2016 International Conference on Indoor Positioning and Indoor Navigation (IPIN), 4-7 October 2016, Alcalá de Henares, Spain

Foot-mounted Indoor Pedestrian Positioning System Based on Low-Cost Inertial Senors

Ao Peng, Lingxiang Zheng, Wencheng Zhou, Chaohui Yan, Yizhen Wang, XiaoYang Ruan, Biyu Tang, Haibin Shi, Hai Lu
School of Information Science and Engineering
Xiamen University
Xiamen, China
lxzheng@xmu.edu.cn

Huiru Zheng
School of Computing and Mathematics
University of Ulster
Newtownabbey, UK
h.zheng@ulster.ac.uk

***Abstract*—In this paper, we present an indoor positioning system using foot-mounted low cost Micro-Electro-Mechanical System (MEMS) sensors to derive the position and attitude of the wearer and plot the trajectory on the smartphone in realtime. The pedestrian's motion information is collected by accelerometers and gyroscopes to achieve Pedestrian Dead-Reckoning (PDR) which is used to estimate the pedestrian's rough position. A new zero velocity update (ZUPT) algorithm is developed to detect the standing still moment. The testing results show good performance of the proposed system.**

***Keywords*—foot-mounted; ZUPT; Kalman filter; inertial sensor bias;**

I. Introduction

There is a significant demand for seamless positioning service in current consumer-based smart life solutions. In outdoor scene the satellites-based navigation systems, such as GPS or BDS can provide continuous positioning service with accuracy of several meters. However, indoor navigation technologies still remain immature, although a pretty large amount of human activities happens in the indoor environment. Current indoor positioning solutions can be generally divided into two types: 1) radio based solutions which use Wi-Fi, Bluetooth and other opportunity wireless signals [1]. In such solutions, the pre-configured radio infrastructures are needed; 2) self-sustainable solutions using information from variable types of sensors such as geo-magnetometer, barometer, inertial sensor, camera and so on [2]. Among all of these indoor positioning systems, the inertial sensor, including accelerator and gyroscope, based solution is extremely attractive since the system consisting of Micro-Electro-Mechanical System (MEMS) sensors is cheap and small, which can be mounted easily, and requires no pre-configured infrastructures nor any pre-knowledge of the environments.

Inertial sensor based positioning systems use integrations of acceleration and angular velocity measured by sensors to estimate the relative distance and direction of movement. The noise in measurement is accumulated during time integrations which leads to serious positioning error after the system working for a long time. So it's important to calibrating the system by some aiding information. In the proposed pedestrian positioning system, the motion feature of human's body is used as the aiding information. During each pace of a pedestrian, there is an interval when the foot remains relatively static to the ground. It ensures that zero velocity updates (ZUPT) can be used in every pace to eliminate the problem of error accumulation over time. Then the ability of the pedestrian positioning system based on low cost inertial sensors to maintain desired accuracies for longer periods can be significantly extends [3].

In this paper, we propose an infrastructure-free approach to achieve high precision indoor positioning using a low cost sensor. Pedestrian dead-reckoning (PDR) is used in this paper to sequentially estimate the pedestrian's position. PDR consists of the double integration of current inertial sensor readings. When using PDR to calculate the position and velocity, the system will eventually be led to divergent because of the sensor error [4]. To solve this issue, we use Kalman filter model as basis model. It consists a prediction process and an update process. When there is an appropriate observation, Kalman filter can compensate the error by the update equation to keep the system relatively stable. ZUPT can detect the time accurately when a pedestrian is standing still, i.e. the velocity of the pedestrian is zero. We use this information as the observation in Kalman filter, so it can eliminate system errors greatly.

The rest of this paper is organized as follows: Section 2 introduces details of the design, framework and the processing method. Section 3 presents the experiments and results. Section 4 concludes the paper.

II. Methods

The overall design and execution framework of the system is shown in Fig.1. The system consists of four modules: data acquisition (accelerometer, gyroscope and barometer), strapdown inertial calculation (Kalman filter prediction), ZUPT algorithm, and error elimination (Kalman filter update).

The data acquisition module gathers data from accelerometers, gyroscopes and barometer. The outputs of the accelerometers and gyroscopes are sent to Kalman filter prediction module to calculate the movement of the foot. The barometer is used to measure the height information. The acceleration and angular velocity information is also used for Foot-still detection, which detect the time when the vertical velocity of pedestrian is zero. When ZUPT is satisfied, the module of Kalman filter update will complete the correction of velocity. The corrected velocity is then fed back to the trajectory of velocity, heading and position information.

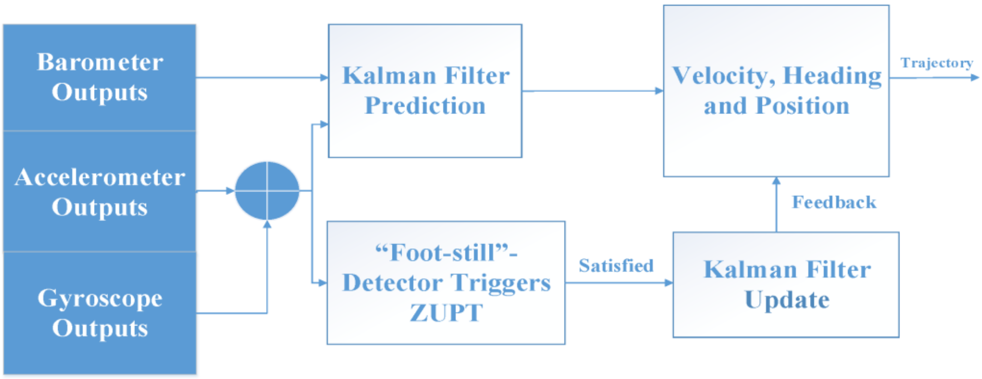

Fig. 1. Algorithm architecture

Fig.2 illustrates the system architecture. Walking data are collected by a foot-mounted sensor and is sent to the Edison Development Board to complete the calculations. Then the trajectory data is sent to smart phone via WIFI and the users can view the trajectory on their phones.

Fig. 2. System architecture

A. Zero Velocity Update Algorithm

The ZUPT (zero velocity update) algorithm has been proved to be an effective method to control and eliminate data drift errors. ZUPT is triggered when the foot is stationary on the ground. The existing solutions for ZUPT mostly came from paper [5]. It considered multiple conditions using the information output from accelerometers and gyroscopes. In [5], three conditions (C1, C2 and C3) were used to determine whether the foot is stationary on the floor. The conditions are defined as follow:

$$C1=\begin{cases}1 & a_{\min}<\left|a_{k-total}\right|<a_{\max}\\ 0 & otherwise\end{cases} \tag{1}$$

$$C2=\begin{cases}1 & \sigma_{a_k}^2>\sigma_{a-\min}\\ 0 & otherwise\end{cases} \tag{2}$$

$$C3=\begin{cases}1 & \left|\omega_{k-total}\right|<\omega_{\max}\\ 0 & otherwise\end{cases} \tag{3}$$

There are too many thresholds in these functions, and these thresholds are not suitable for everyone. Even when same person walked by different velocity it may not worked well.

In this paper, we proposed a new algorithm for ZUPT. First, we use Fourier transform to estimate the period of walking. Then in the next period, we search the point in acceleration data and variance of acceleration which meet the conditions of zero velocity. Finally, we adjustment the conditions according to different period to adapt different walk type.

B. Pedestrian Movement Model

In this paper, we use Kalman filter to build a pedestrian movement model. Navigation parameters used in the model are pedestrian position, velocity, and attitude information. The detailed description of the predicted state $\hat{x}_k^-$, covariance P_k, state transition matrix F and observation matrix H can be found in our previous work [6]. Here we introduce the IKZ (Inertial Navigation System & Kalman Filter & ZUPT) model designed in this paper.

Firstly, The Inertial Navigation System calculated the position s_k^T, velocity v_k^T, and altitude ϕ_k^T of pedestrian. The state X_k^- predicted by KF is:

$$\hat{X}_k^- = \begin{bmatrix} s_k^T & v_k^T & \phi_k^T \end{bmatrix}^T \tag{4}$$

Secondly, the ZUPT is true when the pedestrian was standing still, which means that the velocity of the pedestrian is zero. This information is used as a measurement value of Kalman filter, and the posterior $\hat{X}_{k|k}$ is calculated in Eq. (5):

$$\hat{X}_{k|k}=\hat{X}_{k|k-1}+K_k\left(O_{3*1}-H_k\hat{x}_{k|k-1}\right) \tag{5}$$

where O_{3*1} is a 3*1 zero matrix and each element of the matrix is 0.

As it is described above, the drift error can be minimized effectively though the design. As for the bias error in the MEMS sensor, the existing approaches assume that the bias error is a constant of the system under static conditions, and thus a one-time compensation is made in the system application. In reality, the bias error is not a constant after a long time of continuously working or with influence of the temperature change [7]. To address this issue, we use Kalman filtering to estimate necessary compensation. Firstly, we expand the Kalman filter state matrix from 9 dimensions to 15 dimensions, where the new entrants are accelerometer bias error ε_b for 3 dimensions and gyroscope bias error α_b with another for 3 dimensions as described in Eq. (6)

$$X_k = \begin{bmatrix} s_k^T & v_k^T & \phi_k^T & \varepsilon_b^T & \alpha_b^T \end{bmatrix}^T \tag{6}$$

After Kalman filter update, the gain of velocity is obtained. We use the gain of velocity to estimate the bias of acceleration. In the next step, we subtract the deviation with the raw acceleration data to reduce the error of next step calculation. This method is suitable not only for correction of acceleration but also for gyroscope.

III. Experiment Result

In this experiment, the subject is a 24 years old healthy male. The inertial sensor (MPU 6050) is mounted on the right side of the right foot. The test location is Technology of Xiamen University. We made a participant walk on a predetermined route, which length is 46.8m. The route including many different turn angles, so it can demonstrate the performance of our system in many aspects. The experimental result and the predetermined route is shown below:

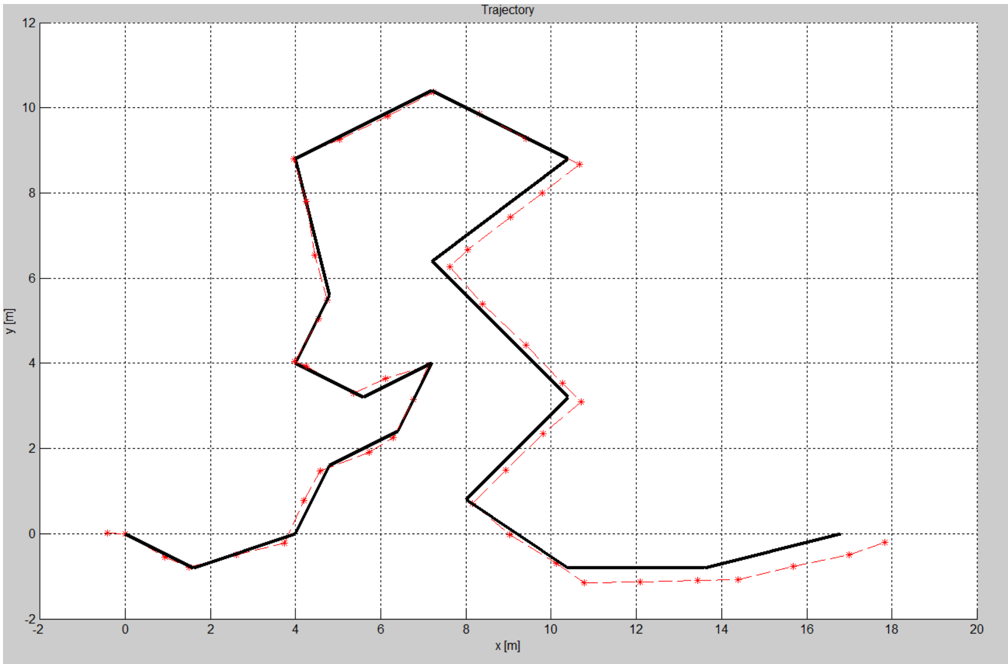

Fig. 3. Experiment of indoor positioning

In Fig. 3, the red line is the trajectory calculated by our algorithm, and the black line is the real trajectory. The distance of real trajectory is 46.8m, and the distance of calculated is 48.5m. Besides, we have another experiment in long distance which is 1360m. The final error is 5.36m and error rate is 0.4%.

IV. Conclusion

This paper presents a model for achieving indoor positioning based on foot-mounted sensors. We used ZUPT algorithm to detect the time when a pedestrian was standing still, and this information was used in Kalman filer to eliminate systematic errors. In addition, we compared the proposed algorithm to our previous algorithm under the conditions of 9D KF and 15D KF, respectively. The new algorithm performed better with lower error rates and the higher trajectory stability.

References

[1] H. Liu, H. Darabi, P. Banerjee and J. Liu, "Survey of Wireless Indoor Positioning Techniques and Systems," in IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), vol. 37, no. 6, pp. 1067-1080, Nov. 2007.

[2] L. Zheng et al., A 3D indoor positioning system based on low-cost MEMS sensors, Simulation Modelling Practice and Theory (2016).

[3] S. Godha and G. Lachapelle, "Foot mounted inertial system for pedestrian navigation," Measurement Science and Technology, vol. 19, p. 075202, 2008.

[4] Titterton D, Weston J L. Strapdown inertial navigation technology[M]. IET, 2004.

[5] Jiménez A R, Seco F, Prieto J C, et al. Indoor pedestrian navigation using an INS/EKF framework for yaw drift reduction and a foot-

mounted IMU[C]//Positioning Navigation and Communication (WPNC), 2010 7th Workshop on. IEEE, 2010: 135-143.

[6] Zheng X, Yang H, Tang W, et al. Indoor Pedestrian Navigation with Shoe-Mounted Inertial Sensors[M]//Multimedia and Ubiquitous Engineering. Springer Berlin Heidelberg, 2014: 67-73.

[7] Chen X, Yang P, Chen Y. Analysis and Processing on Zero Position Error of MEMS Gyroscope [J][J]. Chinese Journal of Sensors and Actuators, 2012, 5: 017.