An Estimation of Road Surface Conditions Using Participatory Sensing

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Abstract

When natural disasters occur, some roads could be blocked and cannot be used. Road surface conditions also deteriorate. Thus, collecting and providing the information on usable roads and road surface conditions can allow people to be evacuated safely. In this study, we proposed an estimation system of the road surface conditions by collecting accelerometer data from pedestrians' smartphones. The method estimates whether the road surface condition is a flat pavement road, a rough road, a slope or a stair by using supervised machine learning method. From the results of experiment, we found that the system can estimate six types of road surface conditions with a high accuracy when training the model with the data from the users.

Keywords: Smartphone, participatory sensing, machine learning, road surface conditions

1. Introduction

When natural disasters occur, some roads could be blocked and cannot be used. Road surface conditions also deteriorate due to such factors as wooden branches, rubble and fragments of window glass. These are difficult to pass or use by injured people, pregnant woman and elderly people and may lead a tripping hazard. Hence, collecting and providing the information on road surface conditions can allow people to be evacuated safely after a natural disaster occurrence.

In this study, we propose an estimation system of the road surface conditions after a natural disaster by using pedestrians' smartphones. In addition, we evaluate the usability of the proposed estimation method based on the accuracy evaluation.

2. Related Research

A previous study [1] proposed a safety route guidance system which can be used after a natural disaster by using a participatory sensing. The system generates an evacuation map by using collected GPS data from users' smartphones during walking. Moreover, the system has a capability of detecting risk locations and safe locations by the data from accelerometer. If a three-axis composite acceleration exceeds a threshold value, the system determines that an accident occurred, such as a tumble and a stumble. However, it is not enough to use only the threshold value when the system detects the tumbles and the stumbles.

Methods for estimating road surface conditions by using sensors attached to a wheeled vehicle have been proposed [2][3]. Those methods can estimate road conditions for user of vehicles with high accuracy. However, it's difficult to estimate road conditions for pedestrians. This is because, after natural disasters, pedestrian can go to evacuation area by using any route or by walking through gardens, collapsed buildings, fields, narrow roads. Vehicles cannot pass through such places. An estimating method by using sensors attached to pedestrians' shoes have also been proposed [4]. In the method, sensors need to be attached to user's shoes in order to operate the system.

In order to immediately collect road surface information of pedestrians, we propose a method using the pedestrians' smartphones as sensor device.

3. Proposed System

The system overview is shown in Figure 1. First, the system collects accelerometer data and GPS data from pedestrians' smartphones during walking and these data will be sent to the server. Second, the server stores the received data in database and generates a usable route map by using the GPS data. Then, the system does not consider default maps information, because survivors can go to evacuation area by walking through gardens, collapsed buildings and fields. Thus, the system generates nodes and links by comparing between the collected data [1]. In addition, the server estimates the road surface conditions by using accelerometer data. The details of method for estimating road conditions are described in Chapter 4. The information of the estimated road conditions will be linked with the

GPS coordinates. Finally, the estimated road conditions will be sent to user as a map which will be sketched the road conditions of each route by using color.

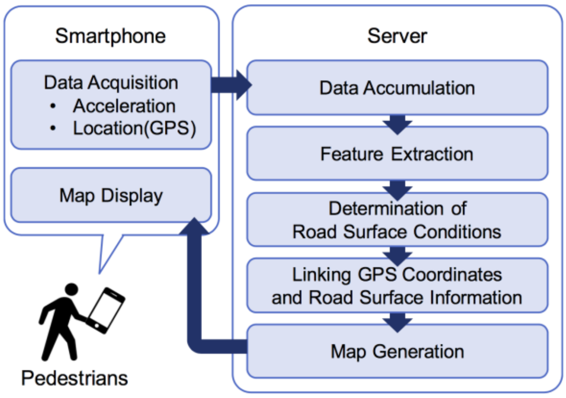

Figure 1. Road Surface Estimation System

4. Estimation of Road Conditions

4.1. Data Collection

Three-axis acceleration data during walking are collected from user's smartphone. We assume that the smartphone is placed in a pocket of clothing so that they can walk with both hands free during the evacuation. It is difficult to have the users' smartphones in the desired direction. For this reason, we use a three-axis composite acceleration as the accelerometer data. In addition, the collected data include the effects of the gravity. From this, we remove the effects of the gravity by using high-pass filter.

4.2. Feature Extraction

Several features are extracted from collected acceleration data. As a first step of this study, we use features such as mean, variance, standard deviation, root mean squared (RMS), maximum and minimum, autocorrelation coefficient, peaks of spectral. These feature values are extracted for each data of x-axis, y-axis, z-axis, and three-axis composite acceleration, and 84 features are extracted for each data.

4.3. Classification

We use Support Vector Machine (SVM) [5] as the training algorithm. SVM is a supervised machine learning algorithm and is used for classification. We prepare a set of training data by gathering a plurality of accelerometer data of each road surface conditions and extract feature values of the training data. Given the set of the training data, SVM builds a classification model of the road surface conditions. The system can estimate the road surface condition of new given data by using the generated classification model.

5. Experiment

5.1. Experimental Environment

We conducted experiments to evaluate the usability of the proposed estimation method based on the accuracy evaluation. In this experiment, six types of road surface conditions were estimated as shown in Table 1. It was difficult to regenerate assumed the road surface conditions after a natural disaster, therefore we chose the road surface conditions which is difficult for people, especially injured persons and pregnant women, to walk on. We collected accelerometer data during walking on each road surface from eight subjects by using our sensing application. Figure 2 shows the mounting position of a smartphone during data collection. A smartphone is placed in a front pocket of pants in this experiment. We used Xperia Z3 and Xperia M for collecting accelerometer data and the sampling frequency was set to 100 Hz. The collected data was separated every 2.56 seconds, and a dataset was created by extracting the feature values for each separated data. The number of separated data for each condition is shown in Table 1. We used scikit-learn library of Python for implementation of SVM.

In this experimental environment, we obtained the accuracy rate for two cases.

(1) Both the test data and the training data included data from all subjects

(2) The test data consists of data from one subject and the training data consists of data from the other subjects

Table 1: Collected Data

Road Surface Conditions	Number of Data
(a)Flat Paved Roads	1481
(b)Rough Roads	855
(c)Up Stairs	244
(d)Down Stairs	245
(e)Upslope angles of 5° or above	612
(f)Downslope angles of 5° or above	619

Figure 2. Mounting Position of User' Smartphone

5.2. Results and Discussion

Table 2: The Accuracy of Each Road Surface Conditions in Case 1

Labels	Precision	Recall	F1-score
a	0.8987	0.8871	0.8929
b	0.8118	0.8779	0.8436
c	0.9130	0.8936	0.9032
d	0.9744	0.8261	0.8941
e	0.8016	0.8080	0.8048
f	0.8824	0.8607	0.8714

Table 3: The Confusion Matrix in Case 1

		Estimated Labels					
		a	b	c	d	e	f
True Labels	a	275	16	1	0	17	1
	b	7	151	1	0	6	7
	c	0	3	42	1	1	0
	d	2	0	2	38	0	4
	e	14	8	0	0	101	2
	f	8	8	0	0	1	105

In case 1, the prediction accuracy was 86.61%. Table 2 shows the accuracy rate of each road surface conditions and table 3 shows the confusion matrix. The accuracy of stairs (label: c, d) was especially high, and both the up stairs and the down stairs was classified with accuracy greater than 90%. The other four conditions (label: a, b, e, f) are also identified with accuracy of 80% or more, however, there are many wrong discrimination between the four conditions. Therefore, it is necessary to consider feature extraction methods which are effective to identify of the four conditions.

In case 2, the average prediction accuracy was 40.96%. In particular, the accuracy for two subjects was lower than 30%, and the two subjects walked faster than the other subjects. This result occurred because the number of subjects was small, therefore, we need to collect more data by having more subjects. Moreover, it is necessary to use more effective features.

For the future work, we are going to implement other feature extraction methods to improve accuracy in case 2. For example, Cepstral analysis is commonly used for speech recognition. Cepstral analysis is used to separate between the spectrum envelope and the fine structure of a spectrum. The spectrum's fine structure is a finely fluctuating element that is easily affected by acquisition environment such as road surface conditions. Therefore, we considered that cepstral analysis can be used for the estimation of the road conditions. In addition, when walking on rough roads, step size has a tendency to vary as compared with the case of walking on the other road conditions. Therefore, we are going to consider to use the change in step size during walking to estimate rough roads.

6. Conclusion

In this paper, we proposed an estimation system of the road surface conditions after a natural disaster by collecting accelerometer data from pedestrians' smartphones. The method estimates whether the road surface condition is a flat pavement road, a rough road, a slope or a stair by using supervised machine learning method. The results of experiment revealed the system can estimate six types of road surface conditions with high accuracy number of 86.61% in the best case. We are planning in the future work to implement effective feature extraction methods and collect more data by having more subjects in order to improve the prediction accuracy.

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