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Improving indoor positioning precision by using received signal strength fingerprint and footprint based on weighted ambient Wi-Fi signals☆

Jenq-Shiou Leu*, Min-Chieh Yu, Hung-Jie Tzeng

Department of Electronic and Computer Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan

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ABSTRACT

Positioning is the foremost process in the location based service (LBS). With the GPS signal strength obstructed by the wall, indoor users cannot obtain their positions with the assistance from the global positioning satellites. Most of the indoor positioning systems have relied on received signal strengths (RSSs) from indoor wireless emitting devices, such as Wi-Fi access points (APs). Integrating indoor position information into the application on the modern handheld devices can increase the application diversity and quality in an indoor environment. In this paper, we propose a novel indoor positioning scheme assisted by the RSS fingerprint and footprint. Smartphone users can get their indoor position based on RSSs from the surrounding Wi-Fi APs. With the assistance of collecting ambient Wi-Fi RSSs from not only the intrinsic APs but also the extrinsic APs, filtering RSSs by directions/orientations, and mitigating signal fluctuation, our proposed scheme can overcome the severe signal instability problem in the indoor environment and raise the positioning accuracy. In order to reduce the time complexity of the indoor positioning procedure, we design a close designated location set (CDLS) algorithm that only uses the designated locations with the similar footprints of current user's position to determine the user's location. The proposed RSS fingerprint and footprint matching mechanism can speed up the positioning process. Meanwhile, to lessen the possible negative effect of extrinsic APs, the weighted voting positioning (WVP) algorithm would assign higher reference weights to the signals from the intrinsic APs, and adjust the weights to the signals from the extrinsic APs by their failure probability. The evaluation results show that our proposed scheme can achieve a certain level of accuracy in the indoor environments and outperform other solutions.

1. Introduction

Location based service (LBS) can help people visit an unfamiliar place. For example, backpackers can easily obtain the local information from LBS while they arrive at a strange place. LBS can also be applied to commercial promotion. For example, when people take a stroll in a shopping mall, a nearby shop they approach can send electronic coupons to them to achieve an effective advertising. However, the foremost issue for LBS is how to accurately obtain visitor's position. The more accurate position can be determined, the more precise information can be provided. The quality of LBS can be therefore raised.

Assisted by Global Positioning System (GPS), people in the outdoors can easily get their positions with a certain level of precision. However, there has been far less improvement

☆ A preliminary version of this paper entitled "Received Signal Strength Fingerprint and Footprint Assisted Indoor Positioning Based on Ambient Wi-Fi Signals," has been presented in The 75th IEEE Vehicular Technology Conference. The video clip for the proposed positioning application can be accessed through http://www.youtube.com/watch?v=Km8Zq4yNsfw.

* Corresponding author. Tel.: +886 2 2737 6386.
E-mail addresses: jsleu@mail.ntust.edu.tw (J.-S. Leu), d10002103@mail.ntust.edu.tw (M.-C. Yu), m9802138@mail.ntust.edu.tw (H.-J. Tzeng).

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on the indoor positioning. Most of past works focusing on indoor positioning intuitively use the radio emitters likes Wi-Fi APs or ZigBee sensor nodes as fixed reference points. Then the positions of the targets which were normally nomadic laptop computers would be estimated based on the RSSs from these points. Nowadays, numerous Wi-Fi APs are established by some network owner or some individuals. Wi-Fi signals are perceived almost everywhere. Hence, the accuracy of the estimated position can be raised by referring to ambient signals from not only the intrinsic Wi-Fi APs, which is self-constructed so that the corresponding referred signals are stable and reliable, but also the extrinsic Wi-Fi APs, which is not self-constructed so that the corresponding referred signals may not be stable or reliable. Meanwhile, with recent developments in mobile communications technologies, smartphones have become an indispensable device than a laptop computer for most people. Intensifying the positioning function on smartphones by adding in the indoor positioning function can realize a ubiquitous LBS concept from outdoors only to almost anywhere.

Based on above, we propose a practical design philosophy for indoor positioning. The proposed positioning scheme is based on the radio strengths from Wi-Fi APs and is mainly composed of two stages. In the first stage, called an offline stage, the positioning system collects the ambient signal strengths at some designated locations to construct the RSS fingerprint. The ambient signals not only come from the intrinsic APs but also from the extrinsic ones. To prevent burst noise signals from affecting the correctness of the RSS fingerprint, filtering out these burst signals is needed. Also, to make a more precise fingerprint as a reference basis for the second stage, the RSS fingerprint is confined in orientation and direction. Meanwhile, the related strengths received from the intrinsic APs in the RSS footprints are also noted for raising the positioning precision.

In the second stage, called an online stage, a Wi-Fi enabled smartphone can be positioned based on the collected information in the offline stage. The strengths of ambient signals from APs surrounding the smartphone are collected by the phone first. The smartphone then forwards the collected signals to the positioning system. In order to reduce the time complexity of the indoor positioning procedure, we design a close designated location set (CDLS) algorithm that only selects the designated locations with the similar footprints of current user's position to determine the user's location. After that, a weighted voting positioning (WVP) algorithm is used to determine the final position based on the collected ambient signals by comparing the RSS fingerprint and footprint database in the positioning system.

The main contribution of the proposed work is the idea of also using extrinsic APs. Since the placement of the extrinsic APs cannot be controlled by the service owner and the extrinsic APs may disappear or be moved after the training phase, so the extrinsic APs may not function stably as intrinsic ones do. Therefore, how to give extrinsic APs suitable weights in the positioning process is important for the proposed system. To lessen the possible negative effect of extrinsic APs, the WVP algorithm would assign higher reference weights to the signals from the intrinsic APs, and adjust the weights to the signals from the extrinsic APs by their failure probability. Thus, extrinsic APs still can facilitate to raise the accuracy of positioning system by the evaluation results. This paper focuses on how to craft the proposed indoor positioning system. Meanwhile, our comprehensive evaluations validate the effectiveness of the proposed scheme in an indoor environment. The rest of this paper is organized as follows. Section 2 illustrates some related works about positioning. Section 3 describes the system architecture and the proposed scheme. Section 4, we theoretically and practically evaluate the performance of the proposed system and conduct a performance comparison with other positioning schemes. A brief conclusion is presented in Section 5.

2. Related works

Recently there has been a shift in attention from a focus on outdoor positing to a concentration on indoor positioning. Using the received signal strengths surrounding the user is the most intuitive way. The authors in [1] utilized the received-signal-strength index (RSSI) of radio signals radiating from fixed reference nodes and reference tags placed at known positions to locate the user. The signals come from the self-established radio radiators only. However, taking other ambient signals for reference may be beneficial to promote the positioning precision. Other reference information may be used to identify the user position, such as a vision based mechanism using prior knowledge about the layout of the indoor environment [2]. However, the positioning system may need a large space to store the sequences of images and image sequence matching could result in more time consumption compared to character sequence matching.

Among many RSS based indoor positioning techniques, the most common wireless signal is Wi-Fi since the IEEE 802.11 APs are pervasively deployed as a wireless local area network (WLAN) nowadays. Before the Wi-Fi technique becomes popular, the radio-frequency (RF) based RADAR system in [3] has been proposed according to empirical measurements by recording and processing signal strength information from multiple base stations to determine user location. Meanwhile, some hybrid indoor location estimation methods were proposed, such as using the two-dimensional marker to complement the Wi-Fi strength [4] or using different wireless technologies involving the cellular GSM, DVB, FM and WLAN to locate the user [5]. However, the network access point with a higher radio coverage, such as GSM, FM base stations, may contribute less to indoor positioning which normally requires a fine scale. Some researchers tried to combine other low-power technologies to build the indoor positioning system, like RFID [6], and ZigBee [7]. However, these technologies need a lot of low-power devices to support the positioning process. Deng et al. [8] pointed out that a multi-source data combined positioning technology can enhance the positioning accuracy, but the cost of the system would also rise significantly. Therefore, we would not use different wireless signals in the proposed indoor positioning system.

The placement of access points can affect the precision of location estimation. A new SNR defined in [9] trying to make the signal maximized and the noise minimized simultaneously is used to deploy APs for reducing positioning errors. However, APs may be displaced unintentionally. Different influence weights should be assigned to different APs with