Complex Environmental Localization of Scenic Spots by Integrating LANDMARC Localization System and Traditional Location Fingerprint Localization

Shasha Song[1]*, Cong Li[2]
Tourism College, Yellow River Conservancy Technical Institute, Kaifeng, 475004, China[1]
The Information Engineering Institute, Yellow River Conservancy Technical Institute, Kaifeng, 475004, China[2]

***Abstract*—The scenic spot contains complex and changeable indoor and outdoor environments, some of which may be difficult to work effectively due to signal occlusion, multipath effect and other factors. In response to this problem, this paper proposes a method of Location Identification Based on the Dynamic Active Radio Frequency IDentification Calibration system and fingerprint localization system. It aims to improve positioning accuracy and reliability in the complex environment in the scenic spot. Firstly, the Location Identification Based on Dynamic Active Radio Frequency IDentification Calibration system is analyzed and improved. Then the improved positioning algorithm is applied to the complex environment of the scenic spot. Finally, the positioning results of the improved positioning algorithm in the complex environment of the scenic spot are tested. The experimental results show that when the K value is set to 4, the reader is arranged in the four corners and the center of the area, and the label density is set to 6×6, the average error of the research system in terms of error control is only 0.32, which is 0.28 less than that of the ultrasonic positioning system. All in all, the combination of Location Identification Based on Dynamic Active Radio Frequency IDentification Calibration system and traditional location fingerprint location of the scenic spot complex environment positioning scheme, it has shown great advantages in positioning accuracy, stability and real-time.**

Keywords—LANDMARC; localization system; fingerprint localization; environmental localization; scenic spot

I. INTRODUCTION

In today's rapidly changing technology, location localization services for scenic spot tourists have become indispensable tools for improving tourist experience and optimizing scenic spot management [1-2]. However, the unique and complex environmental characteristics of scenic spots, such as variable terrain, dense buildings, and pedestrian flow, pose unprecedented challenges to the accuracy and stability of positioning systems. These complex environmental factors may not only hinder the propagation of signals, leading to biased localization results but also cause the localization system to fail in certain areas due to signal interference and occlusion. In recent years, the Location Identification Based on Dynamic Active Radio Frequency Identification Calibration (LANDMARC) localization system has become a focus in the field of indoor localization due to its advantages based on Radio Frequency Identification (RFID) technology, such as high localization precision, excellent stability, and easy deployment. Domestic and foreign scholars have conducted extensive and in-depth research on the performance of the LANDMARC localization system, with a particular focus on improving localization precision and enhancing system stability and environmental adaptability. Duan et al. raised an innovative method to solve the sensitivity of the LANDMARC localization system to environmental noise, which uses Newton interpolation to calculate the distance between the tested label and the reader. This method effectively improved the stability and localization precision of the system, making the LANDMARC localization system more reliable in practical applications [3]. In addition, Duan et al. optimized and improved the original indoor localization algorithm to address the issue of pre-deploying a large number of reference labels in the LANDMARC localization system. Through MATLAB simulation experiments, it verified the significant effect of the improved LANDMARC (I-LANDMARC) localization algorithm in reducing localization errors and improving localization precision [4].

However, the LANDMARC localization system also has some limitations, such as sensitivity to environmental noise and the need to deploy a large number of reference labels in advance. However, traditional location fingerprint localization methods construct a location fingerprint library by collecting environmental signal features, and use machine learning and other algorithms for location estimation. This method does not require additional equipment deployment and exhibits certain robustness to environmental noise. With the vigorous advancement of machine learning, deep learning and other technologies, traditional location fingerprint localization methods have made significant progress in localization precision, real-time performance, and robustness. For example, Lu et al. proposed a fingerprint database matching localization method with homologous multi-channel pseudo satellites, and verified its localization performance under dynamic and static conditions through extensive experiments. In an indoor testing environment, the dynamic average localization precision of this method reached 0.39 meters, with a 95% localization error better than 0.85 meters. In a real airport environment, the dynamic average localization accuracy was 0.75 meters, the maximum localization error was 1.69 meters, and 92% of the localization error was better than 1 meter [5]. At the same time, Han et al. proposed dynamic fusion features as a new fingerprint formation method and tested it in indoor environments. This method improved the system's feature resolution in both fingerprint features and similarity measurement, had good noise resistance, and effectively reduced localization errors [6]. In addition, to improve the localization effect of GPS in indoor environments, the Uradzinski team proposed a method based on average threshold and effective data domain filtering to optimize the fingerprint database of ZigBee technology. Indoor experiments conducted by Waemmia and Mazuri University denoted that this method extends the localization distance by more than 30 meters without reducing localization precision [7].

Based on this, the study proposed a complex environment localization system for scenic spots that integrates LANDMARC localization system and traditional location fingerprint localization. The research combined the positioning accuracy characteristics of LANDMARC with the environmental adaptability of location fingerprints, filling the gap in the market for high-precision and stable positioning in the complex environment of scenic spots, and opening up a new path for the development of positioning technology. At the same time, by integrating the advantages of the two positioning technologies, the research can effectively overcome the limitations of single technology application and promote the further development of positioning technology and even the entire Internet of Things field.

The research is divided into four sections. Section I is the introduction, which introduces the research method and lays the foundation for the research. Section II is the method of the research, which analyzes the I-LANDMARC localization algorithm and its application in the location of the complex environment of scenic spots. Section III is the result of the research, which is the analysis of the application results of I-LANDMARC localization algorithm in the location of scenic complex environment. Section IV is the conclusion part, that is, the analysis and evaluation of the experimental results of the research model.

II. METHODS AND MATERIALS

A. LANDMARC Localization System

The LANDMARC localization system is an indoor localization system based on RFID technology. The core algorithm is based on the Received Signal Strength Indication (RSSI) and utilizes the centroid weight algorithm to correct blind spots in traditional localization by real-time obtaining the RSSI value of the reference label, thereby improving the accuracy of object localization [8-9]. In RFID systems, readers are also known as interrogators, readers, or RFID devices. It can read or write data from electronic tags, independently perform data reading and processing, and can also be combined with computers to perform related operations on tags [10-11]. The basic components of the reader are illustrated in Fig. 1.

As shown in Fig. 1, the basic components of the reader mainly include radio frequency (RF) interface module, logic control unit, and antenna. The RF interface module is the core part of the reader, responsible for generating and receiving wireless RF signals [12]. The RF interface module sends energy and information to the electronic tag through an antenna and receives response signals from the electronic tag [13-14]. The logic control unit is the control center of the reader, which receives instructions from the backend application software system and controls the RF interface module to send and receive signals. The logic control unit is also responsible for decoding the response signal of the electronic tag, extracting the data information from it, and transmitting it to the computer's data management system for processing. The antenna is the physical interface for wireless communication between the reader and electronic tags. It is responsible for sending out wireless RF signals generated by the RF interface module and receiving response signals from electronic tags. The layout diagram of the LANDMARC localization system is denoted in Fig. 2.

Assuming that the number of readers in the Spider system is N, the amount of reference tags is Y, and the amount of test tags is P, the expression for the signal strength vector matrix E of the reference tags on each reader is defined, as shown in Eq. (1).

$$E=\begin{bmatrix} E_1^1 & E_2^1 & \dots & E_n^1 \\ E_1^2 & E_2^2 & \dots & E_n^2 \\ \vdots & \vdots & \vdots & \vdots \\ E_1^y & E_2^y & \dots & E_n^y \end{bmatrix} \tag{1}$$

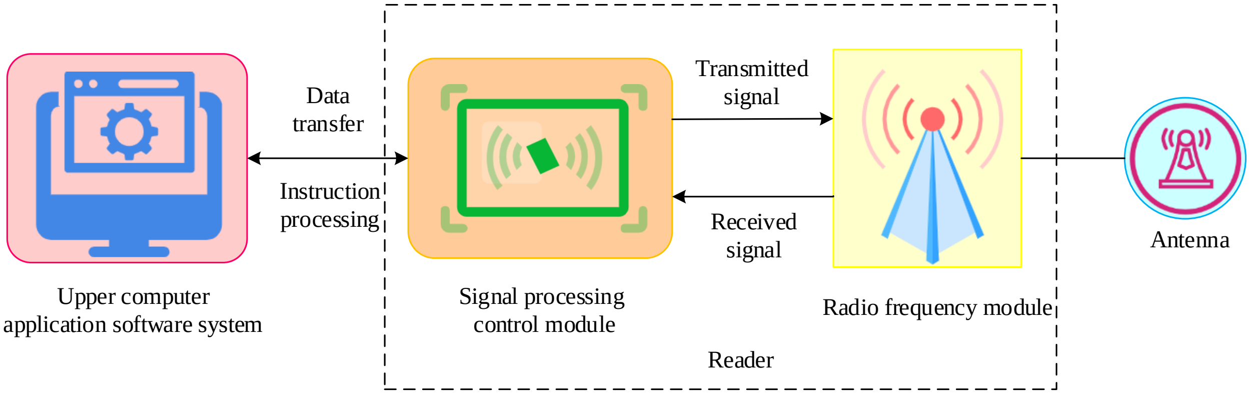


Fig. 1. Schematic diagram of the basic components of the reader.

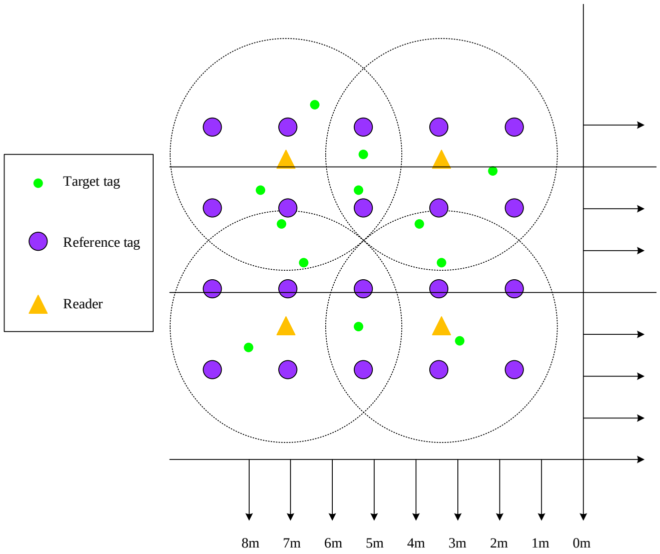


Fig. 2. LANDMARC localization system layout.

In Eq. (1), E_n^m represents the RSSI value when the n th reader reads the y th reference tag. Assuming that the signal strength vector received by the reader when reading an unknown point label is M, the expression for M is shown in Eq. (2).

$$M = \begin{bmatrix} M_1^1 & M_2^1 & \dots & M_n^1 \\ M_1^2 & M_2^2 & \dots & M_n^2 \\ \vdots & \vdots & \vdots & \vdots \\ M_1^x & M_2^x & \dots & M_n^x \end{bmatrix} \tag{2}$$

In Eq. (2), M_n^x represents the RSSI value of the unknown point label x on the n th reader. The LANDMARC localization system utilizes the k-Nearest Neighbor (KNN) algorithm as part of its localization mechanism. The LANDMARC system first collects signal strength or other relevant information about reference labels, and constructs a database containing the location information of these labels [15-16]. Then, when the system receives signals from unknown labels, it calculates the similarity between these signals and the reference label signals in the database, usually measured using metrics such as Euclidean distance. After obtaining the RSSI value of the target label, it is matched with the virtual label in the positioning area. If the difference is less than a specific threshold, the virtual label is marked as valid. If the difference is greater than a specific threshold, it is considered an invalid virtual label and filtered out from the valid neighboring electronic map. The low probability position filtering diagram of adjacent electronic maps is shown in Fig. 3.

Finally, the KNN algorithm finds k reference labels that are most similar to the unknown label signal, and this process is usually achieved by combining the positions of these reference labels through example weighting [17]. The expression for the constructed distance matrix D is shown in Eq. (3).

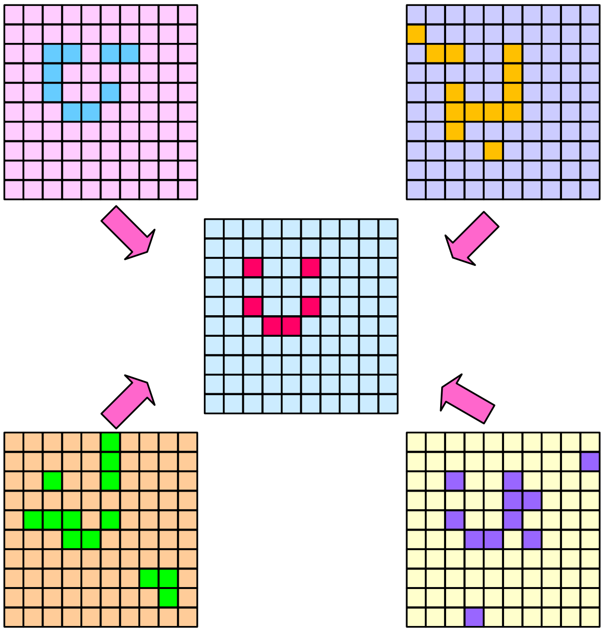


Fig. 3. Small probability location filtering of adjacent electronic map.

$$D = \begin{bmatrix} D_1^1 & D_2^1 & \dots & D_y^1 \\ D_1^2 & D_2^2 & \dots & D_y^2 \\ \vdots & \vdots & \vdots & \vdots \\ D_1^x & D_2^x & \dots & D_y^x \end{bmatrix} \tag{3}$$

In Eq. (3), D_y^x represents the Euclidean distance between the unknown point label D_y^x and the y th reference label, as expressed in Eq. (4).

$$D_y^x = \sqrt{\sum_{k=1}^{n}(E_k^y - S_k^x)} \tag{4}$$

In Eq. (4), k represents the nearest neighbor reference label (NNRL), S_k^x represents the RSSI value of unknown point tag x on reader n. In the LANDMARC indoor localization system, the smaller the D_y^x, the higher the similarity or proximity between the unknown point label and the reference label. For the unknown point label x, the known coordinate information and corresponding weights of k nearest neighbor labels can be used for calculation. The coordinate calculation expression for the unknown point label x is shown in Eq. (5).

$$(e, f) = \sum_{i=1}^{k} w_i (e_i, f_i) \tag{5}$$

In Eq. (5), i means the number of NNRLs, w_i represents the weight, and the calculation method for w_i is shown in Eq. (6).

$$w_i = \frac{\frac{1}{(D_i^x)^2}}{\sum_{i=1}^{k}\frac{1}{(D_i^x)^2}} \tag{6}$$

The RSSI value label correlation mainly refers to the relationship between RSSI values between different reference points in wireless communication or localization systems. Due to the influence of various factors during the propagation of wireless signals, there may be some correlation between RSSI value labels between different reference points. Assuming two variables are H,Z, the expression for the correlation coefficient is shown in Eq. (7).

$$r_{H,Z} = \frac{Cov(H,Z)}{\sigma_H,\sigma_Y} = \frac{\frac{1}{j}\sum_{i=1}^{j}(h_i - u_H)(z_i - u_Z)}{\sigma_H,\sigma_Y} \tag{7}$$

In Eq. (7), $Cov(H,Z)$ represents the covariance difference of H,Z, σ_H,σ_Y represent the variance of H,Z, u_H,u_Z represent the mean of H,Z, and j represents the number of samples.

B. LANDMARC Localization System based on Position Fingerprint Localization

LANDMARC localization technology has shown its unique advantages in many application scenarios, however, its technology precision is still limited. The main drawback is that the precision of LANDMARC localization is highly dependent on the precision of reference label sampling values. In complex environments, due to the presence of various interference factors, the real-time RSSI values obtained fluctuate greatly, and the degree of interference received by adjacent labels varies. This inconsistency brings errors to the position calculation of unknown points. To further raise the precision and stability of the LANDMARC localization algorithm, the study combines the stable fingerprint library of the position fingerprint method with the real-time signal strength information of the LANDMARC system. The position fingerprint localization method is an advanced technology based on wireless signal features for position estimation. This method achieves precise localization by linking different positions in the actual environment with their unique "fingerprints". Among them, fingerprint data is usually established by collecting RSSI values received at various locations, which represent the unique signal characteristics of each location. The fingerprint database localization process is shown in Fig. 4.

In the process of building a fingerprint information database, the study first built a LANDMARC localization system, which reads and collects the RSSI values of all reference labels through multiple readers [18-19]. These collected data form vectors, each containing RSSI measurements from different readers for the same reference label. Then, for each reference label y, the study extract the corresponding $RSSI$ value from each set of vectors. In order to evaluate the stability and distribution of these $RSSI$ values, statistical analysis was conducted on these signal samples, and the mean u and variance σ of the $RSSI$ samples for each label were calculated. The expression for calculating the sample mean u is indicated in Eq. (8).

$$u = \frac{1}{l}\sum_{y=1}^{l} RSSI_y \tag{8}$$

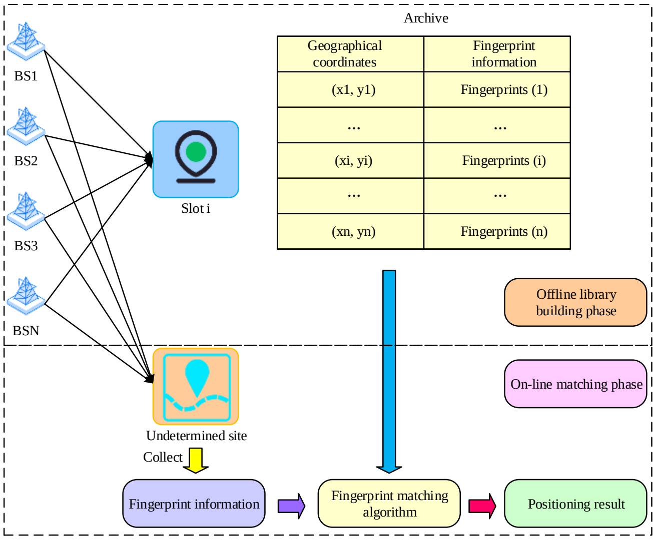


Fig. 4. Fingerprint database localization process.

In Eq. (6), l means the total amount of samples, and $RSSI_y$ represents the $RSSI$ value of the reference label y in the table. In order to fully utilize the collected data and improve positioning precision, study needs to ensure that fingerprint information contains as much and effective evidence as possible. To this end, the variance information of the reference point is included in the fingerprint for calculation. The variance information reflects the degree of dispersion of the RSSI value at the reference point, providing important information about the stability of the signal at that point [20-21]. The calculation formula for variance σ is shown in Eq. (9).

$$\sigma = \frac{1}{l}\sum_{y=1}^{l}(RSSI_y - u)^2 \tag{9}$$

In the process of constructing a fingerprint information database, to raise the stability and reliability of the data, a limited amplitude sliding filter algorithm was studied to preprocess the sequence composed of every seven consecutive sample data. The processed data is statistically calculated to obtain the mean u of each group of data and the variance σ of the original data, which together constitute the fingerprint information F_y of the reference label y. The expression for the fingerprint library value F_y of the reference tag y is shown in Eq. (10).

$$F_y = (a_y, b_y, u_1, ..., u_k, \sigma_1, ..., \sigma_k) \tag{10}$$

In Eq. (10), (a_y, b_y) represents the position coordinates of reference label y, and u_1 represents the sample mean. In the final stage of building a fingerprint database, the study will summarize the fingerprint information of all reference labels processed on all readers, in order to establish a complete and comprehensive fingerprint database. The flowchart of the LANDMARC localization system based on location fingerprint localization is shown in Fig. 5.

C. Application of I-LANDMARC Localization Algorithm in Complex Environment Localization of Scenic Spots

The research will apply the LANDMARC localization system based on location fingerprint localization to a certain scenic spot, where n readers and y reference tags will be deployed to achieve precise location estimation of tourists or other moving targets. However, due to the unique geographical environment and limitations of the scenic spot, the layout of reference labels did not follow the traditional regular layout. The schematic diagram of the location environment of a certain scenic spot is shown in Fig. 6.

Due to the irregular layout of the scenic spot, it may lead to the misselection of neighboring or problematic labels, resulting in a decrease in localization precision. Therefore, the study introduces a quadratic weighted localization method to precisely calculate the coordinates of the labels to be located [22-23]. Firstly, by calculating the Euclidean distance between the reference label and the label to be located, k reference labels with the smallest distance are selected as the set of NNRLs, denoted as k1, k2, k3, and k4. Then, based on the NNRL, the weighted position coordinates of the label to be located are preliminarily calculated, denoted as O (x ', y'), as

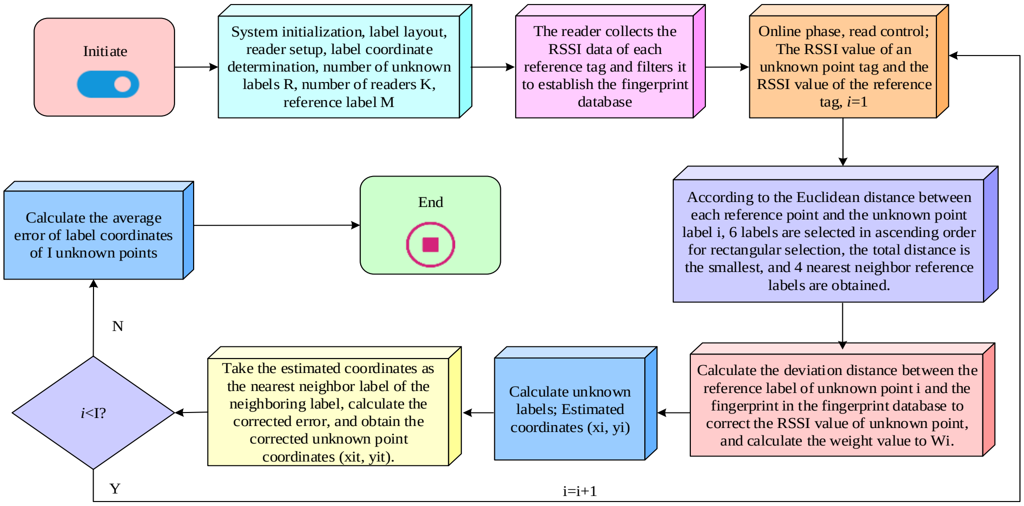


Fig. 5. Flowchart of LANDMARC localization system based on location fingerprint localization.

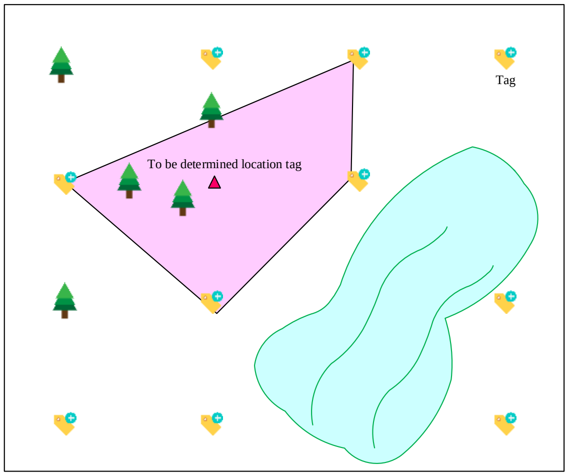


Fig. 6. Location environment diagram of a scenic spot.

In Fig. 7, in the irregular quadrilateral region, the line segment formed by connecting point O (x ', y') with four known points k1, k2, k3, and k4 is divided into four triangular sub regions. To determine the center coordinates of the inscribed circles in each triangle subregion, the study labeled these centers as O1, O2, O3, and O4. Since the process of solving the center of the inscribed circle in each triangle is the same, taking the solution of the center of the inscribed circle O3 in a triangle as an example, assuming that the coordinates of points A, B, and C are A (xa, ya), B (xb, yb), and C (xc, yc), respectively. Based on these coordinate points, the expression for the slope k_{AB}, k_{BC}, k_{AC} of the equation of the line segment AB, AC, and BC can be derived, as shown in Eq. (11).

$$k_{AB}=\frac{y_a-y_b}{x_a-x_b}, k_{BC}=\frac{y_c-y_b}{x_c-x_b}, k_{AC}=\frac{y_c-y_b}{x_c-x_b} \quad (11)$$

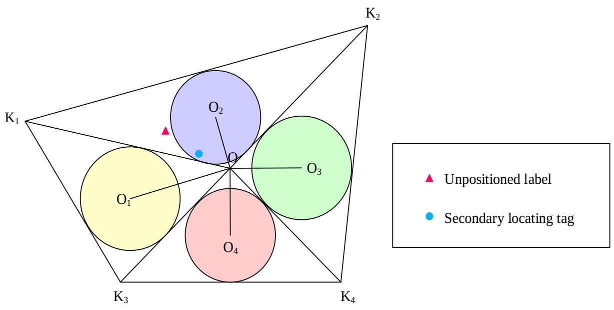


Fig. 7. The irregular layout of labels.

From Eq. (11), the linear equations of AB, AC, and BC can be obtained, and the calculation method for the linear equations of AB, AC, and BC are shown in Eq. (12).

$$\begin{cases} L_{AB}: k_{AB}x - y + b_1 = 0 \\ L_{BC}: k_{BC}x - y + b_2 = 0 \\ L_{AC}: k_{AC}x - y + b_3 = 0 \end{cases} \tag{12}$$

The calculation method for b_1, b_2, b_3 in Eq. (12) is shown in Eq. (13).

$$\begin{cases} b_1 = \dfrac{y_b x_a - y_a x_b}{x_a - x_b} \\ b_2 = \dfrac{y_b x_c - y_a x_c}{x_c - x_b} \\ b_3 = \dfrac{y_b x_c - y_a x_c}{x_a - x_c} \end{cases} \tag{13}$$

In triangle ABC, it assumes that the coordinates of the center O3 of its inscribed circle are (x3, y3). Due to O3 being the center of an inscribed circle, according to the properties of the inscribed circle, the distance between O3 and the three sides AB, AC, and BC of triangle ABC must be equal [24-25]. This property can be formalized through a mathematical expression, where the vertical distance between O3 and edges AB, AC, and BC have the same value, as shown in Eq. (14).

$$\frac{k_{AB}x_3 - y_3 + b_1}{\sqrt{k_{AB}^2 + (-1)^2}} = \frac{k_{BC}x_3 - y_3 + b_2}{\sqrt{k_{BC}^2 + (-1)^2}} = \frac{k_{AC}x_3 - y_3 + b_3}{\sqrt{k_{BC}^2 + (-1)^2}} \tag{14}$$

By using Eq. (14), the coordinates of the three inscribed circle centers O3 (x3, y3) of triangle ABC can be determined, and the same method can be applied to obtain the coordinates of the other three inscribed circle centers O1 (x1, y1), O2 (x2, y2), and O4 (x4, y4). To evaluate the relationship between the centers of these four inscribed circles and the preliminary estimated position of the target label, the study calculated the distance between the centers of these four inscribed circles and the first weighted position coordinates (x ', y') of the target label, denoted as d_1, d_2, d_3, d_4. The calculation expression for d_1, d_2, d_3, d_4 is shown in Eq. (15).

$$\begin{cases} d_1 = \sqrt{(x_1 - x') + (y_1 - y')^2} \\ d_2 = \sqrt{(x_2 - x') + (y_2 - y')^2} \\ d_3 = \sqrt{(x_3 - x') + (y_3 - y')^2} \\ d_4 = \sqrt{(x_4 - x') + (y_4 - y')^2} \end{cases} \tag{15}$$

The study uses d_1, d_2, d_3, d_4 as weight factors for quadratic weighted localization, which reflect the proximity between the target label and the center of each inscribed circle, and can be used to optimize the accuracy of localization results. The expression for calculating the weight of quadratic weighting is shown in Eq. (16).

$$\omega_j^{'} = \frac{\dfrac{1}{d_j^2}}{\sum_{j=1}^{k} \dfrac{1}{d_j^2}}, \ j = 1, 2, ..., k \tag{16}$$

The coordinates obtained from the second weighted calculation are used as the final position coordinates of the label to be located, denoted as (x ", y "). This coordinate needs to comprehensively consider the geometric relationship between the center of each inscribed circle and the label to be located, in order to ensure the accuracy and reliability of the final position coordinates. The calculation method for coordinates (x ", y ") is shown in Eq. (17).

$$(x'', y'') = \sum_{i=1}^{k} \omega_j^{'}(x_i, y_i) \tag{17}$$

In order to evaluate the accuracy of positioning, the study introduced positioning error e'. The localization error e' represents the degree of difference between the actual position and the final position calculated by the algorithm. The expression for localization error e' is shown in Eq. (18).

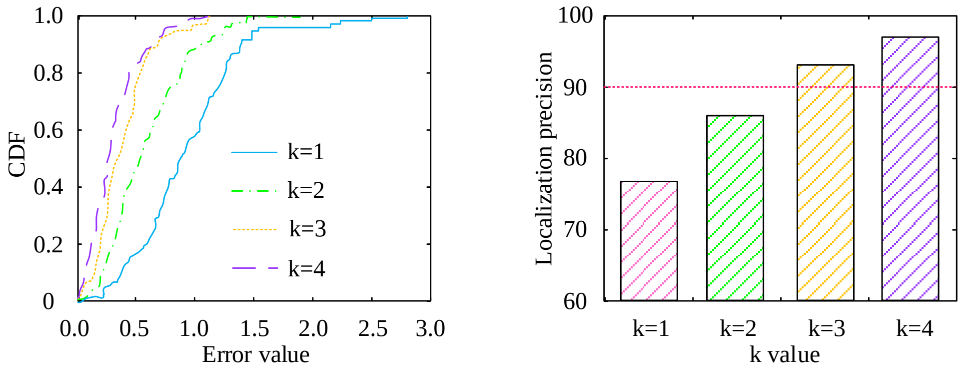
$$e' = \sqrt{(x'' - x_0)^2 - (y'' - y_0)^2} \tag{18}$$

III. RESULTS

A. Simulation Analysis of I-LANDMARC System based on Fingerprint Library

To ensure the stability of the performance of the I-LANDMARC system based on fingerprint library, it is first necessary to determine the k value of the KNN algorithm. In practical applications, it needs to select the appropriate k value with specific scenarios and requirements. This usually requires experimentation and simulation of the system to find the optimal k value setting. Set different k values for experiments and compare the error and localization precision of the system with different k values, as indicated in Fig. 8.

As shown in Fig. 8 (a), as the amount of NNRLs k gradually increased from 1 to 4, the probability of positioning error less than 2m significantly increased from 50% to 70%. This trend indicated that increasing the value of k helps to improve the precision of the localization system. In Fig. 8 (b), when the k value was set to 4, the localization precision was highest at 98.27%, while when the k value was set to 1, the localization precision was lowest at 78.61%. In summary, under the condition of k=4, studying the positioning system can obtain the best localization results, which not only ensures the precision of localization but also takes into account the performance of the system. Therefore, the study chooses to set the k value of the system to 4. In order to verify the impact of reader placement and its correctness on the performance of the localization system, a study randomly placed 100 test points and tested them through different layout schemes of the system reader. The cumulative distribution function (CDF) of errors corresponding to different reader placement methods is shown in Fig. 9.



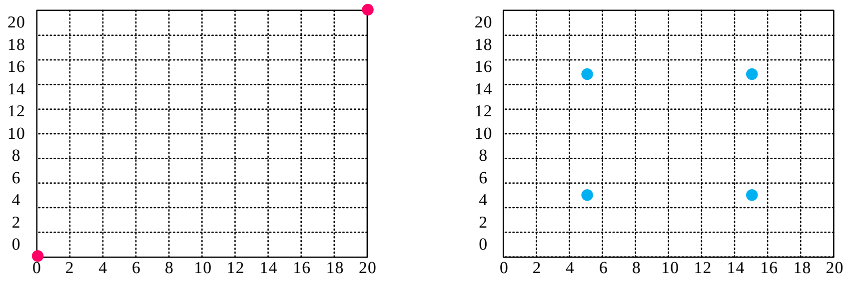
(a) Cumulative function curves for different values of k

(b)Localization precision different K values

Fig. 8. Comparison chart of error and localization precision of different k values.

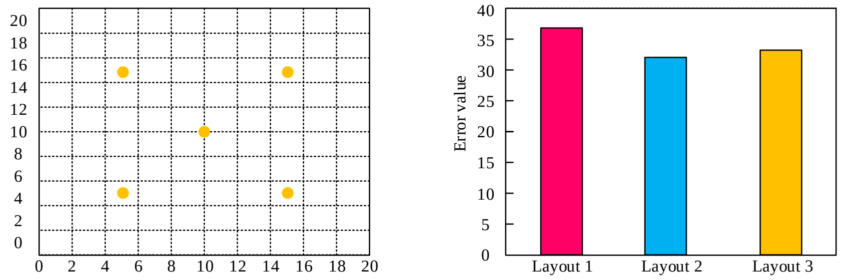
Fig. 9 (a) shows the layout 1 of the reader in the original LANDMARC system, where the reader was located at four corner positions (0,0), (0,20), (20,0), and (20,20), with a localization error value of 36. Fig. 9 (b) shows the improved position layout 2 of the reader, as shown in Fig. 9 (b). The position coordinates of the reader were (5,5), (5,15), (15,5), and (15,15). At this point, the localization error value of layout 2 was 32. Fig. 9 (c) shows a layout 3 where a reader was added to the center of the region based on the improved layout 2, with its center coordinates located at (10,10). At this point, the localization error value of layout 3 was 34. Therefore, the study chose layout 2 as the localization scheme. Node density refers to the average connectivity of nodes in a network. A high node density indicates good network connectivity and more frequent communication between nodes, which can improve localization precision. Under other unchanged conditions, the value of k was set to 4, and the reader adopted the optimal layout 2. Simulation experiments were conducted on different placement densities of reference labels, and the simulation results of reference label layout with different densities are shown in Fig. 10.

Fig. 10 (a) is a dense layout 1 of 21 × 21, and 441 reference labels were required for this layout. In this layout, the localization error value of the system was 33. Fig. 10 (b) is layout 2 of 11 × 11, and 121 reference labels were required for this layout. Under this layout, the localization error value of the fixed system was 31. Fig. 10 (c) is a layout 3 of 6 x 6, and 36 reference labels were required. Under this layout, the localization error value of the system was 28. Through comparative analysis, it was found that the localization error gradually decreased as the density of the reference labels increased. Taking into account localization precision, system complexity, and cost, the optimal choice for the research was the 6 × 6 layout 3. This layout maintained high localization precision while also controlling the complexity and cost of the system, providing feasible solutions for practical applications. To assess the localization effect of the research system, a network consisting of four readers and 36 reference labels was constructed. These reference labels were evenly distributed at intervals of 4 meters, and 100 test labels were randomly placed. The localization outcomes of the research system are denoted in Fig. 11.



(a) Layout 1

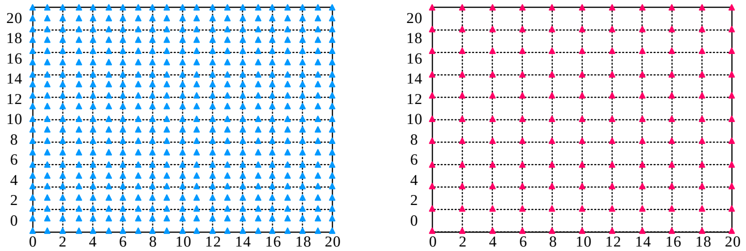
(b) Layout 2



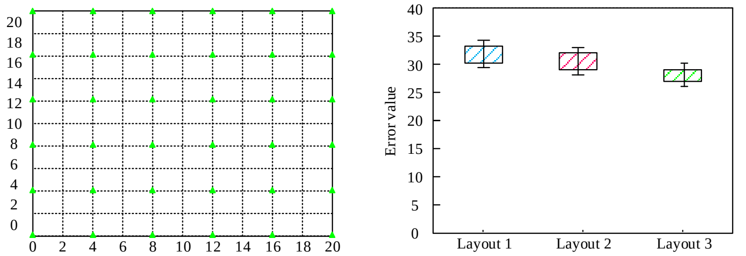
(c) Layout 3

(d) Error values for different layouts

Fig. 9. The cumulative error distribution function graph of different reader placement modes.



(a) Layout 1 (b) Layout 2



(c) Layout 3 (d) Error values for different layouts

Fig. 10. Reference label layouts of different densities.

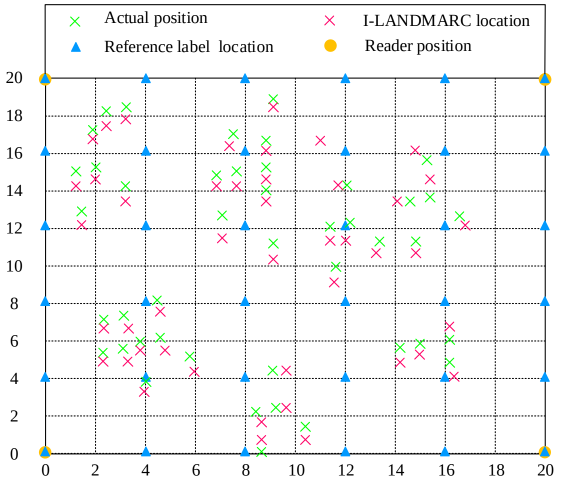


Fig. 11. Research system localization results in schematic diagram.

In Fig. 11, the research system also showed significant advantages in locating label locations. The research system was able to precisely locate the position of labels, thanks to its unique algorithm design and optimization, as well as the full utilization of reference label data. Specifically, the research system utilized advanced signal processing techniques, machine learning algorithms, or optimization algorithms to precisely calculate the distance or angle relationship between the tested label and the reference label, thereby determining the precise position of the label. In addition, the research system also considered the influence of environmental factors on the localization signal. Through appropriate compensation and correction, the localization precision was further improved, making the research system have greater potential and value in application scenarios that require high-precision localization.

B. Analysis of Application Results of I-LANDMARC Localization Algorithm in Complex Environmental Localization of Scenic Spots

To prove the practical application effect of the research localization system in scenic spots, a simulation testing environment was designed, in which four readers, 20 reference tags, and 8 labels to be located were deployed. The reference labels were arranged with a regular spacing of 2m to ensure that the localization algorithm was evaluated under unified and standard conditions. The simulation diagram of the scenic spot is denoted in Fig. 12.

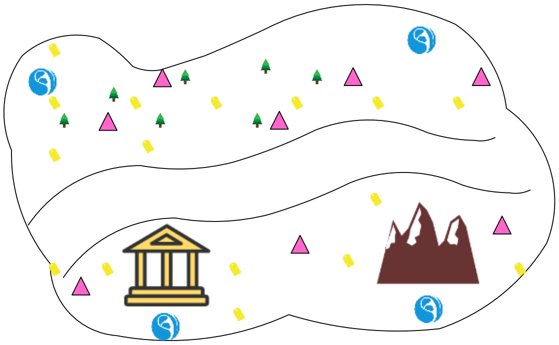


Fig. 12. Scenic spot simulation diagram.

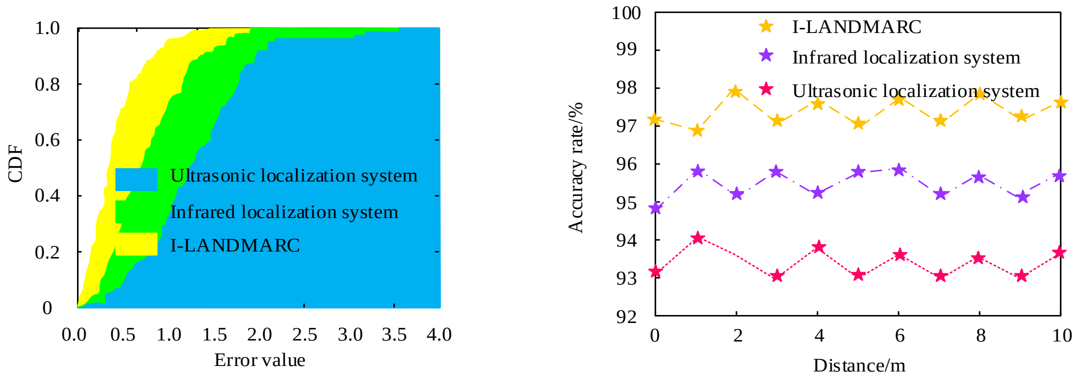
The research system's development environment and operation environment are indicated in Table I.

TABLE I. SYSTEM DEVELOPMENT AND OPERATION ENVIRONMENT

Operating system	**Microsoft Windows7 Service Packl**
Monitoring and development platform	LABVIEW
Development language	C, C++, VB, G
Database	Microsoft SOLServer2005 database
Other software and platform	Chengdu Wireless Long CC2431 positioning system, MATLAB
Operating system	Microsof Window system: CPU frequency :200 MHZ or higher, 500MHz or higher recommended, minimum memory: 2GRAM. Resolution: pixel cannot be less than 800*600;

To prove the effectiveness of the I-LANDMARC system based on fingerprint database, a comparative experiment was conducted on the error of traditional localization systems such as ultrasonic positioning system, infrared localization system, and LANDMARC localization system based on fingerprint database. Among them, the ultrasonic positioning system mainly determines the position of the object by measuring the time or phase difference of the ultrasonic signal propagating in space, and the infrared positioning system mainly uses the infrared propagation characteristics for positioning. The CDF and precision comparison of different localization systems are shown in Fig. 13.

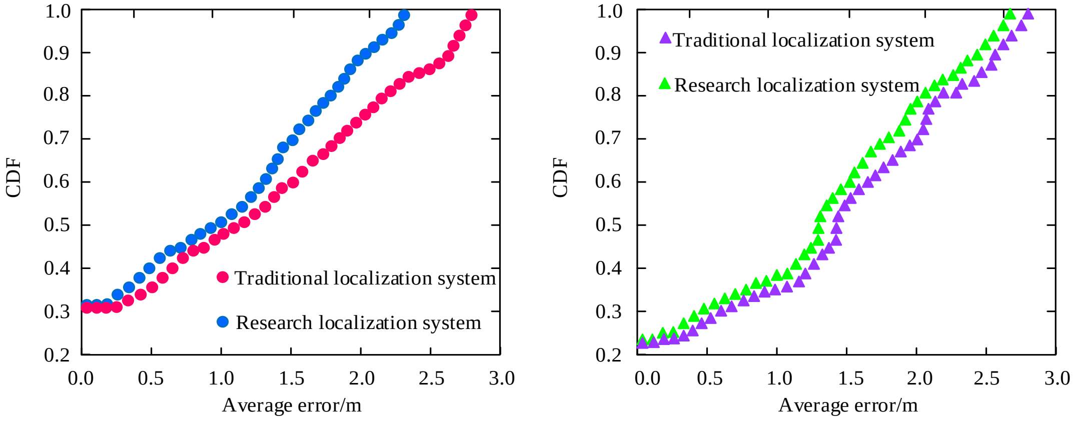
Fig. 13 (a) shows a comparison of the CDFs of different localization systems. From Fig. 13 (a) when the error value of the research system reached 1.86, its CDF curve gradually tended to stabilize, indicating the stability and efficiency of the research system in error control. Fig. 13 (b) shows a comparison of the accuracy of different localization systems. It can be seen from Fig. 13 (b) that the accuracy curve of the research system fluctuated around 97.6%, the accuracy curve of the ultrasonic localization system fluctuated around 95.8%, and the accuracy curve of the infrared localization system fluctuated around 93.4%. In summary, the average error of the research system was significantly lower than the other two traditional localization systems, which effectively reduced the generation of large errors. At the same time, the accuracy of scenic spot localization was extremely high. In practical applications, localization systems may face various complex environments and conditions. To prove the effectiveness of traditional localization systems and research localization systems in practical applications, a total of 500 sets of localization experiments were conducted to compare the effectiveness of traditional localization and research localization systems. The effect diagram of unknown point label distance and deviation localization is shown in Fig. 14.



(a) Comparison of CDFs of different localization systems

(b)Comparison of average errors of different localization systems

Fig. 13. CDF and accuracy of different positioning systems.



(a) Unknown point label distance localization effect

(b) Unknown point deviation localization effect diagram

Fig. 14. Unknown point label distance and deviation from the localization effect.

Fig. 14 (a) shows the effect of unknown point label distance localization. As shown in Fig. 14 (a), when the average error value of the research system reached 2.37, the value of the CDF rapidly increased to 1. However, traditional localization systems required a higher average error value of 2.83 to achieve a CDF value of 1. Fig. 14 (b) shows the localization effect of unknown point deviation. From Fig. 14 (b), when an unknown point deviated, traditional positioning systems needed to reach an average error value of 2.76 in order to achieve a CDF value of 1. Under the same deviation conditions, the research system only needed an average error value of 2.53, and the CDF value reached 1, indicating that the research system can still maintain high localization precision and stability when facing unknown point deviations. In summary, the research system has shown superior performance in both unknown point label distance localization and unknown point deviation localization in scenic areas compared to traditional localization systems, especially in terms of localization precision and stability, with significant improvements.

C. Discussion

In the research of complex environment positioning in scenic spots, high-precision and efficient localization services are crucial for tourist safety, scenic spot management, and personalized services. The LANDMARC localization system has been widely used in the field of wireless localization due to its unique working mechanism and advantages. However, a single technology often fails to meet the localization requirements in complex environments. Therefore, combining LANDMARC with traditional location fingerprint localization technology can integrate the advantages of both and achieve high-precision and high-efficiency localization. This fusion technology not only improves localization precision, but also reduces computational complexity and time cost through optimization algorithms. This is similar to the results obtained in the study of progressive target localization for underground tunnels based on compressed sensing grids by Tian et al. [26].

The study first explored the key parameters that affect the localization system. The value of k, as an important parameter for the amount of NNRLs, has a significant impact on localization precision. Research has found that increasing the k value appropriately can effectively improve the accuracy of the localization system. However, excessively high k values could also increase computational complexity and time costs. Therefore, in practical applications, it is necessary to balance localization precision and calculation speed, and choose an appropriate value of k. In the study, k=4 has been proven to be the best compromise solution, providing valuable reference for similar research in the future. In the study, k=4 proved to be the best compromise, which is consistent with the results of Ashenafi's team, Q's team, and K's team [27-29]. The placement of the reader also has a significant impact on localization precision. Research has found that moving the reader from the boundary to the middle can significantly improve localization precision. However, when the amount of readers increased to a certain extent, the improvement of localization precision by further increasing the number became limited. Therefore, in actual deployment, it is necessary to choose the appropriate number and placement of readers based on specific circumstances and cost factors. The layout of reference labels also had a significant impact on positioning accuracy. Research has found that localization error gradually decreased with the increase of reference label density, indicating that increasing the number of reference labels could improve localization precision. Therefore, the selected 6 × 6 layout scheme in the study maintained high localization precision while also controlling the complexity and cost of the system. This is consistent with the results of Rahmatillah et al. in the study on time difference detection of reference signals from in orbit cubic satellites based on atomic clocks [30].

To comprehensively evaluate the performance of the research system, the study compared it with ultrasonic and infrared localization systems. The localization accuracy of three systems were tested under the same testing environment and conditions. The data showed that the accuracy curve of the research system fluctuated around 97.6%, the accuracy curve of the ultrasonic localization system fluctuated around 95.8%, and the accuracy curve of the infrared localization system fluctuated around 93.4%, indicating the superiority of the research system in the field of scenic spot localization. Furthermore, in-depth research has been conducted on two aspects: distance localization of unknown point labels and deviation localization of unknown points. In terms of distance localization of unknown point labels, 500 sets of experiments were designed to simulate the random movement of tourists within the scenic area. When the average error value of the research system was 2.37, the value of the CDF quickly rose to close to 1, indicating that the system can accurately complete localization within this error range. This result was similar to the results obtained by Zhang et al. in their study on corner detection using point to the center of mass distance technology [31]. In terms of unknown point deviation positioning, the study simulated the possible deviation path of tourists in the scenic spot. Traditional localization systems needed to achieve an average error value of 2.76 to achieve a CDF value of 1. However, under the same deviation conditions, the research system only needed an average error value of 2.53 to achieve a CDF value of 1, indicating that the research system can still maintain high localization accuracy and stability when facing unknown point deviation. Hassan et al. also obtained similar results in the review of system integration and current integrity monitoring methods for localization in intelligent transportation systems [32].

IV. CONCLUSION

A complex environment positioning system for scenic spots that integrates LANDMARC positioning system and traditional location fingerprint positioning was proposed to address the issue of low localization effectiveness. Its effectiveness was verified through simulation experiments and actual deployment tests. This system showed significant advantages in localization precision, stability, and practicality, which was significantly improved compared to traditional ultrasonic and infrared localization systems. Especially in terms of distance localization of unknown point labels and deviation localization of unknown points, the system showed better performance than traditional localization systems, providing effective solutions for scenic spot localization problems. Although the research system showed superior performance improvement, there were still some potential shortcomings. The system has a high dependence on hardware devices, including the layout and density of readers and labels, which may require further optimization and adjustment in practical applications. Future research can further explore how to reduce the system's dependence on hardware devices, improve the system's robustness and scalability, and better adapt to different scenic environments and localization needs. At the same time, it is possible to conduct in-depth research on various challenges and problems that the system may face in practical applications, in order to propose more effective solutions and improvement measures.

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