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Improvement of Kalman filters for WLAN based indoor tracking

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ABSTRACT

Location Based Service (LBS) cannot be realized unless the location of the user is available. For indoor LBS, indoor positioning must be utilized and many researchers have been working on indoor positioning and tracking. For example, Extended Kalman filter (EKF) was exploited in Bluetooth based indoor positioning. Nowadays, WLAN (Wireless Local Area Network) is available virtually everywhere. Thus, WLAN based indoor positioning and tracking is more economical than Bluetooth based ones. This paper proposes a new WLAN based EKF indoor tracking method by extending existing Bluetooth based EKF positioning method. After analyzing the experimental results of it, we modified it to use K-NN method in the measurement stage of it. Then we propose to further improve the accuracy of indoor tracking by adjusting the parameter values referring to the map information. Experimental results comparing our method with other previous methods are discussed.

1. Introduction

Location-Based Service (LBS) is information service where the location of the user is utilized (Virrantaus, Markkula, Garmash, & Terziyan, 2001). Many useful LBSs including navigation, emergency management, etc are available nowadays. Generally, they use GPS (Global Positioning System) to determine the user's location and 'Timed net with Choice Probability' can be used for the analysis of a Location Based Service system (Yim, Joo, & Lee, 2006).

LBS are so useful that providing indoor LBS is very desirable. For instances, many huge buildings in metropolitan area, large scale companies, factories, universities, and so on are especially demanding LBS. However, GPS alone cannot provide sufficient data for determining the user's location when the user is inside of a building. Therefore, techniques for indoor positioning have been studied by many researchers. Active Badge (Want, Hopper, Falcao, & Gibbons, 1992), positioning by sensing infrared signal, Active Bat (Harter & Hopper, 1997) and Cricket (Priyanthat, Chakraborty, & Balakrishnan, 2000), positioning by using the difference between the propagation times of ultrasound and RF signal, and RADAR (Bahl & Padmanabhan, 2000), positioning by using the strength of the received UDP signal, are examples of the most representative indoor positioning systems. These systems are highly accurate. But they require special equipments dedicated for positioning.

Many indoor positioning systems which do not require special equipments have also been developed. Most of them utilize WLAN (Wireless Local Area Network) equipments. Nowadays, wireless LAN is being serviced everywhere including college campuses, airports, hotels and even homes. The indoor tracking system we are going to introduce in this paper is a WLAN-based tracking system. A WLAN-based tracking system determines a user's position referring to the received signal strengths (RSS) of the signals from access points (APs). The most popular method they use to determine user's position is the fingerprinting method (Bahl & Padmanabhan, 2000; Madigan et al., 2005; Wann & Lin, 2004; Youssef, Agrawala, & Shankar, 2003; Youssef & Agrawala, 2004; Yim, 2008). Many techniques are utilized in fingerprinting method and K-NN (Nearest Neighbor) (Bahl & Padmanabhan, 2000) is one of the very basic ones.

The deployment of a fingerprinting method consists of off-line phase and real-time phase. During the off-line phase, the location fingerprints are collected by performing a site-survey of the RSS from multiple APs. The vector of RSS values at a point is called the location fingerprint of that point. During the real-time phase, the method gathers RSSs the user receives at the moment and matches them with fingerprints to determine the user's location.

It is known that the fingerprint method is fairly accurate. However, it has a serious shortcoming. That is, the off-line phase is extremely time consuming process. An alternative choice is RF propagation loss model based methods (Lassabe, Canalda, Chatonnay, & Spies, 2005). RF propagation loss model is a simple mathematical expression representing the relationship between the RSS and the distance between the sender and the receiver. However, RSS is influenced by so many environmental parameters and establishing an appropriate RF propagation loss model is very dif-

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ficult. As the result, RF propagation loss model based positioning method is less accurate than fingerprinting method.

Kalman filter is a good candidate tool in dealing with such noisy data as RSS. In fact, Kotanen, Hannikainen, Leppakoski, and Hamalainen (2003) has already introduced Extended Kalman filter method for Bluetooth-based indoor positioning. The process of Kalman filter iteratively predicts and corrects the prediction with measurements until some termination criteria met. The Kalman filter introduced in Kotanen et al. (2003) measures Bluetooth signal strengths and adjusts the predicted user's position with them. One of the contributions of this paper is to extend the Bluetooth based EKF positioning (Kotanen et al., 2003) to WLAN based tracking. However, our experimental results of the WLAN-based tracking EKF show that the average error of it is considerably large.

Therefore, we have decided to use fingerprinting method at the measurement stage as (Wang, Lenz, Szabo, Bamberger, & Hanebeck, 2007) does. Wang et al. (2007) introduced Kalman filter for tracking. The measurement of the Kalman filter in Wang et al. (2007) is the 2-Dimensional user's position obtained by applying K-NN positioning. The second contribution of this paper is to improve the accuracy of the KF tracking by adjusting parameter values referring to the map information. Experimental results evaluating our methods will be discussed.

2. Related works

This paper introduces an Extended Kalman filter method of WLAN-based indoor tracking. The Extended Kalman filter for Bluetooth-based positioning (Kotanen et al., 2003) and the Kalman filter tracking with K-NN (Wang et al., 2007) are closely related to this paper. Trilateration which is a method of positioning with distances between the mobile terminal and APs is also closely related with this paper. Therefore, K-NN, trilateration and Kalman filter are discussed in this section.

2.1. K-Nearest neighbors (K-NN)

In K-NN, we build a look-up table in the first phase, or off-line phase. The entire area is covered by a rectangular grid of points called *candidate points*. At each of the candidate points we measure the RSSIs many times. Let $\mathrm{RSSI_{ij}}$ denote the jth received signal strength of the signal sent by $\mathrm{AP_i}$. A row of the look-up table is an ordered pair of (coordinate, a list of RSSIs). A coordinate is an ordered pair of integers (x, y) representing the coordinates of a candidate point. A list of signal strengths consists of five integers, $\mathrm{RSSI_1}, \mathrm{RSSI_2} \ldots$, where $\mathrm{RSSI_i}$ is an average of signal strengths $\mathrm{RSSI}_{\mathrm{ij}}$ received at (x, y) and sent by $\mathrm{AP_i}$. An example of look-up table is shown in Table 1.

In the second phase, or real-time phase, the positioning program gathers RSSIs the user receives at the moment. If the positioning program is running on the user's handheld terminal, then the terminal itself will collect RSSIs. Let $\mathrm{X} = (\mathrm{RSSI_1}, \mathrm{RSSI_2} \ldots)$, be the vector of the collected RSSIs, K-NN then searches the look-up table to find the K closest candidate points and returns the average of the K coordinates of them as the user's current location.

Table 1
An example look-up table of K-NN (C.P stands for candidate points, CP_i is the coordinates of ith C.P, APi is the MAC address of ith AP).

CP	AP				
	AP1	AP2	AP3	AP4	AP5
CP1	−39	−55	−56	−70	−67
CP2	−40	−56	−55	−69	−66
CP3	−44	−42	−62	−45	−61
...	...	...	...	...	...

2.2. Trilateration

If we know three measured distances, D_0, D_1, D_2, from three base stations, N_0, N_1, N_2, to the mobile terminal, M, and we also know the coordinates, $(X_0, Y_0, Z_0), (X_1, Y_1, Z_1), (X_2, Y_2, Z_2)$ of the base stations as shown in Fig. 1, then we can estimate the coordinate of M by using trilateration. Let the coordinate of M be (x, y, z), then D_i^2 can be expressed as the following:

$$(x - X_i)^2 + (y - Y_i)^2 + (z - Z_i)^2 = D_i^2, \quad (\text{for } i = 0, 1, 2, \ldots, m-1)$$

When the coordinates are 3-dimensional, we need to have at least four base stations. We can obtain a linear equations with three unknown, $A\vec{x} = \vec{b}$, where

$$A = \begin{bmatrix} 2(X_1 - X_0) & 2(Y_1 - Y_0) & 2(Z_1 - Z_0) \\ 2(X_2 - X_0) & 2(Y_2 - Y_0) & 2(Z_2 - Z_0) \\ 2(X_3 - X_0) & 2(Y_3 - Y_0) & 2(Z_3 - Z_0) \\ \cdots & \cdots & \cdots \\ 2(X_{m-1} - X_0) & 2(Y_{m-1} - Y_0) & 2(Z_{m-1} - Z_0) \end{bmatrix}, \quad \vec{x} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

$$\vec{b} = \begin{bmatrix} (X_1^2 - X_0^2) + (Y_1^2 + Y_0^2) + (Z_1^2 + Z_0^2) - (D_1^2 + D_0^2) \\ (X_2^2 - X_0^2) + (Y_2^2 + Y_0^2) + (Z_2^2 + Z_0^2) - (D_2^2 + D_0^2) \\ (X_3^2 - X_0^2) + (Y_3^2 + Y_0^2) + (Z_3^2 + Z_0^2) - (D_3^2 + D_0^2) \\ \cdots \\ (X_{m-1}^2 - X_0^2) + (Y_{m-1}^2 + Y_0^2) + (Z_{m-1}^2 + Z_0^2) - (D_{m-1}^2 + D_0^2) \end{bmatrix}.$$

The solution of the equations can be (x', y', z') that minimizes the δ defined by the following:

$$\delta = (A\vec{x}' - \vec{b})^T (A\vec{x}' - \vec{b}), \quad \vec{x}' = \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}$$

Applying MMSE (Minimum Mean Square Error) method, we can obtain $\vec{x\prime}$ with the following expression:

$$\vec{x}' = (A^T A)^{-1} A^T \vec{b}. \tag{1}$$

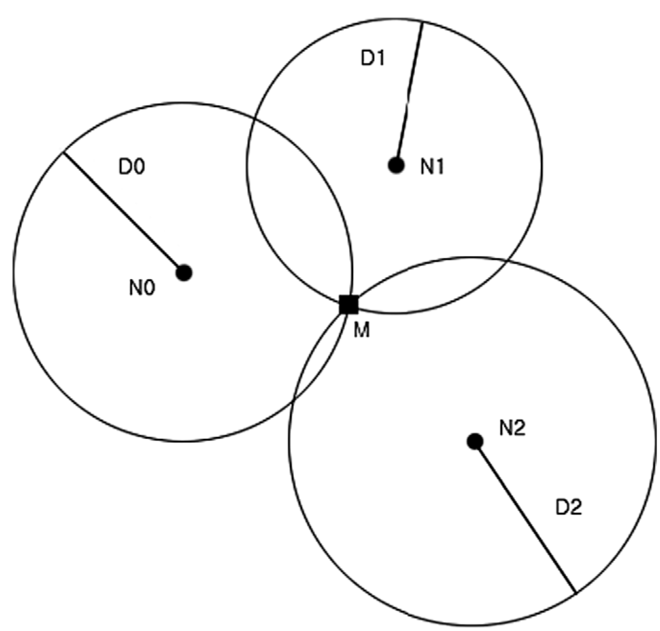

Fig. 1. Given distances, we can determine the position of M.