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A novel radio map construction method to reduce collection effort for indoor localization

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ABSTRACT

Indoor localization using the fingerprinting technique, namely, the radio map, has attracted much attention in the research community recently. However, constructing a complete radio map is extremely labor-extensive and time-consuming, especially for a wide area. Although some works have been done to reduce the number of calibration points, the accuracy decreases if there are not enough fingerprints. In this paper, we propose a novel method based on the radio propagation model to construct a radio map with full fingerprints. In the radio map, the calibration points (CPs), i.e., fingerprints, are classified into two categories: the primary CPs chosen to collect received signal strength (RSS) artificially, and the secondary CPs obtained through some calculations. Based on the radio map constructed, we employ the Voronoi diagram to divide the area into several Voronoi regions and restrict the localization algorithm to run in a specific Voronoi region to reduce computational complexity. The comparison results show that our method saves a lot of time and human effort in collecting RSS samples, and achieves much higher accuracy than other existing schemes.

1. Introduction

Global positioning system (GPS) plays an important role in localization and navigation in recent years. However, GPS is not applicable to indoor localization due to the absence of GPS signal inside buildings. Thus indoor localization using a Wireless Local Area Network (WLAN) has become a promising method. However, radio signal can be attenuated due to the multipath of wireless transmission and the shadowing in an indoor environment, which can result in major positioning errors. Recently, fingerprinting based indoor localization has attracted much attention in the research community. The advantage of the approach is relatively effective, simple and inexpensive compared to other existing techniques such as time-of-arrival (TOA) [1], angle-of-arrival (AOA) [2], and time difference of arrival (TDOA) [3]. That motivates the work in this paper.

The basic idea of fingerprinting based indoor localization technique is to collect location-dependent characteristics such as the received signal strength (RSS) at specific positions, store them into the fingerprinting database, which is also called *radio map*, and use the information to decide the actual location of the localization target. Specifically, the technique is usually separated into two phases in the process of localization, offline phase and online phase. In the offline phase, the RSS values are collected from the Access Points (APs) on Line-of-Sight (LOS) at pre-selected points referred to as Calibration Points (CPs) [4] on the grid and stored in the radio map. In the online phase, the real-time RSS values are collected in the same way as that in the earlier phase and compared with the fingerprints in the radio map to estimate the location of the target. Clearly, the localization algorithm used in fingerprinting matching is of great importance in ensuring the accuracy of localization.

In recent years, to improve the performance of indoor localization, Voronoi diagram method and naive Bayes method have been adopted in offline and online phases, respectively [4–7]. On one hand, the localization algorithms based on Voronoi diagram were proposed to achieve the matching in the offline phase for indoor localization. In [8], Voronoi diagram is a proximity graph used for predicting the performance of location fingerprints and reducing the number of the fingerprints so as to reduce the size of the fingerprinting database and the cost of localization algorithm. However, the reduction of fingerprinting points will lead to the decrease of the number of vertexes in proximity graphs, and in turn cause the decrease of localization accuracy. On the other hand, the localization algorithms based on Bayes method were

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introduced in [4,5,9–11]. The Bayes theorem describes the probability of an event occurring based on the conditions that might be related to the event. Naive Bayes classifiers are a family of simple probabilistic classifiers which apply Bayes' Theorem with naive independence assumptions among the features. In the fingerprinting based indoor localization, it is necessary to assume that the received signal strength of each calibration point is independent. However, it incurs too much computation overhead to calculate the likelihood between the target and each calibration point in the radio map. Moreover, the offline phase is also a radio map construction process, which is an important part of indoor localization. Much effort has been made on constructing or reconstructing radio map aiming to reduce the size of huge inner structure and computation load [26,8,4]. To the best of our knowledge, there are few works on jointly utilizing Voronoi diagram method in the offline phase and naive Bayes method in the online phase to improve the localization precision, which is also one of the motivations for this work.

Based on the above consideration, in this paper, we propose a new indoor localization method jointly employing Voronoi diagram and naive Bayes method to improve the location precision. In particular, for the offline phase we provide a novel radio map construction algorithm with full fingerprints. At the beginning of our algorithm, we first randomly select a few calibration points to collect their RSS values in the location area in advance. Due to the effect of multipath propagation and fluctuation of radio signal, we use Gaussian filter for pretreatment to smooth the signal. Specifically, we define two kinds of calibration points in the radio map, the primary CPs and the secondary CPs. The former is a small number of the pre-chosen points whose RSSs can be collected artificially while the latter is the points used to patch radio map whose RSSs are calculated by the RSS of primary CPs. In addition, the construction and reconstruction of radio map greatly affects the accuracy and precision of indoor localization [9,12,13].

Accordingly, we patch the radio map based on the propagation properties of wireless signal to perform the reconstruction and self update of radio map, which is expressed as a radio propagation model, by considering the inner structure of the building such as the wall and floor. Furthermore, we propose a Voronoi diagram algorithm on the basis of primary calibration points i.e., Voronoi generators, to divide the location area into several Voronoi regions. Moreover, we propose an indoor localization algorithm based on the naive Bayes method to make a good match between the observation and calibration values within a specific Voronoi region. Simulation results show that our indoor localization method saves a lot of time and human effort in collecting RSS samples, and achieves high effectiveness and accuracy.

The rest of this paper is organized as follows: In Section 2, we discuss the related work on indoor localization techniques. Section 3 introduces the properties of received signal strength, and describes the radio signal model with Gaussian filter, naive Bayes method and Voronoi diagram, respectively. Then we propose an approach to patch the radio map based on radio propagation model in 4 and the localization algorithm based on Voronoi diagram and naive Bayes method in Section 5. We conduct some experiments in Section 6 to verify the performance of our algorithm. Finally, Section 7 draws the conclusion of this paper.

2. Related work

In the past several years, fingerprinting based indoor localization has attracted much attention in the research community and has been used in different applications. RADAR [14] is a representative system proposed by Microsoft and is the first indoor localization system based on wireless local area networks (WLANs) which matches the target location with the fingerprints by K-Nearest Neighbors (KNN) algorithm [15]. However, the accuracy of KNN is easily affected by the deployment, density and number of chosen reference points, as well as the number of RSS samples. Although the method has been conducted on fingerprinting based indoor localization with RSS, it hardly overcomes the high cost and time consumption in offline phase. Therefore, the measure proposed in [16] is to track users' location by using the inertial sensor in a smart phone, collect the location fingerprints and perfect the fingerprinting database simultaneously and automatically. The habit of using cellphones is also discussed to make it more credible. In [6], the authors proposed a fingerprinting based localization approach using RSS technique, which is implemented by dividing the tracking area into subareas and assigning a unique feature to each subarea through ranging the RSS values from different reference points. Ni et al. proposed a LANDMARC called location-sensing prototype system based on Radio Frequency Identification (RFID) technology for locating objects inside the buildings [17]. The HORUS system [18] uses location-clustering techniques to reduce the computational requirements of the algorithm, and the techniques aim to achieve high accuracy and low computational complexity. From the discussion above, we can see that wireless radio signal is essential in the process of indoor localization. However, the variation of indoor environment and wireless propagation will make it fluctuate over time and further affect the localization accuracy.

Voronoi diagram method was applied to indoor localization in [8], in which proximity graphs are used in an analytical model for approximating the probability distribution of error distance based on a given fingerprinting database. This approach is mainly based on analyzing the fingerprinting database and deleting redundant information. However, the decrease of fingerprints will make the location result inaccurate. In [19], Voronoi diagram was also used for localization in an indoor parking lot based on the fingerprinting database to test and verify the effectiveness and efficiency. In [9], Chai and Yang used the user traces, i.e., the sequences of signal strength recording a user's movement, to improve the performance while requiring only a small fraction of the calibration data. In [13], the inherent spatial correlation of RSS measurements was exploited to reduce the required calibrating fingerprints and perform direct localization without a full radio map. Clearly, the most important task of offline phase is to construct the fingerprinting database. However, insufficient fingerprints cause the poor location accuracy while excessive fingerprints can require more collection time and effort.

In addition, Bayes theorem has been used for indoor localization in many works. SEAMLOC [4] is a seamless indoor localization algorithm based on the reduced number of calibration points, which was shown to have high accuracy. The use of interpolation algorithm is to patch the radio map, which reduces the calibration time. However, its processing time is very similar to that of other approaches. In [11], a probabilistic localization algorithm is presented based on off-the-shelf active RFID technology, Gaussian filter and wheel graph model. The system is not only compatible with the future smart spaces and ubiquitous computing systems, but also suitable for large-scale indoor localization. In [5], Bayes learning algorithms and some commonly-used machine learning algorithms were investigated based on the data set characteristics. However, the problem of zero probability in those algorithms may cause significant decrease of accuracy.

3. Preliminaries

In this section, we introduce the properties of received signal strength and use Gaussian filter to make the RSS values more