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A NOVEL HIGH ACCURACY INDOOR POSITIONING SYSTEM BASED ON WIRELESS LANS

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Abstract—A novel indoor positioning system based on received signal strength (RSS) in wireless networks with high accuracy is presented in this paper. The three improvement mechanisms, called signal strength filter, user location filter and path tracking assistance, are employed to improve the positioning accuracy of the system. The comprehensive performance of the proposed system is analyzed in detail and compared with the Radar system. Experimental results demonstrate that the proposed system in this paper can improve 80% accuracy in 3 meters of Radar system to 93% in typical office building testbed. Therefore, the indoor positioning system presented in this paper has the advantages of high accuracy, low cost and easy expansibility, and it can be used to locate people and assets in the fields of logistics, healthcare, and manufacturing.

1. INTRODUCTION

Indoor positioning systems have become very popular in recent years. Knowledge of the positions of users combined with user profiles could significantly help in network planning, load balancing, logistics tracking, caching of information closer to the user and radio resource management. The primary progress in indoor positioning systems has been made during the recent ten years. Therefore, both research and commercial products in this area are new, and many people in academia and industry are currently involved in the research and development of these systems, such as Active Badges [1], Cricket [2], Smart Floor [3], LANDMARC [4], etc.

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Although the above mentioned projects have obtained some achievements, these positioning systems are still complex, expensive and not scalable because new hardware is required.

On the other hand, wireless local area networks (WLAN) based on 802.11 have been deployed in campus and office buildings. The WLAN positioning technique based on received signal strength (RSS) is based on the principle that the received signal strength from access points varies with the distance between users and access points. Compared with techniques of time of arrival (TOA) and angle of arrival (AOA), it has lower cost, because it can make full use of the existed WLAN infrastructures, and does not need additional devices to precisely synchronize in TOA or expensive directional antennae or array of antennae in AOA. Therefore, the indoor positioning technology based on received signal strength in wireless networks is becoming more and more attractive [5].

At present, the indoor positioning technique based on received signal strength has the following main problems and difficulties:

(1). Because of the harsh multi-path environment in indoor areas, techniques that use triangulation or direction are not very attractive and often can yield highly erroneous results [6]. Location fingerprinting refers to techniques that match the fingerprint of some characteristic of the signal that is location dependent. In WLANs, an easily available signal characteristic is the received signal strength (RSS) and this has been used in [7] for fingerprinting.

However, the received signal strength is interfered by various types of noise, such as band interference among access points, sudden person walking and opening or closing of windows and doors, and so on. These random disturbances of received signal strength will seriously decrease the accuracy of indoor positioning systems.

(2). At real-time tracking stage, indoor positioning systems must calculate the location of users in a short time. Therefore, the number of received signal strength samples scanned by wireless network card is less, and the standard deviation of forecasted user location is larger, which will seriously decrease the performance and stability of indoor positioning systems.

(3). In real life, people always move according to a certain paths, for example, walking from one side of corridor to the other side of it, can not pass through the wall, and so on. Therefore, all kinds of possible paths could be predefined, then the indoor positioning systems can make full use of these paths to further improve the positioning accuracy.

Therefore, the main purpose of this paper is to solve the above-mentioned problems and present a novel indoor positioning system based on received signal strength in wireless networks with high accuracy. The three main improvement mechanisms, called signal strength filter, user location filter and path tracking assistance, were employed to improve the positioning accuracy of the system to the greatest degree.

This paper is organized as follows. In Section 2, we present a novel indoor positioning system, named WiTracker, based on received signal strength in wireless networks. In Section 3, three improvement mechanisms, called signal strength filter, user location filter and path tracking assistance, are proposed to improve the positioning accuracy of the WiTracker system to the greatest extend. Section 4 analyzes the comprehensive performance of the WiTracker system and compares it with the Radar system. In Section 5, two key influence factors to positioning accuracy are further discussed and analyzed. Finally, Section 6 summarizes the paper and gives possible future research directions.

2. IMPLEMENTATION OF WITRACKER INDOOR POSITIONING SYSTEM

2.1. Positioning Algorithms

There are at least four location fingerprinting-based positioning algorithms using pattern recognition technique so far: probabilistic methods, k-nearest-neighbor (kNN), neural networks, and support vector machine (SVM) [8, 9].

In our WiTracker system, the Probabilistic Methods and kNN Method are used to forecast and calculate the user location.

1) Probabilistic Methods: One method considers positioning as a classification problem [10]. Assuming that there are n location candidates L_1, L_2, L_3, ..., L_n and s is the observed signal strength vector during the online stage, the following decision rule can be obtained:

Choose L_i if $P(L_i\,|s) > P(L_j\,|s)$, for $i, j = 1, 2, 3, \ldots, n,\ j \neq i$.

Here, $P(L_i\,|s)$ denotes the probability that the mobile node is in location L_i, given that the received signal vector is s.

2) kNN Methods [11]: The kNN averaging uses the online RSS to search for k closest matches of known locations in signal space from the previously-built database according to root mean square errors principle. By averaging these k location candidates with or without adopting the distances in signal space as weights, an estimated location is obtained via weighted kNN or unweighted kNN. In this approach, k is the parameter adapted for better performance.

2.2. Implementation of WiTracker Indoor Positioning System

The WiTracker indoor positioning system consists of three components, called WiTracker Server, WiTracker Location Survey and WiTracker Client, which communicate by 802.11 a/b/g wireless LANs.

The framework of the WiTracker indoor positioning system is depicted in Figure 1.

(i). WiTracker Server runs on Windows XP and Windows 2003 Server, and its main function is to display the current real-time location of tracking devices.

(ii). WiTracker Location Survey runs on Windows XP, and its major functions include: New Project, Open Project, Import Map, Define Sub-space, Define Reference Point, Define Map Scales, Survey Calibration, Survey Test, Signal Strength Analysis, Error Vector Analysis, Accuracy Statistical Analysis, Real-time Tracking and Wireless NIC Settings.

(iii). WiTracker Client runs on Windows XP/2000, Windows Pocket PC 2003 or Windows CE 5.0, and its key purpose is to calculate the location of tracking device and send forecasted location information to WiTracker Server by User Datagram Protocol (UDP).

To obtain the RSS for different wireless network cards, in this study we used a small program that captures RSS data based

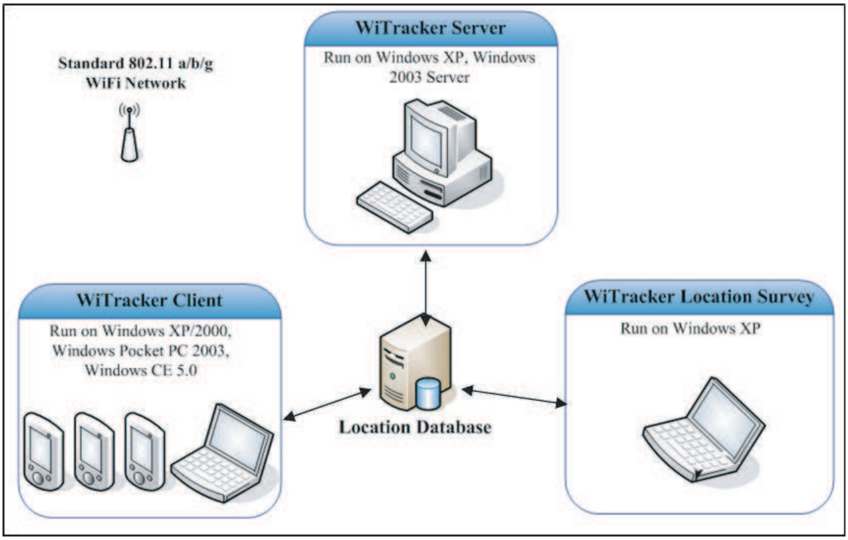

Figure 1. The framework of the WiTracker indoor positioning system.

on available example code from Microsoft's Windows XP driver development kit (DDK) [12] and the University of California at San Diego's Wireless Research API (WRAPI) [13]. The program utilizes Windows XP's Network Device Interface Specification (NDIS). It is a kernel layer standard API which defines the interface between the network interface card and the medium access control (MAC) protocol driver. A WIN32 API called *DeviceIoControl* allows any user's application to query Microsoft's object identifier (OID) such as *OID_802_11_RSSI* to obtain received signal strength indication (RSSI) on a wireless network card. The RSSI returned by Windows's miniport driver is measured in dBm and has typical values between −10 and −100 [14].

3. THREE IMPROVEMENT MECHANISMS OF WITRACKER SYSTEM

3.1. Signal Strength Filter

The received signal strength is interfered by various types of noise, such as band interference among access points, sudden person walking and opening or closing of windows and doors, etc. These random disturbances of received signal strength will seriously decrease the accuracy of indoor positioning systems.

Therefore, three different filtering methods, named Max Filter Limit Filter and MA Filter are analyzed in detail in this paper in order to improve the positioning accuracy of system because of harsh multi-path environment and all kinds of disturbance in indoor areas.

The descriptions of these three different filtering methods are as follows:

(i). **Max Filter** [15]. The received signal strength is interfered by noise, such as sudden person walking and opening or closing of windows and doors. However, the noise always decreases the value of RSS, and does not increase the value of it. Therefore, we can calculate the maximum RSS value of N continuous samples in order to filter the lower RSS which is interfered by noise. Figure 2 is the simulation experiments of Max Filter when the parameter N is set to 5 and the total number of signal strength samples is 120.

(ii). **Limit Filter**. The initial value is set to the average value of samples. If the changes between the next sample and the current sample exceed the maximum *Limit*, then the next sample is invalid. Otherwise, the next sample is valid. Figure 3 is the simulation experiments of Limit Filter when the parameter *Limit* is set to 15 dB and the total number of signal strength samples is 120.

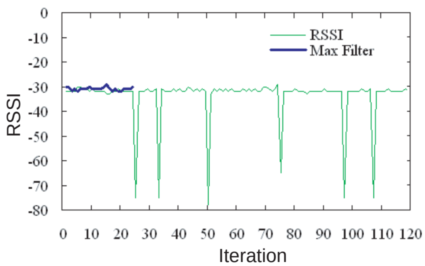

Figure 2. Simulation experiments of Max Filter.

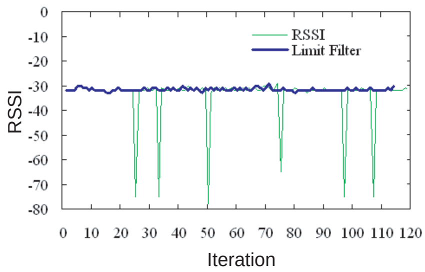

Figure 3. Simulation experiments of Limit Filter.

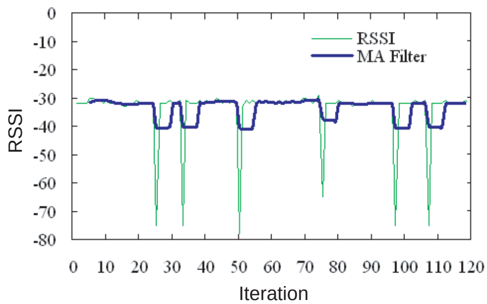

Figure 4. Simulation experiments of MA Filter.

(iii). **MA Filter**. In Move Average Filter, called MA Filter, the size of time sliding window is set to *WindowSize*. Figure 4 is the simulation experiments of MA Filter when the parameter *WindowSize* is set to 5 and the total number of signal strength samples is 120.

Figure 5 is the effect of three filter methods on accuracy of kNN method. The experimental results of Figure 5 show that the Max Filter, Limit Filter and MA Filter can improve the accuracy in 2.5 meters of 89% to 96%, 92% and 90%, and improve the accuracy in 3 meters of 92% to 98%, 95% and 93% respectively.

Therefore, from the experimental results of Figure 5, we can draw a conclusion that the proposed Max Filter and Limit Filter could improve the positioning accuracy of indoor positioning system remarkably in this paper. However, the MA Filter is not suitable to filter the received signal strength. In WiTracker system, the Max Filter is employed to filter the received signal strength and decrease the random disturbance of noise.

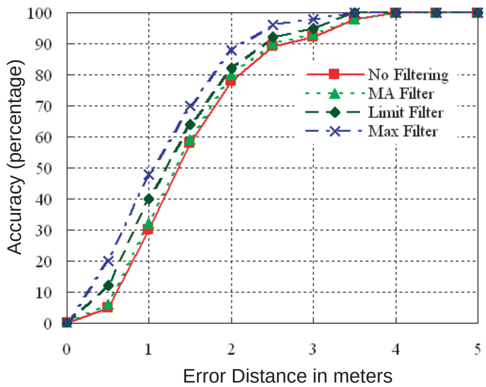

Figure 5. Effect of three filter methods on accuracy of kNN method.

3.2. User Location Filter

At real-time tracking stage, indoor positioning systems must calculate the location of users in a short time. Therefore, the number of received signal strength samples scanned by wireless network card is less, and the standard deviation of forecasted user location is larger, which will seriously decrease the performance and stability of indoor positioning systems.

Therefore, we can use Kalman filter algorithm to filter the forecasted user location in order to further improve the performance and stability of WiTracker system. The process and measurement equations for the Kalman filter are given as follows [16]:

$$\begin{aligned} x_k &= F_k x_{k-1} + w_k, \quad w_k \sim N(0,Q), \quad x(0) \sim N(X(0), V(0)), \\ z_k &= H_k x_k + v_k, \quad\quad v_k \sim N(0,R). \end{aligned} \tag{1}$$

The process and measurement noise are assumed to be independent, and are defined by the covariance matrices Q and R. They are initially estimated by measuring the covariances of different paths, and then are used for all the experiments. In this paper, the Q_k is set to 1×10^{-2}, and the R_k is equal to 4.

The predict and update stages for the Kalman filter are as follows:

1. Predict Stage for the Kalman Filter

$$\widehat{x}_{\bar{k}} = F\widehat{x}_{k-1}, \quad P_{\bar{k}} = FP_{k-1}F^T + Q \tag{2}$$

2. Update Stage for the Kalman Filter

$$\begin{gathered} K_k = P_{\bar{k}} H^T \left(HP_{\bar{k}}H^T + R\right)^{-1}, \widehat{x}_k = \widehat{x}_{\bar{k}} + K_k \left(z_k - H\widehat{x}_{\bar{k}}\right), \\ P_k = (I - K_k H) P_{\bar{k}} \end{gathered} \tag{3}$$

In the beginning, a prediction of the current location is made using the previous location. This estimate is updated using the observations weighted by the Kalman gain K_k. If the variance of observations is higher, the process noise covariance matrix R will be larger, which will decrease the Kalman gain and the effect of the observations. On the other hand, if the R is smaller, observations will be more trustworthy and weighted more heavily by the Kalman gain. If a posteriori error covariance P_k^- is lower, it will make the Kalman gain smaller, which will give more importance to the predictions.

The two dimensional model describing the motion of the user location is taken as follows:

$$\begin{bmatrix} x_k \\ y_k \\ V_k^x \\ V_k^y \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{k-1} \\ y_{k-1} \\ V_{k-1}^x \\ V_{k-1}^y \end{bmatrix} + \begin{bmatrix} w_k^x \\ w_k^y \\ w_k^{V_x} \\ w_k^{V_y} \end{bmatrix},$$
$$\begin{bmatrix} z_k^x \\ z_k^y \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_k \\ y_k \\ V_k^x \\ V_k^y \end{bmatrix} + \begin{bmatrix} v_k^x \\ v_k^y \end{bmatrix}. \tag{4}$$

The current location of the user is assumed to be the previous location plus the velocity, while the received signal strength samples are scanned at each second, and is subject to Gaussian noise whose covariance is constant and pre-estimated based on off-line trials. The current observation is the current user location disturbed with the Gaussian noise.

The simulation experimental results of Kalman filter are shown in Figure 6 and Figure 7. Figure 6 depicts the Kalman filter result for x-coordinate of user location, and Figure 7 gives the Kalman filter result for y-coordinate of user location correspondingly.

From the experimental results of Figure 6 and Figure 7, we can find that when without filter, the forecasted x-coordinate and y-coordinate of user location are far away from the real coordinates of user location. However, when with Kalman filter, the forecasted x-coordinate and y-coordinate are much closer to the real coordinates of user location.

3.3. Path Tracking Assistance

In real life, people always move according to a certain paths, for example, walking from one side of corridor to the other side of it, not pass through the wall, etc. Therefore, all kinds of possible paths could be predefined, then the indoor positioning systems can make full use of these paths to further improve the positioning accuracy.

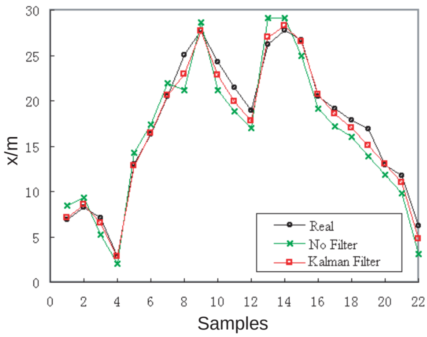

Figure 6. Kalman filter result for x-coordinate of user location.

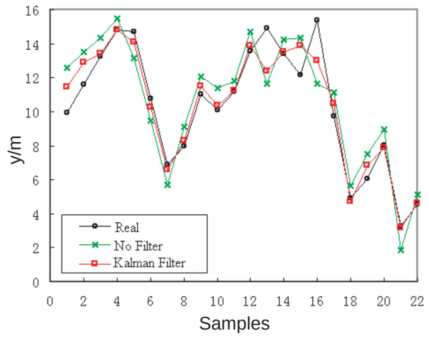

Figure 7. Kalman filter result for y-coordinate of user location.

The process of path tracking assistance in detail is as follows:

Firstly, we define the subspaces for the indoor environment. Secondly, the possible existent paths between these subspaces are defined. At positioning stage, the WiTracker system firstly calculates the subspace of user. When the system forecasts the next position of user, it only searches the current subspace and the subspaces which are connected with the current subspace. Those subspaces that are not connected with the current subspace are ignored and not considered. Therefore, the forecasted location coordinates of user will be more stable and accurate, and its forecasted location is impossible to pass through the wall because the path of passing through the wall does not exist at all. Furthermore, the computing time of indoor positioning algorithm will decrease remarkably because the number of searched subspaces has been greatly reduced.

Figure 8 gives a demonstration about definition of subspaces and paths for the indoor environment.

From Figure 8, we can see that the whole experimental testbed is divided into eight subspaces, named Room 1, Room 2, Room 3, Room 4, Entrance 1, Hallway_1, Elevator and Exit. The lines in the figure refer to the paths which connect two subspaces.

For example, the number of subspaces which are connected with Entrance 1 is two, named Room 4 and Hallway_1. Thus, if the current subspace of user is Entrance 1 that means the user is at the entrance of room. Then the next position of user only has the following three possible situations:

(1). In the subspace Entrance 1, that means, the user still stays at the entrance of office room.

(2). In the subspace Room 4, that means, the user is moving to the Room 4.

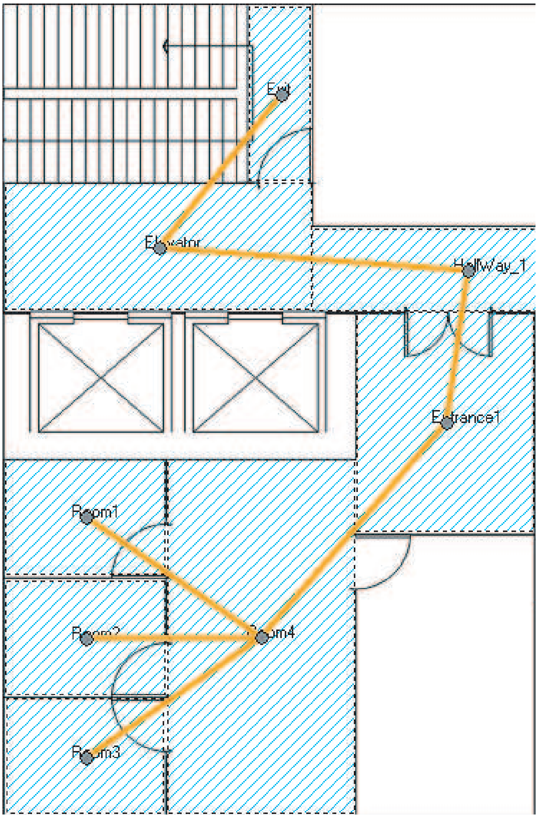

Figure 8. The definition of subspaces and paths for the indoor environment.

(3). In the subspace Hallway_1, that means, the user is moving to Hallway_1 and leaving the office room.

Therefore, when the system forecasts the next position of user, it only searches the current subspace Entrance 1 and the subspaces Room 4 and Hallway_1 which are connected with the current subspace Entrance 1.

Those subspaces Room 1, Room 2, Room 3, Elevator and Exit that are not connected with the current subspace Entrance 1 are ignored and not considered. Therefore, the forecasted location coordinates of user will be more stable and accurate, and its forecasted location is impossible to skip to subspace Exit from subspace Entrance 1 because the path of skipping to Exit from Entrance 1 does not exist at all.

Furthermore, the computing time of indoor positioning algorithm will decrease remarkably because the number of searched subspaces has been greatly reduced. For the above-mentioned situation, the system only searches three subspaces, named Entrance 1, Room 4 and Hallway_1, and the other five subspaces, named Room 1, Room 2, Room 3, Elevator and Exit, are not considered. Thus, the number of searched subspaces has been reduced to 3/8 or 37.5%.

4. COMPREHENSIVE PERFORMANCE OF WITRACKER SYSTEM

4.1. Experimental Testbed

The experimental testbed is located in the 11th floor of Cherry Blossom Building of Wuhan which is the typical indoor office environment. The floor has dimensions of 15 meter by 27 meter and includes more than 15 rooms.

In this work, we choose the TP-LINK TL-WA501G as our experimental access points (APs) because of its low cost. The wireless LANs consist of six access points, and the MAC, SSID and operating channel of these access points are listed in Table 1.

The survey trail and AP placement of experimental testbed is shown in Figure 9. The AP placement of experimental testbed refers to the conclusion of literature [17], that is, the access points should be scattered asymmetrically and should be placed around the site in a "zigzag" pattern rather than placing several APs close together or placing them on a straight line.

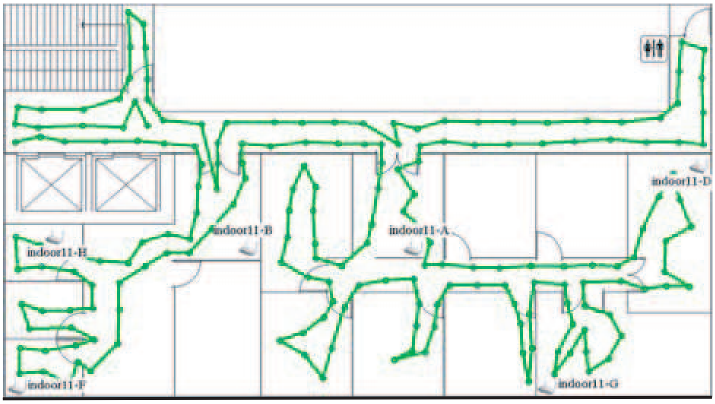

Figure 9. The survey trail and AP placement of experimental testbed.

Table 1. MAC, SSID and channel of experimental access points.

MAC	SSID	Channel
00:1D:0F:43:CA:7F	indoor11-A	9
00:1D:0F:43:CA:80	indoor11-B	6
00:1D:0F:43:CA:87	indoor11-D	1
00:1D:0F:43:CB:A7	indoor11-F	11
00:1D:0F:43:CB:A8	indoor11-G	1
00:1D:0F:43:CC:28	indoor11-H	7

4.2. Experimental Results

In recent years, a large number of indoor positioning systems with different wireless technologies have been reported, such as Ubisense system [18] with UWB technology, LANDMARC system with Active RFID technology, TOPAZ system [19] with Bluetooth technology, and GSM fingerprinting [20] using GSM cellular network technology.

However, indoor positioning systems based on WLAN RSS technology have rarely been proposed, and only RADAR [21], Horus [22] and Ekahau [23] have been well presented so far. Furthermore, RADAR system is more typical than Horus and Ekahau because it is developed by Microsoft Corporation, and its positioning algorithm based on k-nearest-neighbor is well-known and no secret. Therefore, in this paper, we only compare the comprehensive performance of WiTracker system with Radar system because of time constraints. The proposed three improvement mechanisms, called signal strength filter, user location filter and path tracking assistance in this paper should also be effective to other indoor positioning systems based on WLAN RSS technology, such as Horus and Ekahau.

The experimental results and comparison between two indoor positioning systems, called WiTracker system and Radar system, for the testbed are shown in Figure 10 and Table 2.

From Figure 10 and Table 2, we can find that the comprehensive performance of Radar system is worse, which only can obtain the Average Error of 2.2 meters, the 90% Error of 4.5 meters, the Zone Accuracy of 68%, and the Accuracy in 3 meters of 80%. However, the comprehensive performance of WiTracker system is better, which can obtain the Average Error of 1.4 meters, the 90% Error of 2.8 meters, the Zone Accuracy of 76%, and the Accuracy in 3 meters of 93%.

Therefore, the comprehensive performance of WiTracker system

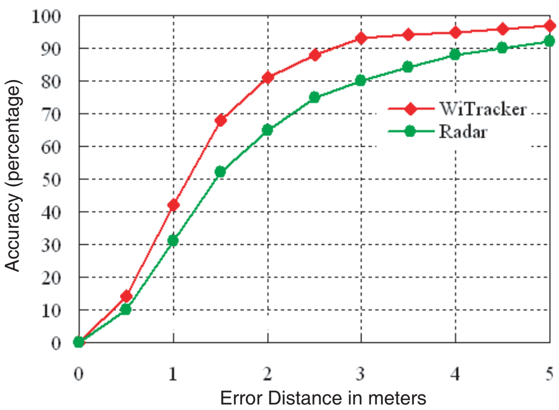

Figure 10. Accuracy comparison of two indoor positioning systems.

Table 2. Performance comparison between two indoor positioning systems.

Method	Average Error (m)	90% Error (m)	Zone Accuracy (%)	Accuracy in 3 meters (%)
Radar	2.2	4.5	68	80
WiTracker	1.4	2.8	76	93

proposed in this paper is better than Radar system remarkably. Experimental results demonstrated that the proposed WiTracker system can improve the 80% accuracy in 3 meters of Radar system to 93% in a typical office building testbed.

5. TWO KEY INFLUENCE FACTORS TO POSITIONING ACCURACY

5.1. Number of Access Points

The experimental results and comparison among different number of access points for the testbed described in Section 4 are shown in Figure 11 and Table 3.

From Figure 11 and Table 3, we can find that when the number of access points increases from 1 to 4, the positioning precision can obtain remarkable improvement. However, when the number of access points rises from 4 to 6, the effect of number of access points on positioning performance is less.

Table 3. Effect of number of access points on positioning performance.

AP Number	Average Error (m)	90% Error (m)	Zone Accuracy (%)	Accuracy in 3 meters (%)
AP Number = 1	4.9	8.2	11	26
AP Number = 2	3.3	6.0	33	50
AP Number = 3	2.1	4.5	60	79
AP Number = 4	1.6	3.0	71	92
AP Number = 5	1.4	2.9	71	94
AP Number = 6	1.4	2.8	76	93

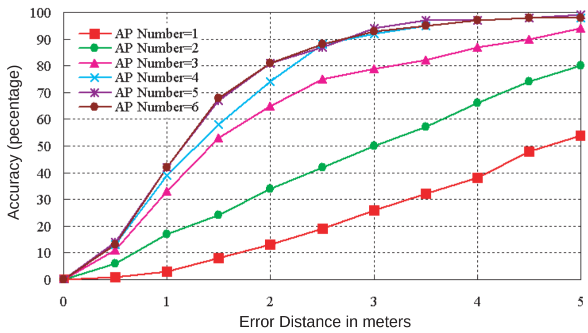

Figure 11. Effect of number of access points on positioning accuracy.

Therefore, for the testbed in this paper, the optimal number of access points should be 4 because it can achieve higher positioning accuracy by using less access points which will decrease the hardware cost of indoor positioning system.

5.2. Spacing between Sampling Points

The experimental results and comparison between different spacing of sampling points, for the testbed are shown in Figure 12 and Table 4.

From Figure 12 and Table 4, we can find that the positioning accuracy is better when the spacing between sampling points is set to 1.5 meters, which can obtain the Average Error of 1.4 meters, the 90% Error of 2.8 meters, the Zone Accuracy of 76%, and the Accuracy in 3 meters of 93%. And the positioning accuracy becomes worse when the spacing between sampling points is set to 3.0 meters, which can obtain the Average Error of 1.4 meters, the 90% Error of 2.9 meters, the Zone Accuracy of 76%, and the Accuracy in 3 meters of 91%. However, the

Table 4. Effect of spacing between sampling points on positioning performance.

Spacing (m)	Average Error (m)	90% Error (m)	Zone Accuracy (%)	Accuracy in 3 meters (%)
Spacing = 1.5	1.4	2.8	76	93
Spacing = 3.0	1.4	2.9	76	91

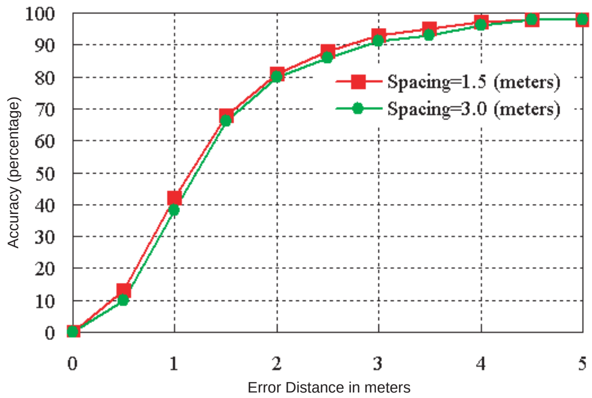

Figure 12. Effect of spacing between sampling points on positioning accuracy.

positioning accuracy of two spacing is very close to each other.

Therefore, for the testbed in this paper, the optimal spacing between sampling points should be set to 3.0 meters because it can achieve higher positioning accuracy by using less sampling points which will decrease the time cost of sampling survey.

6. CONCLUSION

In this paper, a novel indoor positioning system based on received signal strength in wireless networks with high accuracy was presented. The three improvement mechanisms, called signal strength filter, user location filter and path tracking assistance, were employed to improve the positioning accuracy of the system to the greatest extend. The comprehensive performance of the proposed system was analyzed in detail and compared with the Radar system. Furthermore, two key influence factors to positioning accuracy were further discussed and analyzed, including number of access points, and spacing between sampling points.

Experimental results demonstrated that the proposed system in this paper can improve the 80% accuracy in 3 meters of Radar system to 93% in typical office building testbed. Therefore, the indoor positioning system presented in this paper had the advantage of high accuracy, low cost and easy expansibility, and it could be used to locate people and assets in the fields of logistics, healthcare, and manufacturing.

Future research directions are as follows: 1) How to combine machine learning method such as artificial neural network (ANN), gene expression programming (GEP) [24] with location fingerprinting technique in order to further improve the indoor positioning accuracy of system. 2) Further analyze the noise characteristics of received signal strength from theoretical level in order to choose the most appropriate filtering method. 3) Wireless combined with other technologies such as DOA [25], UWB [26], RFID, for indoor location is another trend. 4) How to integrate indoor and outdoor positioning system such as GPS [27] is another potential area of research.

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