Accelerometer-based Smartphone Step Detection Using Machine Learning Technique

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***Abstract*—Under the limitation of GPS measurement in indoor environment, one of alternatives for smartphone navigation is using embedded inertial sensors. In order to perform pedestrian dead reckoning with accelerometers and gyroscopes, step should be preferentially detected. In addition, there are a variety of smartphone placements such as handheld, texting, and trouser pocket. In this paper, step detection methods for various placements of smartphone are proposed using machine learning technique and attitude computation of the device. The experimental results show that the proposed method is able to detect steps robustly under handheld, texting, trouser back and front conditions.**

Keywords— step detection; PDR(Pedestrian Dead Reckoning); Smartphone;

I. INTRODUCTION

Pedestrian dead reckoning (PDR) is a type of pedestrian navigation system (PNS) based on inertial sensors, which does not rely on infrastructure. A microelectromechanical systems (MEMS) inertial measurement unit (IMU), which contains three-axis accelerometers, gyroscopes, and magnetometers, is used to estimate pedestrian positions in a PDR. Over the past few years, MEMS technology has allowed the production of small, low-power, accurate, and inexpensive systems. MEMS technology also has useful properties for portable navigation systems, but the performance of low-cost MEMS technology remains relatively poor. Therefore, various types of PDR algorithms have been developed to offset the disadvantages of this type of technology. Given the amounts of time people spend indoors, the demand for indoor navigation systems is increasing with the increased number of complex and very large buildings such as shopping centers. In indoor environments where GPS is unavailable, the wide adoption of smartphones with embedded sensors provides new opportunities for research on indoor positioning.

Inertial sensor-based navigation system for pedestrian is referred to as PDR system which is one of indoor PNS. PDR is a dead-reckoning system which assumes that the position of a pedestrian changes with step movements. Hence, PDR estimates the position of a pedestrian by observing the movement of steps and integrating inertial sensor measurements overtime. Smartphone-based indoor navigation systems are normally based on a PDR algorithm which is independent of the integration of acceleration outputs. In order to implement a PDR system based on a smartphone, several steps are necessary. A smartphone-based dead-reckoning (DR) system is composed of a step-detection algorithm along with step-length estimation and heading estimation steps. In a smartphone-based DR system, the position of a pedestrian is calculated using the step length and heading estimation between each detected step. Therefore, accurate step detection is the foundation upon which precise estimates of the position can be made in the PDR method. Even if the step length step detection algorithm is accurate, errors when estimating the position can be considerable due to inaccuracies in the step detection process. There are several existing step detection techniques, including the peak detection method, the zero-crossing detection method, and the stance-phase detection method, as shown in figure 1 [1]. These methods use the outputs of accelerometers and gyros [1]-[3]. The peak detection method has the advantage of being able to detect a step accurately at the moment of a heel strike, but there is a high possibility of misdetection in case local minimum for the various speed of pedestrian. The zero crossing method is easy to implement the algorithm to the system but sensitive to the jitter around threshold. Lastly, the stance-phase detection method which is also called as flat zone detection works well when sensor is attached to the foot. However, detecting zero velocity zone is hardly made under the condition that user is carrying a smartphone on hand or backpack.

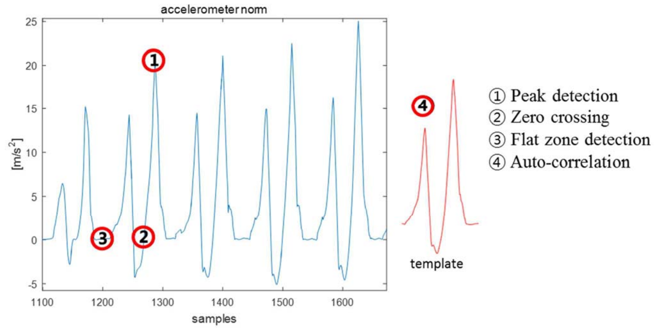

Fig. 1. Step detection algorithm

When it comes to navigate a pedestrian with smartphone or tablet, placements of the device should be considered. According to the Brajdic and Harle, the possible placements for

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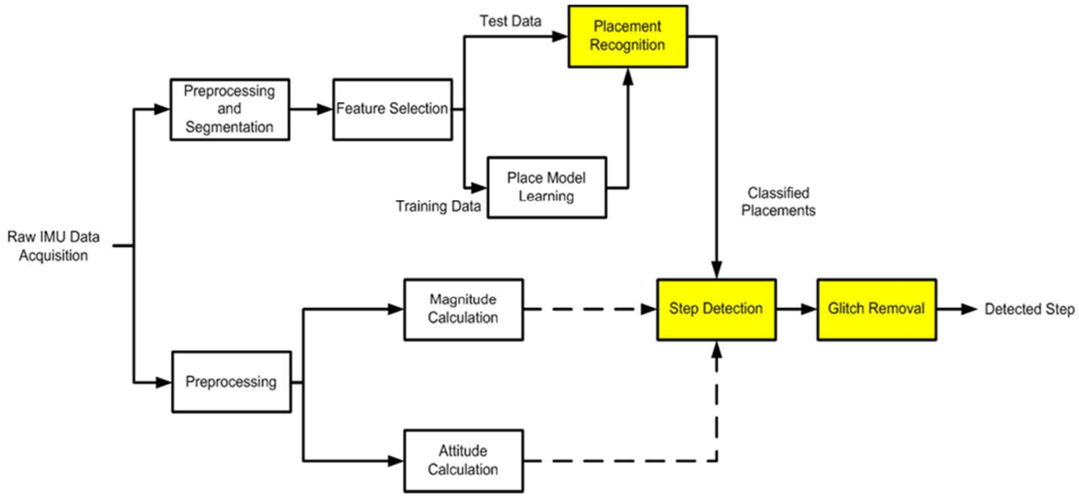

Fig. 2 Placement recognition-based step detection algorithm

unconstrained smartphone include handheld, texting, calling, trouser back and front pocket, handbag, backpack, and shirt pocket [4], and those are usually classified through the machine learning techniques.

In this paper, step detection methods of smartphone for PDR based on accelerometer using support vector machine (SVM) are proposed. To be specific, the status of smartphone is classified using the SVM classifier, and zero crossing method detects steps with accelerometer and attitude features the following the placements.

The rest of the paper is organized as follows. In section 2, the overall step detection algorithm with placement recognition is proposed. Section 3 and 4 describes experimental results using unconstrained smartphone walk data and conclusion, respectively.

II. Overall Step Detection Algorithm

The overall step detection algorithm considering the placements of unconstrained smartphone is shown in figure 2, which are largely composed on three parts. Firstly, SVM classifies current place of the device. Then the step is detected using accelerometer magnitude and calculated sensor attitude with the zero crossing method. In order to remove detection errors around zero, the frequency of user is considered.

A. Placement Recognition

Prior to step detection, the placement is recognized for increase in the detecting accuracy. For example, the trend of signal is different following the position of the device even if pedestrian walks in a same manner. Therefore, the representative supervised learning based classifier, SVM, is adopted for the classification due to its high accuracy result on average. Once inertial data is acquired from the smartphone, preprocessing and data segmentation are performed. Then, feature vector generated by tri-axial accelerometer and gyroscope data is selected for the efficiency of the classification. Using the selected features, placement training model for the classifier is determined beforehand, and placement recognition result is classified in real-time with the training data. The target placements for unconstrained smartphone in the paper are handheld, texting, calling, and trouser front and pack pocket because those are the commonly happened positions in general for daily smartphone usage.

B. Step Detection

Using the information of the classified smartphone placement by SVM, step is detected using zero crossing methods. In case of trouser front pocket and handholding case including texting and calling, the device is able to move freely while walking, so magnitude of accelerometer shows the motion flow of a pedestrian well. However, when smartphone is placed at the back pocket of the user, it is hardly moving during motions. In addition, it is close to the pivot of legs which reflects high angular motion of user but low acceleration magnitude. Therefore, attitude in Eq. (1) is additionally calculated using accelerometer output with gravitational vector. With the mentioned data, accelerometer magnitude and sensor attitude, step is able to detected while the data is crossing zeros.

$$\phi = \tan^{-1}\left(\frac{f_y}{f_z}\right), \theta = \tan^{-1}\left(\frac{f_x}{\sqrt{f_y^2 + f_z^2}}\right) \qquad (1.1)$$

C. Glitch Removal

When the generated signal for step detection crosses over zero in short period of time, detection error is repeatedly caused. In addition, there are additional errors when the speed of a pedestrian is changed. In order to eliminate possible misdetections, walk frequency of a user is considered. If the candidate steps using zero crossing are less than half of the walking frequency, it is eliminated as a misdetected step.

III. Experimental Results

In order to prove the performance of the proposed algorithm, the actual data in [5] collected from smartphone, Galaxy Nexus, is adopted for the test. The sampling rate of the collected data is 100Hz. Test subjects are 27 in total ranging from the age of between 15 and 29 year old. There are 9 women and 18 men with various heights. Multiple smartphones are placed on the various positions such as hand and trousers, and they are instructed to walk in normal, slow, and fast speed in a certain point.

A. Placement Recognition Results

Trained and classified smartphone placement based on SVM is in table 1. The open source code for SVM is adopted for the results [6]. The overall classification accuracy is 97.32% on average, and the recognition errors of handheld data are mainly data imbalance of the calling situation. The trouser classification errors are caused by the phone orientation change while walking.

B. Step Detection Results

Zero crossing based step detection results are represented in table 2 and figure 3. In case of handheld and trouser front pocket experiments, accelerometer magnitude based step detection shows high accuracy compared to peak detection method also commonly used in smartphone step detections. Wrong steps are frequently detected with peak of accelerometer signal under the change of the user speed due to local maximum errors. When the device is placed in back pocket of trouser, the magnitude based method which works well in other places is unable to detect correct steps, but the detection with calculated attitude shows high accuracy over the whole speed-changing trajectory. Meanwhile, computational time to detect the given test data of 27 people is less than 40 seconds in MATLAB software, which could be implemented in further development of the PDR system.

IV. CONCLUSION

In this paper, step detection methods considering smartphone placements are proposed. The place recognition is primarily made through a SVM classifier, and steps are detected based on zero crossing method with magnitude of accelerometer and attitude of the sensors. The proposed algorithm is able to detect steps accurately even under the condition that a pedestrian changes speed while walking regardless of the placements. The overall accuracy of the step detection algorithm is 97.09%.

TABLE I. SVM-BASED SMARTPHONE PLACEMENT RECOGNITION

Accuracy [%]	Handheld	Trouser Pocket (Back)	Trouser Pocket (Front)
Handheld	98.13	0.32	1.56
Trouser Pocket (Back)	0.00	94.83	5.17
Trouser Pocket (Front)	0.00	0.99	99.01

TABLE II. STEP DETECTION ACCURACY

	Handheld	Trouser Pocket (Back)	Trouser Pocket (Front)
Accuracy [%]	98.70	96.46	96.12

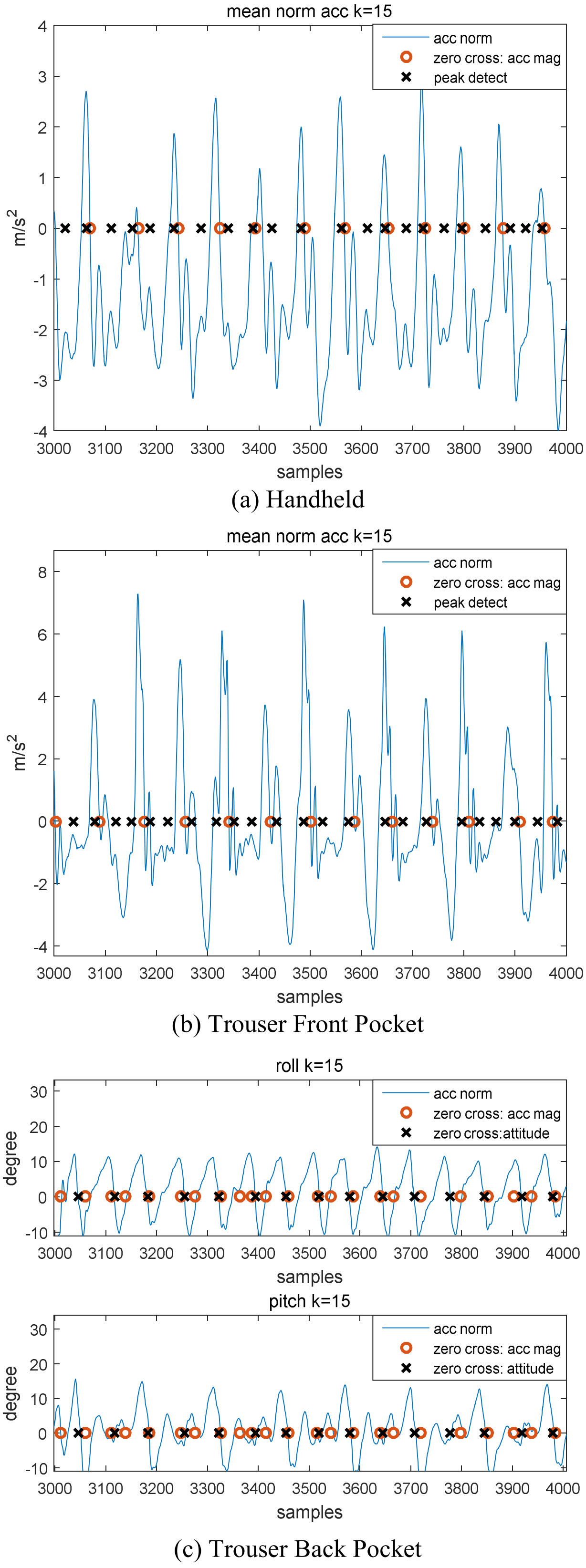

Fig. 3. Step detection results of various placements

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