Society for Science and Education
United Kingdom

TNC Transactions on Networks and Communications

Volume 6, No. 6
ISSN: 2054 -7420

Research and Implementation of Bluetooth Indoor Auto-Tracking System

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ABSTRACT

In recent years, outdoor positioning technology has been widely used and indoor positioning technology has gradually matured. Relevant applications such as: Indoor Location Based Service, Ambient Assistant Living, Indoor Navigation, Location Based Advertising, and the like have begun to show up in daily life and bring people with diversity and rich service content. The proposed study focuses on the research of real-time indoor dynamic positioning and dynamic tracking related mechanisms and algorithms, and uses the "microcontroller module" and "Bluetooth communication module" to actually detect the operational mechanism of the Bluetooth dynamic positioning system. This prototype system uses the smart phone as the locator of the traced person, named tracee (a new word created in this paper). The three-wheeled carrier acts as the tracer's body. On the locator, the processor is used to dynamically calculate the dynamic positioning of the tracee, and the calculated positioning result is transmitted to the tracer through the Bluetooth. The tracer calculates the distance and orientation, and then controls the axle motor so that the three-wheeled carrier closely follows the smart phone. Although many self-propelled vehicles have been sold on the market at present, and most of the follow-up signal uses infrared rays, ultrasonic waves, or Wi-Fi to complete the tracking action. However, the first two signals often require the tracee to carry an additional signal transmission device so as to assist in tracking. Due to the current popularity of mobile phones, although Wi-Fi and Bluetooth chips are already installed on the phone, yet the power consumption of Wi-Fi is still much higher than that of the Bluetooth. Therefore, in this study, Bluetooth was used to complete the indoor positioning system. Bluetooth belongs to 2.4GHz wireless technology; when using the Bluetooth signal for tracking, the signal strength is likely to cause many noises due to shielding, signal diffraction, or reflection, resulting in a deviation between the calculated transmission distance and the actual distance. The purpose of this study is to design a prototype of an Indoor Automatic Tracking System (hereafter named IATS) and explorer how to reduce the Bluetooth signal strength deviation so as to improve the accuracy of positioning is the main object of this study.

Keywords: Bluetooth, Auto-tracking System, RSSI, Indoor Location.

1 Introduction

Indoor positioning technology (IPT) [1] has gradually matured, with related applications such as: Indoor Location Based Service (ILBS)[2], Ambient Assistant Living (AAL) system[3], Indoor Navigation (IN)[4],

DOI: 10.14738/tnc.66.5808
Publication Date: 27th December 2018
URL: http://dx.doi.org/10.14738/tnc.66.5808

Location Based Advertising (LBA)[5] and the like services began to show up in daily life, and in the meantime, brought up more diversified and rich services content.

The origin of the present research is the observation of daily life such as: e-commerce shopping and warehouse management, home shopping for pre-school children, return of library books, nursing staff in medical centers, and other relevant staff all have the need to focus on other things in the work/family context and create the demand for an indoor automatic tracking system. The implementation of an Indoor Automatic Tracking System (IATS) must be supported by indoor positioning technology so that the IATS and tracee (a new word created in this paper, which means a traced person) can maintain proper distance under the auto-following operating mechanism. Using the pre-school children's home shopping as an exemplary, the IATS is a shopping cart, the tracee (parent) is the object to be followed. When the tracees move during the shopping process, the IATS can automatically position and control the IATS (shopping cart) to move or turn through control the motor so that the IATS (shopping cart) and the tracee is always at a fixed distance so as to achieve the object of automatic follow-up.

The indoor positioning technology uses the camera, infrared, laser (iGPS), ultrasonic or other communication technologies, in conjunction with corresponding spatial positioning algorithm to achieve indoor positioning. In the wireless communication technology portion, H. Liu [6] uses resolution and system scale to label the related technologies as shown in Fig. 1. Wherein, wireless communication technology with indoor positioning accuracy of less than 10 meters can be applied. From left to right, they are UWB, RF&IR, RF&Ultrasonic, WLAN, Bluetooth, DECT, ZigBee and other technologies, respectively. In accordance with recent academic research, UWB related research is mostly focused on algorithm improvement [7][8][9] and system design enhancement[10][11]; although RF&IR, RF&Ultrasonic can perform high-precision positioning, yet was not included in this study due to special device must be used to transmit the signal [12][13]; DECT [14] and ZigBee [15] are also constrained by the transmission device and the positioning accuracy is lower than RF&IR, RF & Ultrasonic, so they were not used in this study; WLAN and Bluetooth are supported by general smart phones, and their popularity is high. However, Bluetooth performance in terms of power consumption is more suitable for application program development [16][17], hence, this study uses Bluetooth as the communication technology for IATS implementation.

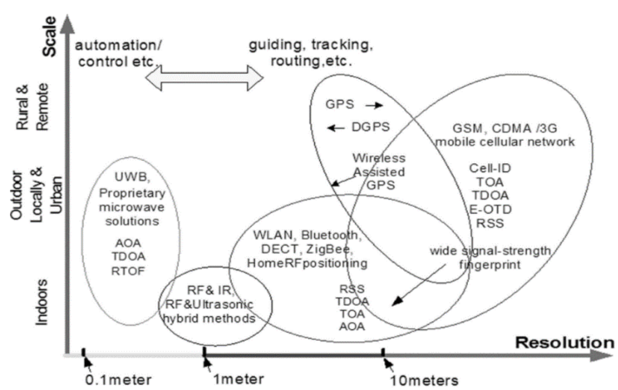

Fig. 1: Resolution and System Scale in Wireless Communication Positioning

In the recent academic research of Bluetooth, there is no lack of indoor positioning relevant research [18][19], but most of them are focused on the moving target with a fixed Bluetooth signal transmitter, and the IATS proposed in this study has four features: 1) Virtual movement, 2) Instant positioning, 3) Closely following and 4) Dynamic environment. Details are described as follows:

a. Virtual movement: Both IATS tracer and tracee have the feature of being moved at any time.
b. Instant positioning: In terms of system computing capability, it must meet the requirements of the instance (less than 2 seconds per positioning).
c. Closely Following: The accuracy of the path calculation must in conformance with the condition of following in a short distance (less than 2.5 meters)
d. Dynamic environment: Barrier caused by the turn or movement of tracee will affect the tracking system operation

Up to the present, research on the use of Bluetooth in indoor positioning has not explored the 1), 3), and 4) items of the above features. Therefore, the research using Bluetooth technology aims to achieve indoor dynamic positioning and obstacle avoidance following shall be extremely challenging.

2 Background

The relevant technologies and research of the present paper are described as follows:

2.1 Bluetooth

Bluetooth is a wireless communication technology standard. It was jointly proposed mainly by the manufacturers of Ericsson, IBM, Intel, Toshiba and Nokia in 1998, and established the Bluetooth SIG to update and maintain technical specifications. Bluetooth technology alliance currently has more than 30,000 manufacturers in communications, computers, networks, and consumer electronics joined the membership. In terms of technology, Bluetooth uses Ultra High-Frequency radio waves as a transmission medium and operates in the Industrial Scientific Medical Band (2.4 to 2.485 GHz). It is used as the Personal Area Network (PAN) in stationary, mobile, and architectural applications. On the other hand, the current version used in the industry is Bluetooth 4.0 to 4.2, and the main difference between the 3.x and the current version is the improving power consumption and achieving a communication distance of 100 meters. Therefore, the Bluetooth 4.x version is called Bluetooth Low Energy (BLE).

2.2 Bluetooth Indoor Positioning System

The research of Bluetooth indoor positioning systems over the past few years is the system, through the signal transmitting device installed indoor, and based on the signal intensity to positioning. This type of method is called the Fixed Indoor Positioning System. Relevant research subjects are described as follows:

1) Positioning through the signal transmitted by the Bluetooth device beacon

Scholar P. Dickinson, et al [20] used low-power Bluetooth communication device beacon and install a beacon at the shopping corridor in the store every 5.4 meters or 8.1 meters, and use the pre-installed applications to transmit the Received Signal Strength Indicator (RSI) for various beacons at their current locations; the strongest beacon on the signal represents the consumer's proximity to the area, so as to understand the time and the path consumers spend and walk in various areas of the store.

2) Research using Wi-Fi and Bluetooth on Positioning

Scholar Vibhu Varshney et al [21] uses pre-arranged Wi-Fi and Bluetooth communication networks for positioning in the indoor environment. The positioning method was calculated using the most common RSSI in conjunction with triangulation method, and 10 measurements were performed. The experimental results indicate that at the area in space, the result for the coordinate of Wi-Fi positioning, the accuracy of the X-axis is 77.59%, the accuracy of the Y-axis is 88.41%, and in the Bluetooth portion, the accuracy of the X-axis is 89.1%, and the accuracy of the Y-axis is 73.3%.

The above-related studies are focused on the algorithm of the fixed Bluetooth positioning system and are different from the Bluetooth dynamic positioning system explored in this study. In accordance with the survey of this study, at present, there is no research concerning the use of Bluetooth for indoor tracking systems.

3 Methods

The present study focuses on the research of mechanisms and algorithms related to "instantaneous indoor dynamic positioning" and uses the "microcontroller module" and "Bluetooth communication module" to actually detect the operational mechanism of the Bluetooth dynamic positioning system. The system uses the smart phone as a tracee, and uses the three Bluetooth modules as a tracer body to be installed for dynamic positioning, and use algorithm the to instantly know the distance between the tracee and the tracer.

As shown in Fig. 2, the present study will install three Bluetooth modules on the auto-trace system. The Bluetooth module broadcasts the signal. The phone set detects the signal strengths of the three Bluetooth modules and derivate the current auto-trace system centered location information and transmitted back, when the auto-trace system receives the position message and controls the motor to automatically trace the smartphone held by the tracee to perform a three-wheeled carrier Bluetooth dynamic positioning system.

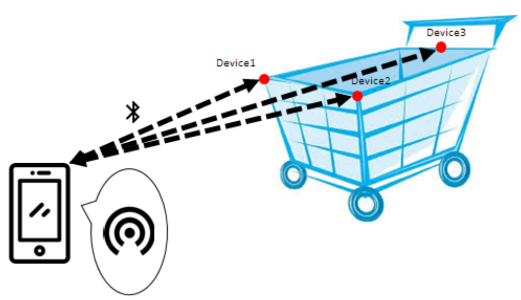

Fig.. 2: Schematic View of Bluetooth Dynamic Positioning System

The Bluetooth dynamic positioning system is composed of two systems: the Tracer and the Tracee. The system architecture is shown in Fig. 3. In practice, the tracee is a smart phone with Bluetooth module and has a smart phone mobile application (Mobile APP) to achieve Bluetooth reading and Real-Time Bluetooth positioning (RTBP) function; the tracer system is a microcontroller platform in conjunction with an external Bluetooth module. The microcontroller platform can be subdivided into two subsystems, namely Path Estimation (PE) and motor. Control (MC). Description is provided as follows: 1) Path estimation: This subsystem comprises four Bluetooth communication modules, three for indoor positioning and one for communication. The trace system (namely, smart phone) forms a pair with the Bluetooth communication module and responsible for communication. After the smart phone completes the Bluetooth pairing, it will periodically capture the signal strength of the Bluetooth communication module used for indoor positioning, and calculate the position information of the current trace system and transmitted back to the subsystem, and this subsystem is based on trace system location information for motor control. 2) Motor Control: This subsystem is responsible for periodically receiving instructions for path estimation so as to control the axle motor to achieve the direction and speed required by the tracer.

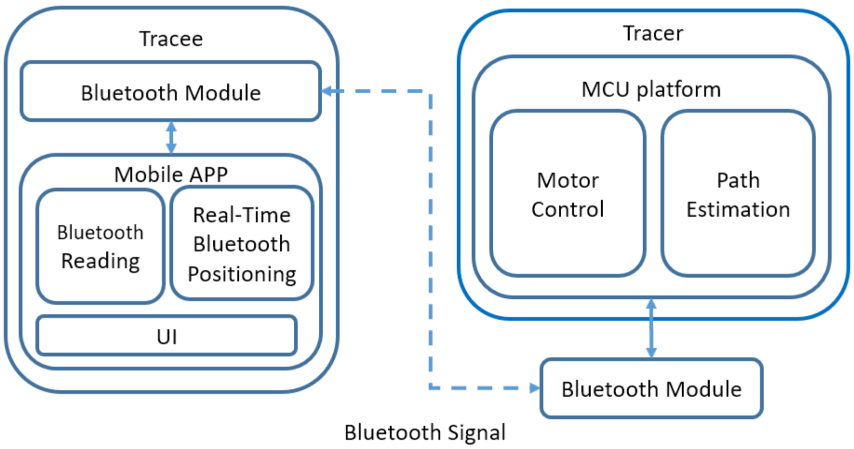

Fig. 3 System Architecture of Bluetooth Dynamic Positioning System

3.1 Real-Time Bluetooth Position

The most basic Bluetooth two-dimensional positioning system consists of one Positioning Node (PN) and three reference nodes (RNs)[22]. Under this architecture of the present study, a smart phone was used as a PN and the three vertices, AP1 to AP3, of the tracer were used as RNs. Based on the RSSI value measured by mobile phone for the three vertices to the tracer system to calculate the distance between the three vertices of the mobile phone to the tracer system, and then the coordinates of the mobile phone can be obtained through the trilateration method [23].

In indoor positioning related research, the signal sent by the transmitter is often converted to RSSI, the definition is shown as Equation 1:

$$RSSI = 10 \times \log(\frac{P_r}{P_{ref}}) \quad (1)$$

wherein, Pr is the power received by the receiver antenna, Pref is often 1mW.

The simplified relationship between received signal strength and distance can be expressed as Equation 2:

$$P_d = P_0 - 10 \times n \times \log_{10}(d) \quad (2)$$

Where P_d is the received signal strength (dBm), which is the distance from the transmitter source (dBm), that is, the so-called RSSI; P_0 is the received signal strength (dBm) from 1 meter from the transmitter; n is the path attenuation index. Equation 2 can be organized into the relationship between distance and RSSI as Equation 3:

$$d = 10^{\frac{P_0 - P_d}{10 \times n}} \quad (3)$$

On the basis of the trilateration method, the smartphone coordinates derived through three Bluetooth devices are shown in Fig. 4:

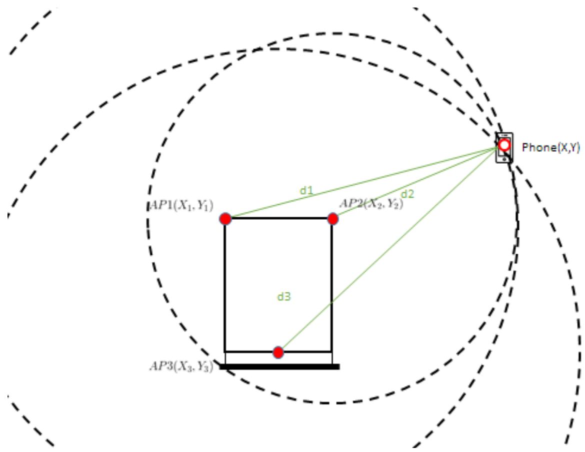

Fig. 4 Schematic Diagram of the Bluetooth Indoor Positioning Algorithm

The distance between each transmitter and receiver can be expressed as Equation 4, wherein the three devices are set to 1.2, 1.5, and 1.5, respectively. Substituting (x_i, y_i) into Equation 4 and solving 3 simultaneous equations can obtain the coordinates (x, y) of the mobile phone.

$$d_i^2 = (x - x_i)^2 + (y - y_i)^2, i = 1,2, \dots, N \quad (4)$$

The reason that the n path attenuation index is set in this way is due to the present study collects the RSSI values for each device at 1m, 2m, and 3m first, respectively and substitutes them into Equation 5 for the inverse n value.

$$n = \frac{P_0 - P_d}{10 \times \log(d)} \quad (5)$$

wherein, P_0 is derived by substituting the RSSI average value when the device distance is at 1m, and then substitutes the RSSI average of 2m and 3m into P_d to derive the value of n. Then, the resulting n value is fine-tuned so that the result of the RSSI transferring to distance formula is close to the actual value.

3.2 Enhance Positioning Accuracy

Bluetooth is a 2.4GHz wireless technology. This band is prone to many noises due to shield, signal diffraction or reflections. Therefore, the selection of signals and averaging are quite important. The present study uses Equation 6 to complete the average calculation.

$$X(t) = \alpha X + (1 - \alpha) X(t-1)\ ; 0 < \alpha < 1 \quad (6)$$

wherein, X(t-1) is the average value obtained the previous time, X_(t) is the mean value obtained this time, and X is the RSSI value obtained this time..

However, how to set the value of the signal screening condition so will not exclude too much data. The process is shown in Fig. 5

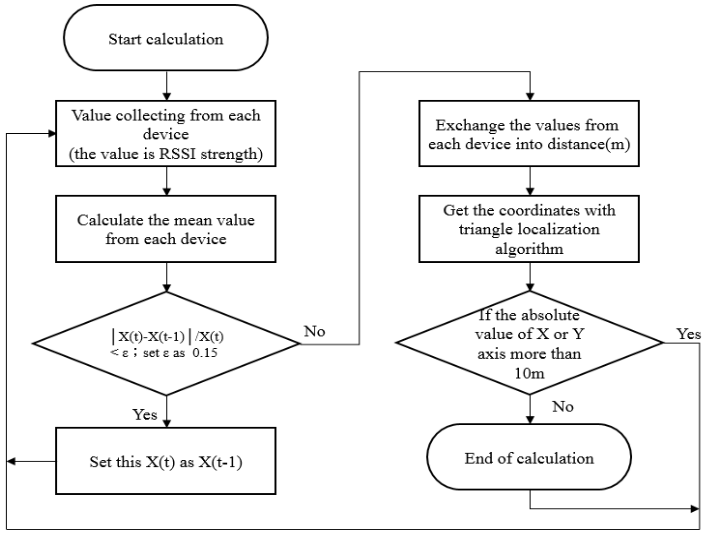

Fig. 5: Positioning Calculation Process Chart

Furthermore, after the mean value of each device is obtained, a filter condition is added to exclude the value that is too large due to excessive RSSI floating during the movement. The filter condition and the usage are shown in Equation 7.

$$\frac{|X(t)-X(t-1)|}{X(t-1)} < \alpha \; ; \; \alpha = 0.15 \qquad (7)$$

4 Results

The test environment of the present study is located in a home with Wi-Fi, and the three Bluetooth devices used for positioning are placed on a plane with a length, width and height of 1m*1m*0.42m, and the three Bluetooth devices are placed in the same position on the plane. The tester holds the mobile phone with the positioning APP installed and stand to measure in front of the desk. Fig. 6 below shows the three device RSSI values measured at 1, 2 metrics and measured without any screening.

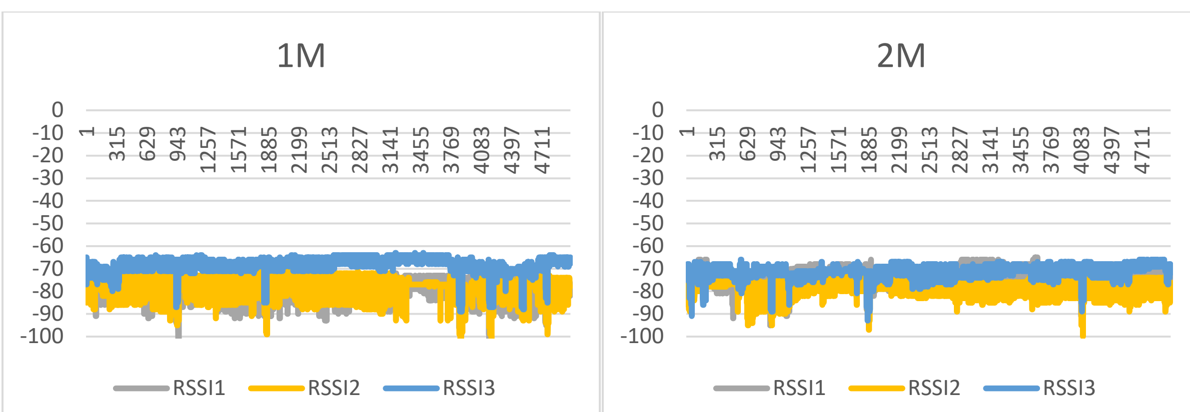

Fig. 6: RSSI Values for Three Devices

Fig. 6 contains 5,000 pieces of data in 1M and 2M respectively. It can be seen from the Fig. that the RSSI value is always up and down in one interval, wherein the standard deviations of devices 1 to 3 are 1M: 5.35, 5.99, 3.99, 2M: 4.49, 4.25, 3.46, respectively, in addition, the maximum deviation reaches up to 32%

for the consecutive data. However, the substitution of this equation into the distance equitation will make the difference more significant. Hereafter, it will cause using the trace to estimate the distance between the tracer and the tracee has too much deviation and not easy to control the output of the motor. Therefore, it is necessary to use the mean value calculation to reduce the standard deviation and the effect of consecutive data difference.

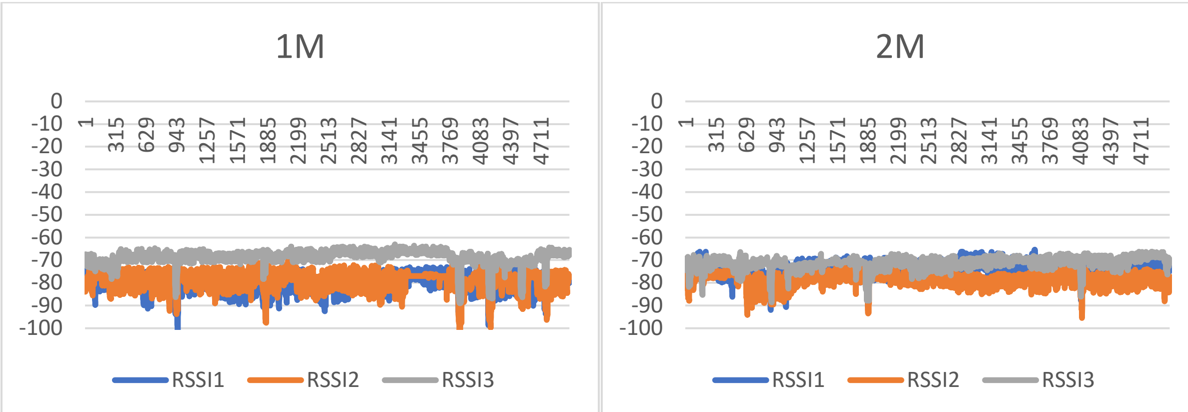

Fig. 7: RSSI Value after Averaging 3 Devices

After adding the average calculation, the standard deviation is 1M: 4.16, 4.4, 3.43, 4.25, 3.05, 2.71, and the consecutive data difference is reduced to 9%. It can be seen from the Fig. that after the screening, the numerical change (that mean the curve in the Fig.) is more gradual. However, the above is the result collected by the mobile phone in the fixed state. When the Bluetooth RSSI signal is in the moving state, the jump amplitude will be more proportional to the distance. Therefore, at present, the present study chooses the range of data difference within 15% to ensure that the data will not be deleted too much, and can have the function of excluding excessive changes.

Fig. 8 below shows the changes in the RSSI values presented by adding the average and the screening algorithm, and walking from distance 0M to 3M.

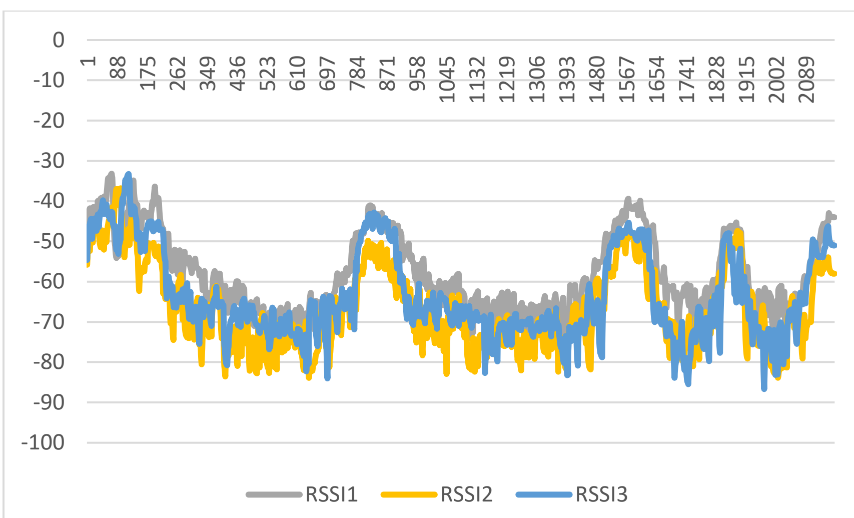

Fig. 8: RSSI Values from 0M to 3M Walking Back and Forth

Fig. 8 has a total of 2178 pieces of data, and its adoption rate is 90%. The screening condition is that when the data difference exceeds 15% before and after, the calculation results are excluded. After adding the average calculation, the intensity of the Bluetooth RSSI signal will exceed 15% before and after the movement.

5 Conclusion

Indoor Positioning Technologies (IPT) is getting mature, relevant applications such as: Indoor Location Based Service (ILBS), Ambient Assistant Living (AAL) system, indoor navigation (IN), Location Based Advertising (LBA) and the like began to show up in daily life, and also brought more diversified and rich service content to people.

The purpose of the present study is to design a prototype of the Indoor Automatic Tracking System (IATS). The main object of the present study to explore how to reduce the deviation of the Bluetooth signal strength to improve the accuracy of positioning. The Bluetooth is a 2.4GHz wireless technology. This frequency band is prone to many noises due to shielding, signal diffraction or reflection. Therefore, the selection of the signal and the calculation of the average value are very important. The present study completes the average value calculation using Equation 6 and uses Equation 7 to add the screening conditions to eliminate the excessively large difference in RSSI due to excessive floating in the movement, so that the result will be up to 35% of the original data difference before and after calculation. After the algorithms is controlled at less than 10%, the utilization rate is 100%, and the difference between the data before and after moving will be higher than the 15% set in the present study, but the adoption rate is still 90%, and no excessive information will be excluded so as to make measurement data have a certain degree of accuracy.

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