and 7 women with different weights and heights. They are also diverse in term of body pattern and their position when they are falling from bed. The average height is 1.68 meter, and the average weight is 62 kilogram. During the experiment, each participant has to fall down from the bed that is set up in the room with SaFloor placed directly next to it for 10 times each. We recorded the time between when a participant fell down on the floor and the time the notification is received by the user's mobile device. Each participant will fall for 10 times. If a notification is note received, it is counted as missed detection. If a notification is received, it is counted as a successful detection.

The steps of falling can be seen in Fig. 7 through Fig. 10.

B. Experiment Result

The result of the experiment is shown as in Fig. 11. The Y-axis represents the average time in seconds between when each participant fell down and when notification via Line application is received. The X-axis represents the weight of each participant in kilograms. Furthermore, the average detection time of every participant has been deducted 0.0067 second as this amount of delay of Line application server. The result shows that participant who has heavier weight will use less average time to detect than those who are lighter, as can be seen from the two clearly separated groups of data points in the graph.

The success rate of fall detection that obtained from the experiment from both 7 males and 7 females is 88%. While, the walking detection success rate is only 32%. Fig. 12 shows

Fig. 7. The participant is assigned to lay down on the bed.

Fig. 8. The participant is assigned to pretend to be falling the bed from the lay down position.

Fig. 9. The Participant is assigned to stay still right after he/she fell down and this is where the timer is started to count.

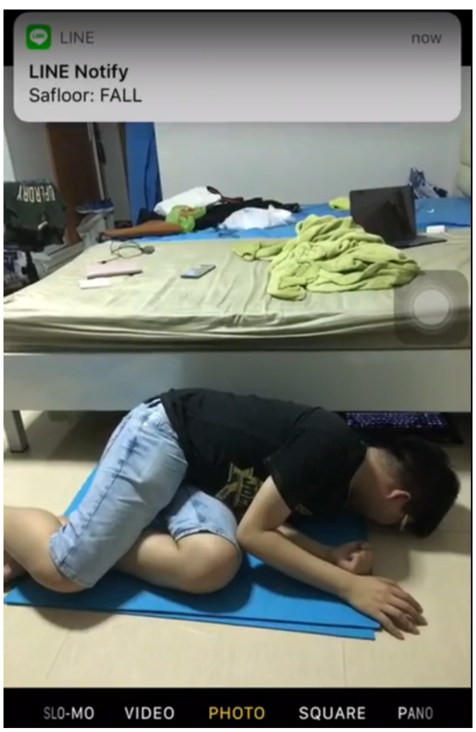

Fig. 10. The timer is stopped as the notification is received. The data of the measured time is now collected.

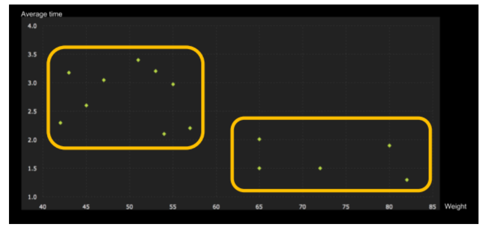

Fig. 11. The summarized data of participants, which indicated the weight of each participant in x-axis and the average time when a notification is sent when participant fall from a bed.

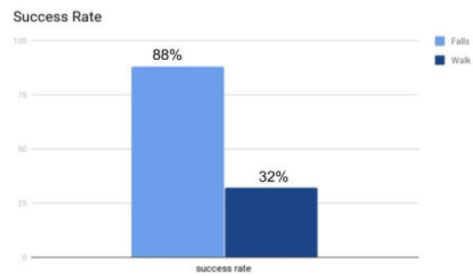

Fig. 12. The success rate from an experiment, which are falling and walking.

the comparison between 2 types of detection. When the 2 genders are considered separately, the success rate of fall detection among a group of female participants is higher than the group of male participants. Success rate of the female group is approximately 89% , while success rate of the male group is approximately 86%. The comparison of 2 groups of participants is shown in Fig. 13.

C. Discussion

The system evaluation is based on the experiment on 14 participants. The results from the experiment shows that the success rate at 87.85%. However, there is a delay time when participant fell down on the floor and received the notification. The delay ranges from less than 1 second up to almost 8 second. From the result, it can be seen that the weight is an important factor that determine the time delay of fall detection. It can be clearly seen that heavier weight participant has shorter time delay.

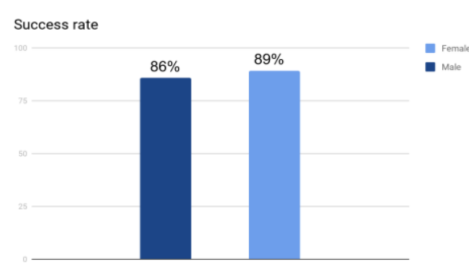

Fig. 13. The success rate between male and female participants that can detect a fall.

D. Limitation

Limitation of our system is it still not be able to deliver the notification to the users immediately after a fall event occurred. There remains the delay time between the time of falling down and receiving the notification via Line since this event depends also depend on Line server that we are using for delivering notification. Another limitation is that it cannot detect the fast walking posture as the walking can be altered according to the person who falls.

V. Conclusion and Future Development

The study proposed the fall detection system designed specifically for the elderly. The main objective is to have a device that does not get the way of daily living, as well as does not require any effort on the part of the elderly to use the device, which only has to be setup only once. The device consists of a soft mat with force sensors embedded inside, which can detect fall by watching for specific patterns of high pressure area over a certain period of time. The system can also send out notification when a fall is detected, while the softness of the mat itself helps with reducing the actual impart of the fall. Our device can detect falls quite reliably with an accuracy of 88%.

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