Design and Implementation of Indoor Positioning Performance Test System for IoT Intelligent Communication Terminal

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Abstract. Indoor positioning technique is the foundation of Internet of Things (IoT) and location big data, which provides IoT function and location data for retail, manufacturing, energy, medical, emergency, logistics, robotics and other industries. Indoor positioning performance is an important performance indicator of IoT intelligent communication terminals. In order to accurately evaluate the indoor positioning performance of IoT intelligent communication terminals, this paper constructs an indoor positioning performance test system for IoT intelligent communication terminals. The test results show that the uncertainty of horizontal positioning accuracy of Wi-Fi positioning and Bluetooth positioning can be limited within 0.32 m ($k=2$).

1. Introduction

The new generation of information and communication technology (ICT), which represented by mobile internet, Internet of Things (IoT), cloud computing, big data, etc., is growing rapidly and promoting the new scientific and technological revolution and industrial transformation. With the integration with other ICT, the IoT is integrating into more fields, such as manufacturing technology, new energy and new materials. The research of this paper can realize the online indoor positioning performance test system for IoT intelligent terminals in local area network. In the future, this test program can be connected with the wide area network (WAN) server, and the related information of IoT intelligent terminals can be obtained from the server. Finally the analysis can realize the online detection ability, which provides a working foundation for online test of IoT intelligent terminals.

2. Main positioning technology

2.1. WLAN-based indoor positioning technology

Wireless local area networks (WLAN) has been widely used in various fields. WLAN has a lot of protocols, the most used of which is wireless fidelity technology (Wi-Fi) [1]. The WLAN-based indoor positioning system mainly consists of three parts, including terminals, hot spots with fixed positions (Access Point, AP) and positioning platforms. Fingerprint positioning technology based on fingerprint strength is adopted by this system, which can locate the space by the IEEE802.11 standard wireless network. As shown in Fig. 1, the implementation of fingerprint positioning technology can be divided into two stages: offline database construction and real-time positioning [2].
The main work of offline database construction includes: determining a number of sampling points at a certain distance interval in the WLAN signal coverage area, forming a relatively uniform distributed grid of sampling points, then scanning hot spot signals on WLAN channels with intelligent terminals. Different hotspots are identified by MAC addresses in data frames, and their received signal strength indicator (RSSI) are recorded [3]. The major tasks in the real-time positioning phase are to measure the signal strength of the visible WLAN hotspot with the intelligent terminals in real-time, compare the signal strength information with the recorded data in the location fingerprint database. Universally the position of the sampling point with the largest signal similarity is taken as the positioning result, sometimes the weighted average value of several similarity points is used as the positioning result [4].

![Figure 1. Two stages of WLAN-based indoor positioning system](image)

2.2. Bluetooth-based indoor positioning technology

Bluetooth-based indoor positioning is a positioning method based on RSSI, which use Bluetooth low energy (BLE) technology. Therefore this positioning technology has the advantages of low cost and convenient application [5].

Bluetooth positioning technology is based on measuring signal strength to locate, which has the characteristics of low power consumption and short distance. This positioning method must be equipped with Bluetooth LAN access points indoors. Easy integration of mobile devices is the greatest advantage of Bluetooth-based indoor positioning technology [6]. As long as the mobile terminals open Bluetooth function, the positioning system can then locate their position. Compared with infrared technology, Bluetooth positioning is not affected by visual distance, and it is easy to detect and accept external signals. However, the Bluetooth positioning system has a slightly poorer positioning accuracy in complex environments, also this positioning method is susceptible to noise interference [7].

Bluetooth technology uses the 2.4 GHz band, which does not need to apply for licenses. The band of 2.4 GHz is divided into 79 channels, and the data are equally divided into these 79 channels by frequency hopping technology. By the above method, interference can be effectively avoided, and the utilization of band can also reach the highest.

Bluetooth positioning technology has many advantages such as high security, low cost, low power consumption and small size. At present, most mobile phone terminals are equipped with Bluetooth module, so Bluetooth positioning system is easy to deploy on a large scale. However, the Bluetooth technology is vulnerable to external noise interference, so improving anti-jamming capacity is still the research emphasis of Bluetooth positioning in the future.

3. System framework composition

Indoor positioning performance test system mainly includes location server, test program, Bluetooth, WIFI, electronic map and tested terminals. Location server is configured to store the location and time information returned by the tested terminals, test program is used to calculate the
positioning accuracy of the tested terminal, Bluetooth and WIFI are used as test APs for transmitting signals, and electronic map is applied to display the location of the tested terminal. At present the tested terminals are generally mobile phones which are widely used. The Frame diagram of the system is shown in Fig. 2.

Figure 2. System framework diagram

The main functions of the test system are as follows:
(1) Development of Wi-Fi-based indoor positioning performance test program. The test program can detect the positioning accuracy and response time of Wi-Fi-based indoor positioning system based on IoT intelligent communication terminals, and can perform statistics and analysis of the positioning results, and realize the automatic detection function, thereby realizing an automatic detection function.

(2) Development of Bluetooth-based indoor positioning performance test program. The test program can detect the positioning accuracy and response time of Bluetooth-based indoor positioning system based on IoT intelligent communication terminals, and can perform statistics and analysis of the positioning results, and realize the automatic detection function, thereby realizing an automatic detection function.

(3) Development of indoor integrated positioning based on Wi-Fi and Bluetooth test program. The test program can detect the positioning accuracy and response time of indoor integrated positioning based on Wi-Fi and Bluetooth, and can perform statistics and analysis of the positioning results, and realize the automatic detection function, thereby realizing an automatic detection function. At the same time, with the help of the test results, the performance of integrated positioning and single positioning can be compared and analyzed.

4. Verification of experimental results
On the basis of the indoor positioning system mentioned above, by adding the elements of the positioning accuracy test, establishing the positioning accuracy test environment, the effective testing methods is obtained.

4.1. Test requirements and test procedures
The test steps are as follows:
(1) Select a certain floor as the positioning area;
(2) Plan multiple test paths and randomly select test points in the paths;
(3) Open the positioning server and APP of the test terminal, so that the positioning system enters the positioning state;
(4) Beginning at a certain point, the tester walks normally to the stop point. At the same time, tester should mark the test points on the electronic map, which correspond to the actual spatial position, then records the true position of the test point and the position information from the positioning system.

4.2. Positioning accuracy assessment

The positioning accuracy evaluation method of the IoT intelligent terminals is as follows:

1) First, calculate the horizontal positioning error of each test point as follows:

\[ d_i = \sqrt{(x_i - x_{0i})^2 + (y_i - y_{0i})^2} \]  \hspace{1cm} (1)

In the formula:
- \(d_i\) — the positioning error of the \(i^{th}\) test point;
- \((x_i, y_i)\) — the estimated coordinates of the \(i^{th}\) test point;
- \((x_{0i}, y_{0i})\) — the true coordinates of the \(i^{th}\) test point.

2) After the horizontal positioning error of each test point is calculated, these following indicators are used to evaluate the positioning accuracy of the positioning system.

1) Mean positioning error (ME)

\[ ME = \frac{1}{N} \sum_{i=1}^{N} d_i \]  \hspace{1cm} (2)

In the formula:
- \(N\) — number of test points.

2) Root mean square error (RMSE)

RMSE is used to evaluate dispersion of positioning error, as shown in the following equation:

\[ RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - x_{0i})^2 + (y_i - y_{0i})^2} \]  \hspace{1cm} (3)

3) Cumulative distribution function (CDF)

Evaluate the ratio of positioning times to total positioning times below the allowable positioning error threshold. The commonly used positioning accuracy thresholds are 1 m, 3 m, and 5 m, which can be expressed as CDF (1), CDF (3), and CDF (5).

4.3. Uncertainty assessment

(1) Test experimental data

The positioning error results for a certain test point are as follows in Table 1:

| Test serial number | Positioning error (m) |
|--------------------|-----------------------|
| 1                  | 0.00                  |
| 2                  | 0.23                  |
| 3                  | -0.27                 |
| 4                  | 0.59                  |
| 5                  | 0.85                  |
| 6                  | 0.66                  |
| 7                  | 0.00                  |
| 8                  | 0.41                  |
| 9                  | 0.18                  |
| 10                 | 0.00                  |
| 11                 | -0.45                 |
| 12                 | 0.05                  |
| 13                 | -0.41                 |
| 14                 | 0.82                  |
| 15                 | 0.73                  |
| 16                 | 0.13                  |
| 17                 | 0.04                  |
| 18                 | 0.80                  |
| 19                 | 0.94                  |
| 20                 | 0.00                  |
(2) Evaluation model

\[ S = S_0 + S_1 \]

In the formula:
\( S \): Horizontal positioning accuracy;
\( S_0 \): 50 times of repeated measurements;
\( S_1 \): Error between test point position and real position.

(3) Propagation coefficient

The propagation coefficient of \( S_0 \) to \( S \) is:
\[ c_1 = \frac{\partial S}{\partial S_0} = 1; \]

The propagation coefficient of \( S_1 \) to \( S \) is:
\[ c_2 = \frac{\partial S}{\partial S_1} = 1. \]

(4) Uncertainty evaluation of experimental results

1) Source of uncertainty
   a. The standard uncertainty component \( u(T_0) \) introduced by the changes of 25 repeated measurements (class A).
   b. The standard uncertainty component \( u(T_1) \) introduced by the real position error of marked test points (class B).

2) Standard uncertainty component evaluation
   a. Evaluation of the standard uncertainty component \( u(T_0) \)
      Average value of measurement:
      \[ \bar{d} = \frac{1}{n} \sum d_i = 0.27 \text{m} \]
      Standard deviation of single experiment:
      \[ s_0 = \sqrt{\frac{1}{n-1} \sum (d_i - \bar{d})^2} = 0.43 \text{m} \]
      So mean experiment standard deviation: \( u(T_0) = 0.096 \text{m} \).
   b. Evaluation of the standard uncertainty component \( u(T_1) \)
      The real marked position error on the electronic map to is less than 20 cm, and assuming that the variation is uniform distribution, under this circumstance the standard uncertainty component \( u(T_1) \) is:
      \[ u(T_1) = \frac{0.2}{\sqrt{3}} = 0.12 \text{m} \]

3) Determination of the synthetic standard uncertainty
   The standard uncertainty list is as follows in Table 2.

   **Table 2. List of Standard Uncertainty Components.**

   | Standard uncertainty component | Source of uncertainty                      | The value of standard uncertainty \( u(x_i) \) | Propagation coefficient \( c_i \) | \( u(x_i) = |c_i| \cdot u(x_i) \) |
   |-------------------------------|---------------------------------------------|---------------------------------|---------------------------------|---------------------------------|
   | \( u(T_0) \)                  | Measured repeatability                     | \( u(T_0) = 0.096 \text{m} \)    | 1                               | 0.096                           |
   | \( u(T_1) \)                  | The real position error of marked test terminals | \( u(T_1) = 0.12 \text{m} \)    | 1                               | 0.12                           |

4) Calculation of synthetic standard uncertainty \( u_c \)
   Due to the input values are approximately uncorrelated, so the synthetic standard uncertainty is:
   \[ u_c = \sqrt{u_{(T_0)}^2 + u_{(T_1)}^2} = 0.16 \text{m} \]
5) Evaluation of extended uncertainty
When measuring the positioning accuracy, the extended uncertainty $U$ can be obtained by taking $k=2$. The extended uncertainty of the positioning deviation measurement result is:

$$U = k \times u_c = 2 \times 0.16m = 0.32m \ (k = 2)$$

6) Report and representation of measurement uncertainty
The measurement uncertainty of the positioning accuracy:

$$U = 0.32m \ (k = 2)$$

5. Conclusion
The establishment of indoor positioning performance test system for IoT intelligent terminals greatly promote the development of indoor positioning industry. The performance test system in this paper has expansibility and flexibility of application. This test system can expand the testing methods, in order to meet the requirements of industry standards and the increasing detection demand. Depending on the construction of the National Satellite Navigation and Positioning Service Product Quality Supervision and Inspection Center of our institute, we can provide positioning performance testing services for relevant companies and enterprises in our region.

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