Chinese Journal of Aeronautics, (2015), 28(6): 1725–1734

Chinese Society of Aeronautics and Astronautics
& Beihang University

Chinese Journal of Aeronautics

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A novel particle filter approach for indoor positioning by fusing WiFi and inertial sensors

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Received 12 December 2014; revised 24 July 2015; accepted 7 August 2015
Available online 19 October 2015

KEYWORDS

Fusion algorithm;
Indoor positioning;
Inertial sensor;
Rao Blackwellized particle filter;
WiFi fingerprinting

Abstract WiFi fingerprinting is the method of recording WiFi signal strength from access points (AP) along with the positions at which they were recorded, and later matching those to new measurements for indoor positioning. Inertial positioning utilizes the accelerometer and gyroscopes for pedestrian positioning. However, both methods have their limitations, such as the WiFi fluctuations and the accumulative error of inertial sensors. Usually, the filtering method is used for integrating the two approaches to achieve better location accuracy. In the real environments, especially in the indoor field, the APs could be sparse and short range. To overcome the limitations, a novel particle filter approach based on Rao Blackwellized particle filter (RBPF) is presented in this paper. The indoor environment is divided into several local maps, which are assumed to be independent of each other. The local areas are estimated by the local particle filter, whereas the global areas are combined by the global particle filter. The algorithm has been investigated by real field trials using a WiFi tablet on hand with an inertial sensor on foot. It could be concluded that the proposed method reduces the complexity of the positioning algorithm obviously, as well as offers a significant improvement in position accuracy compared to other conventional algorithms, allowing indoor positioning error below 1.2 m.

1. Introduction

Global navigation satellite system (GNSS) could provide accurate positioning in the outdoor environment.[1] However, the limitation of signal propagation makes this technology difficult for indoor positioning. Therefore, various systems offering high performance for indoor localization have been proposed. Due to the popularity and wide spread inside building, WiFi positioning was recently introduced as a potential alternative to GNSS in satellite signal denied areas.

In WiFi networks, the principal source of information is the received signal strength (RSS). WiFi positioning requires the use of a propagation model which describes the change in RSS with distance. The log fading model is widely used for this purpose. Recently, for indoor positioning, the prevalent technique is WiFi fingerprinting, which requires the database creation of RSS values from each access point (AP).[2] When positioning, user's device records its own value of RSS and

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Peer review under responsibility of Editorial Committee of CJA.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.cja.2015.09.009

matches it against the pre-recorded database. Location is then calculated based on good matches between new and stored values. The accuracy depends on the number of positions registered in the database. Besides, signal fluctuations over time could induce errors and discontinuities in the user's trajectory. In Ref.[3], an energy efficient WiFi indoor positioning algorithm is proposed, using the probabilistic fingerprinting method, to eliminate the fluctuations. Hybrid positioning systems were employed to enhance the performance of WiFi indoor positioning in Ref.[4]. Furthermore, the collaborative RSS fingerprinting system was utilized to overcome the cost and time-consuming problem of WiFi RSS positioning in Ref.[5].

To minimize the fluctuation of RSS, other methods such as the low-cost inertial sensors have been used. Due to their complementary advantages, fusing both systems could increase the positioning accuracy.[6] Pedestrian step is detected by the inertial sensors and the estimated walking direction and step length are fed into the particle filter as a motion model to predict the new particles. The weight of the particle is updated by computing the distance between the particle and the WiFi localization result.[7] Ref.[8] presents a sequential importance resampling particle filter to fuse the accelerometer and WiFi signals. Also, an augmented particle filter is proposed to simultaneously estimate location, step length and user heading. The user heading could be estimated by the inertial sensor, then updated by the user's trajectory in the measurement model of the augmented particle filter.[9] Inspired by our previous study on inertial positioning, the pedestrian heading could be obtained by the principle heading of building on map.[10]

Theoretically, for indoor positioning, Particle filter (PF) can be employed for any state model, but the major disadvantage of PF is that sampling in high dimensional states can be inefficient.[11–13] For large area mapping, some approaches divide the whole environment into several sub-areas which are estimated independently, and then these local maps are joined through a global optimization algorithms.[14,15]

This paper proposes a novel particle filter approach for indoor positioning by fusing WiFi and inertial sensors. The measurement model is developed using WiFi fingerprinting, which accurately characterizes the RSS relation and could measure the related noise. For the state model, the heading information and the step length could be computed by fusing the accelerometer and gyroscopes. In the proposed algorithm, local areas are estimated independently by a local filter, and then the trajectory of the local map origin is estimated by a global filter. So the implementation of proposed Rao Blackwellized particle filter (RBPF) for indoor positioning could not only induce the complexity reduction, but also offer better accuracy compared to other conventional algorithms.

The remaining sections of this paper are organized as follows: Section 2 presents the basic techniques of pedestrian inertial sensor. The WiFi-based measurement method is described in Sections 3 and 4 demonstrates the proposed RBPF algorithm. Section 5 gives the trial setup and preliminary results. Finally, the conclusion is drawn in Section 6.

2. Pedestrian inertial sensor method

Fig. 1 presents the architecture of the proposed fusion approach. The proposed method takes the WiFi RSS sensors and inertial sensors as input and outputs the user's location upon each step.

The algorithm includes three major components: inertial sensors, WiFi RSS and the RBPF. Inertial segment computes the steps of the user and the length of each step. It also calculates the heading information aided by building layout, as illustrated in our previous study.[10] The pedestrian motion vector, [length, direction, time], would pass to RBPF as the state model.

WiFi RSS records values periodically from all Aps as a RSS vector of [rss1, rss2, rss3, . . ., time]. WiFi fluctuations could cause notable variety in RSS vectors. The behavior of user turning and entering room could mislead the inertial sensor, due to the insufficient scanning of low-cost inertial sensor. So the algorithm contains the turn distinguishing and entrance discovering, as illustrated in Section 3.

PF method redistributes each particle according to the pedestrian state at the particle propagation phase. At the correcting phase, the algorithm corrects the weight of each particle according to the map and calculates the center of the particles. Finally, in the resampling phase, the new center of weighted particles is output as the current estimated position.

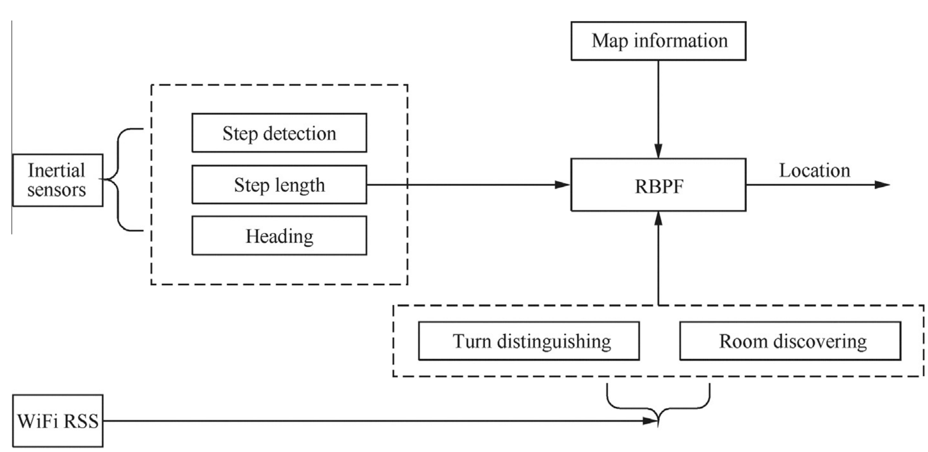

Fig. 1 Architecture of the proposed fusion approach.