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Autonomous smartphone-based WiFi positioning system by using access points localization and crowdsourcing

Y. Zhuang [a,*], Z. Syed [b], J. Georgy [b], N. El-Sheimy [a]

[a] *Department of Geomatics Engineering, University of Calgary, Calgary, Canada*

[b] *InvenSense Inc., Calgary, Canada*

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ABSTRACT

The survey of WiFi access points (APs) locations and their propagation parameters (PPs) is a time and labour consuming process, which makes WiFi positioning impractical. In this paper, a novel crowdsourcing method is introduced. The proposed method is used for automatic AP localization and PPs estimation by employing an inertial navigation solution, such as Trusted Portable Navigator (T-PN). The proposed system runs on smartphones, from which it builds and updates the database autonomously and adaptively to account for the dynamic environment. A WiFi positioning method, based on the generated database, is also discussed. The proposed system is validated by both simulated and experimental tests.

1. Introduction

The rapid development and improvement of smartphones has enabled smart devices to become powerful tools for pervasive computing applications such as positioning, navigation, and context capture [1,2]. Because smartphones are frequently used, they have become ideal platforms for the development of applications for people's daily life. Furthermore, smartphones are also widely used as platforms for navigation because they have sophisticated and powerful microprocessors, efficient operating systems, and embedded multi-sensors [3]. Fast computation for navigation applications is ensured by the microprocessors and operating systems, while embedded multi-sensors guarantee sufficient data to support the design of navigation algorithms.

Today's smartphones commonly contain the following multi-sensors: Global Navigation Satellite System (GNSS), accelerometers, gyroscopes, magnetometers, barometers, as well as WiFi and Bluetooth transceiver modules. These sensors and transceivers can be used together for positioning and navigation applications. GNSS is the most popular navigation system when it is available [4]. However, GNSS cannot provide a reliable indoor navigation solution because the GNSS signals are degraded and attenuated by ceilings, walls, and other objects. Used as an alternative to GNSS, MEMS (Microelectromechanical system) sensors can provide a navigation solution in any environment [5,6]. However, the accuracy of the MEMS sensors' navigation solution will degrade with time due to the integration of noise which causes drift of the solution without other aiding sources [7]. WiFi-based positioning is another candidate navigation technology because it provides location information through the use of pre-existing WiFi infrastructures. Currently, most public buildings, such as universities, homes, airports, shopping malls, and office buildings already have well established WiFi infrastructure. WiFi positioning solutions do not drift as compared to standalone inertial navigation solutions using MEMS sensors. However,

* Corresponding author. Tel.: +1 4032107897; fax: +1 4032841980.
E-mail addresses: zhy.0908@gmail.com, zhuangy@ucalgary.ca (Y. Zhuang).

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current WiFi positioning systems usually require pre-survey to provide locations of access points (APs), propagation parameters (PPs) or radio maps [8–10]. The pre-survey is time and labour consuming, which makes most current WiFi positioning systems impractical. Complementary characteristics of these navigation technologies can be used together to improve the overall navigation accuracies.

This paper addresses smartphone-based automatic WiFi positioning systems. An efficient and practical WiFi positioning system is proposed to overcome the extensive survey needed by traditional systems. The main purpose of this paper is to reduce the labour needed for the survey of a WiFi database. Currently, most of the WiFi positioning systems based on trilateration assume that AP locations and PPs are available from pre-surveys [11]. In fact, even if this information is available, it may not be suitable for real-time WiFi positioning due to the changing environment. Changes in the environment could be caused by:

- removal or addition of WiFi routers;
- temporary loss of signals from one or more routers;
- or changes in the obstruction pattern from survey time to data collection time.

Consequently, real-time automatic estimation for AP locations and PPs is an effective way to ensure accurate WiFi positioning. An autonomous system will also reduce the labour and time costs for surveys to maintain the databases because crowdsourcing will be updating the databases in the background. Unfortunately, most current methods cannot estimate AP locations and PPs in real-time while adapting to the changes in the environment.

In order to implement an automatic and practical WiFi positioning system, we first propose novel algorithms based on the navigation solution from the Trusted Portable Navigator (T-PN) for AP localization, PPs estimation, and autonomous crowdsourcing. The T-PN is highly customizable software that converts any quality and grade of inertial sensors into navigation capable sensors that can be used on many smartphone operating systems (e.g. Android). AP locations and PPs are estimated using nonlinear iterative least squares (LSQ) and the corresponding information is recorded in the database when some pairs of the T-PN solution and corresponding Received Signal Strength (RSS) values meet the preset requirements. Additionally, the estimation accuracy of AP localization is also stored in the database to be used for WiFi positioning in the future.

The core function of autonomous crowdsourcing is to update the AP information in the database and keep this data accurate. The database update happens automatically in the background, without any restriction on the user; thus making the crowdsourcing completely autonomous.

The WiFi positioning phase essentially contains two steps. First, RSS values are converted to ranges using the propagation model based on PPs from the automatically surveyed database. Next, user position is estimated based on nonlinear LSQ and positioning result optimization. Some may ask why we need WiFi positioning when an accurate inertial navigation solution such as T-PN is available. Although a good inertial navigation system may not drift very quickly, it still occurs. Therefore, it cannot provide a long-time accurate indoor navigation solution. Thus, some wireless positioning systems (GPS or WiFi) may be required. However, in most cases GPS is unavailable or inaccurate in indoor environments. In these scenarios, a WiFi solution is needed to aid the inertial navigation to achieve an accurate indoor navigation solution. Even if GPS is available, sometimes in indoor environments WiFi can still further improve the performance of indoor navigation. The key idea behind this paper is that when T-PN is accurate (i.e. not drift too much), it is used to automatically build a database for trilateration-based WiFi positioning through crowdsourcing. Furthermore, when the database is successfully built the WiFi solution can be used to aid T-PN. Our proposed WiFi positioning system can help T-PN provide a long-term navigation solution in deep indoor environments where GPS is usually not available.

The main contributions of this paper are as follows:

- A convenient and practical WiFi positioning system on smartphones is proposed to reduce the labour of pre-surveying and to improve the positioning accuracy.
- Novel algorithms for estimating AP locations and PPs in the propagation model and autonomous crowdsourcing are proposed.
- The proposed system is implemented on smartphones and evaluated by both simulations and real-world experiments.

For the remainder of this paper, we will introduce the related work in Section 2, and present the algorithms for AP localization, PPs estimation, and autonomous crowdsourcing in Section 3. Section 4 describes the proposed WiFi positioning system and is followed by the evaluation of both simulations and real-world experiments.

2. Related work

2.1. Schemes that estimate AP locations and PPs

Until now, there have been several papers that discuss the estimation of AP locations or PPs for building a WiFi database based on the propagation model. AP locations are computed through the use of averaging and weighted averaging of positions derived from the measurement points in [12]. However, large estimation errors can result from measurement points with bad geometrical distribution. In [13], a "multilateration" method is proposed to estimate the AP locations for the wireless networks. The disadvantage of this method is that it requires distance information from the unknown AP to