Integrated Bluetooth Fingerprinting and Pedestrian Dead Reckoning for Indoor Positioning on Apple's iOS platform

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Abstract. In this paper, we propose an innovative and low-cost hybrid indoor positioning system using various sensors on the mobile platform. This system consists of a pedestrian dead reckoning (PDR) part based on the encapsulated Application Programming Interface (API) of Apple's iOS platform and a low-cost Bluetooth Low Energy (BLE) fingerprinting calibration part. Pedestrian position information can be deduced from the PDR algorithm by applying distance and heading estimation and can be calibrated by a fingerprinting positioning matching algorithm. This hybrid positioning system improves the performance of the conventional PDR position algorithm which suffers from accumulated errors over time. Finally, the results obtained from evaluation test indicate that the proposed positioning system applying hybrid techniques is practical in indoor environment.

Introduction

More and more people are relying on the location based service (LBS) with their smart phones. However, Global Positioning System (GPS) cannot afford an accurate indoor navigation service because of the difficulty of GPS reception in the indoor environment. Therefore, a number of systems have been proposed for indoor positioning based on wireless infrastructure and the inertial sensors [1].

As smartphones have been incorporating more powerful computing capability and sensor functions, pedestrian dead reckoning (PDR) system based on the inertial sensors becomes an effective technology for indoor positioning and navigation applications on the mobile platform. However, it is difficult to use PDR to obtain stable location because of the accumulated errors over time [2]. On the other hand, techniques based on received signal strength (RSS) are commonly used for INS due to the broad availability of wireless infrastructure including Wi-Fi access points (APs) and BLE beacons. Fingerprinting technique is one of the popular methods based on RSS [1]. However, The accuracy of the fingerprinting is usually 5-10 meters [1] which is not enough for the real-time indoor navigation system.

In this paper we propose a hybrid positioning system which integrates the strength of the PDR and fingerprinting technique. The errors caused by PDR mainly come from walking distance and orientation. We utilizes Apple's iOS platform which can provide the real-time walking distance of the user to conquer accumulated errors caused by walk distance [3]. Moreover, fingerprinting algorithms are used to calibrate the orientation errors caused by the compass drift. Since particle filter methods are commonly used techniques for integrating disparate information sources from multiple sensors [4], we choose particle filter as the integration algorithm of our system. The results show that our system achieves an average position error of about 2.01 meters and does not suffer from the the accumulated errors.

The paper is divided into three sections. First, the whole system architecture is presented. The PDR algorithm based on the related API of iOS system and the integration algorithm based on particle filter are described in this section. Second, the results are shown and analyzed. We draw the conclusion in the final section.

System Overview and Implementation. The whole framework architecture is depicted in Fig.1. It shows the basic flow that makes the system work. The system contains three algorithms: the fingerprinting algorithm, the PDR algorithm and the integration algorithm. The detail of the whole system will be presented in the next subsection.

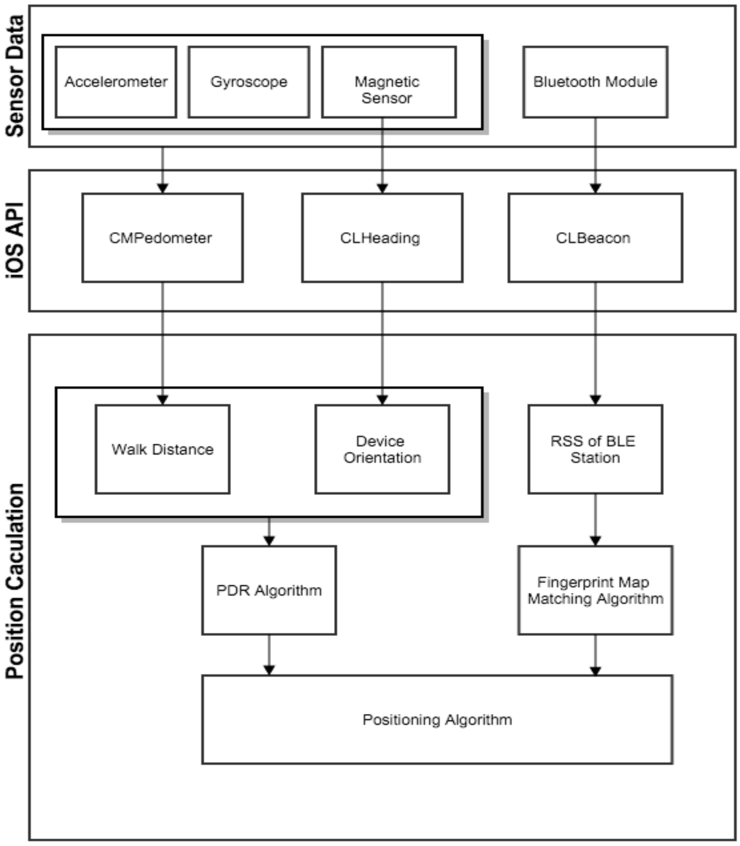

Fig. 1 The architecture of the proposed system

PDR algorithm. The data needed of the PDR algorithm includes the walking distance and the orientation. The iOS system provides two easy-to-use API: CLHeading and CMPedometer [5], [6]. CLHeading encapsulates the data from the magnetic sensor to detect the orientation. CMPedometer is used to acquire the walking distance by processing the raw data coming from the inertial sensors including accelerometer and gyroscope.

$$\begin{pmatrix} x_k \\ y_k \end{pmatrix} = \begin{pmatrix} 1 & 0 & sin(\theta_k - \theta_{k-1}) \\ 0 & 1 & cos(\theta_k - \theta_{k-1}) \end{pmatrix} \begin{pmatrix} x_k \\ y_k \\ s_k \end{pmatrix} \quad (1)$$

The PDR algorithm is straightforward as shown in formula (1) where s_k denotes the walk distance and θ_k denotes the orientation of the device. $(x_k,\ y_k)$ denotes the coordinate of the pedestrians on the map. We suppose the device is held by user horizontally and the screen of the device is upward. The head of the device points towards the user's walking direction.

Fingerprinting algorithm. There is no open-interface to acquire the RSS of the Wi-Fi in the iOS system. As a result, we choose the BLE as a replacement. The RSS of the BLE stations can be obtained from the CLBeacon framework which encapsulates the scanning data of the Bluetooth module. We use the common fingerprinting algorithm as shown in [7] which has two phases: collecting phase and matching phase. In the collecting phase, we develop an application to collect the RSS from different BLE station and build the relationship between the selected reference point (RP) and the coordinates into a fingerprint map database. In the matching phase, we traverse and filtrate the entire fingerprint database to select the most suitable RP. Then the corresponding coordinate of this RP is exported to the integration algorithm.

Integration algorithm. Integration algorithm is used to integrate the results from the PDR and the fingerprinting algorithm. We design a particle filter (PF) to calibrate the orientation errors of the PDR algorithm by the range of the RP from the fingerprinting algorithm. A PF has three major components: a motion model that updates the positions of particles, an observation model that sets particle weights, and a resampling algorithm for modifying distribution to reduce variance [8]. For our system, the motion model is derived from the PDR algorithm as the formula (1) which is used to predict and update the position of the pedestrian. The observation model is a restrictive condition for the particles in our system. We assume that it is impossible for the pedestrian to walk out of the range of the current RP coming from the fingerprinting algorithm. Therefore, when the position updates, the range of the current RP is used to set a bound for the particles so that the particles having an impossible move can be removed. This process completes after the PDR algorithm updates and the restrictive condition updates when the output of fingerprinting algorithm changes. Accordingly, it is possible to assign a weight $\Pr[x_k \mid x_{k-1}]$ described in [9] as follows:

$$Pr[x_k \mid x_{k-1}] = \begin{cases} P_n & if\ a\ particle\ exceeded\ the\ range \\ 1 - P_n & if\ a\ particle\ did\ not\ exceed\ the\ range \end{cases} \quad (2)$$

P_n is set to zero because of the aforementioned observation model. The resampling is a critical part for the filter. We chose the resampling approach presented in [8]: the regularized particle filter. This approach is more convenient because it locally introduces a new diversity after the resampling. This is useful in some situations when the pedestrian walk across the border between two adjacent RPs.

Analysis and Results. In this section, the operation and results of the proposed system is demonstrated. First, we estimate the walking distance by using CMPedometer. Then the result of the proposed location system is described and analyzed. We developed our localization application for the iOS platform by using iPhone 6, on its capability of being used for PDR algorithm and BLE fingerprinting. The version of the operating system is iOS 9.0.

The experiment of the proposed system was conducted on the underground floor of our college building in Tongji University. The location of the BLE stations is indicated as red point in Fig. 2. In the collecting phase of the fingerprint module, we choose twelve RPs shown in Fig. 2 which have uniform distribution along with the walking trajectory and the fingerprint map is recorded in the smartphone database.

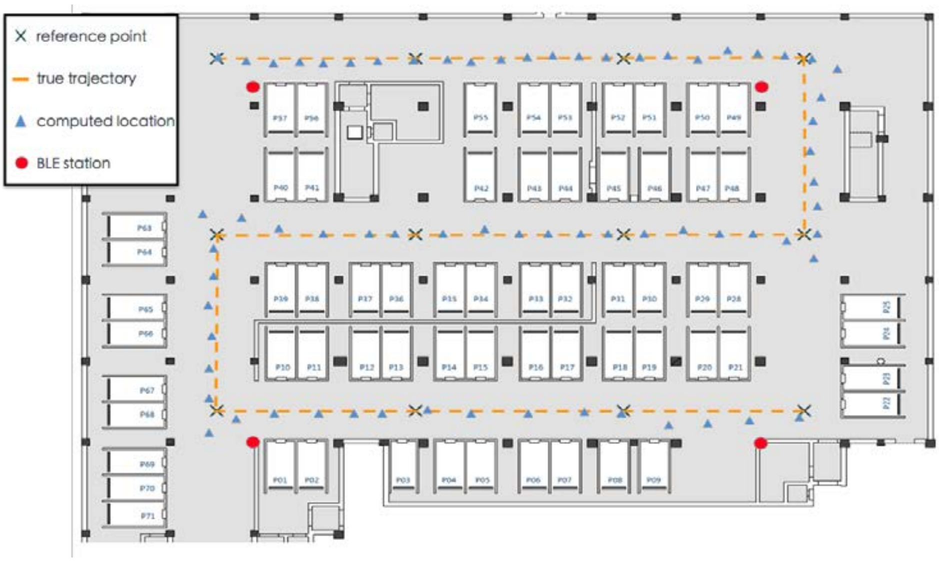

Fig. 2 Evaluation of indoor test

The test route started indoors with the left-top point in Fig. 2, followed by about 200m walking distance and reaching right-bottom point. In this process, the user kept constant speed. Fig. 2 shows the track results. The true route is shown in orange line. The blue triangle indicates the proposed integrated algorithm and the average estimates converge to a point about 2.01m from the true route. At the corners, the average errors become 3.73m. The reason is that the compass of the device had some delay when direction of the device changed. Another factor is the update frequency of CMPedometer which is only about 0.4Hz [9].

The results show that the integration algorithm brings an improvement as the average errors reduce about 4.36m (Compared to the 6.37m of with the fingerprinting algorithm presented in [1]). Meanwhile, the system solves the accumulated error of the conventional PDR algorithm in [2] so that the application based on the proposed system has high applicability for the mobile platform.

Conclusion

In this paper we have presented an indoor positioning system for mobile device integrating Pedestrian Dead Reckoning with BLE fingerprinting algorithm by utilizing the API of the iOS system. This hybrid positioning algorithm improves the location performance on the mobile device via easy implementation model and low power consumption. The accuracy of the hybrid positioning system was evaluated in a practical environment, and the results showed that the proposed method has much higher positioning accuracy than the fingerprinting algorithm or PDR alone. Further work should focus on how to fix the orientation variation when user change the posture of the mobile device such as putting the device into the pocket. More sensors could be incorporated, as well as the information of the history of users' paths so that the device can locate itself in the background mode regardless of the posture of the device.

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