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Interoperable localization for mobile group users

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ABSTRACT

This paper studies the problem of real-time wireless localization for mobile group users, which can be used in many applications such as fire rescue and safety management in construction sites. However, due to the mobility of users and the instability of wireless signals, we find that traditional localization methods do not perform well, and the localization accuracy is thus not acceptable. To solve this problem, we propose to localize mobile users by exploiting their interrelated information. The mutual distance information among the users are exploited to get better localization performance for all the users. We first theoretically prove that the proposed scheme can improve the localization probability and accuracy. Furthermore, an Interoperable Localization Method (ILM) is designed, which extends the Kalman filter to alleviate the influence of noisy and unstable wireless signals. Finally, extensive experimental results demonstrate that our method outperforms the fixed anchor-based methods by 20%–45% in terms of localization accuracy and 20%–50% in terms of localization probability.

1. Introduction

In recent years, wireless localization has attracted considerable research interest because of the increasing demand for location-based services in the military, industry and Wireless Sensor Networks (WSNs) [1,2]. Among them, localization for mobile objects is one of the most significant applications [3]. For example, indoor localization, which attempts to find the accurate positions of person and object inside a building, mall, ..., etc [4], can provide the position information to provide services in various categories including the location detection of firefighters in a building on fire, location detection of products stored in a warehouse, location detection of medical personnel or equipment in a hospital, and finding tagged maintenance tools and equipment scattered all over a plant, tracking, monitoring, healthcare, billing and so on [5–7]. For example, if we can know the exact position of the firefighters, we can get more information about the fire, monitor the security situation of firefighters and direct rescue operations. Another example is that, the high-risk construction industry in Hong Kong accounts for nearly 1/5 of all industrial accidents. This accident occurrence rate could be greatly reduced if safety management systems could continuously monitor the real-time locations of mobile workers and automatically issue warnings when these workers are close to some hazardous areas. However, because of the mobility and sheltered by barrier, the signal from fixed anchors may not well received.

The Global Positioning System (GPS) is one of the most well-known and widely used localization techniques [8]. However, two factors limit its application for mobile group users indoor. First, the localization error, which is approximately 10 m, is too large to satisfy the demand of location-based services. Second, it performs poorly in indoor environments such as mines, markets, airports and warehouses. Fortunately, we have another type of localization technology: localization with wireless signals, e.g., Time of Arrival (TOA) [9], Time Difference of Arrival (TDOA) [10], Angle of Arrival (AOA) [11] and Received Signal Strength Indication (RSSI) [12]. These approaches require a set of specialty nodes known as anchors, which know their own location either through manual configuration or through a GPS receiver [13]. These technologies work well for the localization of static users. However, due to various reasons, such as the mobility of users, the instability of the wireless signal [14], multipath propagation and Non-Line of Sight paths (NLOS) [15], these localization techniques do not perform

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well for mobile users. Moreover, the solutions provided by these localization algorithms are acceptable only when there is sufficient distance information from the anchors. However, in certain scenarios, due to sparse anchor deployment, short radio communication ranges, and physical obstacles, a sufficient number of accurate measurements may not be available. In such cases, the localization accuracy declines sharply [16,17]. Hence, developing a reliable algorithm to address these localization problems is important and requires more study.

With the development of the electronics manufacturing technology, mobility has been available for many devices, such as sensors [18,19], therefore mobility-based researches have been more and more popular nowadays [20]. Mobility-aided localization methods, in which mobile anchors are exploited to aid in localization, have been investigated recently in studies such as [21] and [22]. A mobile anchor can follow mobile users in mobility-aided localization methods, which can improve the localization performance. However, it is well known that a moving anchor can cover only a small area within a reasonable time [23]. Obviously, adding more mobile anchors in the network area leads to better performance, but this incurs high costs. Moreover, the movement of the anchor increases energy consumption and introduces greater hardware support requirements, such as mobile devices. Therefore, mobility-aided methods still cannot solve the localization problem for mobile group users, which may include many users.

Another research interest is cooperative localization, in which the information among the users are exploited to help the localization [24,25]. The most common idea is that some users are localized first and then they can be exploited as virtual anchors to localize others who cannot. Thus there is a delay of the positioning for the users, which also influences the localization accuracy. Another problem is that, they focus on localizing the users who are immobile. If the users are mobile, due to the users' mobilities and signal noise, the localization accuracy is limited. For example, in [26], the localization accuracy achieved in the static network seems feasible, but failed in the dynamic networks. Patwari N et al. present cooperative measurement-based statistical models and give the localization error analytically in [27]. They propose a distributed localization algorithm by successive refinement, which still cannot avoid the delay problem. In [28], the authors propose convex SDP (semidefinite programming) estimators specifically for the RSS-based localization in both noncooperative and cooperative schemes, and the maximum likelihood estimator is appended to the convex estimator. However, the localization error is more than 1.5 m in most cases, which is too large.

This paper presents a novel approach for localizing mobile group users. In the proposed approach, the mobile users not only communicate with several fixed anchors but also with other mobile users. Then, the distances among them can be calculated. Based on these information, the mobile users can help themselves (as a whole) to get better localization performance. This localization idea is designed and combined with the extension of KF, which further improves the localization performance. The main contributions of this paper are listed as follows:

1. To localize mobile group users, we introduce the idea of interoperable localization, in which mobile users serve as "mobile anchors" to help locate each other.
2. A series of theoretical analyses regarding why the localization performance can be improved are presented.
3. We extend the Kalman filter algorithm to alleviate the influence of the noise in the environment and the unstable of wireless signals.
4. We conduct extensive experiments to compare the proposed solution with traditional solutions, and the effectiveness is validated by the experimental results.

The remainder of this paper is organized as follows. Section 2 reviews related work. The experimental results of the traditional fixed anchors-based localization method is presented in Section 3. The details of the proposed localization scheme are elaborated upon in Section 4. Section 5 demonstrates the experimental results. We conclude the paper in Section 6.

2. Related work

Nowadays, with the rapidly development of cloud computing [29–31] and mobile computing, applications based on wireless localization are becoming increasingly common. The localization problem has received tremendous attention from the research community because the localization performance is an absolute necessity for correct operation of the systems [23]. The existing localization schemes proposed are broadly categorized into five groups: distributed algorithm, centralized algorithm, iterative algorithm, mobility-assisted approach and statistical approach according to [32] and are divided into "sparse vs. dense", "anchor based vs. anchor free", "indoor vs. outdoor", "cooperative vs. noncooperative" and "static vs. mobile" according to [33]. According to whether the distance information between anchors and users is required, wireless localization methods can be broadly divided into two categories: range-based localization and range-free localization [34,35]. While according to whether the users can cooperative with each other, wireless localization methods can be divided into cooperative localization and non-cooperative localization [36]. In this paper, we focus on range-based cooperative localization methods. The major studies related are summarized into three groups and the details are illustrated as follows.

2.1. Range-based localization scheme

Normally, the range-based localization approach utilizes the ranging information between the user and anchors whose locations are already known. For example, in [37], the authors consider a problem of TOA-based localization for a passive object. They propose linearizing the system model by introducing a range variable first and then solve the linearized localization problem via the Tikhonov regularization method. However, the ranging information is always contaminated by the environment or uncertainty, which affects the performance of the localization method. To solve this problem, some studies propose combining two or more of the methods to improve the localization accuracy and reduce the energy consumption [38]. For example, a hybrid TOA and RSS linear least squares localization method is derived in [39]. However, these combined methods increase the algorithm complexity. Moreover, if the anchors are sparsely deployed, the deployment of the anchors is extremely irregular, or there are too many obstacles in the environment, the real-time positions of the users still cannot be achieved. Consequently, these methods have special requirements for anchor quantity and distribution.

2.2. Mobile anchor-based localization scheme

In addition to the use of stationary anchors, several other studies introduce mobile anchors to help with the localization process [40]. In [41], a single mobile anchor is introduced to enable the sensor nodes to construct two chords of a communication circle, and the intersection of the perpendicular bisectors of these two chords is then calculated to pinpoint the sensors positions. However, it introduces only one mobile anchor due to the hardware costs and this anchor moves randomly through the sensing field. Thus, it is possible that some of the sensor nodes cannot be localized. To solve this problem, a path planning-based scheme is proposed in [42] that not only improves the localization accuracy but