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Indoor positioning via subarea fingerprinting and surface fitting with received signal strength

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ABSTRACT

The fingerprinting technique based on received signal strength (RSS) has been intensively researched for indoor localization in the last decade. Instead of using discrete reference points to build fingerprint database, this paper applies the surface fitting technique to construct RSS spatial distribution functions and proposes two location search methods to find the target location. We also propose to use subarea division and determination scheme to improve the fitting accuracy and search efficiency. In the offline phase, we divide the whole indoor environment into several subareas, construct a fingerprint for each subarea, and build a RSS distribution fitting function for each access point in each subarea. In the online phase, we first determine to which subarea a target belongs, and then search its location according to the proposed exhaustive location search or gradient descent based search algorithm. We conduct both extensive simulations and field experiments to verify the proposed scheme. The experiment results show that for the same reference point granularity, the proposed localization scheme can achieve about 22% localization accuracy improvement, compared with the classical nearest neighbor-based fingerprinting method.

1. Introduction

Indoor location information has been becoming more and more important for location-based applications and services. Some indoor localization technologies have been developed, which have different hardware requirements and localization accuracies. Due to the wide deployment of *wireless local area networks* (WLANs) as indoor access systems, indoor localization based on the *received signal strength* (RSS) from *access point* (AP) has become a hot research topic in recent years [1,2].

Fingerprinting is the most popular distance-free indoor localization technique [3–6]. Generally, it is composed of two phases: the offline training phase and online positioning phase. For a given indoor environment, the RSS profiles of some predetermined *reference points* (RPs) with known coordinates are measured, processed and stored as fingerprints in the offline phase. In the online phase, the RSS profile of a mobile device is used to produce its own fingerprint that will be compared with those pre-stored fingerprints to determine its location. A widely used positioning method is to select the location of a RP with the minimum fingerprint difference as the estimated location for the mobile device.

The performance of fingerprinting methods is dependent on the number of RP per unit area, viz the RP granularity. It has been reported that in general, increasing the number of RP per unit area helps to improve localization accuracy [3,7].

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However, the RSS measurements are very time-consuming and labor-intensive, and using more RPs will increase lots of the workloads and costs for localization.

Some approaches have been proposed to reduce the training efforts, while trying to maintain satisfactory localization accuracy [7–12]. Some propose to exploit unlabeled data, such as measurements of user casual movement traces, to improve the calibration of RSS distributions, when the field calibration data from reference points are insufficient [8–11]. Another approach is to create some virtual reference points and obtain their fingerprints by interpolating the fingerprints of nearby training locations [7,11,12]. Although these methods help to improve the localization accuracy with reduced training efforts, they are still a kind of discrete approach. Because their fingerprint comparison space is represented by some discrete yet limited reference points, unlabeled data or virtual reference points.

In this paper, we propose to use the surface fitting technique to generate fingerprint for an arbitrary indoor space point. This is done by constructing continuous RSS spatial distribution functions only from a few RP fingerprints. Such a fitting function describes the indoor RSS characteristics and only requires a few number of function coefficients. For example, let $\phi_j(x, y)$ denote the RSS from the jth AP at the space point (x, y). After we obtain ϕ_j for all available APs, we then construct a fingerprint for (x, y). Despite its simplicity, it is rather effective and can achieve much satisfactory localization accuracy. Furthermore, we apply a subarea division and determination scheme for surface fitting and location search. The basic idea is to divide the indoor environment into some subareas, say for example, according to walls and rooms. As rooms are often divided by concrete that generally introduces noticeable radio attenuations, we propose and use rooms as subareas in this paper. In each subarea, we create a subarea fingerprint and construct fitting functions based on the fingerprints of those RPs only within the subarea. The subarea division scheme is needed because it helps to improve fitting functions' accuracies. Furthermore, the use of subarea division scheme for localization not only helps to reduce the online comparison computations, but also provides a coarse positioning service for those applications with low positioning accuracy requirement.

In this paper, we propose two location search algorithms to find the location of a mobile device after subarea determination, namely, exhaustive location search (ELS) and gradient descent location search (GLS). Both are to minimize the fingerprint difference between the mobile device and a space point within the subarea. The former is to divide the subarea into many grid points (more than the number of RPs within the subarea) and compute their fingerprints based on the surface fitting functions built before. The latter is to iteratively search the global minimizer for an objective function of fingerprint difference. It utilizes the slope characteristics of the objective function by setting the negative gradient descent direction as the search direction, and it also applies an adjustable step size in the iterative search process. We have conducted extensive simulations and field experiments. The results show that on average 10% and 22% improvement of localization accuracy for the two proposed algorithms can be achieved, compared with the traditional fingerprinting algorithm.

The rest of this paper is organized as follows: Section 2 briefly gives the related work about fingerprint-based localization. Sections 3 and 4 give the offline work and online work of our method respectively. In Section 5, we conduct both simulations and field test experiments to verify our algorithm. Finally, we conclude this paper in Section 6.

2. Related work

Generally, fingerprint-based localization can be divided into two kinds: deterministic method [13,14] and probabilistic method [11,14–16]. For the former, it is to find a RP with the minimum fingerprint difference to the mobile fingerprint, for example, the nearest neighbor algorithm (NN) [14]. For the latter, it is to find a RP at which the mobile target is most likely appeared based on a probability distribution function (PDF) [13]. Most of these methods are a kind of discrete scheme. That is, all the possible searching locations are limited into a set of finite RP locations. Therefore, the performance of such fingerprint-based localization is constrained by the RP granularity. In general, a finer RP granularity provides more detailed description of radio propagation characteristics, and often leads to a higher localization accuracy. However, a finer RP granularity means that more RPs per unit area should be measured in the offline phase, which introduces prohibitive costs of time and labor in turn.

To relieve the training burden, some previous work [8–11] suggest exploiting unlabeled data, such as measurements of user casual movement traces, to improve the calibration of RSS distributions. In [8,9,11], the EM algorithm is used to improve the fingerprint distributions based on a small fraction of training reference points and the collection of user traces. In [10], the relative locations of access points and mobile targets are first determined by using some unlabeled data in the offline phase. In the online phase, their absolute locations are recovered to help locating a target for a given set of labeled data. Generally, these approaches help to reduce the fingerprint calibration efforts, but they are still a kind of discrete scheme with limited fingerprints.

Some work suggest enriching the reference points by creating virtual reference points and interpolating their fingerprints based on the spatial correlation of radio propagation. The interpolation can be done either in the offline phase [7,11,12] or in the online phase [17]. However, both of the two methods need a large storage space to store the fingerprints. The online interpolation is also very time-consuming, because one should first select several candidate RPs during the online phase and then conduct interpolation in the area surrounded by these RPs. Our proposed surface fitting method could save the storage space efficiently, as only a few of fitting function coefficients need to be saved. Furthermore, it has been shown in our simulations and experiments that the proposed GLS method can obtain the positioning location only by a few iterations.

To reduce the online fingerprint comparisons, fingerprint clustering methods have been proposed to group fingerprints into some clusters [18–21]. In the online phase, a mobile is first determined to which cluster it belongs, and then comparisons