Sit-Down and Stand-Up Awareness Algorithm for the Pedestrian Dead Reckoning

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ABSTRACT

In this paper we present an context awareness algorithm of sit-down, stand-up and walks behaviors of a pedestrian for an adaptive step length estimation algorithm of PDR (Pedestrian Dead Reckoning). PDR consists of MEMS accelerometers, gyros and magnetometers. In general PDR is attached to a body of the pedestrian and provides the position information of the pedestrian. The developed PDR is assumed that it is embedded in the cellular phone. Thus only a single sensor module is used to develop the context awareness algorithm. In order to compute the walking distance precisely, various behaviors must be classified estimated as well. PDR detects steps of the pedestrian and estimate step length and heading. It means that large step detection error can cause large position error in PDR. Therefore, it is necessary for PDR the context awareness algorithm. In this paper, we classified sit-down, stand-up and walking of pedestrian using a variance of horizontal attitudes (roll and pitch) of the PDR module and the norm of the horizontal accelerations in the navigation frame. The developed method can be applied to USN (Ubiquitous Sensor Network) and u-health monitoring system for the mobile system.

I. INTRODUCTION

The navigational techniques for providing the position information of vehicles have been adopted for computing that of a human. PDR system requires low-power on-body wireless sensors attached to mobile users that interact with an ubiquitous computing environment. Recently PDR has been researched actively. PDR is one of many applications based on the MEMS accelerometer and gyro. Also PDR is very useful in providing the human's walking distance regardless of indoor or outdoor.

The portable navigation system has been developing based on the E911 (Enhanced 911) implementation requirements. The portable navigation system has been implemented using GPS, CDMAs pilot signals, AGPS/TDOA, etc. However, these techniques have several limits such as restrictions on the use of GPS signals, many error sources in the CDMA signals, etc.

Another research area for the navigation system is MEMS based pedestrian navigation system. In recent years, MEMS technology has allowed production of inexpensive lightweight and small-size inertial sensors with low power consumption. These are all desirable properties for components of a portable navigation system. The quality of the MEMS inertial sensors is, however, conspicuously low. So, a new algorithm is required to enhance the performance of the portable navigation system implemented using the MEMS inertial sensors. The technical limit and necessity led the development of algorithms for PDR. Provided that a pedestrian moves only by walking behavior, PDR is based on the step information, which can be obtained using inertial sensors. The main idea is to find accurately the walking distance from the number of steps and the estimated step length. PDR can be utilized anywhere, anytime and any circumstances because it is autonomous and not susceptible to external jamming.

One of the key difficulties in PDR is to estimate the step length according to the status of walk or run. Various systems and algorithms for PDR have been introduced. Most of the proposed methods utilize inertial sensors and step detection algorithms. *Jirwimut* modeled the step length error as a first-order Gauss-Markov process, and the step length is estimated using a Kalman filter and GPS [1]. The step length is modeled as a linear combination of a constant and step frequency [2], as that of a constant, step frequency and variation of the accelerometer [3,4], or as that of a step frequency, variance of the measured acceleration magnitude and the vertical velocity [5]. *Sagawa* and *Cho* calculated the step length by integrating the accelerometer and compensating for the bias using the information that the velocity of the foot is zero when the walking phase is a stance phase [6,7]. *Gabaglio* modeled walking speed as a linear combination of a constant and a function of acceleration variability [8]. *Aminian* proposed a neural network to estimate the inclination and the walking speed [9].

The research about the awareness of the user's context has been performed. Attempts have been made at recognizing user's activity from accelerometer data [10,11]. Bao & Intile have used 5 biaxial accelerometers on different parts of the body as they performed a variety of activities like walking, sitting, running, etc[12]. Lukowicz & Ward have developed the recognizing workshop activity using body worn microphones and accelerometers[13].

In this paper we propose the context awareness algorithm of sit-down, stand-up and walks behaviors of a pedestrian for an adaptive step length estimation algorithm of PDR. Section II describes the PDR hardware module. In section III, the walking navigation algorithm we used are introduced. Section IV presents how to recognize the sit-down, stand-up and walks. Experimental results are described in section V. Finally, the conclusions are drawn in Section VI.

II. SYSTEM DESCRIPTION

So far, several types of PDR are proposed on the papers and patents. The system can be attached on the pedestrian. The proposed system consists of 3-axis accelerometer, 3-axis gyros, 3-axis magnetometers and a bluetooth module. The components of the system are small-sized and low-cost. Figure 1 shows the developed MEMS-based personal navigator.

Figure 1. PDR module

III. WALKING NAVIGATION ALGORITHM

A. Step Detection Algorithm

Recently, step detection methods using accelerometers have been presented in PDR investigation. There are three types of methods: peak detection, zero crossing detection and flat zone detection using acceleration differential. The peak detection method is not appropriate to detect steps because the peak of the accelerometer output is greatly affected by the user's walking velocity.

The flat zone of the signal is not detected when the accelerometer is attached to the user's waist belt. In this paper, therefore, the user's step is detected using a zero crossing method which is resilient to the user's walking velocity.

The accelerometer sensors attached to the body are influenced not only by the acceleration of the body but also noise and other factors such as the bias of the accelerometer, gravity, etc. In order to remove the noise, the signal is summed over the sliding window established previously and is differentiated to eliminate various error sources. The step is detected with this signal. Figure 2 shows the result of step detection algorithm.

B. Step Length Estimation Algorithm

According to the result of our investigation, the step length is influenced in linear pattern by walking frequency and a variance of the accelerometer signals during one step. Figure 3 shows the relations between step length and walking characteristics such as walking frequency and acceleration variance.

Therefore we can determine the step length using a linear combination of walking frequency and variance of the accelerometer as Eq. 1 and Eq. 2. Eq. 1 shows step length and Eq. 2 shows walking distance. The linear combination is pre-learned during a pre-calibration stage.

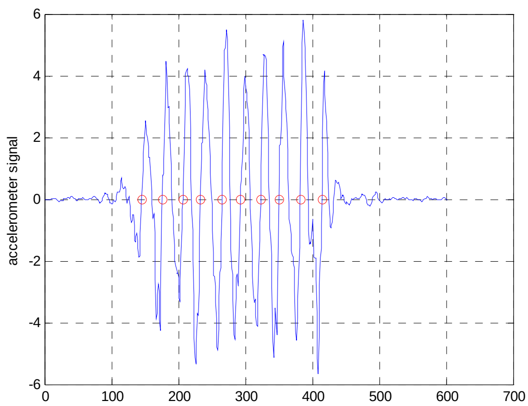
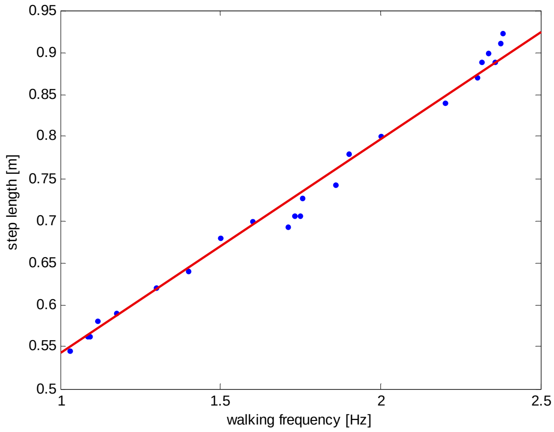
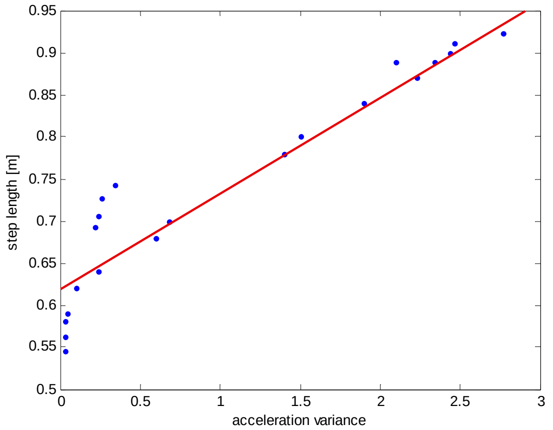


Figure 2. Step detection



(a) Walking Frequency versus step length



(b) Acceleration Variance versus step length
Figure 3. Walk data for learning

$$\text{Step Length} = \alpha \cdot f + \beta \cdot v + \gamma \qquad (1)$$

$$\text{Walking distance} = \sum_{i=1}^{n} (\alpha \cdot f_i + \beta \cdot v_i + \gamma) \qquad (2)$$

where,

α, β = weights of walking parameters

γ = constant

f_i = walking frequency of the i-th step

v_i = acceleration variance of the i-th step

Thus step detection is an easy problem in PDR investigation as a whole. If, however, there are some false or miss detections, it can cause considerable error in the estimation of a total walking distance. Because the total walking distance is calculated using the summation of every estimated step length. But various behaviors of the pedestrian like sit-down, stand-up can cause false step detection. Because when the pedestrian sits down and stands up there is the zero crossing point of the accelerometer signal, too. Therefore the context awareness algorithm for sit-down, stand-up and walks is required.

IV. CONTEXT AWARENESS ALGORITHM OF SIT-DOWN AND STAND-UP

User context awareness is one of the important concepts for application services in the ubiquitous computing environment. In general, user context means user's posture, movement, situation and etc. When developing context-aware systems, a practical and reliable context inference method is positively necessary. In order to enhance the performance of the PDR accuracy, context awareness algorithm which can recognize postures (sit-down and stand-up) is proposed.

The developed PDR is supposed to be embedded into a cellular phone and the PDR is assumed to be located on a pedestrian's waist belt. In this work, two parameters are used to develop the sit-down/stand-up awareness algorithm. These are the variance of horizontal attitudes of the PDR module and the norm of the horizontal accelerations in the navigation frame. According to our experiments, the variation of the attitude (roll and pitch) of sit-down/stands-up is larger than that of walks. Fiture 4 shows this feature. When the variation of roll and pitch angle is larger than the threshold, the context of the pedestrian is sit-down or stand-up. This is why the movement of the waist of the pedestrian is large when the pedestrian sits down and stands up.

And the norm of horizontal acceleration in the navigation frame is small when the pedestrian sits down and stands up. Figure 5 shows the norm of horizontal acceleration in the navigation frame. When the pedestrian sits down and stands up, displacements of the PDR module attached to the waist belt are very small. On the other hand, it is pretty straightforward that the displacement of the waist is much large when the pedestrian walks in figure 6..

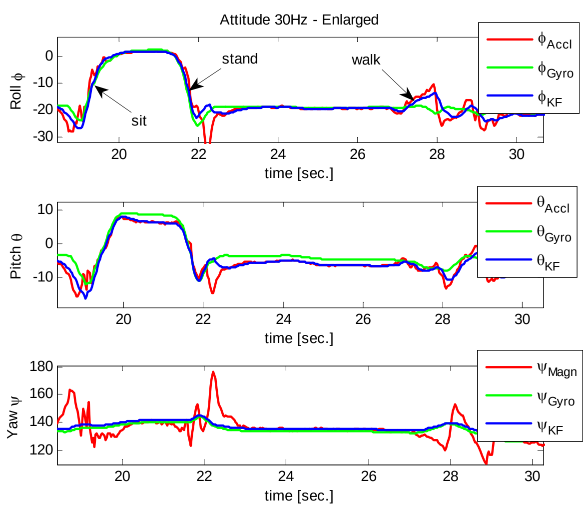


Figure 4. Attitude of the PDR module

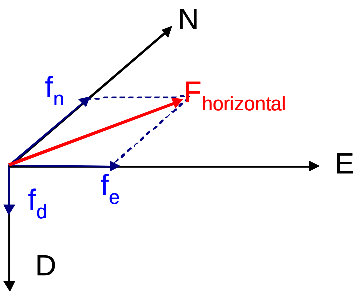


Figure 5. The definition of the horizontal acceleration norm in the navigation frame (NED frame)

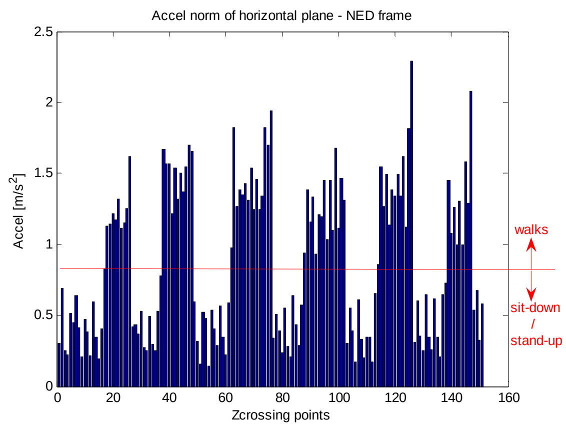


Figure 6. The norm of the horizontal acceleration in the navigation frame

If the variance of the attitude is large enough and the norm of the horizontal acceleration is small, the context is most likely sit-down/stand-up. Otherwise it is most likely walk. The adaptive step length estimation algorithm based on sit-down/stand-up awareness algorithm is developed using these two parameters. When the context is 'walk', PDR estimates the step length of the pedestrian. When the context is 'sit-down/stand-up', however, PDR determines the step length is zero.

V. EXPERIMENTAL RESULTS

Walking tests were conducted in order to verify the performance of the proposed adaptive step length estimation algorithm based on the sit-down/stand-up awareness algorithm. Step length estimation parameter learning is first done on the appropriate trajectory. And then tests were performed on the assumption that pedestrians normally walk and run. Highly non-uniform motions such as pedestrians commute, which might be found during daily life, were not considered. As a result, the error of the sit-down/stand-up awareness algorithm is about 10% at the worst.

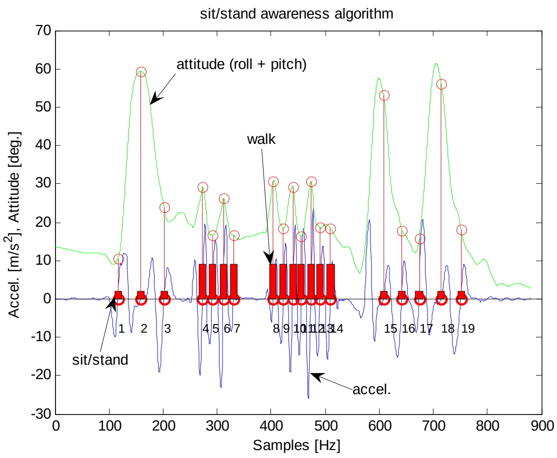


Figure 7. The result of the awareness algorithm

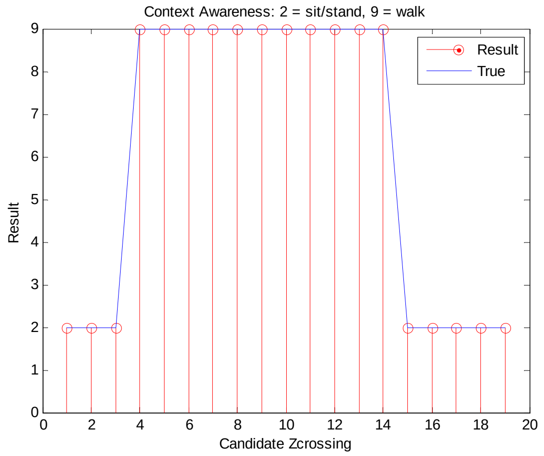


Figure 8. The result of the awareness algorithm (enlarged)

Table 1. The result of the adaptive step length estimation algorithm (without context awareness)

	Without context awareness		
	True [m]	Result [m]	Error [%]
1	28.4	42.0539	48.0771
2	56.8	89.5592	57.6747
3	56.8	88.0623	55.0393
4	56.8	95.9199	68.8730
5	56.8	106.9398	88.2743

Table 2. The result of the adaptive step length estimation algorithm (with context awareness)

	With context awareness		
	True [m]	Result [m]	Error [%]
1	28.4	28.7971	1.3982
2	56.8	54.5424	3.9476
3	56.8	59.5942	4.9194
4	56.8	59.1458	5.1458
5	56.8	59.5639	4.8661

If the variation of the attitude is large enough and the norm of the horizontal acceleration is small, the context is most likely sit-down/stand-up in figure 7. Otherwise it is most likely walk. Figure 8 is an enlarged figure 7. The adaptive step length estimation algorithm based on sit-down/stand-up awareness algorithm is developed using these two parameters. When the context is 'walk', PDR estimates the step length of the pedestrian. When the context is 'sit-down/stand-up', however, PDR determines the step length is zero. Table 1 and 2 show the result of the adaptive step length estimation algorithm using the sit-down/stand-up awarenss.

VI. CONCLUDING

This research demonstrates the context awareness algorithm of sit-down/stand-up and walks behaviors of a pedestrian for an adaptive step length estimation algorithm of PDR. In order to develop the sit-down/stand-up awareness algorithm, two features are used (the variation of the horizontal attitude of the PDR module, the norm of the horizontal acceleration in the navigation frame). In order to verify the performance of the proposed algorithm, walking tests are conducted. Results show that the proposed the context awareness algorithm for the adaptive step length estimation algorithm can inprove the accuracy of the walking distance estimation of the pedestrian.

ACKNOWLEDGEMENTS

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