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Mobile target indoor tracking based on Multi-Direction Weight Position Kalman Filter

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A B S T R A C T

Radio Frequency Identification (RFID)-based fingerprint indoor positioning and tracking technology is one of the key technologies in the study of wireless sensor network, and has been widely used in noisy environment. However, due to the time and space fluctuation in Received Signal Strength Indicator (RSSI) of RFID, indoor positioning accuracy is not satisfactory. In this work, we present a Multi-Direction Weight Position Kalman Filter (MDWPKF) according to the spacial feature of RSSI. This algorithm combines the Multi-Direction data collection method, with Standard Kalman Filter and fingerprint matching algorithm to achieve the signal fluctuation reduction, noise removal and 2D fingerprint mapping. At the same time, the Improved Position Kalman Filter (IPKF) in our proposed MDWPKF takes the advantages of Gaussian weight computation and velocity estimator to refine the position and velocity estimates. Compared with traditional PKF, the MDWPKF improves the positioning accuracy by 17.7%, and the velocity accuracy by 10.2%. Compared with Fingerprint Kalman Filter (FKF), the MDWPKF can be used for the tracking of both moving target (including position and velocity estimates) and stationary object.

1. Introduction

Since the Global Positioning System (GPS) cannot provide the same precision as outdoor localization in indoor environment, and the requirement of tracking for moving target in indoor environment increase rapidly, the indoor localization service has become a hotspot in the field of wireless sensor network. And how to achieve accurate indoor localization to satisfy the positioning requirement for users in complex indoor environments, also become a hot research topic in recent years [1].

Nowdays, the commonly used technologies for indoor localization include: Infrared-based [2], bluetooth-based [3], ZigBee-based [4], WiFi-based [5], UWB-based [6], RFID-based technology [7,8] and so on. Compared with other technologies, indoor positioning system based on infrared usually need to deploy the expensive ultrasonic sensors to achieve high accuracy in indoor environment and bring high hardware cost. Extracting the Doppler or phase shift information from WiFi has to modify the Network Interface Card (NIC) driver in Linux kernel also limit its application. Considering the limitation above, in this paper, we utilize RFID technology whose manufacturer provides various interfaces including phase shift to achieve high accuracy positioning in indoor environment.

Due to the fact that the fluctuation of Received Signal Strength Indicator (RSSI) exists in time and space, and the process and measurement noise caused by moving target in indoor environment, indoor positioning accuracy is not satisfactory. Many researchers have made contribution to the reduction of signal fluctuation and noise interference. In particular, the signal processing algorithm including Kalman Filter is used to noise removal and state estimate. For instance, authors in [9] combined Extended Kalman Filter (EKF) with Standard Kalman Filter (SKF) and Fuzzy Logic to propose an intelligent localization technique for autonomous maneuvering of robots, and the proposed framework worked well. Authors in [10] firstly proposed the Fingerprint Kalman Filter (FKF) algorithm in 2009, and Fang in [11] combined FKF, with SKF and Noise Covariance Estimator (NCE) to achieve the noise-aware adaptive Kalman Filter. Although these algorithms assume that the probability distribution of process noise is known, which may not be appropriate in practice, they still refine the positioning accuracy.

However, there are some other problems with these algorithms. Firstly, authors in [8–11] do not consider the RSSI fluctuation in

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time and space, and the off-line calibration fingerprint data set is not representative. Secondly, algorithms proposed by authors in [10,11] are limited to the positioning of stationary target, and can not achieve the velocity estimate of moving target. Thirdly, authors in [8] separate the Kalman Filter and velocity estimator, namely velocity estimate is not taken into the loop of Kalman Filter, and limit the accuracy of velocity estimate.

In this paper, we propose a Multi-Direction Weight Position Kalman Filter (MDWPKF) for mobile target tracking. The novel MDWPKF combines the Multi-Direction data collection method, with Standard Kalman Filter and fingerprint matching algorithm to achieve the signal fluctuation reduction, noise removal and 2D fingerprint mapping. The Improved Position Kalman Filter (IPKF) of MDWPKF takes the advantages of Gaussian weight computation and velocity estimator in the IPKF's measurement update stage, where Gaussian weight computation fuses four rough position estimates into one position measurement, and velocity estimator utilize the position measurement and phase shift to estimate the velocity of moving target.

1.1. Contributions

Our main contributions are listed as follows:

(1) An innovative Multi-Direction Weight Position Kalman Filter is constructed, which breaks the limit of Fingerprint Kalman Filter that can be only used for the positioning of stationary target. At the same time, MDWPKF achieves the accuracy improvement of position and velocity estimates.
(2) MDWPKF takes the Multi-Direction data collection method, Standard Kalman Filter, fingerprint matching algorithm and Improved Position Kalman Filter to adapt to the wireless signal fluctuation and noise interference in indoor environment. At the same time, our proposed MDWPKF also improves the accuracy of position and velocity estimates. The effectiveness of MDWPKF is verified by a large number of practical experiments. Compared with traditional PKF algorithm, MDWPKF improves the localization accuracy by 17.7%, and the velocity accuracy by 10.2%.
(3) MDWPKF utilizes phase shift to estimate the velocity of mobile target instead of acceleration or other sensors. Although the accuracy may be not as good as dedicated sensors, MDWPKF really achieves the state estimate of mobile target by single sensor, and reduces the cost of indoor localization and tracking.

1.2. Organization

The rest of this paper is organized as follows. Section 2 introduces the previous work related to our algorithm. And Section 3 presents the proposed Multi-Direction Weight Position Kalman Filter algorithm. Then, Section 4 shows the results and analysis of the experiments. Finally, Section 5 concludes this paper.

2. Related work

In this section, the previous research related to our proposed algorithm is introduced.

2.1. Indoor positioning algorithm

At present, the indoor positioning algorithm can be divided into two categories: one category is Range-Based or Distance-Based, and the other is Range-Free or Distance-Free [12–15]. In the field of Range-Based method, the Received Signal Strength Indicator (RSSI) based, the Time of Arrival (ToA) based, the Time Difference of Arrival (TDoA) based, and the Angle of Arrival (AoA)[16–20] based algorithms are widely used in indoor positioning system. Especially, the RSSI based indoor positioning algorithm which is based on the attenuation of the signal strength over distance has become popular due to the low-power consumption and cost competitiveness [21]. According to the properties of RSSI, researchers have presented path loss model based, interval-based, trilateration-based, and fingerprint-based algorithms. Among them, fingerprint-based method outperforms other algorithms in some conditions and attracts more attention.

Compared with the Range-Based positioning algorithm, the Range-Free method estimates the distance between different nodes or the coordinates of different nodes by network connectivity instead of measuring the distance directly [7]. And the typical Range-Free positioning algorithms such as improved DV-Hop [22] and the Self-Positioning Algorithm (SPA) [23], have lower accuracy of positioning and some restrictions [7]. As a result, researchers in both academia and industry pay more attention to the Range-Based algorithm instead of Range-Free.

2.2. Kalman filter

Recent years, researchers introduce machine learning, deep learning, and fuzzy set theory into fingerprint-based positioning algorithm. At the same time, some traditional navigation algorithm are also be introduced into localization service for mobile target tracking and noise removal. Kalman Filter as one of the most popular state estimate techniques for linear Gaussian system is widely used in spacecraft navigation and signal processing. For instance, authors in [9] combined Extended Kalman Filter with Standard Kalman Filter and Fuzzy logic to present an intelligent localization technique for autonomous maneuvering of robots.

From a traditional point of view, Kalman Filter has experienced three stages: Standard Kalman Filter (SKF), Extended Kalman Filter (EKF) and Unscented Kalman Filter (UKF). Standard Kalman Filter is named after Rudolf E. Kalman who is one of primary developers of its theory, and it is often used for navigation and noise removal in linear movement. Because of the limitation of linear movement in SKF, researchers present Extended Kalman Filter (EKF) for the estimate of nonlinear system and measurement. EKF takes Taylor series expansion for the nonlinear system and measurement, and keeps the linear term in the corresponding equation, then use the SKF to deal with the linearized system and measurement equations. As a result, EKF is still a Standard Kalman Filter in fact. On the other hand, since EKF gives up the second-order and higher-order terms in system and measurement equations, EKF can only be used for the estimate of weakly nonlinear object. Unscented Kalman Filter (UKF) is more suitable for nonlinear system and measurement compared with EKF, and it skips the step of linearization for system and measurement equations. In effect, UKF at least achieves the second-order approximation of nonlinear object, and is more suitable for estimate of strong nonlinear object. Each of the three kinds of Kalman Filter can not be replaced by two others, this is because they are suitable for different environments. People who use UKF for linear system and measurement will get worse result than SKF.

After researchers combine Kalman Filter with indoor positioning algorithm, a new point of view about Kalman Filter classification is presented, namely Position Kalman Filter (PKF) [24,25] and Fingerprint Kalman Filter (FKF) [10,11]. Compared with FKF, the PKF uses the position estimated by the fingerprint matching algorithm as the system measurement instead of the RSSI, which does not directly filter the noise of RSSI, but only indirectly reduces the fluctuation in the position estimates caused by the RSSI's noise [11]. As a result, PKF works well when we have the reasonably accurate static