Stand-up Activity Prediction from Textile Pressure Sensors

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1. Abstract

This paper presents a stand-up activity prediction system using textile pressure sensors to reduce unexpected falls. To achieve this, we equipped a wheelchair with textile pressure sensors to collect data on wheelchair users' activities, such as sitting, exercising, and trying to stand up. In a lab environment, we collected activity data from three users to forecast sudden attempts to stand up, which may lead to falls.

In this study, the effectiveness of the personalized model and the leave-one-subject-out (LOSO) method were compared. Also, we compared the performance with different feature sets. With four general statistical features, we achieved an 84% accuracy and an 81% F1-score to predict trying to stand-up activity in the one-person leave-out method. Then, the accuracy and F1-score increased to 86% and 83%, respectively with six additional features. Finally, personalized models produced the highest accuracy and F1-score of 91% and 94%, respectively for the stand-up activity.

Overall, the results demonstrate the potential of predicting wheelchair activities using textile pressure sensors, contributing to a lower risk of falling from the wheelchair.

2. Introduction

Along with longevity, labor shortages are becoming a severe problem in today's society, especially in nursing homes. Caregivers are not growing at the same rate as the aging population, making accurate monitoring difficult. It is not possible for a caregiver to monitor every movement of the elderly all the time, especially when they are sitting in a wheelchair. Accidents are more likely to occur when they try to stand up from the wheelchair. Also, many times these accidents occur in a location where it is difficult for a nurse to monitor these issues at all times.

On the other hand, in addition to the increase in the elderly population in Japan, dementia patients are also increasing rapidly. Based on data analysis results from research by Kyushu University, it is estimated that by 2025, 1 in 5 adults over 65 will be affected by dementia [1]. Movement and balance-related brain regions can be impacted by dementia. Many people with Alzheimer's disease or another kind of dementia eventually lose the capacity to move and carry out daily duties. Also, patients with dementia often forget their current state. As a result, they can fall when they suddenly try to stand up from their sitting position. In nursing homes, people with dementia experience fall an average of 4.05 times a year compared to 2.33 times annually for other patients [2]. To prevent these accidents, it is vital to establish the proper provisions after completing assessments on the relevant patients. Using a textile pressure sensor-based prediction system that alerts caregivers when patients attempt to stand up from their wheelchairs is one solution to this issue.

Electronic textile structures have attracted much attention over the past 20 years in research and development due to their innate softness, breathability, and flexibility. These features produce a satisfying platform for sensing various inputs like pressure, temperature, and strain [3, 4, 5]. However, to support the daily lives of the elderly, professional life-logging technologies have also started to arise, and context-aware solutions with sensor devices are being introduced. Attaching several sensors to the body makes it possible to obtain much information about human movement and activity. Wearable technology should be incorporated into daily life use products,

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as attaching several devices may involve labor or additional expense. At the same time, having many sensors attached to the body can feel unsteady for elderly or dementia patients. As a result, we concentrated on wheelchair cushions since they are commonly used for elderly and dementia patients and can be used to monitor body pressure and postural position, allowing us to get many data on human behavior.

If activity were predicted from the pressure sensors built into cushions, it would be possible to naturally sense human behavior during movement. This capability would be helpful in many situations, not only in daily life but also in nursing homes or hospitals. Also, such cushion-type technology would become comfortable for wheelchair users who are not used to charging or discharging devices, so they might be employed in technologies used for dementia patients or the elderly.

Currently, there are many methods of using wearable sensors for fall detection; however, the sudden effort of the elderly to stand up has never been predicted. Also, the ideal sensor configuration for predicting states must be thoroughly researched. The rate of unexpected falls will drastically decrease if we can investigate the posture movement before standing up and alert the nurses via the alarm system.

This paper proposes a method for predicting body postural movements before standing up from a wheelchair using e-textile pressure sensors embedded in wheelchair cushions. We designed a supervised machine learning model to address the trying-to-stand-up activity prediction system utilizing textile pressure sensor data. In a lab setting, we started by collecting a series of raw pressure data. The instances of raw data were then aggregated, with each instance labeled with the activity that took place while the data was being collected. Then, using machine learning techniques, we created predictive models for stand-up activity prediction systems.

The rest of the paper is organized as follows: Section 3 discusses the related research, then Section 4 describes the details of the proposed method, Section 5 analyzes the results, and finally, Section 6 summarizes the entire paper.

3. Related Research

Nowadays, detecting the posture and daily activities of the elderly is a hot research topic worldwide. These activities, or posture detection, are done with different sensors, such as accelerometers, gyroscopes, force, and pressure sensors. Because pressure sensor-based smart cushions are unobstructed, they have been used in various related studies to track the comfort and well-being, posture, fatigue, and physical activity of regular chair and wheelchair users [6, 7]. On the other hand, researchers have proposed many methods by which it is possible to detect the fall of the elderly. In this case, also, fall detection is done by various wearable sensors and cameras [8, 9, 10].

Xu et al. [11] proposed the smart textile-based sensor in the cushion to recognize human sitting postures. The binary representation of a gray-scale image was evaluated using data on the binary pressure distribution that had been collected. By employing dynamic temporal warping to analyze the pressure distributions, they could pinpoint specific postures of the sitting position. Also, Kamiya et al. [12] used an 8 x 8 pressure sensor matrix placed in a chair cushion to recognize the sitting postures. They used Support Vector Machine (SVM) with a radial basis function for classification.

On the other hand, Khan et al. proposed a camera-based technique for an abnormal human activity detection system [13]. They proved that this method could be used for elderly care using Kernel discriminant analysis and the Hidden Markov model. Similarly, Pavan et al. analyzed the video signals by applying manifold learning to identify human activities [14].

Sensor systems with early bed-leaving behavior predictions have been researched to prevent fall accidents. Asano et al. [15] proposed a depth camera-based detection system to avoid fall-related incidents. After optimizing parameters and motion variables with distinct participants' body size, location, and orientation, they used SVM to recognize bed-leaving behavior patterns. After 68 iterations, their experimentally produced result had a 92.65% recall rate. On the other side, the authors in [16] provided the bed-leaving behavior identification system. They employed bed pad sensors on a bed and a rail sensor placed inside a rail to detect bed leaving behavior. Additionally, they generated a benchmark dataset of ten subjects' continuous and discontinuous behavioral patterns. According to the experimentally collected results, Random forest achieved 91.1% accuracy in their benchmark dataset.

However, different bed-leaving sensors are now widely available from manufacturers. For instance, clip sensors, infrared (IR), and mat sensors are often used in hospitals and nursing homes. The most practical method currently available, clip sensors, is simple to use, but because they are fastened directly to the patient's nightwear, care recipients are confined by sensor wires. Furthermore, a care recipient's neck could get wrapped around a sensor wire. Consequently, the usage of clip sensors has recently been discouraged. Due to the lack of constraints, mat sensors which are more affordable than clip sensors, are frequently utilized in clinical settings. One drawback of mat sensors is that they take a long time to detect and react when a care recipient places their feet on the mat while seated at the bed terminal.

As clip and mat sensors have some drawbacks, and wearable sensors are always difficult to use for older adults, we proposed a textile pressure sensor-based stand-up activity prediction system that can prevent any accidental event in a nursing home. Our proposed method has been discussed in the following section.

4. Proposed Method

The smart wheelchair contains an e-textile pressure sensor in the seat cushion and the backrest. These sensor data can be used to recognize postural movement activities such as sitting, exercising, and trying to stand up. The pressure sensors must be connected to a Raspberry Pi via Bluetooth to get the raw activity data. When the device is connected, it can even detect very slight postural movement. Figure 1 shows the overview of our smart wheelchair. In this section, we discuss our proposed system architecture.

4.1. System Architecture

As it is a textile pressure sensor-based smart wheelchair system, the pressure sensor can detect when someone is sitting in a wheelchair. After that, the pressure sensor starts collecting each postural movement data. So, from that data, it is easily possible to recognize the users' regular activities. This system cannot be able to detect when someone is standing up from the wheelchair and fall immediately. Moreover, many established methods are available for fall detection-related alarm systems in nursing homes or hospitals. Nevertheless, when patients already stand up from their wheelchairs may already be too late for caregivers to take necessary actions. Keeping this in mind, we have proposed a system that can give an alarm when someone is trying to stand up from their sitting position.

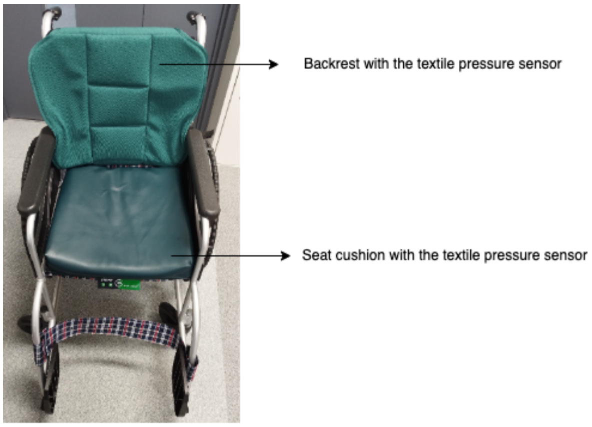

図 1　e-textile 圧力センサを搭載した車いす

Figure 1　Wheelchair with e-textile pressure sensors

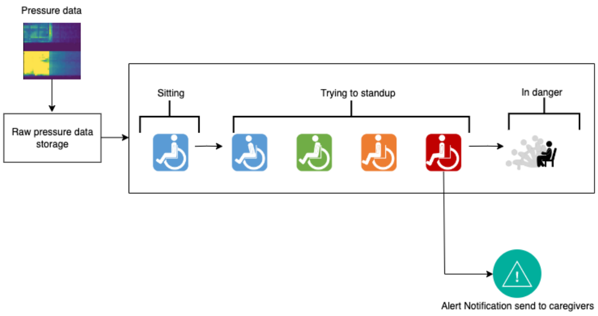

図 2　織物圧力センサを用いた転倒防止システムのアーキテクチャ提案

Figure 2　Proposed architecture of the textile pressure sensor-based fall prevention system

Figure 2 shows our proposed system architecture. Seat and backrest pressure sensors gather pressure data when a person is seated in a wheelchair. An older person or a patient's posture frequently alters as they attempt to stand up from a wheelchair. Their backrest pressure sensor and seat pressure sensor both experience a gradual reduction in pressure as they lean forward. They consequently slowly adopt a dangerous position. Our system alerts the caregivers to take action since the patient could unexpectedly stand up from the wheelchair or fall while seated in a risky position.

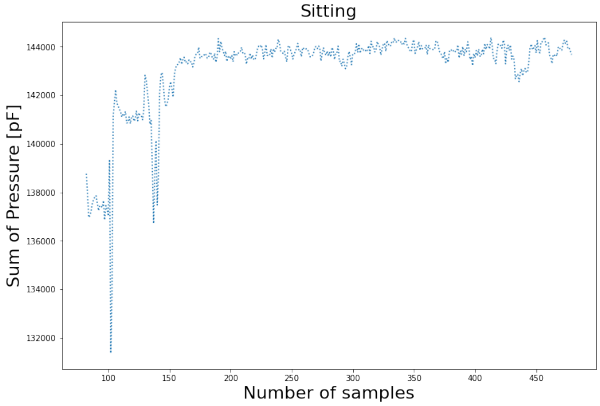

図 3　座位動作の圧力センサデータ（単位：約ピコファラド、pF）

Figure 3　Pressure sensor data for sitting activity (approximately in picofarad, pF)

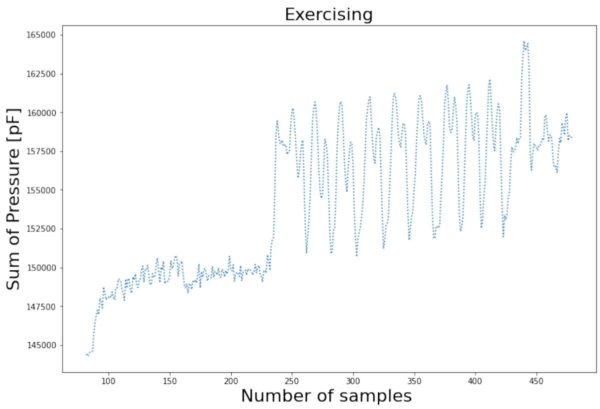

図 4　運動時の圧力センサデータ（単位：約ピコファラド、pF）

Figure 4　Pressure sensor data for exercising activity (approximately in picofarad, pF)

4.2. Experimental Setup

We collected a sequence of three activity data such as sitting, exercising, and trying to stand up using wheelchair pressure sensors. We analyze those data using a machine learning algorithm to predict the activity in different methodologies. The time duration for conducting each activity is 60 seconds. Data were collected at a constant rate of 8Hz from e-textile pressure sensors. For the first experiment, in the laboratory environment, we collected three subjects' data, and we considered 2-person data for training and different 1-person data for testing. Figures 3-5 show the sum of each activity's pressure data (approximately in picofarad, pF).

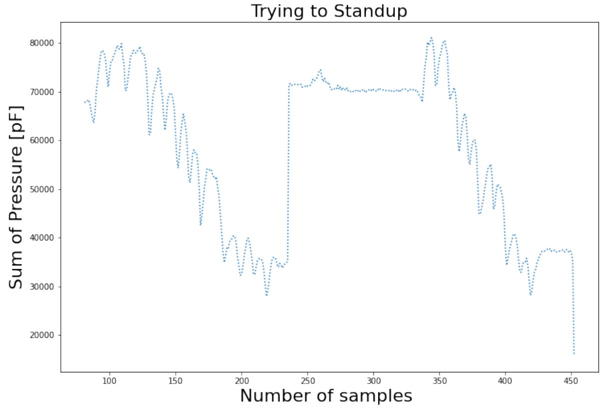

図 5　立ち上がり動作に挑戦する圧力センサデータ（単位：約ピコファラド、pF）

Figure 5　Pressure sensor data for trying to stand-up activity (approximately in picofarad, pF)

We obtained 16,000 columns of textile pressure sensor data for each activity in our experiments. Since the pressure sensor data is complicated, we did three experiments for better accuracy. We extracted mean, variance, minimum, and maximum features from the raw pressure sensor data for the first experiment. Using a 1-second window size, we set the features for 50% overlapping data. We used one traditional machine learning model K-Nearest Neighbor (KNN), for predicting the activity. In the second experiment, we extracted ten statistical features, i.e., mean, median, standard deviation (STD), minimum, maximum, median absolute deviation (MAD), interquartile range (IQR), Kurtosis, skewness, and variance. Then for the third experiment, we again collected data with one person on a different date. Moreover, we used the same subject data for training and testing, but they were collected on different dates.

5. Result Analysis

In the first experiment with four statistical features and one person leave out the method, we achieved 84% accuracy. For trying to stand up activity, we got 81% F1-score. Then we extracted six more statistical features, and with them, our model achieved 86% accuracy and 83% F1-score for trying to stand up activity prediction. In the personalized experiment, we achieved 91% accuracy and 94% F1-score for trying to stand-up activity prediction. The result of our experiment with trying to standup prediction demonstrates that adding more sta-

表 1　マルチクラス分類の結果

Table 1　Multi-Class Classification Results for three experiments, showing Macro average and weighted average for precision (Prec.), recall (Rec.), and F1-Score (F1)

Activities	**Experiment 1: Leave-one-out 4 features**			**Experiment 2: Leave-one-out 10 features**			**Experiment 3: Personalized models 10 features**		
	Prec.	**Rec.**	**F1**	**Prec.**	**Rec.**	**F1**	**Prec.**	**Rec.**	**F1**
Sitting	0.95	0.93	0.94	0.96	0.93	0.95	0.86	0.93	0.89
Exercise	0.87	0.68	0.76	0.86	0.75	0.80	0.90	0.93	0.91
Trying to Stand-up	0.73	0.90	0.81	0.78	0.90	0.83	1.00	0.88	0.94
Accuracy	0.84			0.86			0.91		
Macro Average	0.85	0.84	0.84	0.87	0.86	0.86	0.92	0.91	0.91
Weighted Average	0.85	0.84	0.84	0.87	0.86	0.86	0.92	0.91	0.91

Prec.: Precision, Rec.: Recall, F1: F1-Score

tistical features has increased the accuracy of our model. In particular, we observed that the accuracy of our model improved from 84% to 86% when utilizing a one-person leave-out method by increasing the number of statistical features from four to ten. Table one shows the detail prediction result. From experiment 1 and 2, we observed that with one person leave out method, exercise data are mostly misclassified with trying to stand up activity data. However, we achieved the highest accuracy with the personalized model because of less misclassification between exercise and trying to stand up data. Figure 6-8 shows confusion matrix for each experiment, respectively.

6. Conclusion

The smart technology described in this paper uses e-textile pressure sensors and machine learning algorithms to detect attempts to stand up by wheelchair users. This system's deployment attempts to reduce the possibility of unintentional falls happening in healthcare facilities, including hospitals and nursing homes. The personalized model showed the highest level of accuracy at 91% by combining a pressure matrix array configuration with the KNN algorithm. According to these findings, a wheelchair system with an e-textile pressure sensor is a helpful tool for preventing unexpected falls. The suggested technology is intended to anticipate attempts to stand up from a wheelchair, which can also carry a significant risk of injury.

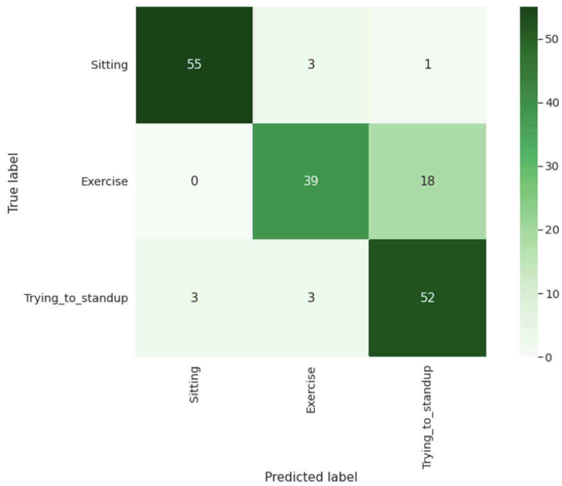

図 6　4 つの特徴量の場合の混同行列

Figure 6　Confusion matrix with 4 statistical features

In summary, the safety and well-being of older adults and dementia patients at risk of falling can be significantly improved using e-textile pressure sensors in fall prevention systems. These sensors can recognize movement patterns and pressure variations, enabling early identification of falls and other abnormalities. These devices can assist in preventing falls and lowering the risk of injuries by providing real-time feedback and alarms to caregivers and healthcare professionals. E-textile pressure sensors have the potential to be an essential factor

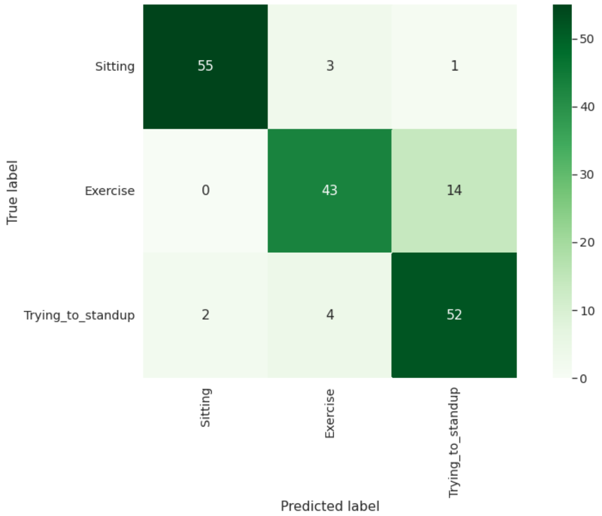

図 7　10 個の特徴量の場合の混同行列
Figure 7　Confusion matrix with 10 statistical features

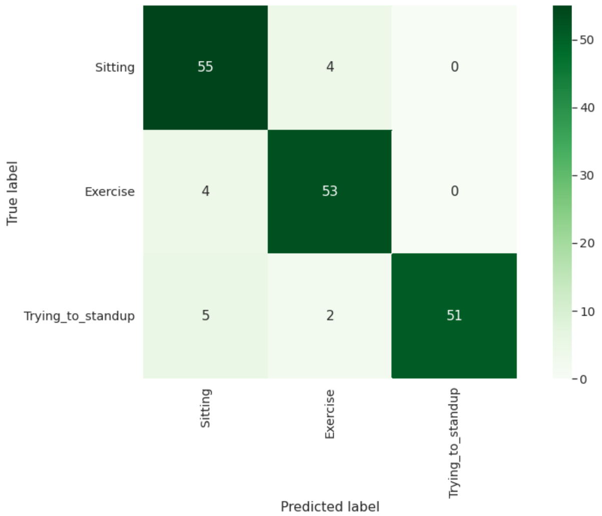

図 8　10 個の特徴量の場合の個人化モデルの混同行列
Figure 8　Confusion matrix for personalized model with 10 statistical features

in the ongoing endeavor to enhance fall prevention techniques and support healthy aging. In the future, we will collect real-field data from nursing homes to make this system more robust and valuable.

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