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Retraction

Retracted: Indoor and Outdoor Seamless Positioning Technology Based on Artificial Intelligence and Intelligent Switching Algorithm

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] P. Wang, W. Li, and X. Diao, "Indoor and Outdoor Seamless Positioning Technology Based on Artificial Intelligence and Intelligent Switching Algorithm," *Wireless Communications and Mobile Computing*, vol. 2023, Article ID 7075834, 12 pages, 2023.

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Research Article

Indoor and Outdoor Seamless Positioning Technology Based on Artificial Intelligence and Intelligent Switching Algorithm

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Navigation and positioning is a new growth point of wireless services. And seamless positioning is the current development trend of navigation and positioning services. In view of the problems that dynamic handover cannot be performed during site movement, STA only selects the optimal AP according to the indication of received signal strength, and the handover delay is too long. This paper proposes a research on indoor and outdoor seamless positioning technology based on artificial intelligence and intelligent switching algorithm. The purpose is to study the influence of reducing the positioning data with too large error on the final positioning result. The method of this paper is to propose an intelligent switching algorithm and then discuss the research status and development direction of indoor positioning technology and outdoor positioning technology, respectively, and point out the switching methods between them. The role of these methods is to analyze the current situation of indoor and outdoor navigation technology, especially the development route of seamless positioning technology. It determines the strategy of integrating heterogeneous positioning systems to build a seamless positioning system to maximize the use of existing positioning system resources. This paper studies the design and implementation of the seamless positioning system through the simulation experiment of the intelligent switching algorithm and finally tests the system through the experimental vehicle. The online experiment results show that the system can achieve high positioning accuracy in indoor and outdoor environments, especially at its junction, and the positioning errors in all directions are within 0.2 m.

1. Introduction

With the development of science and technology, information science and technology have penetrated into all aspects of life. As one of the most advanced technologies, positioning and navigation technology has developed significantly. At present, the outdoor positioning technology is basically mature. LBS services based on the global navigation satellite system (GNSS) have largely satisfied the outdoor navigation services in the civilian sector. However, in complex environments such as indoors or urban canyons, GNSS technology cannot yet provide reliable positioning services. As a strategic emerging industry, location-based services widely exist in people's lives. It has become an important part of economic construction and social life.

Seamless positioning technology refers to the integration of multiple positioning methods in different scenarios of human activities to provide complete coverage of positioning signals. It can realize smooth docking of positioning methods and seamless migration of different scenarios, saving time and space. Currently available indoor and outdoor seamless positioning systems have few applications. Therefore, it is of practical significance to design and realize the application of high-performance indoor and outdoor seamless positioning system. This paper adopts intelligent design indoor and outdoor seamless positioning technology. It switches between GNSS positioning methods and WiFi positioning methods to achieve a seamless positioning system using the Android platform. The research and development of indoor and outdoor seamless positioning technology improves people's quality of life and the activity of the entire positioning and navigation business. It is of great practical significance to bring better benefits and development to human production and life.

This paper proposes an intelligent handover algorithm between different positioning systems. Aiming at the heterogeneity of indoor and outdoor positioning systems, the characteristics and research focus of handover between positioning systems are systematically analyzed. In the research of switching technology between systems, this subject proposes an intelligent switching algorithm based on artificial intelligence. It evaluates each positioning result based on the geometric distribution of the selected reference points. This algorithm can be used for handover between positioning systems. According to the indoor and outdoor seamless positioning method of the intelligent handover algorithm proposed in this paper, the software design and development of the indoor and outdoor seamless positioning system are carried out in this paper. It verifies the effectiveness of the system through the real vehicle online experiment in the actual scene and then proves the effectiveness of the indoor and outdoor seamless positioning system.

2. Related Work

Indoor and outdoor positioning technology is becoming more and more mature, and scholars are doing more and more research on this technology. Wu et al. proposed a nonuniform mobile communication intelligent handover algorithm. Simulation results show that the proposed method can provide good intelligence for mobile communication channel switching in the case of uneven distribution of scatterers. It provides an output communication signal with good spatial focusing ability to reduce propagation delay and intersymbol interference [1]. Z. Li et al. introduced the technical status of smart switchgear for power distribution and compared different smart switch schemes. They analyzed the problems and reasons of low integration of intelligent switches, put forward a technical scheme for the integrated design of distribution intelligent switchgear, and introduced the test implementation of intelligent distribution switches. They studied the problems existing in the use of intelligent switching algorithms and analyzed the technical development trend of intelligent switching algorithms [2]. Ma et al. proposed that indoor positioning is known as the "last mile" problem due to the inability of global navigation satellite systems (GNSS) to work indoors. They proposed a new indoor positioning scheme. The scheme uses pseudolite technology combined with a navigation signal simulator. This antenna transmits the "real" satellite signals in space processed by the navigation signal simulator to indoor users [3]. Mushtaq et al. presents a comparison between performance investigations of location-based routing protocols and contextual information collected from the global positioning system (GPS) and the framework for internal navigation and discovery (FIND), respectively. The results of their research can be deployed in different fields such as indoor navigation, hospital patient tracking, smart city environment-aware service provisioning, and industrial deployment [4]. Q. Zeng et al. propose a smartphone fusion localization method optimized by indoor and outdoor detection. They integrates light sensor signals, magnetic sensor signals, and global navigation satellite system (GNSS) signals into navigation algorithms to improve the accuracy of position recognition. When the device is detected outdoors, the system introduces GNSS and sensors to aid navigation [5]. Capurso et al. performed an energy consumption analysis of the positioning methods available on Android smartphones and suggested adding an indoor positioning mechanism. The mechanism can be triggered based on detecting whether the user is indoors or outdoors. Popular uses of location information include geotagging on social media sites, driver assistance, and navigation and querying nearby locations of interest [6]. Li et al. proposed a seamless outdoor-indoor crowd-sensing localization (SoiCP) system. Among them, radio maps are automatically constructed based on pedestrian dead reckoning (PDR) trajectories, without the need for professional site surveys. The radio maps they constructed are robust to inaccurate PDR trajectories and do not rely on prior knowledge of the floor plan [7].

3. The Method of Seamless Positioning

3.1. Intelligent Switching Algorithm. The intelligent handover algorithm is different from the traditional handover method. The main reference indicator in the traditional handover method is RSS (received signal strength). The smart switching strategy not only considers RSS but also some other influencing factors. The comprehensive measurement of these factors enables timely and accurate handover decisions. The intelligent handover strategy in this paper is mainly based on artificial intelligence to make handover decisions. The following first introduces some theoretical knowledge of relevant fuzzy technology and formulates a fuzzy switching strategy based on this theory. The intelligent handover strategy proposed in this paper makes intelligent vertical handover decisions based on various parameters that affect wireless network selection and fuzzy logic theory [8]. The chapter concludes with a theoretical analysis of the strategy.

This paper uses intelligent reasoning techniques to decide whether to switch. The input parameters of the intelligent handover algorithm are mainly the three types listed above: the signal strength RSS of each network, the network traffic, and the speed v of the terminal moving. There is only one output value, that is, the probability that each network is selected. Finally, the optimal target network to be switched is determined by comparing the probability of each network being selected [9]. The flow of the intelligent switching algorithm is shown in Figure 1.

(1) The sampling module performs sampling periodically. It also inputs the sample values into the averaging window module to determine the RSS value of the surrounding network

(2) The average window module, its size depends on the moving speed of the terminal. If the speed is high, then the window size is reduced, which can reduce the switching delay. If the speed is relatively low, the window size is increased to avoid unnecessary

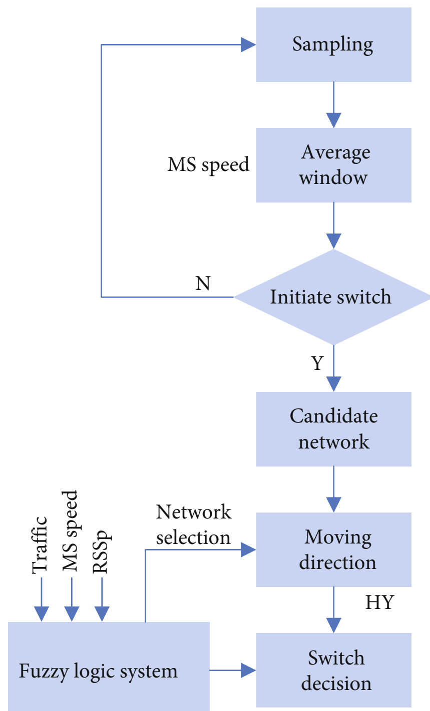

Figure 1: Flowchart of intelligent switching algorithm.

switching. The size of the averaging window varies as follows:

$$N = [9 - 0.1v], \quad (1)$$

where N represents the size of the window, v is the movement speed of the mobile terminal, and [.] represents the size of the window as an integer. The size of the form changes with the speed of the terminal movement, and the maximum will not exceed 9

(3) In the startup switching module, it is judged whether the switching is executed. Its working mechanism is consistent with the traditional algorithm

(4) The candidate network module selects the best cell for handover mainly by comparing the RSS of each surrounding network

(5) In the fuzzy logic system module, the moving speed of the terminal, the predicted RSS value, and network traffic are used as input parameters, and the output parameter is the probability of each network being selected

This subsection mainly introduces the proposed intelligent handover algorithm. MDP is an intelligent model. First, the constructed MDP model is introduced [10]. MDP includes agents, states, actions, and rewards. Since the network has infinitely many states, a fully connected neural network is used to approximate the value of each state. Therefore, the training process of the network is introduced next, and finally, the intelligent switching algorithm is introduced. The state space of the MDP model contains all network states, defined as $S = \{s1, s2 \cdots sm\}$. S is an infinite space set, and the state of the STA collected by the controller from the network at time t is defined as

$$S_t = \{\mathrm{RSSI}_1, \mathrm{RSSI}_2 \cdots \mathrm{RSSI}_M\}, \quad (2)$$

where M is the number of APs and RSSI_1 represents the distance between STA and AP1. Since this paper studies the handover problem in WLAN, the action space $A = \{a1, a2 \cdots am\}$ is set. In the handover of the WLAN, the QoS of the STA is guaranteed mainly by improving the system throughput, the STA throughput, and the fairness of the BSS where the STA is located. Therefore, the reward setting of the algorithm not only considers the STA throughput, but this paper sets the change of the system throughput and the throughput fairness of the BSS where the STA is located as an element of the reward. The reward at time t is defined as

$$r_t = w_1\left(\sum_{j=1}^{M} T_j^t - \sum_{j=1}^{M} T_j^{t-1}\right) + w_2 T_{k,j}^t (1 - Q), \quad (3)$$

where w_1 and w_2 are weights and $w_1 + w_1 = 1$, T_j^t represents the throughput of AP_j at time t, and $\sum_{j=1}^{M} T_j^t$ represents the system throughput. T_j^t is defined as

$$T_j^t = \sum_{i=1}^{N} T_{i,j}^t, \quad (4)$$

where N is the number of stations associated with the AP and $T_{i,j}^t$ represents the STA_i throughput at time t, when STA_i continuously sends data to AP_j. $\sum_{i=1}^{N} T_{i,j}^t$ represents the sum of the throughput of all STAs associated with AP_j, that is, the throughput of BSS_j. STA_k is the observation station, and Q is the throughput fairness of the BSS.

$$Q = \sqrt{\frac{\sum_{i=1}^{N}\left(T_{i,j}^t - \bar{T}_j^t\right)^2}{N}}. \quad (5)$$

At the junction of indoor and outdoor, the positioning terminal can receive one or both of GNSS and WiFi signals. The introduction of the intelligent handover algorithm can realize the handover between different positioning technologies. The smart switching algorithm is based on a counting and thresholding mechanism, which relies on a simple counting function with low computational complexity. It is specifically defined as

$$a(0) = 0, \quad (6)$$

$$\mathrm{RSSI}(L) \geq R_{\mathrm{rssi}}, a(L) = a(L-1) + 1, \quad (7)$$

$$\mathrm{RSSI}(L) < R_{\mathrm{rssi}}, a(L) = a(L-1) * D. \quad (8)$$

In these equations, the number of times the measured RSSI value is greater than R_{rssi} is recorded, denoted as $a(L)$

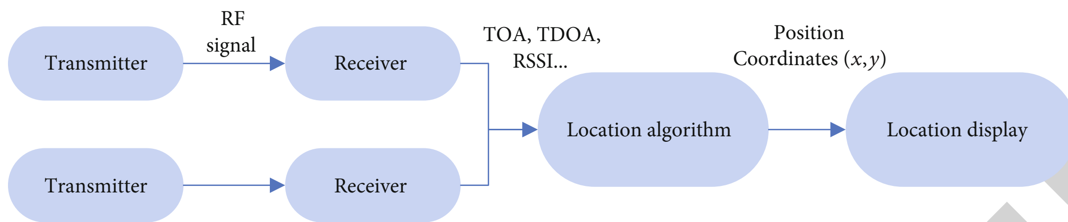

Figure 2: Flowchart of indoor positioning.

, the discrete time variable is denoted as L, and the count threshold is denoted as R_{rssi}. The comparison value switching threshold for judging algorithm switching is recorded as a_T. The decrement rate of the count function when the currently received RSSI value is below the count threshold recorded as D. If the value of the count function $a(L)$ is greater than the switching threshold a_T, the positioning mode is switched. The accuracy of switching between positioning algorithms depends on the value of the switching threshold a_T and the reduction rate D. When the values of a_T and D are larger, the switching between positioning modes is more reliable. But this also reduces the speed of handover, thereby increasing the time required for handover judgment. In addition, the values of the switching threshold a_T and the reduction rate D are also affected by the number of times the RSSI value is measured per second and the moving speed of the user.

3.2. Indoor Positioning Technology. Due to the unique limitations of positioning technology, no positioning technology can independently meet the technical needs of human location-based services in complex urban environments. To this end, the researchers propose the concept of seamless localization. Seamless positioning technology integrates two or more positioning methods in scenes with frequent human activities such as shopping malls and underground parking lots. It allows users to receive positioning signals at the same time in any location and in any scene. It provides seamless connectivity and a smooth transition between positioning methods, ultimately enabling high availability and accurate positioning.

When the target is in the reference coordinate system of the indoor environment, determining the position of the target is an important aspect of indoor positioning. In indoor environments, many people use WiFi to estimate the location of objects [11]. This is because WiFi network signals can cover a wider area. Because radio waves have a strong penetrating ability, they can penetrate most obstacles. The indoor positioning architecture can be divided into two types: base station type and mobile terminal type. Positioning and ranging information can be divided into time of arrival (TOA), time difference of arrival (TDOA), angle of arrival (DOA), and received signal strength (RSSI). The process of indoor positioning is shown in Figure 2.

The positioning algorithm based on WiFi ranging is based on mastering the distance from each node of the WiFi AP to the target. It estimates the location coordinates of the target through the known location of the AP node. The most basic localization algorithms are trilateration, hyperbolic measurement, and least squares [12].

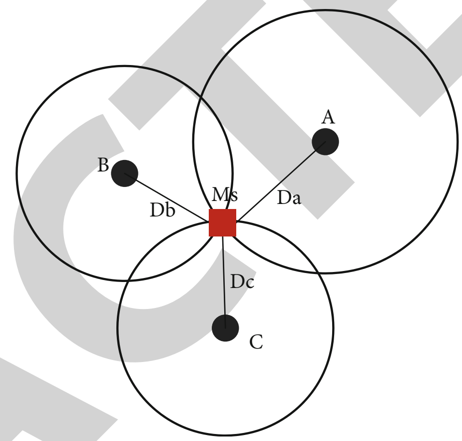

Figure 3: Trilateration.

Three-range multipoint positioning is the basic method for estimating the target position. The essence of this method is to solve the intersection of the three circles as the target position according to the known centers and radii of the three circles.

It is assumed that points A, B, and C in Figure 3 are WiFi nodes APa, APb, and APc, respectively. The corresponding coordinates are (x_a, y_a), (x_b, y_b), and (x_c, y_c). The point MS is the target, and the coordinates are (x, y). And the distances from MS to A, B, and C have been measured as d_a, d_b, and d_c, respectively. When there are no obstacles and noises in the environment where the target is located, it can be known from the geometric relationship:

$$\begin{cases} (x - x_a)^2 + (x - x_a)^2 = d_a^2, \\ (x - x_b)^2 + (x - x_b)^2 = d_b^2, \\ (x - x_c)^2 + (x - x_c)^2 = d_c^2. \end{cases} \quad (9)$$

In the hyperbolic positioning method, points A, B, and C are AP1, AP2, and AP3, respectively, and the corresponding coordinates are (x_1, y_1), (x_2, y_2), and (x_3, y_3). Point M is the position of the target measurement signal, and the coordinates are (x, y). Second, the distances from point M to each AP are $d1$, $d2$, and $d3$, respectively.

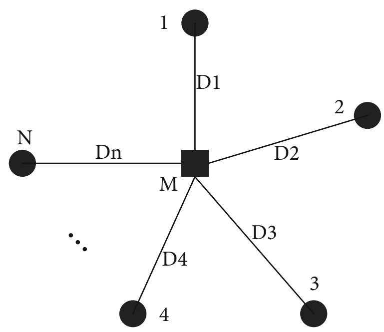

Figure 4: Least squares method.

From the geometric relationship of the hyperbola, the distance difference between the target and AP_i is

$$d_{i,1} = \sqrt{(x - x_i)^2 + (y - y_i)^2} - \sqrt{(x - x_1)^2 + (y - y_1)^2}, i = 2, 3. \quad (10)$$

The distance from the target to the i-th AP node is

$$d_i = \sqrt{(x - x_i)^2 + (y - y_i)^2}, i = 2, 3. \quad (11)$$

It expands this formula to

$$d_{i,1}^2 + 2d_{i,1}d_1 + d_1^2 = x_i^2 + y_i^2 - 2x_i x - 2y_i y + x^2 + y^2. \quad (12)$$

The target of a WiFi network often receives signals transmitted by more than three access points APs in practical applications. It also measures the distance between the target M and the AP; at this time, the multilateral measurement method is generally used [13], as shown in Figure 4.

The coordinates of $1, 2 \cdots n$ AP access points are (x_1, y_1), $(x_2, y_2)\ldots(x_n, y_n)$. It is known that $d_1, d_2 \ldots d_n$ are the distances from n AP nodes to the target M. It assumes that the coordinates of the target M are (x, y), and the formula system can be established by using the above relationship:

$$\begin{cases} (x_1 - x)^2 + (y - y_1)^2 = d_1^2, \\ \vdots \\ (x_n - x)^2 + (y - y_n)^2 = d_n^2. \end{cases} \quad (13)$$

Because there is an error N in the measurement process, this paper uses the least squares method to obtain the following values.

$$Q(z) = \|N\|^2 = \|b - Az\|^2. \quad (14)$$

To find the minimum value of z, the derivative of formula (14) can be obtained:

$$\frac{dQ(z)}{dz} = 2AA^T x - 2AB = 0. \quad (15)$$

If AA^T is a nonsingular matrix, solving for z gives

$$z = \left(A^T A\right)^{-1} A^T B. \quad (16)$$

Finally, the solved z is the least squares position estimate of the target.

3.3. Outdoor Positioning Technology. The spatial part of GNSS (taking GPS as an example) consists of 24 satellites (21 working satellites and 3 spare satellites) evenly distributed in 6 orbital planes [14]. When the user terminal receives the satellite signal, it can measure the pseudo distance and the distance change rate between the receiving satellite and the antenna and obtain data such as satellite orbit parameters. These data are processed and calculated to obtain the latitude, longitude, altitude, and other information of the user's current location. Figure 5 shows the principle of GNSS positioning.

Since it is known that the propagation speed of the satellite signal is the speed of light, the distance between the GNSS satellite and the user terminal can be obtained by obtaining the time when the user terminal receives the satellite signal. In order to obtain the user's position, this paper needs to establish a quadratic formula system between the user terminal and four different satellites. Its calculation simultaneous formula is

$$\begin{cases} \sqrt{(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2} + c(V_{t1} - V_t) = d_1, \\ \sqrt{(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2} + c(V_{t2} - V_t) = d_2, \\ \sqrt{(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2} + c(V_{t3} - V_t) = d_3, \\ \sqrt{(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2} + c(V_{t4} - V_t) = d_4. \end{cases} \quad (17)$$

In the formula, $P(x, y, z)$ is the spatial coordinates of the user, and S1-S4 are the spatial coordinates of the four satellites. V_{ti} is the clock error of satellite i, V_t is the clock error of the user terminal, d_i is the distance between satellite i and the receiver, and c is the speed of light. The above formula is only a brief description of GNSS positioning. There are many other error factors in the actual positioning environment. Therefore, it is necessary to introduce as many GNSS satellites as possible to establish equations to improve the accuracy of GNSS satellite positioning.

In an open outdoor environment, a good GNSS signal can be obtained. With the help of RTK positioning technology, high-precision positioning can be achieved. However, the quality of its signal will change due to changes in the positioning environment. Therefore, the combination of GNSS and inertial navigation is used to achieve continuous outdoor positioning [15]. The long-term positioning of inertial navigation will cause the accumulation of errors, and the accuracy of its positioning mainly depends on the heading angle and the design of the algorithm. Therefore, in order to improve the positioning performance of the GNSS

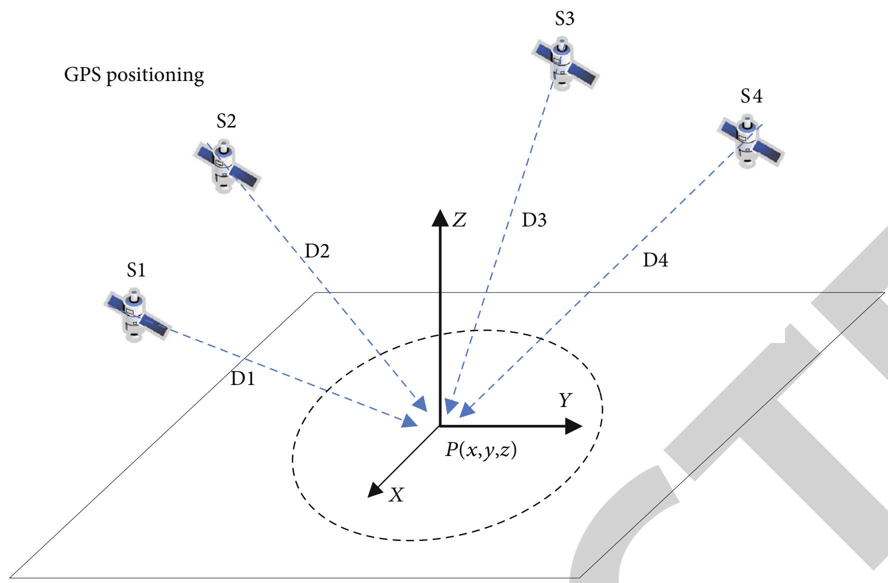

Figure 5: Schematic diagram of GNSS positioning principle.

combined INS and improve the positioning accuracy, a heading angle correction algorithm based on Kalman filter is proposed, which combines the heading angle a of RTK positioning with the heading angle Δa of inertial navigation positioning. Through the data fusion solution, the heading angle measurement error is reduced. The specific algorithm processing design process is as follows: first, let the state quantity of the system be 1. Taking the carrier of linear motion as the research object, a linear formula of state model is established:

$$X_n = AX_{n-1} + W, \tag{18}$$

where A is the state transition matrix, $A = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix}$, and W are the state noise. The observation formula model Y is

$$Y_n = HX_n + V, \tag{19}$$

where H is the observation matrix and V is the observation noise.

The absolute angle of the current RTK positioning is equal to the sum of the absolute angle of the RTK at the previous moment and the relative angle of the inertial navigation change. After it is processed by the filtering algorithm, the combined heading angle can be obtained [16]. Next, it uses the combined heading angle, RTK positioning information, and inertial navigation positioning information to design the combined navigation heading angle correction algorithm. Based on two positioning sources, GNNS and INS, taking Kalman filter as an example, let the observation matrix and state transition matrix be as in formula (20).

$$A = \begin{bmatrix} 1 & T & 0.5T^2 \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix}. \tag{20}$$

The working process of combined navigation is shown in Figure 6. Its first terminal processing equipment will integrate inertial measurement unit and satellite signal receiver.

Using GPS satellite signals, the inertial measurement unit is used to measure the carrier's attitude information such as acceleration and angular velocity. It obtains the current longitude, latitude, altitude, speed, acceleration, and other information through the satellite signal receiver. Then, the position is predicted and updated through the data fusion processing unit on the terminal device, and the movement trajectory of the carrier is obtained to realize the positioning.

4. Positioning System Simulation and Analysis

4.1. Smart Switch Simulation. In this section, according to different scenarios, two parts of simulation experiments are designed to verify the indoor and outdoor seamless positioning method proposed in this chapter. The first part is the comparison experiment of intelligent switching method. The second part is the validation of the artificial intelligence-based indoor and outdoor seamless localization method [17].

Before starting the experiment, it first need to use the web page to log in for related configuration. In the experiment, it needs to enter the IP address in the address bar. After logging in, it can view the current firmware version, temperature, time, running time, tracking satellites, location information, etc., and configure the output serial port number, data frequency, etc. It sets the serial port numbers of the locator as serial port 1 and serial port 4, and the output

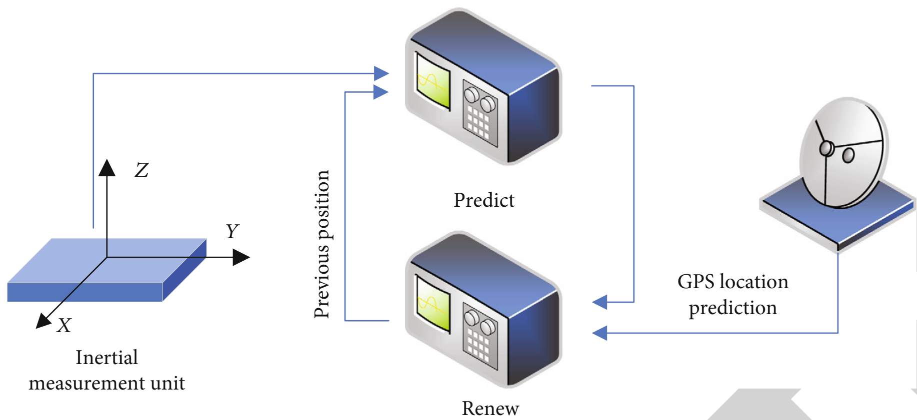

Figure 6: Block diagram of combined navigation position prediction update.

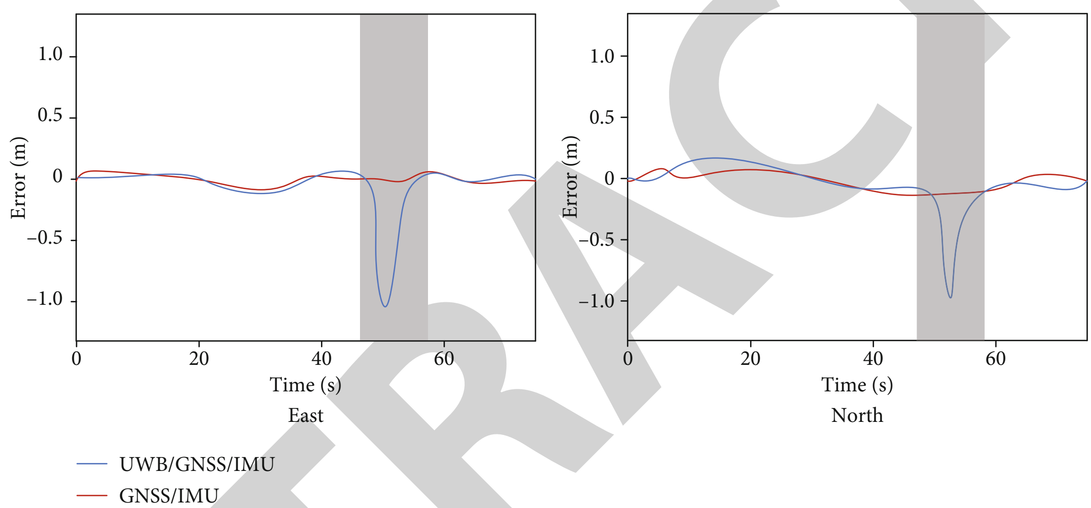

Figure 7: Easting and northing positioning errors.

frequency is 1 Hz. The GNSS positioning test is carried out in an outdoor open environment. The receiver moves around the building with the experimental positioning vehicle and exports the positioning results to Google Earth. It can be seen from the positioning results that the GNSS module can complete the normal satellite capture, tracking, positioning, and data transmission functions. The system can complete the normal data collection and transmission functions. Since the location reference information was not added during the test, the positioning accuracy of the system was not investigated [18]. This paper needs to analyze the combined positioning performance of the system and at the same time verify the effectiveness of the seamless positioning adaptive filtering algorithm and the UWB base station layout algorithm. In this section, a seamless positioning experiment is further carried out, and the position reference information is provided by a combination of satellite navigation and a high-precision fiber optic gyroscope independently developed by the laboratory. Among them, the bias of the fiber optic gyro is 0.01°/h, and the bias of the accelerometer is 10^{-4} g. The experimental site is selected in a science park in China, and the experimental positioning vehicle is equipped with a combined positioning platform to move for a week along the road near the science park. Considering the fact that the experimental positioning vehicle is inconvenient to enter and exit the laboratory building of the building, indoor and outdoor interaction areas cannot obtain accurate location reference information, and UWB base station deployment is susceptible to interference. Therefore, in the test, the GNSS signal is artificially removed in a certain period of time in the measurement data of the complete outdoor operation route. And add noise to the UWB and GNSS output observations to simulate the problem of the degradation of the UWB and GNSS signal quality caused by the experimental

Table 1: Statistics of positioning error results.

Positioning error (m)	UWB/GNSS/IMU	GNSS/IMU
East (RMS)	1.08	4.83
North (RMS)	0.26	1.05
East (MAX)	0.84	2.70
North (MAX)	0.94	4.08
Average error	0.78	3.17

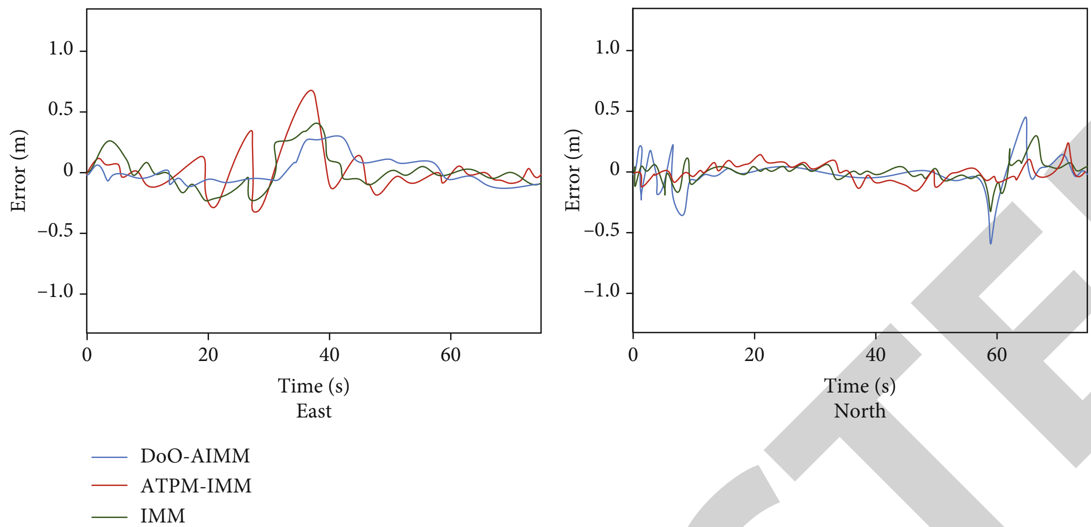

Figure 8: Comparison of east and north positioning error curves.

Table 2: Statistics of positioning error results of three algorithms.

Positioning error (m)	DoO-AIMM	ATPM-IMM	IMM
East (RMS)	0.47	1.17	0.36
North (RMS)	1.21	0.44	0.55
East (MAX)	1.20	10.12	1.99
North (MAX)	0.60	7.93	1.72
Average error	0.87	4.92	1.155

positioning vehicle entering the indoor environment or due to the occlusion of the floor building. According to the demand, the experiment was carried out four times. Figure 7 shows the variation curve of the east and north positioning errors of the experimental positioning vehicle in the test.

The shaded area represents the time period of joining UWB observation. The blue line represents the combined GNSS/IMU mode without UWB observations, and the red line represents the combined UWB/GNSS/IMU positioning mode. No UWB observations were added outside the shaded area. The errors of the two modes are the same, but the difference is larger in the shaded area [19]. Table 1 summarizes the maximum and root mean square values of the east-north positioning error in the two modes.

The traditional IMM algorithm, the ATPM-IMM algorithm, and the DoO-AIMM algorithm proposed in this paper are used to process the experimental data in this time period, respectively. The east and north positioning error curves are shown in Figure 8. The maximum and root mean square value statistics of the positioning errors of the three algorithms are shown in Table 2.

It can be seen from Figure 8 that when the noise of the external information source changes, the combined positioning accuracy will also change accordingly. However, due to the adaptive ability of the algorithm to noise, the algorithm can well adjust the probability of GNSS/IMU and UWB/IMU submodels and maintain the positioning accuracy of the system.

It can be seen from Table 2 that compared with the IMM and ATPM-IMM algorithms, the DoO-AIMM algorithm proposed in this paper improves the adaptability of the algorithm to model changes due to the use of the transition probability correction method based on the observability. At the same time, it avoids too much dependence on historical information and has higher positioning accuracy. The root mean square value of the overall positioning error is 0.32 m in the east and 0.33 m in the north, and the maximum error is not greater than 1.36 m.

Table 3 summarizes the maximum positioning error of the DoO-AIMM algorithm in different time periods. It can be seen that, processed by the DoO-AIMM algorithm, the positioning error of the experimental positioning vehicle in the area with UWB layout is not greater than 0.28 m in the test. The positioning error in the non-UWB area is not more than 1.36 m. When 1/2 of the model matches the current real model, that is, the physical meaning is that both UWB and GNSS can provide good observation information that conforms to the system model, the system positioning accuracy is better than 0.25 m. This can meet the needs of seamless positioning of the experimental positioning vehicle [20].

4.2. Design and Implementation of Seamless Positioning System. Artificial intelligence is now being used for open source operations on mobile devices. This technology is a complete, open, and free technology. Using artificial intelligence can create a stable, secure, and open platform. It is also a stage full of opportunities and challenges. This paper designs an indoor and outdoor seamless positioning system that integrates artificial intelligence and intelligent switching algorithms and uses artificial intelligence and intelligent switching algorithm to realize the seamless positioning system. That is, the user can obtain their current location information by means of a mobile device with Android installed. In order to achieve seamless indoor and outdoor positioning, this positioning system combines three positioning methods: GPS positioning, WiFi positioning, and base

Table 3: Statistics of the maximum positioning error of the DoO-AIMM algorithm in different time periods.

Period	True submodel	Corresponding combination mode	Positioning error (east/m)	Positioning error (north/m)
0-30	Model 1	GNSS/IMU	0.71	1.19
30-60	Model 2	UWB/IMU	0.26	0.71
60-90	Model 1,2	UWB/GNSS/IMU	0.35	0.30
90-120	Model 1	GNSS/IMU	1.12	0.68
Average error			0.61	0.72

station positioning. According to the characteristics of the positioning method, in this paper, GPS positioning is only used for outdoor positioning, and WiFi fingerprint positioning is only used for indoor positioning. Due to the wide coverage of cellular signals, cellular fingerprint positioning is used to supplement the defects of the other two positioning methods. It can be used for both outdoor positioning (canyon blind spots caused by tall buildings) and indoor positioning (areas without WiFi, such as parking lots, between passages).

The indoor and outdoor seamless positioning system designed in this experiment includes multiple mobile terminals and indoor positioning terminals. Among them, the mobile terminal includes a fusion positioning module, a GNSS module, an INS module, and a communication module. The indoor positioning terminal includes edge computing nodes, indoor positioning equipment, and communication modules. Among them, indoor positioning equipment uses Lidar and UWB equipment to achieve positioning. The indoor positioning terminal detects the target in real time through a group of indoor positioning equipment and generates target position data. The edge computing node uses the PDA algorithm to fuse the Lidar positioning data and the UWB positioning data. The target tracking algorithm is executed in real time, and the target motion trajectory is output. Finally, the positioning data of the target is sent to the mobile terminal of the corresponding target through the communication module [21]. The integrated positioning module of the mobile terminal is based on the received GNSS/INS outdoor positioning data and the indoor positioning data sent by the indoor positioning terminal. The final positioning data is obtained through the intelligent switching algorithm.

This seamless positioning software is mainly divided into five parts: signal fingerprint management module, outdoor positioning module, indoor WiFi signal fingerprint positioning module, map display module, and the most important scene judgment and positioning switching module. The functions of server, client, and database of the whole system are realized by Android smartphones. The system has a total of 5 interfaces. After opening the software, it will enter the main interface, and it can directly jump to the indoor or outdoor positioning map display interface through the main interface, entering the signal fingerprint management interface, and it enter the text location information display interface through the outdoor positioning map display interface.

4.3. Application Examples. In order to verify the effectiveness of the indoor and outdoor seamless positioning method and system proposed in this paper and verify the trajectory maintenance function under multiple indoor positioning terminals, in this chapter, two indoor positioning terminals are deployed to realize the indoor positioning method. The indoor positioning equipment of each indoor positioning terminal is 4 UWB base stations and 1 Lidar. The edge computing node uses an NVIDIA Xavier processor. It has strong computing ability and communication ability, and it can build the scene of indoor positioning experiment platform. The real locations of Lidar and UWB base stations are the same as the scene constructed by collecting data in Chapter 3. The mobile terminal of the positioning target adopts an experimental vehicle with computing and communication capabilities and an experimental vehicle equipped with artificial intelligence positioning equipment. The experimental vehicle is equipped with NVIDIA TX2 processing module for mobile data fusion and network communication. A large-scale wireless local area network is built through a router to realize data communication between the mobile terminal and the indoor positioning terminal [22].

Table 4: Experimental parameter ranges.

Parameter name	Parameter notation	Ranges
Wireless system carrier frequency (MHz)	f	800-2000
Base station antenna effective height (m)	hb	5-25
Mobile station antenna effective height (m)	hm	1-3
Transceiver antenna horizontal distance (m)	d	20-5000

The external part of the laboratory adopts GNSS/INS combined positioning system. Among them, the GNSS module uses differential positioning to improve the positioning accuracy, and the part with good outdoor signal can be approximately regarded as the real value. In the indoor and outdoor connection environment and the indoor environment, the target movement trajectory is set in advance in this experiment, and the target moves strictly along the trajectory [23]. The value range of each parameter in the experimental scene is shown in Table 4.

This application example selects two scenarios. The goal is to drive the test vehicle to the entrance of the indoor parking lot and enter the intersection of indoor and outdoor positioning environments [24]. With the above limitations, this chapter exports the above positioning data. It is drawn

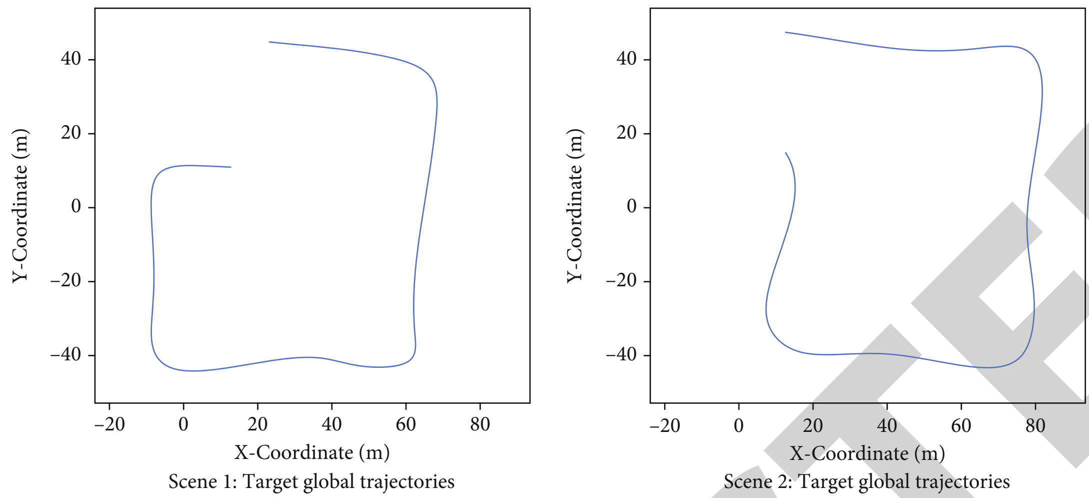

Figure 9: Global trajectories of different scenarios.

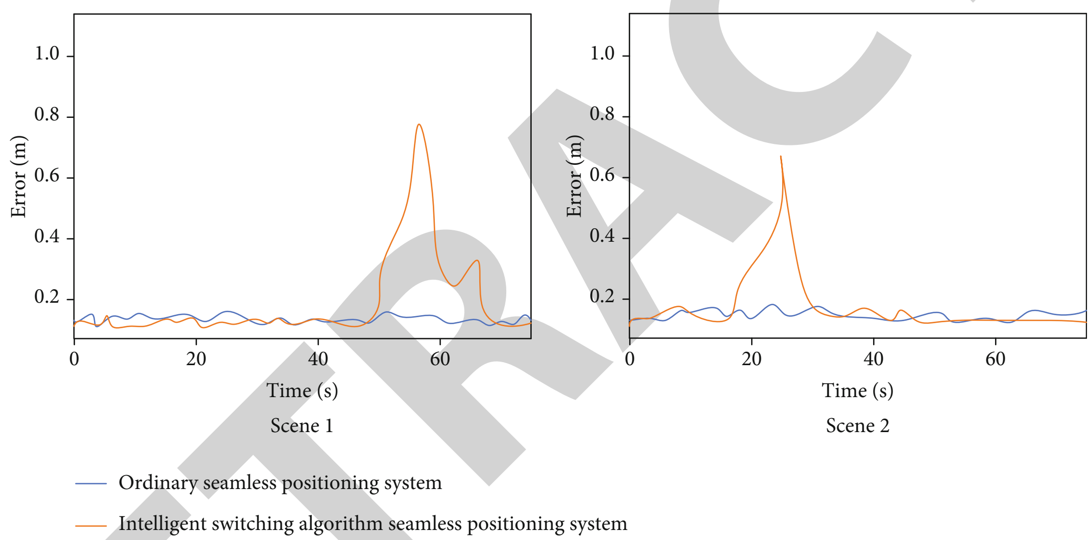

Figure 10: Comparison of the error sizes of the two methods in different scenarios.

in MATLAB software, and the trajectory diagram shown in Figure 9 is obtained.

This experiment realizes the intelligent switching of status mode. An indoor and outdoor positioning method switches the positioning mode only according to the changes of the indoor and outdoor environment. The localization results of this method are compared with the localization results of the method in this chapter. The errors of the two methods are compared with the actual values, as shown in Figure 10.

It is obvious that the localization results of the two methods in the outdoor part and the indoor part are almost the same. However, in the indoor and outdoor connection, the indoor and outdoor seamless positioning method proposed in this paper is obviously better than the indoor and outdoor positioning method without intelligent switching algorithm, and the positioning error is within 0.2 m. The experimental results show that the indoor and outdoor seamless positioning system designed in this chapter can ensure that the target does not need to judge the current environment. It obtains accurate and continuous positioning data, thus proving the effectiveness of the positioning system [25].

5. Discussion

With the mature application of outdoor positioning technology represented by GNSS and the rapid development of various indoor positioning technologies in recent years, it integrates a variety of positioning methods to achieve accurate location information services in any environment. It will be a hot research direction in the field of wireless positioning in the future. On the other hand, there is currently no unified industry standard for indoor positioning technology. Therefore, the improvement and optimization of various indoor positioning technologies is also a very promising research direction in the field of wireless positioning in the future. Although this paper designs and implements a seamless indoor and outdoor positioning system. However, the research content of this topic still needs to be further explored and improved. This thesis uses the lightweight database software that comes with the Android system mobile phone. Once the indoor positioning area is expanded, a huge fingerprint database needs to be established. The current positioning system cannot meet the positioning requirements, and it can be considered to store the fingerprint database on the server in the future. And part of the positioning algorithm works on the server to improve positioning efficiency. This paper has achieved thousands of concurrent user-side positioning requests, which basically meets a large number of user positioning service requests in the experimental environment. However, in practical applications, in the face of massive user demands, there will be various uncertainties. This will be a huge challenge for every platform [26, 27].

6. Conclusions

With the rapid popularization of intelligent terminals and the rapid development of wireless communication technology, people's demand for location-based services is increasing. It is more hoped that the location service is no longer limited by the scene, thus promoting the research and development of indoor and outdoor seamless positioning. This paper mainly focuses on the application research of the key technology of seamless positioning in typical urban environment. In this paper, through the research and analysis of the existing wireless positioning technology, the analysis is carried out for a variety of typical environments. The intelligent switching algorithm is introduced as the main method of positioning switching, and threshold switching and motion state judgment are introduced, in order to eliminate the influence of the "ping-pong" phenomenon that may occur during the handover process. Finally, according to the proposed positioning switching algorithm, this paper designs an indoor and outdoor seamless positioning system and performs performance testing by selecting test scenarios.

Data Availability

No data were used to support this study.

Conflicts of Interest

There is no potential conflict of interest in this study.

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