User Localization
Using Wearable Electromagnetic Tracker and Orientation Sensor

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Abstract

This paper describes a localization method with wearable electromagnetic sensor and orientation sensor for wearable computer users. Many user localization methods have been investigated to realize location-based services in a wide environment. The localization methods usually employ a hybrid approach in which user's position is estimated by using positioning infrastructures and dead reckoning such as a pedometer. However, the installation cost of infrastructures increases when the area expands, and the error of the pedometer is frequently caused by failures in walking locomotion detection and the difference between ideal and estimated step lengths. If the relative distance is accurately estimated by dead reckoning approach, the installation cost of infrastructures can be reduced.

This paper proposes a new localization method that improves the estimation accuracy of step length in dead reckoning approach. The proposed method measures user's orientation and geometrical relationship between user's heel and waist with an orientation sensor and an electromagnetic tracker attached to user's body. When both feet come into contact with the ground, user's position is updated by adding the estimated step length which means the relationship between user's heels and the position estimated in the previous step. The proposed localization method has been experimented using a prototype system to evaluate the accuracy of the proposed method.

1. Introduction

Navigation systems which can provide users with location-based information by acquiring the user's position with a wearable computer have been developed[1, 2]. In order to realize these systems in a wide area not only indoors but also outdoors, a number of localization methods have been proposed. Especially in indoor environments, localization methods can be divided into two steps: 1) absolute position measurement from positioning infrastructures and 2) estimation of relative distance by using wearable sensors such as dead reckoning sensors.

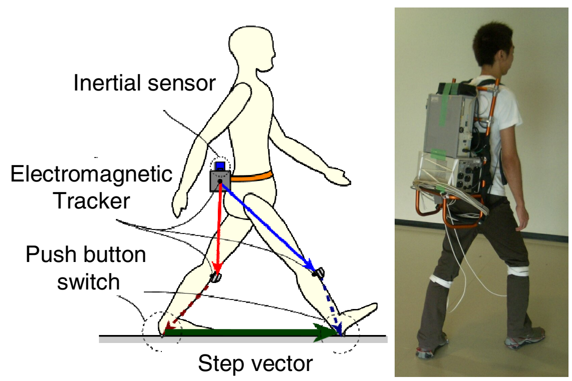

Figure 1. User's equipments in the proposed method.

In general, in order to estimate the user's position, image markers [3, 4] or infrared markers [5, 6] are used as positioning infrastructures. However, the larger the area of positioning infrastructures is, the more the cost is increased. On the other hand, a typical method in the dead reckoning approach is to use a pedometer which measures the user's walking action by using accelerators and a digital compass [7, 8, 9].

In the relative distance estimation by counting steps, it is easy to accumulate the error of distance due to difference of length of user's step or miscount of steps by noise of sensors. To measure the relative distance of user's movement accurately, some methods directly measure the distance of the foot with accelerator attached to user's toe[10]. By combining the approach of relative distance estimation with the approach based on positioning infrastructures, the cost for infrastructure can be decreased[2, 11]. If the accuracy of the relative distance estimation increases, the number of devices of infrastructure decreases and the cost of positioning infrastructure can be low.

In order to decrease the cost for positioning infrastructure, this paper proposed a new method for accurately mea-

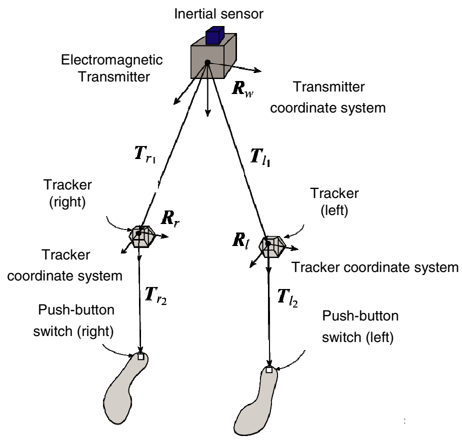

Figure 2. Hardware configuration of the proposed localization method.

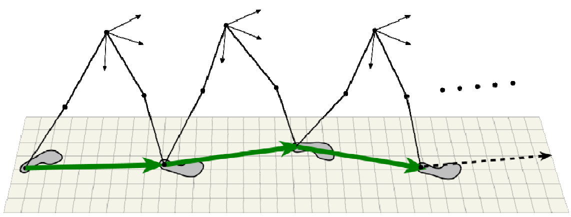

Figure 3. Illustration of summing up step vectors.

suring the relative distance of user's movement. Fig. 1 illustrates an overview of the proposed localization method. The user equips an electromagnetic tracker, inertial sensor and push button switches. The electromagnetic tracker measures the relationship between right and left feet, and the inertial sensor measures the absolute orientation against the real world. The method estimates the user's movement distance by summing up the relationship between left and right feet when both left and right legs are grounded. That is, by detecting the switch timing of the pivot foot, the step vector, which means the relationship between left and right legs when both legs are grounded, is added incrementally.

This paper is structured as follows. Section 2 describes the proposed localization method with wearable electromagnetic tracker and orientation sensor. In Section 3, experimental results with a prototype system are described. Finally, Section 4 summarizes the present work.

2. Localization with 3D position and orientation sensors

2.1. Overview of the proposed method

This section describes the proposed localization method with an electromagnetic tracker, inertial sensor and push button switches. A user equips an electromagnetic sensor (Polhemus Inc.: 3Space Fastrak), an inertial sensor (Intersence, Inc.: inertiaCube2) at user's hip, and push button switches attached to user's both heels, as shown in Fig. 1. By attaching these sensors to user's hip, leg, and heel, the relative position of the left and right legs and absolute orientation of user's hip are estimated continuously. Therefore, the proposed method can measure the distance of user's movement if at least one leg is always grounded. In other words, when the user walks (not run), the relative position can be estimated.

2.2. Measurement of user's position

To estimate the user's position, the distance between left and right legs is added when the pivoted leg is changed. In this paper, let us call this distance a step vector. The step vector can be calculated by using parameters acquired from electromagnetic tracker and inertial sensor shown in Fig 2. The step vector p_{heel} is defined by Eq. (1).

$$\boldsymbol{p}_{heel} = \boldsymbol{R}_w \left((\boldsymbol{T}_{f_1} + \boldsymbol{R}_f \boldsymbol{T}_{f_2}) - (\boldsymbol{T}_{b_1} + \boldsymbol{R}_b \boldsymbol{T}_{b_2}) \right), \quad (1)$$

where

$\boldsymbol{p}_{heel}$:	step vector in the world coordinate system,
$\boldsymbol{R}_w$:	absolute orientation of hip in the world coordinate system,
$\boldsymbol{T}_{f_1}, \boldsymbol{T}_{b_1}$:	position of cnemis (position of electromagnetic tracker) in electromagnetic sensor coordinate system,
$\boldsymbol{R}_f, \boldsymbol{R}_b$:	pose of cnemis in electromagnetic sensor coordinate system,
$\boldsymbol{T}_{f_2}, \boldsymbol{T}_{b_2}$:	distance between cnemis and heel (constant).

Here, f and b mean front and back side legs, respectively. Fig. 3 illustrates the process of estimating user's position. The estimated distance is defined by Eq. (2).

$$\boldsymbol{Distance} = \sum_{i=1}^{n} \boldsymbol{p}_{heel_i} . \quad (2)$$

2.3. Calibration of heel height

In the proposed method, it is ideal that both left and right heels are grounded at the same time when the step vector is added. However, in a human walking action, the heel of back leg usually leaves from the ground before grounding of the heel of front leg as shown in Fig. 4. Therefore, the error of height accumulates as shown in Fig. 5. In order to overcome the problem, we correct the error by estimating the h_{heel} which denotes the height of heel in each step, as shown in Fig. 6. In fact, the parameter h_{heel} is estimated by some trials of walking along a path whose distance is known in advance. Equation for position estimation considering the heel error is defined as follows:

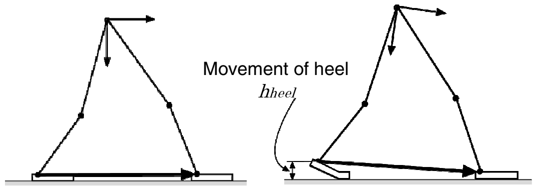

Figure 4. Movement of heel when step vector is added.

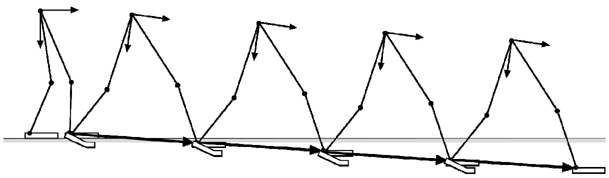

Figure 5. Estimation without heel height calibration.

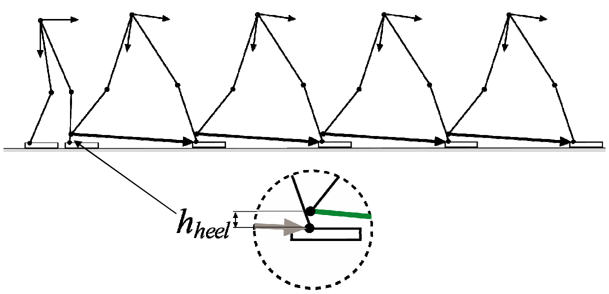

Figure 6. Estimation with heel height calibration.

$$\begin{aligned} \boldsymbol{p}_{heel}{}' &= \boldsymbol{p}_{heel} + \boldsymbol{d}_{heel} \\ &= \boldsymbol{R}_w \left((\boldsymbol{T}_{f_1} + \boldsymbol{R}_f \boldsymbol{T}_{f_2}) - (\boldsymbol{T}_{b_1} + \boldsymbol{R}_b \boldsymbol{T}_{b_2}) \right) + \boldsymbol{d}_{heel} \end{aligned} \tag{3}$$

where $\boldsymbol{d}_{heel} = [0, 0, h_{heel}]$.

3. Expriments

In order to confirm the feasibility of the proposed method, we have carried out the experiments. First, to examine the accuracy of estimated results, three kinds of paths are evaluated: a straight line, a circle and stairs. Figs. 7, 8 and 9 show the estimated trajectories of three paths. Figs. 7 and 8 illustrate the results of walking along a straight line whose distance is 9m and a circle whose radius is 1.5 m, respectively. Fig. 9 shows the results when a user goes up stairs to the upper floor. In this experiment, we have estimated the height error h_{heel} in advance from the three results of user's walking along the paths whose distances are known. We can confirm the proposed method can estimate user position accurately. Here, the error is defined as a ratio of the difference between true and estimated positions and

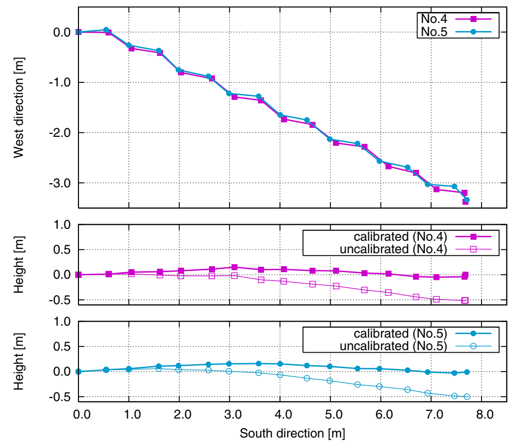

Figure 7. Estimated trajectories of walking along a straight line with and -out calibration.

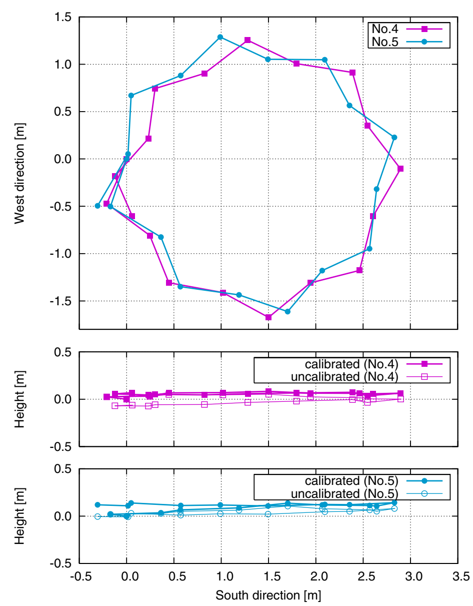

Figure 8. Estimated trajectories of walking along a circle with and -out calibration.

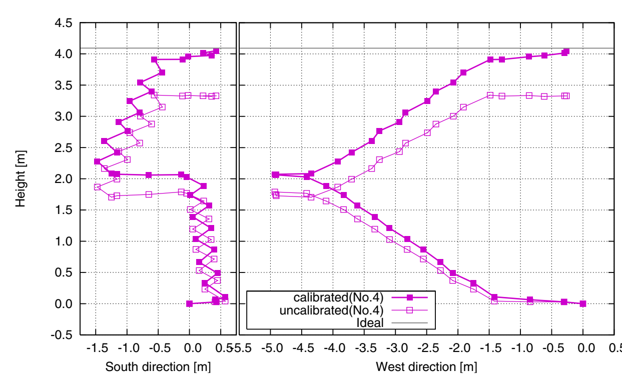

Figure 9. Estimated trajectories of walking up stairs with and -out calibration.

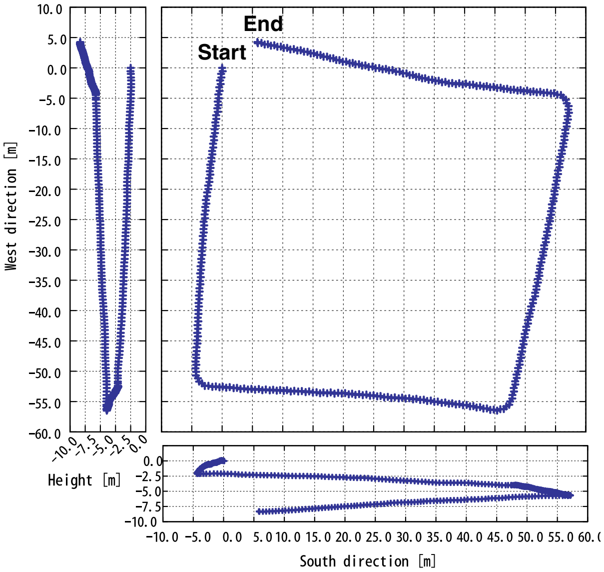

Figure 10. Estimated trajectories of walking along a square(one side is 50m).

the true total distance. Errors in the three paths are 7.2%, 4.2% , and 6.0%, respectively. Figs. 10 and 11 show experimental results of estimating two long paths. One is a sequence of walking along a square whose one side is 50m and the other is that of going up stairs to 7th floor. Errors in estimation are 5.2% and 2.6%, respectively.

4. Conclusions

This paper has proposed a new localization method that improves the estimation accuracy of step length dead reckoning approach. The proposed method measures user's orientation and geometrical relationship between user's heel and waist with an orientation sensor and an electromagnetic tracker that are attached to user's body. In experiments, we have evaluated the accuracy of the proposed method with the prototype system.

References

[1] T. Höllerer, S. Feiner, T. Terauchi, G. Rashid and D. Hallaway: "Exploring MARS: Developing Indoor and Outdoor User Interfaces to a Mobile Augmented Reality System," Computers & Graphics, 23, 6, pp. 779–785, Dec. 1999.

[2] R. Tenmoku, M. Kanbara and N. Yokoya: "A Wearable Augmented Reality System Using Positioning Infrastructures and a Pedometer," Proc. 7th IEEE Int'l Symp. on Wearable Computers (ISWC'03), pp. 110–117, Oct. 2003.

[3] M. Kalkusch, T. Lidy, M. Knapp, G. Reitmayr, H. Kaufmann and D. Schmalstieg: "Structured Visual Markers for Indoor Pathfinding," Proc. IEEE Int'l Augmented Reality Toolkit Workshop (ART'02), Sep. 2002.

[4] L. Naimark and E. Foxlin: "Circular Data Matrix Fiducial System and Robust Image Processing for a Wearable Vision-Inertial Self-Tracker," Proc. Int'l Symp. on Mixed and Augmented Reality (ISMAR'02), pp. 27–36, Oct. 2002.

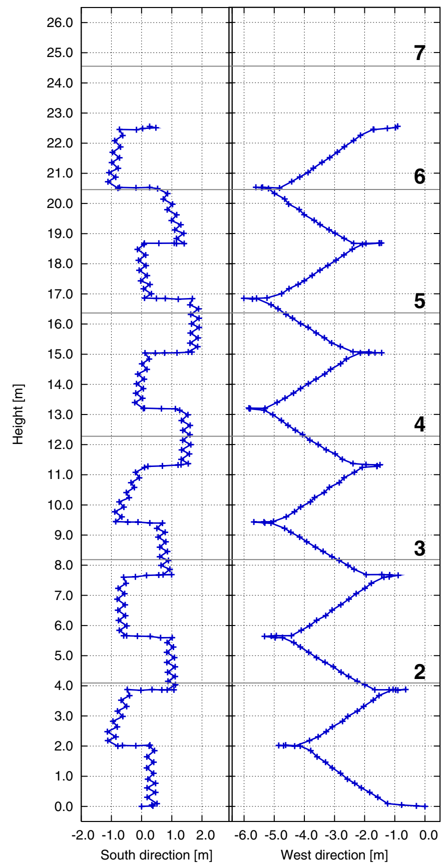

Figure 11. Estimated result of walking up stairs(from first floor to 7th floor).

[5] D. Hallaway, T. Höllerer and S. Feiner: "Coarse, Inexpensive, Infrared Tracking for Wearable Computing," Proc. 7th IEEE Int'l Symp. on Wearable Computers (ISWC'03), pp. 69–78, Oct. 2003.

[6] M. Maeda, T. Ogawa, K. Kiyokawa and H. Takemura: "Tracking of User Position and Orientation by Stereo Measurement of Infrared Markers and Orientation Sensing," Proc. 8th IEEE Int'l Symp. on Wearable Computers (ISWC'04), pp. 77–84, Oct. 2004.

[7] M. Kourogi and T. Kurata: "Personal Positioning based on Walking Locomotion Analysis with Self-Contained Sensors and a Wearable Camera," Proc. 2nd IEEE and ACM Int'l Symp. on Mixed and Augmented Reality (ISMAR'03), pp. 103–112, Oct. 2003.

[8] S.-W. Lee and K. Mase: "Activity and Location Recognition Using Wearable Sensors," IEEE Pervasive Computing, 1, 3, pp. 24–32, Jul.–Sep. 2002.

[9] J. W. Kim, H. J. Jang, D.-H. Hwang and C. Park: "A Step, Stride and Heading Determination for the Pedestrian Navigation System," Journal of Global Positioning System, 3, 1–2, pp. 273–279, 2004.

[10] E. Foxlin: "Pedestrian Tracking with Shoe-Mounted Inertial Sensors," IEEE Computer Graphics and Applications, 25, 6, pp. 38–46, Nov.–Dec. 2005.

[11] D. Hallaway, T. Höllerer and S. Feiner: "Bridging the Gaps: Hybrid Tracking for Adaptive Mobile Augmented Reality," Applied Artificial Intelligence Journal, Special Issue on AI in Mobile Systems, 18, 6, pp. 477–500, Jul. 2004.