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Seamless combination of indoor and outdoor precise positioning technologies

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***Abstract*—The Location Based Service (LBS) mass-market services require high precise and reliable positioning information seamlessly in indoor and outdoor environments. However positioning in the indoor/outdoor transition area would experience problems such as frame coordination, poor signal reception quality and combination graceful implementation, even though multi-positioning systems are employed. This paper focuses on combination of positioning systems i.e., its design and implementation, which provides high precise and reliable services for the LBS users. A coordinate reference frame is defined to unify the time and coordinates within the positioning systems. The core of the software is a Kalman filtering algorithm, which integrates the SBAS and GNSS with the Wi-Fi data. The hybrid system is developed and validated by the simulation on the PDA hardware. Further system development aims to synergy of PPP and Wi-Fi fingerprinting technology to reach the meter positioning level. Recent test results are also presented in this paper.**

Keywords: GNSS; Wi-Fi positioning; Seamless indoor and outdoor positioning; Reference frame; Kalman filter

I. INTRODUCTION

Along with the social economy and science development, the requirement of high precision and high reliability positioning information which based on the LBS mass-market services is also constantly increased. Especially in indoor and outdoor environment, not only the precision of indoor positioning, but also the seamless positioning technology from indoor to outdoor, have become one seething research direction.

GNSS navigation system is widely used to determine the real-time precise location in outdoor, but in complex indoor environment, such as the airport hall, supermarkets, libraries, underground parking lot, the signal is greatly attenuated because of the building influence. Positioning time and accuracy are limited by complex indoor environment. So it is difficult to know the interior personnel specific position information. Therefore, many experts and scholars have researched, and put forwards some practical solutions, such as A-GPS positioning technology, ultrasonic positioning technology, infrared technology, bluetooth technology, radio frequency identification technology, ultra wideband technology, wireless local area network, optical tracking and positioning technology and image analysis, computer vision positioning technology and so on. Regardless of GPS positioning technology, wireless sensor networks and other positioning means, these technologies have its limitations, in a way. The trend of future indoor positioning technology is the combination of satellite navigation technology and wireless positioning technology. Integrating GPS positioning technology with wireless positioning technology organically will play their respective advantages and realize indoor and outdoor seamless and precise positioning with the help of wireless positioning technology.

II. INDOOR POSITIONING TECHNOLOGY BASED ON WI-FI

With the increasing demand of mobile communication, it shows the broad importance to permit access to particular location information in compute and applications. In outdoor environment, positioning system can satisfy certain outdoor location demands based on the SBAS and GNSS satellite navigation. However, these techniques are not well used in indoor positioning system. We must adopt some alternative technologies. Based on the IEEE802.11, wireless local area network (Wi-Fi) provides a new information acquisition platform. It can be used in many application fields to realize complex large-scale positioning, monitoring and tracking. The current mainstream PDA, laptops and other mobile devices have built-in wireless module. This provides convenience from the device for the positioning technology.

In general, the process which uses wireless signal strength to obtain position information of the target is to establish a wireless signal strength and location information stability mapping. The basic principle based on signal strength positioning technology is to calculate distance between signal receiver and the signal source based on the received signal strength. In practical applications, many experts have proposed various schemes, including measurements of the received signal noise ratio (SNR), and the more extensive technology received signal strength indicator (RSSI).

In this paper, based on the Wi-Fi network the wireless indoor and outdoor positioning hybrid system was designed and realized. The hybrid system integrates the SBAS and GNSS data with Wi-Fi data to achieve from indoor to outdoor seamless connection positioning technology. First of all, a coordinate reference frame is defined to unify the time and coordinates within the positioning systems, and then indoor fingerprint matching method positioning was used. Meanwhile from indoor to outdoor, unscented Kalman Filter (UKF) algorithm is used to filter the combined positioning system.

Experiments show that the system can achieve better positioning accuracy.

III. ESTABLISHING INDEPENDENT COORDINATE SYSTEM TRANSFORMATION

The independent coordinates system is defined when the system is surveying. Figure 1 shows the coordinate system. The coordinate axes are defined along the building's outer edge. The x axis is CD direction. The y axis is CB direction. The z axis is CG direction. The origin O is point C. In the four corners of underground parking lot respectively installed 4 signal receivers. It is shown in figure 1.

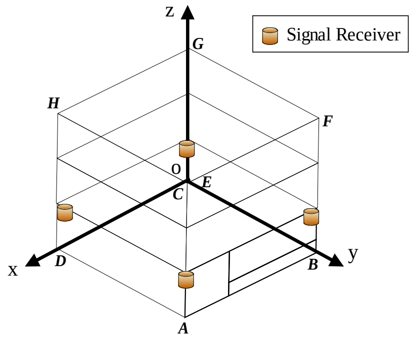

Figure 1. The figure of independent coordinate system

In the new local independent coordinates system, if the elevation is changed, the ellipsoid size will change. So the new ellipsoid parameter will be calculated. If new ellipsoid parameters are calculated, the local independent coordinate system and the national geodetic coordinate system can be transformed mutually. On the assumption that the coordinates of starting point is B, L in the national coordinate system geodetic coordinate. Because the new and old ellipsoid centres are coincident, eccentricity of the ellipsoids are coincident. Longitude and latitude will not change, that is

$$L_{new} = L \tag{1}$$

The latitude is

$$B_{new} = B + d_B \tag{2}$$

$$d_B = \frac{1}{M}\left(\frac{e^2}{W}\Delta a\right)\sin B\cos B \tag{3}$$

$$W = \sqrt{(1 - e^2\sin^2 B)}, \quad M = \frac{a(1-e^2)}{W^3}$$

In the formula, a is national reference ellipsoid semi-major axis; e is national reference first eccentricity of ellipsoid. In the new layout of central meridian, B_{new} 、 L_{new} can be transformed to X_{new} 、 Y_{new} using the Gauss projection formula, and then all observations are subject to a new coordinates system conversion and adjustment. If one wants to transform independent coordinates system coordinates to national coordinates system, one can use Gauss inverse projection formula to calculate B_{new} 、 L_{new} , and then use formula transform national coordinate system B, L. Finally, we can count corresponding central meridian based on the national coordinate system using Gauss projection. Then we can get X, Y.

IV. BASED ON THE RADIO FREQUENCY FINGERPRINT MATCHING POSITIONING METHOD

Wi-Fi wireless signal has strong time-varying characteristics, due to complex indoor environment. Wireless signal propagation attenuation model is hard to describe characterization about the mapping between distance and signal intensity. This paper adopts fingerprint matching method, and it is more robust. Mobile terminal needs to obtain the surrounding (Wireless) access point (AP) RSSI fingerprint characteristics.

Fingerprint matching algorithm relies on experimental data, and it mainly includes the off-line training and on-line positioning two stages. The task of off-line training is to establish the mapping between signal strength vectors and client position, and then form a fingerprint database. Positioning stage uses real-time acquisition of signal intensity vector to match the training fingerprint database. Thereby it can obtain the estimation of target's position.

Fingerprint characteristics can use RSSI mean value of AP. That is

$$F_L = (\overline{S}_{AP1}, \overline{S}_{AP2}, \overline{S}_{AP3}, \cdots) \tag{4}$$

That is, the training phases of all AP values are collected on the same position, and count multiple data averaging. Positioning stage is similar. The difference is that in the training phase more data is collected in order to get as many as possible for information. But, in the positioning stage it collects a little data. This can reduce the delay and improve the real-time performance.

V. THE INDOOR AND OUTDOOR POSITIONING SEAMLESS CONNECTION TECHNOLOGY BASED UKF

The UKF is a nonlinear filtering method which is different from the Extended Kalman Filter (EKF). It does not need linear approximation of nonlinear equations f and h in estimation point, but use the unscented transform (UT) sampling in the estimation of point. Using the sample points shows Gauss density approximation probability density function.

The key step of UKF algorithm is unscented transformation (UT). UT transform is used to calculate the nonlinear transform numerical characteristics of random variables. Its principle is: in the original state according to a rule to get some points, these points mean and covariance are equal to the original state distributions of the mean and variance. The nonlinear function value points set can be obtained by evaluation the nonlinear function. Through these points set can calculate the mean value and covariance after transforming. The sampling points are selected based on the prior mean and a priori covariance matrix of the square root of the associated column to achieve. Specific methods are as follows.

The first step: calculation of 2n+1 sigma points. (There are sampling points, n is the dimension of state, assuming the value is 9)

$$\begin{cases} X^{(0)}=\overline{X} \\ X^{(i)}=\overline{X}+\sqrt{(n+\lambda)P}, i=1:n \\ X^{(i)}=\overline{X}-\sqrt{(n+\lambda)P}, i=n+1:2n \end{cases} \quad (5)$$

The second step: calculation of corresponding weights of the sampling points:

$$\begin{cases} W_m^{(0)}=\dfrac{\lambda}{n+\lambda} \\ W_c^{(0)}=\dfrac{\lambda}{n+\lambda}+(1-\alpha^2+\beta) \\ W_m^{(i)}=W_c^{(i)}=\dfrac{\lambda}{2(n+\lambda)}, i=1:2n \end{cases} \quad (6)$$

Parameter $\lambda=\alpha^2(n+k)-n$ is a scaling parameter. Sampling distribution is controlled by the selection of α . K is parameter which value is no limit, but usually should ensure that the matrix $(n+\lambda)P$ is semi-positive definite matrix. The parameter $\beta \geq 0$ is a nonnegative weight coefficient. It can be associated higher order terms in the dynamic difference. It also can include higher order effects. If the parameters value are designated, for example, $\alpha=0.01$, $k=0$, $\beta=2$, dimension n=9, the value of λ is calculated through $\lambda=\alpha^2(n+k)-n$.

The UT transformation matrix can be written as follows:

$$X=[\overline{X} \quad \overline{X} \quad \overline{X} \quad \overline{X} \quad \overline{X} \quad \overline{X} \quad \overline{X} \quad \overline{X} \quad \overline{X}] + \sqrt{n+\lambda}[0 \quad \sqrt{P} \quad \sqrt{P}] \quad (7)$$

The UKF algorithm can be summarized into the following steps:

First, calculate sigma point state prediction,

$$X^{(i)}(k+1 \mid k)=f[k, X^{(i)}(k \mid k)] \quad (8)$$

System state one step prediction and covariance matrix:

$$\hat{X}(k+1 \mid k)=\sum_{i=0}^{2n}\omega^{(i)}X^{(i)}(k+1 \mid k) \quad (9)$$

$$P(k+1 \mid k)=\sum_{i=0}^{2n}\omega^{(i)}[\hat{X}(k+1 \mid k)-X^{(i)}(k+1 \mid k)] [\hat{X}(k+1 \mid k)-X^{(i)}(k+1 \mid k)]^T \quad (10)$$

Sigma point observation prediction value is:

$$Z^{(i)}(k+1 \mid k)=h[X^{(i)}(k+1 \mid k)] \quad (11)$$

Observation prediction mean and covariance are:

$$\overline{Z}(k+1 \mid k)=\sum_{i=0}^{2n}\omega^{(i)}Z^{(i)}(k+1 \mid k) \quad (12)$$

$$S(k+1)=\sum_{i=0}^{2n}\omega^{(i)}[\hat{Z}(k+1 \mid k)-Z^{(i)}(K+1 \mid k)] [\hat{Z}(k+1 \mid k)-Z^{(i)}(K+1 \mid k)]^T \quad (13)$$

Gain matrix

$$K(k+1)=\left\{\sum_{i=0}^{2n}\omega^{(i)}[\hat{X}(k+1 \mid k)-X^{(i)}(k+1 \mid k)] [\hat{Z}(k+1 \mid k)-Z^{(i)}(k+1 \mid k)]^T\right\}S^{-1}(k+1) \quad (14)$$

After updating the system state estimation and the covariance matrix is:

$$\hat{X}(k+1 \mid k+1)=\hat{X}(k+1 \mid k)+K(k+1)[Z(k+1)-\hat{Z}(k+1 \mid k)] \quad (15)$$

$$P(k+1 \mid k+1)=P(k+1 \mid k)-K(k+1)S(k+1)K^T(k+1) \quad (16)$$

Thus it can be seen that the UKF does not need to be estimated at Taylor series expansion in dealing with nonlinear filter, and then it is approximately about n times. And in the estimation point taking UT transform, the mean and covariance's characteristics of Sigma point set are matched with the original statistical. Then directly taking the Sigma point set to do nonlinear mapping, approximate probability density function. This approximation is a statistical result.

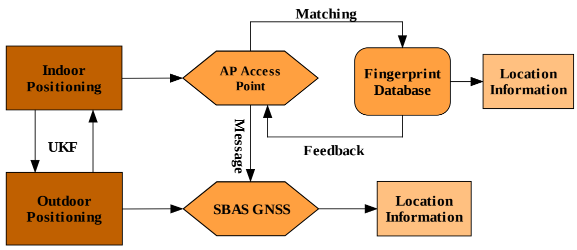

Figure 2. The figure of mobile terminal trajectory

VI. SIMULATION AND EXPERIMENTAL ANALYSIS

In order to verify the hybrid system of indoor and outdoor positioning precision, simulation experiments are carried out. The experimental area is underground parking of one construction. First, in the underground parking we conducted a series of indoor positioning tests, and then moved from indoor to outdoor (outside without shelter), and the change of positioning precision was tested from indoor to outdoor. Through testing, validation of the UKF algorithm is effective for indoor and outdoor positioning and seamless connection. Underground parking plane and the system trajectories of test are shown in Figure 3. (ABCD show the building's basic shape, in the building 11 points were surveyed, and 4 points were surveyed in outdoor).

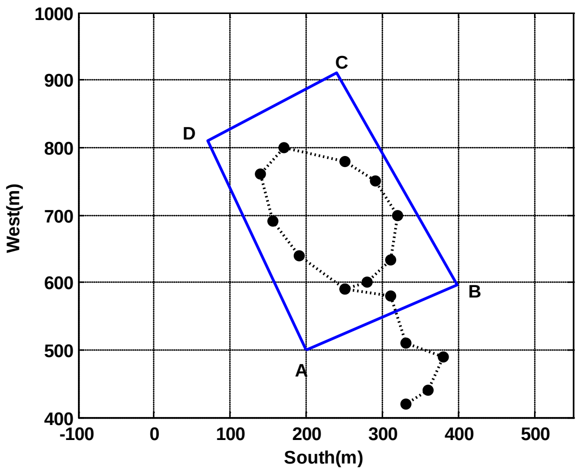

Figure 3. The figure of mobile terminal trajectory

Evaluation precision: First of all, in outdoor selecting 6 points to take GPS static survey about 2 hours. And then the geodetic coordinates of these 6 points are calculated. Then these points' coordinates are introduced into the subterranean parking lot by using the total station instrument. Because indoor positioning system uses a custom coordinates system, so it can not be directly compared with WGS84 coordinates. Therefore, the coordinate transformation was carried out first and the local independent coordinate system is transformed to geodetic coordinate system. Then the Gauss projection formula is used to calculate the national coordinate system corresponding to the central meridian, converted to X, Y. The elevation accuracy can be measured by measuring relative height from the system terminal and the total station to the ground. Figure 4 indicates that the 14 points positioning accuracy without filtering. Figure 5 indicates the 14 points positioning results accuracy after filtering.

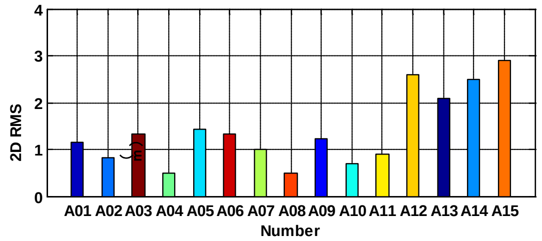

Figure 4. The 14 points accuracy change without filtering from indoor to outdoor

From the figure 4 we can know that the accuracy change from A01 to A11 is smooth. 2D position error is better than 1.5m. The RMS of 2D is 0.35m. The positioning accuracy of 4 outdoor points from A12 to A15 is poor. The maximum RMS of 2D position error reaches nearly 3m.

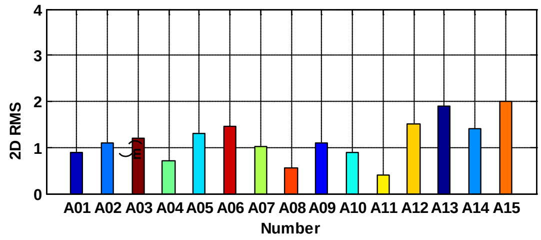

Figure 5. The 14 points accuracy change after filtering from indoor to outdoor

It can be seen that the accuracy from A01 to A11 indoor location remains stable. The UKF positioning accuracy at 4 outdoor points from A12 to A15 are improved, and the maximum 2D errors drop to 2m.

In order to examine the effect of filtering from indoor to outdoor seamless connection, static observations were carried out about 1min at indoor point A11 and outdoor point A12. The accuracy changes before and after filtering are shown in figure 6 and figure 7.

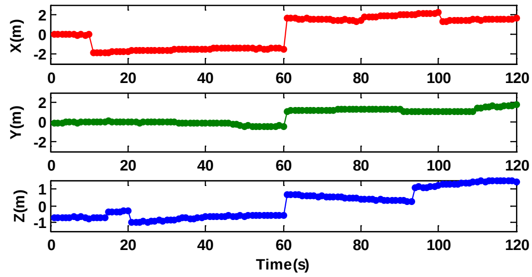

Figure 6. Two points three direction position errors after continuous observation about 1min without filtering

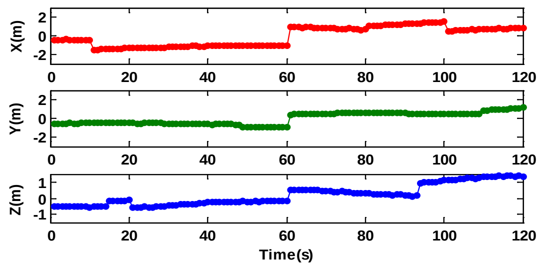

Figure 7. Two points three direction position errors after continuous observation about 1min with filtering

TABLE I. THE PRECISION CHANGE EACH DIRECTION BEFORE AND AFTER FILTERING

Technique	Direction	RMS（m）
Non-filter	2D	1.71
	Height	0.83
filter	2D	1.22
	Height	0.65

From figure 7 and table 1 it can be known that, before filtering indoor and outside the RMS of 3D errors are 1.56m, 0.72m, 0.83m. The 2D position error is 1.71m. After filtering RMS of 3D error are 1.04m, 0.64m, 0.65m. The 2D error is

1.22m. Indoor and outdoor positioning precision has been improved by the UKF filter.

VII. Conclusion and Outlook

In this paper, indoor and outdoor seamless combination location is studied based on the high accuracy and reliability LBS mass-market services. The coordinate systems are defined, and the UKF was introduced. Through simulation and experimental analysis, the results show that the UKF algorithm can realize indoor/outdoor seamless positioning of high accuracy by integration of SBAS and GNSS data with Wi-Fi data for indoor and outdoor positioning.. The indoor and outdoor positioning accuracy is less than 2m in our tests.

GPS precise point positioning (PPP) is a new positioning technology in recent years, It can use GPS satellite precise ephemeris and satellite clock error with zero-difference phase and pseudo-range data with a single receiver to obtain positioning accuracy of decimeter or centimeter level. Real-time precise point positioning service based on internet will be the future development direction. There exists possibility of combining PPP and wireless fingerprint technology for indoor/outdoor positioning technology.

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