An Improved Method and Implementation of Indoor Position Fingerprint Matching Localization Based on WLAN

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Abstract. The position fingerprint matching methods are analyzed, this paper improves the insufficient. In the database establishment phase, an AP selection algorithm based on stability is proposed, the Gaussian filtering method is applied to the processing of WLAN signal, Thus, a more stable signal strength characteristic value is extracted. In the matching phase, an AP selection algorithm based on MAC address is presented, narrow the range of matches, combine with KNN algorithm to Fingerprint matching, to increase the speed of the match. By verify through actual data, the paper analyzes the results of the improved off-line phase, effectively improve the quality of fingerprint database and reduce the burden of database. It not only narrow the matching range, but also improve the accuracy of the localization algorithm. The 3D model is built by 3D Max which is a virtual simulation system for user interaction, Virtual reality technology is applied to indoor positioning to complete the establishment of map. The coordinate transformation algorithm is established, and the position fingerprint matching method is used to present the positioning technology to virtual reality to realize the indoor positioning human-computer interaction based on WLAN.

Keywords: Indoor positioning · WLAN · Access point select

1 Introduction

Based on the application and development of related technology of users' locating information, location-based service has become a basic service requirement of daily work and life. With the increasing demand for indoor positioning and higher precision requirements. The existing satellite positioning system cannot be directly applied to indoor positioning with complex environment because the satellite signal cannot penetrate walls, steel and other obstacles. Other indoor positioning technology came into being [1]. At present, the techniques used for indoor positioning are: ultra-broadband

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technology, RFID (Radio Frequency Identification) Technology, ultrasonic technology, infrared technology, Bluetooth technology and WLAN (Wireless Local Area Networks) technology and so on. Compared with other positioning technologies, WLAN positioning technology has obvious advantages. Firstly, WLAN has wide coverage, easy access, easy extension, and the signal propagation based on WLAN is less affected by obstacles. Secondly, mobile phones or laptops can be used to pick up wireless signals in public places, workplaces and campuses, except for the AP (Wireless Access Point) in those places which are access to the Internet, but also to achieve their own location. Therefore, WLAN technology is more suitable for indoor positioning of buildings.

2 Indoor Location Fingerprint Matching Method Based on WLAN

WLAN is a direct arrival wave, and the distance between the test point and AP can be calculated according to the product of propagation time and propagation velocity. Then the location coordinates of the test points are calculated by using the mathematical geometry algorithm. TOA, TDOA and AOA are typical WLAN-based localization methods. In addition to these three methods, there are RSS-based signal propagation model location method and location fingerprint matching location method. Unlike the other four location methods, location fingerprint matching method does not require ranging, does not require known AP coordinates, and does not require specific equipment. Because it does not need to consider the problem of signal attenuation due to obstruction, it is also less affected by the environment, it only according to the idea of matching, software can be used to achieve positioning. To sum up, the location fingerprint matching method is the most suitable location method based on WLAN. However, due to the interference of environmental factors, the precision of the localization algorithm is not high enough, and the cost is increased or the calculation of location is increased. Therefore, how to study WLAN location fingerprint matching algorithm, and how to improve positioning accuracy and location efficiency, which have become a hot research field of indoor location.

The location of fingerprint matching method is completed in two stages. Firstly, establishing fingerprint library and then making online matching. The establishment of the location fingerprint database means that the location process is half done. In order to determine the position of the reference point, the location area should be divided into several grids. Then, the RSS signals of each reference point are collected in turn, including the number of AP received at the reference point, the signal strength of each AP signal intensity and the MAC address. The coordinate of the reference point is recorded while the RSS signal is collected. After traversing all the reference points, the RSS signal of each reference point and its actual coordinates are recorded in the database. It completes the location fingerprint matching method off-line phase of the database establishment. As shown in Fig. 1.

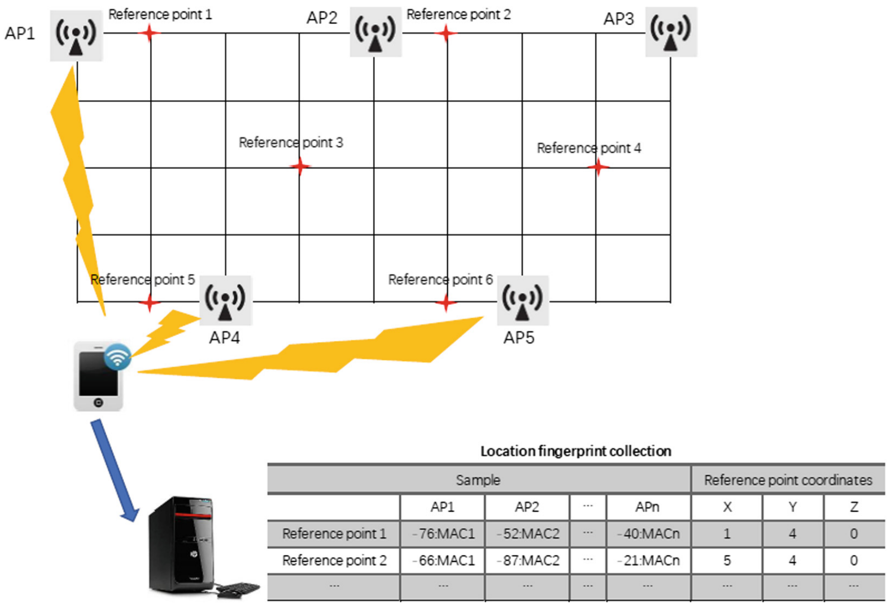

Fig. 1. Construction of indoor location fingerprint matching method

When the location database is established, the terminal at the location point sends the WLAN signal information from the current location to the server, which matches the fingerprint in the database, the matching algorithm is used to calculate and find the most matched fingerprint, then the location is successful.

3 An Improved Method of Indoor Position Fingerprint Matching Localization Based on WLAN

3.1 Extraction of RSS Signal Features Based on Gaussian Filtering Model

The location fingerprint matching method is based on the characteristics of the relationship between RSS signal and actual coordinates, and the establishment of accurate and reliable location fingerprint library are the premise and guarantee of improving positioning accuracy. However, due to the complexity of the indoor environment, radio waves are affected by various factors in the process of propagation, resulting in the acquisition of various types of noise, to a certain extent, these noises will have an uncertain effect on the location results. Therefore, in order to gain more reliable fingerprint data, the existing processing methods include filtering the collected signal by Kalman filter or Gaussian filter.

Kalman filter is a linear extrapolation filter with minimum variance. According to the data of the previous state, the data of the next state is predicted. It can effectively deal with the real problem with time-varying characteristics, but it cannot correct or eliminate the singular value of signal fluctuation, and its error increases with the increase of prediction value. Gauss filter is relatively simple compared with Kalman filter. It is a linear smoothing filter. In the process of processing signal, a Gaussian filter model is established and small probability data are eliminated by the model. The process of retaining high frequency data and finding the mean value of high frequency data.

Because many random variables are subject to or approximate to the normal distribution [2], the signal strength value received after transmission through multiparty channel is generally subject to log-normal distribution. Thus, the classical WLAN signal model can be represented as follows [3]:

$$\mathrm{RSS}(\mathrm{d}) = \mathrm{RSS}(\mathrm{d}_0) - 10\mathrm{nlg}\left(\frac{\mathrm{d}}{\mathrm{d}_0}\right) - \mathrm{X}_\sigma \tag{1}$$

$\mathrm{RSS}(\mathrm{d})$ and $\mathrm{RSS}(\mathrm{d}_0)$ represent the signal strength values measured at distance d and reference point d_0 respectively. X_σ is a Gaussian random distribution variable with a mean of 0 and a standard deviation of σ (usually 4–10). It is a measurement error caused by signal refraction, reflection, people moving around and other reason.

Therefore, assuming that the RSS signal sampling value $\{RSS_1, RSS_2, RSS_3 \ldots\ldots RSS_n\}$ received from a fixed AP at a certain location obeys the normal distribution, the mean value is:

$$\mu = \frac{1}{n}\sum\nolimits_{i=1}^{n} \mathrm{RS} \tag{2}$$

The standard deviation is:

$$\sigma = \sqrt{\frac{1}{n}\sum\nolimits_{i=1}^{n} (\mathrm{RSS}_i - \mu)^2} \tag{3}$$

The probability density function is:

$$\mathrm{F}(\mathrm{RSS}) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(\mathrm{RSS}_i - \mu)^2}{2\sigma^2}} \tag{4}$$

In the above formulas, RSS_i represents the strength of the first signal and i indicates the total number of data collected at a certain location. Selection probability $\mathrm{F}(\mathrm{RSS})$. If the empirical range is greater than 0.6 and less than 1 is the high probability occurrence area, the reserved range is $\mathrm{F}(\mathrm{RSS})$, Greater than or equal to 0.6 and less than equal to 1.

The results of Gaussian filtering vary from amount of the sampled data, and the greater the n of the sampled data, the more accurate the Gaussian probability model is, the closer the filtered RSS data is to the actual *RSS* value. In the off-line data acquisition phase of location fingerprint matching method, more samples need to be collected to establish a database to ensure more accurate online matching and more accurate positioning. Therefore, it is feasible to use Gaussian filtering in off-line phase for data filtering. Figures 2 and 3 are signal intensity figs before and after Gaussian filtering, and the signal intensity distributions before filtering are compared, and the data after Gaussian filtering are more smooth.

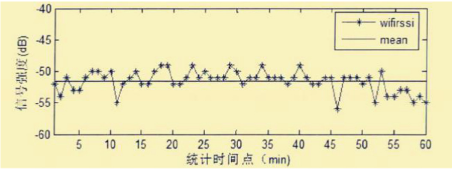

Fig. 2. Pre-filter signal fluctuation diagram

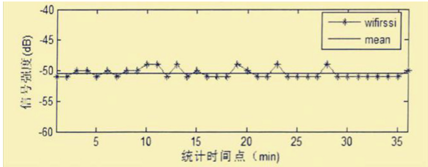

Fig. 3. Post-filtering signal fluctuation diagram

3.2 Implementation of AP Selection Algorithm

Because of the wide coverage of the wireless local area network, WLAN signals can be received and used in many large buildings for location, it is one of the advantages of choosing WLAN technology for indoor positioning [4]. The WIFI integrated analyzer software test found that not all of the AP with the location of the movement of significant changes, that is, not all of the AP is conducive to indoor positioning. If all the *RSS* signals received by the AP are recorded in the database as sample data, this will not only result in poor quality of fingerprint library and lower positioning accuracy, but it also will cause the burden of fingerprint library construction, increase the online matching time and increase the complexity of the algorithm. In the real environment [5], some of the AP signal fluctuations are relatively large, or the mapping relationship with the location is relatively vague, not all of the AP contain useful feature information for location resolution and judgment, so it is necessary to make an effective choice of access point AP, in order to ensure that sufficient AP for location or to ensure that the selected AP signal contains obvious eigenvalues [6].

3.2.1 Stability Based AP Selection Algorithm in Off-Line Phase

In order to select the signal strength of the AP with high frequency and stability in the reference point, we choose the AP after taking sample data off line and building the library. It reduces the burden on the database and ensures accuracy. The location method based on WLAN fingerprint database is based on the mapping relationship between signal intensity and position. If the fingerprint library is established, the signal strength of the AP with large fluctuation is chosen for fingerprint. Therefore, the stability of AP plays an important role in location fingerprint matching. The stability of an AP has two reference points. One is the fluctuation of the signal strength of the AP and the other is the frequency of the AP at the reference point.

Firstly, the AP received at each reference point and its signal intensity are different in the location area, and the sampling I times need to be collected continuously at each reference point. The collection of AP received at the reference point is $\{AP_1, AP_2, AP_3 \ldots\ldots AP_N\}$, The corresponding *RSS* value is $\{RSS_1, RSS_2, RSS_3 \ldots\ldots RSS_n\}$, Then we need to select m stable RSS in n APs. The I sample value for the first AP is represented a $\{RSR_1^1, RSS_1^2, RSS_1^3 \ldots\ldots RSR_1^i\}$, Then the signal fluctuation of the Kth AP can be described by its variance:

$$V(AP_k) = \frac{1}{I}\sum\nolimits_{i=1}^{I}\left(RSR_K^i - \overline{RSS}\right)^2 \tag{5}$$

In Eq. (5), $\overline{RSS}$ shows the mean value of the first sample of the Kth AP, and RSR_K^i indicates the signal strength of the first sample of the Kth AP. The deviation degree between the random variable and its mathematical expectation (mean) is generally measured by the variance of the signal intensity. The smaller the variance, the smaller signal amplitude, the better the stability of the AP [7]. The stability of an AP not only takes into account the signal intensity fluctuation of an AP, but also the frequency of the AP at the reference point. The first K AP continuous I sampling, the frequency can be expressed:

$$F(AP_K) = \frac{Sum_K}{I} \tag{6}$$

In Eq. (6), I indicates the total number of samples taken at the reference point, and Sum_K indicates the number of times the first Kth of AP appears, and the greater the value of $F(AP_K)$, indicating that the frequency of the AP is higher in the I sampling, That is, the more stable the AP is for this reference point. The Eqs. (5) and (6) know that the stability of an AP can be expressed as:

$$Sta(AP_K) = \frac{1}{\frac{1}{I}\sum\nolimits_{i=1}^{I}\left(RSR_K^i - \overline{RSS}\right)^2} * \frac{Sum_K}{I} \tag{7}$$

The larger $Sta(AP_k)$, the better the stability of the AP, from large to small in order, to take the previous maximum of the AP as the choice of the AP, and when m is 5, the positioning accuracy is the highest. In Eq. (7), if the denominator is 0, it is represented directly by Eq. (6), but this is almost impossible because signals sometimes change and there are constant changes at each moment. Therefore, the off-line phase can be completed before building by selecting stable AP and then using Gaussian filter.

3.2.2 Online Phase AP Selection Optimization Match Based on MAC

In the online phase, it just need to match the real-time signal strength and MAC address of each AP received at the site to the fingerprint library. The estimation of location can be achieved by finding the optimal match, the optimal point is that the MAC address and signal strength of the AP received through MAC verification are the same or similar to that of the AP of a fingerprint in the fingerprint library, but considering the need to match all the information with each fingerprint in the database one by one, the calculation is very large. Therefore, before implementing the conventional matching algorithm, the AP selection of fingerprint library is needed to narrow the matching range. Search the MAC address of the most powerful and stable AP that has been received many times online and contains all the fingerprints of this MAC address in the fingerprint library, filter out other fingerprints away from the site to be fixed, and then use the matching algorithm to calculate the location coordinates.

Suppose there are 10 fingerprint samples in the fingerprint library of the signal, respectively:

$$\begin{bmatrix} (RSS_1 : MAC_1, RSS_2 : MAC_2, RSS_4 : MAC_4, RSS_5 : MAC_5, RSS_6 : MAC_6) \\ (RSS_1 : MAC_1, RSS_3 : MAC_3, RSS_5 : MAC_5) \\ (RSS_3 : MAC_3, RSS_4 : MAC_4, RSS_5 : MAC_5) \\ (RSS_1 : MAC_1, RSS_5 : MAC_5, RSS_4 : MAC_4, RSS_7 : MAC_7) \\ (RSS_3 : MAC_3, RSS_6 : MAC_6, RSS_1 : MAC_1, RSS_7 : MAC_7) \\ (RSS_3 : MAC_3, RSS_4 : MAC_4, RSS_5 : MAC_5, RSS_6 : MAC_6) \\ (RSS_2 : MAC_2, RSS_1 : MAC_1, RSS_5 : MAC_5, RSS_8 : MAC_8, RSS_3 : MAC_3) \\ (RSS_6 : MAC_6, RSS_2 : MAC_2, RSS_5 : MAC_5, RSS_1 : MAC_1) \\ (RSS_2 : MAC_2, RSS_4 : MAC_4, RSS_5 : MAC_5, RSS_8 : MAC_8) \\ (RSS_3 : MAC_3, RSS_7 : MAC_7, RSS_2 : MAC_2, RSS_6 : MAC_6) \end{bmatrix}$$

The signals collected online are:

$$(RSS_1 : MAC_1, RSS_2 : MAC_2, RSS_4 : MAC_4, RSS_5 : MAC_5)$$

AP_1 is the strongest signal received, so its MAC as a search condition, in 10 fingerprints, through search screening, including some of the fingerprints left the following fingerprint:

$$\begin{bmatrix} (RSS_1 : MAC_1, RSS_2 : MAC_2, RSS_4 : MAC_4, RSS_5 : MAC_5, RSS_6 : MAC_6) \\ (RSS_1 : MAC_1, RSS_3 : MAC_3, RSS_5 : MAC_5) \\ (RSS_1 : MAC_1, RSS_5 : MAC_5, RSS_4 : MAC_4, RSS_7 : MAC_7) \\ (RSS_3 : MAC_3, RSS_6 : MAC_6, RSS_1 : MAC_1, RSS_7 : MAC_7) \\ (RSS_2 : MAC_2, RSS_1 : MAC_1, RSS_5 : MAC_5, RSS_8 : MAC_8, RSS_3 : MAC_3) \\ (RSS_6 : MAC_6, RSS_2 : MAC_2, RSS_5 : MAC_5, RSS_1 : MAC_1) \end{bmatrix}$$

Through the strongest and most stable AP MAC address, the corresponding fingerprint subset is selected, and then the Euclidean distance is calculated by KNN algorithm. The above is just a list of 10 fingerprints, but in reality, the signal propagation distance of wireless router is not long, and the location reference point in a building is far more than 10. The more advantageous it is, the better it is to adopt this method; In terms of accuracy, the AP received at the close reference point is close to the same, the signal intensity is different, and the AP received at the distance is basically different. The small Euclidean distance can be avoided, but the reference point is not in the vicinity of the site to be fixed, it can effectively improve the positioning accuracy.

4 Implementation of Fingerprint Matching Method for Indoor Position Based on Virtual Reality Technology

4.1 Construction of Virtual Reality Scene Oriented to Indoor Position

The application of virtual reality technology in indoor positioning is a virtual environment simulation based on real data. It is based on graphics and uses 3D MAX 3D modeling software to model scenes. Then using ArcGIS Server and other software as development tools to realize the roaming and interactive functions of the scene. According to the virtual reality technology, the three-dimensional dynamic results are presented to the locator, so that the locator can realize the relevant location information and location scene. Therefore, human-MAC interaction can be realized through the establishment of three-dimensional scene, the transformation of coordinates and the method of location fingerprint matching [8]. Firstly, collecting the geometric data, coordinate data and texture data needed for the virtual reality scene, and then use the data to model the real scene, including the transformation of coordinates. Finally, the real-time rendering of the virtual scene is realized by the three-dimensional engine on the output device, and the roaming of the whole scene is completed [9]. Taking the Yanshan campus of Guilin University of Technology in China as an example, a three-dimensional model was established.

(1) Preparatory: According to the above model data acquisition method to collect information, taking texture photos, as far as possible to record the route and the name of the building, and then use software to build useful images. As shown in Fig. 4.

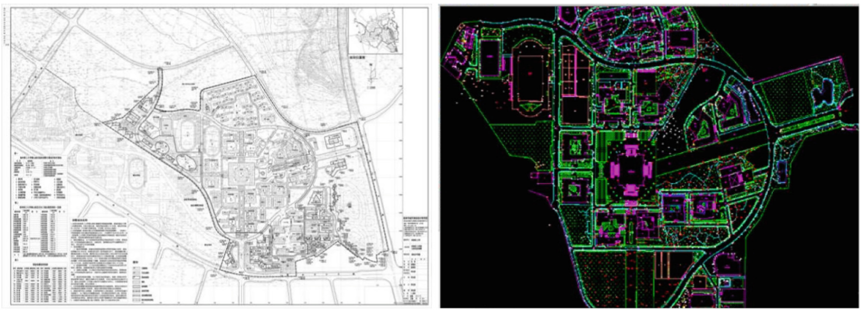

Fig. 4. Planning and 1:1000 topographic map of Guilin University of Technology

(2) Modeling: The CAD plan is introduced into 3D MAX software, according to the length and width of the plan and the height measured, stretch, extrude the column, wall and separate floors, then deal with the floor, windows and other details. Do the same for each scene inside the building, and use the sun and VR light source to make the scene lighting-deployment. As shown in Fig. 5.

(3) Post-processing: To integrate and optimize the model of each scene.

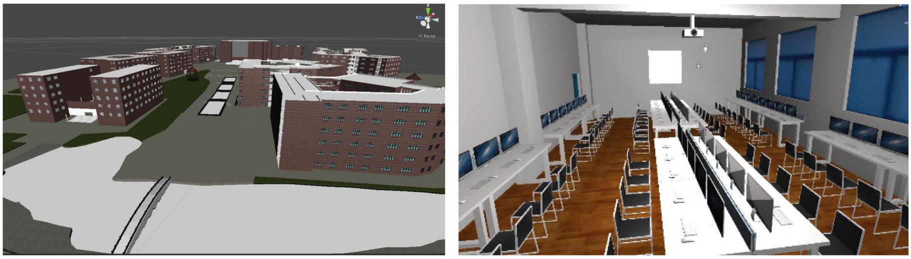

Fig. 5. The overall modeling effect of building

4.2 Implementation of Improved Method for Indoor Fingerprint Matching and Location Based on WLAN

After the building is built with the 3D model of the interior, the coordinate system of the model is only a custom coordinate system. Based on WLAN indoor location, users can estimate their location coordinates by location fingerprint matching method (x, y, z). If the positioning system shows the azimuth target directly in the virtual scene, a series of coordinate transformation is required.

First, the actual longitude and latitude coordinates are converted to the world coordinates, (which are at the pixel points on the plane view), and then the world coordinates are converted into virtual scenes. That is, the local or national coordinate system and virtual scene model coordinate system conversion. The coordinate transformation relationship between the two-dimensional map and the three-dimensional virtual map can be solved by using the coordinate of the two-dimensional plan and the three-dimensional virtual scene. Generally speaking, the control point of a building will manually select three of the ground base points of the building as the control point. The coordinates of [A D], [B E] and [C F] are assumed to be 3 control points. The coordinate of the two-dimensional plan is (Sx, Sy) and the coordinate of the virtual reality scene is (Gx, Gy). The matrix equation based on the least square method is as follows:

$$\begin{bmatrix} A & D \\ B & E \\ C & F \end{bmatrix} = \begin{bmatrix} n & \sum S_x & \sum S_y \\ \sum S_x & \sum S_x^2 & \sum S_x S_y \\ \sum S_y & \sum S_x S_y & \sum S_y^2 \end{bmatrix}^{-1} * \begin{bmatrix} \sum G_x & \sum S_y \\ \sum S_x G_x & \sum S_x S_y \\ \sum S_y G_x & \sum S_y G_y \end{bmatrix} \tag{8}$$

Equation (8) is used to solve A, B, C, D, E, F, and to establish the normal calculation formula of coordinates according to the result:

$$S_x = A * S_x + B * S_y + C \tag{9}$$

$$S_y = D * S_x + E * S_y + F \tag{10}$$

The equation of coordinate inverse calculation is obtained by recounting Eqs. (9) and (10):

$$S_x = \frac{E * G_x - B * G_y - CE + BF}{AE - BD} \tag{11}$$

$$S_y = \frac{D * G_x - A * G_y - CD + AF}{BD - AE} \tag{12}$$

The viewpoint is set up in the virtual scene to realize the 3D geometry transformation. The three-dimensional geometric transformation can be represented by the fourth order matrix T_{3D}:

$$\overline{T_{3D}} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \tag{13}$$

$\overline{T_{3D}}$ can be divided into four sub-matrices, respectively to achieve the graphics to reduce, enlarge, pan, projection transformation and the whole scene of the zoom transformation.

In a three-dimensional geometric transformation matrix, any point $\mathrm{P(x, y, z)}$ can be converted to $\mathrm{P'(x', y', z')}$ by the following expression:

$$\begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \overline{T_{3D}} \begin{bmatrix} x' \\ y' \\ z' \\ 1 \end{bmatrix} \tag{14}$$

Thus, after the relationship between the 3D scene model and the coordinate system transformation, the virtual scene needs to be properly expressed. That is, the design of human-computer interaction function can complete the translation, scaling, rotation and positioning of virtual scene [10]. According to the improved WLAN indoor fingerprint matching method, the location coordinates of the locator are calculated, and the corresponding position of the virtual scene is calculated by the coordinate transformation formula. At the same time, the virtual character is positioned to the corresponding position. The work-flows for online positioning can be represented in Fig. 6.

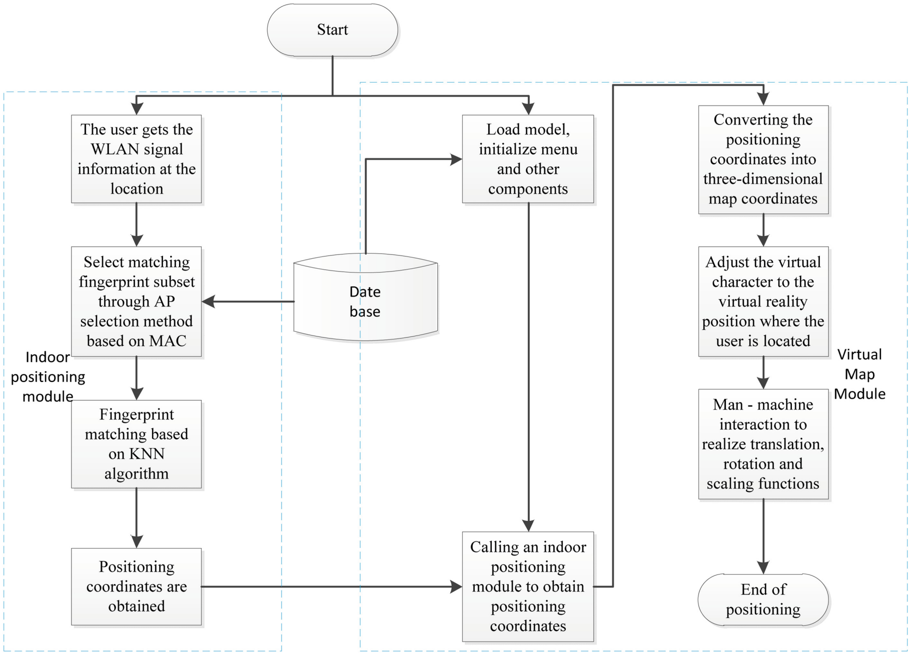

Fig. 6. Work-flows for online location

5 Conclusion

In WLAN-based indoor position method, the accuracy of location fingerprint matching depends on the stability of fingerprint library. And the indoor environment is much more complicated than the outdoor environment. Once the indoor environment changes a lot, the signal received will change a lot. Even if the location of the on-line phase acquisition signal is the same as that of the off-line phase acquisition reference point, the signal will be very different. Therefore, in the matching phase, it is very difficult to match the correct fingerprint, which makes the deviation of location estimation very big, which is the problem of fingerprint database mismatch. Aiming at the shortcomings of the location fingerprint matching method, the two processes of location are improved, and the stability-based AP selection algorithm and Gaussian filtering are established. The quality of the sample signal is improved by the purposeful selection of AP and the processing of RSS signal intensity. In the online location phase, an AP selection algorithm based on MAC address is established to narrow the matching range, and the improved online location algorithm is verified by an example. The accuracy has also been improved to a certain extent. At the same time, compared with two-dimensional maps, virtual reality technology can display more abundant location information, according to the situation of location tracking in three-dimensional form. This realizes the fusion of real space and information space.

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