Real-Time Estimation of Distance Traveled by Cart Using Smartphones

Phuc Huu Truong, Sung-Il Kim, and Gu-Min Jeong

***Abstract*— In this letter, we propose a new method for the real-time estimation of distance traveled based on double integral of acceleration. In smartphone pedestrian dead reckoning systems, locomotion models have been widely applied to estimate the traveled distance. However, for the cart movement, these models cannot be used. In this letter, a direct double integration-based method using a smartphone is presented for the estimation of cart movement. The experimental results show the proposed method outperforms other referenced methods in terms of efficiency.**

***Index Terms*— Movement distance estimation, cart, tri-axial accelerometer, smartphone.**

I. Introduction

THE need to execute indoor positioning applications in smartphone has grown recently, due to the fact that accurately locating a user's position makes it possible to provide efficient position-based services and information to the user [1]. Numerous studies have been conducted to address indoor positioning using smartphones [2]–[4]. A popular approach to locating a user's position is to continuously measure the traveled distances of the user using sensors in a smartphone such as accelerometer, compass and gyroscope sensors. Weinberg [5] utilized the movement of the body along the Z-axis to estimate the distance traveled. Capela *et al.* [6] analyzed the movement characteristic of the human leg to estimate the distance traveled. However, these methods become ineffective when applied to measuring the distance traveled by carts. Because the cart moves by the turning of its wheels, step estimation cannot be utilized.

In this letter, we propose a real-time method for estimating distance traveled by a cart using a smartphone. We conduct experiments of cart movement in a straight line with a fixed floor condition. In these experiments, we used a cart and attached a smartphone to the cart to collect acceleration and angular speed data. After applying a Butterworth filter to the collected data to remove noise, we then examined methods of estimating distance based on a double-integral of acceleration data. The results of these experiments show that the proposed method estimates the distance traveled better than the other reference methods.

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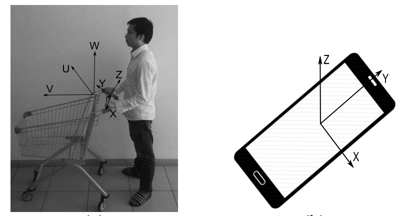

(a) (b)

Fig. 1. Scenario of attaching a smartphone into a cart to estimate the traveled distance. (a) Experimental setting. (b) Coordinates of smartphone.

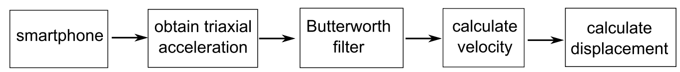

Fig. 2. Proposed distance traveled estimation.

II. Problem Formulation

Measuring the traveled distance of carts enables locating users. Hence, we can extract movement pattern of users and run location-based services. Particularly, in shopping areas, locating a user's position enables efficiently providing information about products to customers. In this study, the cart is moved around by the users as shown in Fig. 1a. In Fig. 1a, we also define the world coordinate system which corresponds to the human movement direction. The axes of acceleration and angular speed data collected from the smartphone are illustrated as in Fig. 1b. Experiments were conducted with movement of the cart along the V-axis.

The conventional step estimation or body movement tracking methods cannot be utilized. Therefore, in this particular case, estimating the distance traveled based on a double integral is an efficient method.

III. Methods of Distance Traveled Estimation

A block diagram depicting the estimation method is shown in Fig. 2. First, we transform the acceleration data in the local coordinates of the smartphone into the world coordinates using angle information of the smartphone. Then, we used a bandpass Butterworth filter with $N = 10$, $f_{c1} = 5Hz$ and $f_{c2} = 10Hz$, to remove noise in the obtained acceleration data. To calculate the distance traveled by the cart, we applied a double integral of the obtained acceleration. In [7], Alvarez *et al.* estimate the movement distance by a double integration of the acceleration in the movement direction. Applying this approach into the movement of the cart on a flat plane, the distance traveled is $s = \int_{t=0}^{T}\int_{t=0}^{T} a_v(t)dt$, where, $a_v(t)$ and T

are the acceleration data on the anterior-posterior direction and the period of movement, respectively. The signal recorded from the smartphone is a discrete signal, thus, the equation above can be described as:

$$v[k] = v[k-1] + \Delta T \cdot a_v[k], \quad s[k] = s[k-1] + \Delta T \cdot v[k], \tag{1}$$

where, $a_v[k]$, $v[k]$, $s[k]$ and $k = \overline{1, 2, ...}$ are the discrete acceleration, velocity, distance and the time index. At the initial state, these variables are set to zeros, $a_v[0] = 0$, $v[0] = 0, s[0] = 0$. Approximating the analog signals by the average values in each sampling period [8], the distance can then be calculated as:

$$v[k] = v[k-1] + \frac{a_v[k-1] + a_v[k]}{2} \cdot \Delta T,$$
$$s[k] = s[k-1] + \frac{v[k-1] + v[k]}{2} \cdot \Delta T, \tag{2}$$

with $s[0] = 0, v[0] = 0, a_v[0] = 0$. We propose the use of a double integral for the acceleration magnitude to estimate the distance traveled. This method can be describe by the equation $s = \int_{t=0}^{T} \int_{t=0}^{T} \sqrt{a_u^2(t) + a_v^2(t) + a_w^2(t)} dt$, where, $a_u(t)$, $a_v(t)$ and $a_w(t)$ are the acceleration data of the lateral, anterior-posterior and vertical directions, respectively. Applying the equation to the discrete case, it becomes:

$$a[k] = \sqrt{a_u^2[k] + a_v^2[k] + a_w^2[k]},$$
$$v[k] = v[k-1] + \Delta T \cdot a[k],$$
$$s[k] = s[k-1] + \Delta T \cdot v[k], \tag{3}$$

with $s[0] = 0, a[0] = 0, a[0] = 0$. Another implementation to estimate the movement distance is double integral of the absolute value of anterior-posterior direction acceleration, $s = \int_{t=0}^{T} \int_{t=0}^{T} |a_v(t)|\, dt$. Similarly, accounting for the acceleration received from the smartphone, we obtained:

$$v[k] = v[k-1] + \Delta T \cdot |a_v[k]|,$$
$$s[k] = s[k-1] + \Delta T \cdot v[k], \tag{4}$$

with $a[0] = 0, v[0] = 0, s[0] = 0$.

IV. Experimental Results

To perform the movement experiments, we used a type of cart which is popular in supermarkets. We attached a smartphone to the holding bar of the cart in an arbitrary angle as shown in Fig. 1a to collect the acceleration and angular speed data during the cart movement. The smartphone utilized in the experiments was the Samsung Galaxy S4. The sampling frequency of the accelerometer was set to 100Hz. Using these experimental settings, we conducted experiments wherein the cart is pushed to move along a 10.25-m straight line on a constant plane. We conduct experiments on a fixed floor condition to test the accuracy of the proposed method in straight movement distance estimation. The experiment was conducted 50 times to test the accuracy of the estimation methods. Fig. 3 shows cumulative distributions of estimation results with different presented methods.

Evaluation information of these methods are described in Table I. The [7], [8], ADI and proposed methods are

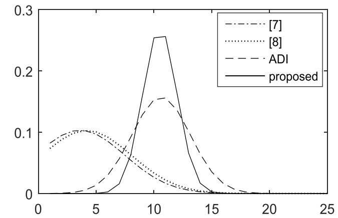

Fig. 3. Cumulative distributions of estimation methods.

TABLE I

Evaluation Results With Different Methods

Method	[7]	[8]	ADI	proposed method
Mean(m)	3.7	4.2	10.6	10.5
Median(m)	3.2	3.8	10.2	10.2
90%(m)	8.6	8.9	13.7	12.7
10%(m)	0.1	0.8	7.9	8.9
Deviation(m)	3.9	3.9	2.5	1.5
Error	65%	61%	20%	11%

the calculation methods in (1), (2), (4) and (3) equations, respectively. The experimental results show that the proposed method provides the best method for estimating the cart's traveled distance. The [7] method provides a result similar to the [8] method because the sampling period is short, $T = 10ms$. The average speed, $\bar{v}[k] = \frac{1}{2}(v[k] + v[k+1])$, in the movement distance of this T period is similar to the speed at the starting point of the movement distance, $v[k]$.

V. Conclusion

In this letter, we proposed a real-time method of estimating distance traveled by a cart based on a double integral of acceleration data collected using the built-in sensors on a smartphone. The smartphone was used to collect acceleration data during the movement of the cart. This information was then filtered and processed on the smartphone to eliminate high frequency noise. A double integral based method was utilized to estimate the distance traveled. The experimental results showed the proposed method outperformed other methods in terms of estimation accuracy.

References

[1] R. Harle, "A survey of indoor inertial positioning systems for pedestrians," *IEEE Commun. Surveys Tuts.*, vol. 15, no. 3, pp. 1281–1293, Jul. 2013.

[2] J. Liu, R. Chen, L. Pei, R. Guinness, and H. Kuusniemi, "A hybrid smartphone indoor positioning solution for mobile LBS," *Sensors*, vol. 12, no. 12, pp. 17208–17233, 2012.

[3] K. Park, H. Shin, and H. Cha, "Smartphone-based pedestrian tracking in indoor corridor environments," *Pers. Ubiquitous Comput.*, vol. 17, no. 2, pp. 359–370, 2013.

[4] M. Strutu, D. Caspari, J. Pickert, U. Grossmann, and D. Popescu, "Pedestrian smartphone based localization for large indoor areas," in *Proc. IDAACS*, vol. 1. Sep. 2013, pp. 450–454.

[5] H. Weinberg, "Using the ADXL202 in pedometer and personal navigation applications," Analog Devices, Norwood, MA, USA, Appl. Note 602, 2002, pp. 1–8.

[6] N. A. Capela, E. D. Lemaire, and N. C. Baddour, "A smartphone approach for the 2 and 6-minute walk test," in *Proc. IEEE 36th Annu. Int. Conf. Eng. Med. Biol. Soc.*, Aug. 2014, pp. 958–961.

[7] J. Alvarez, R. C. Gonzalez, D. Alvarez, A. M. Lopez, and J. Rodriguez-Uria, "Multisensor approach to walking distance estimation with foot inertial sensing," in *Proc. IEEE 29th Annu. Int. Conf. Eng. Med. Biol. Soc.*, Aug. 2007, pp. 5719–5722.

[8] M. Arraigada and M. Partl, "Calculation of displacements of measured accelerations, analysis of two accelerometers and application in road engineering," in *Proc. 6th Swiss Transp. Res. Conf.*, 2006, pp. 1–30.