# The Application and Implementation of Indoor Localization Technology based on ZigBee

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## Abstract

**With the development of localization systems like GPS and Beidou, the outdoor positioning technology is becoming more and more widely used. In contrast, due to these factors such as the over-shadings from buildings, the complexity and variability of indoor environment, signal reflection, diffraction and multipath effects, the application of indoor localization technology has not yet been popularized. In this paper, by using filtering algorithm and k-Nearest Neighbor (kNN) algorithm and through removing the maximum errors in RSSI and establishing fingerprint database in the ZigBee network, a set of indoor positioning system is studied and designed. And the accuracy of this indoor positioning system is analyzed: When the k-value changes, different positioning accuracy is observed and compared. The results of this study indicate that: When k=5, the measurement results of localization are the most stable. And the positioning errors of most indoor scenes designated in this study are controlled within one meter. Finally, the advantages and disadvantages of this designed indoor localization system are discussed, and the challenges in its practical application are pointed out as well.**

## Keywords

**Indoor Localization System; Filtering Algorithm; Zigbee; Fingerprint Database; K-Nearest Neighbor Algorithm; Advantages And Disadvantages.**

## 1. Introduction

With the development of outdoor localization technology and the popularity of various electronic products, outdoor localization has been used in people's daily life, which has made it more convenient for people’s travel. For instance, GPS (Global Positioning System), as a typical representative of the location-based service system, has been widely used around the world for its excellent performance [1]. On the contrary, in terms of the indoor positioning, due to the interference of signals form the over-shadings of buildings and multipath effects in the transmission process [2] as well as the cost of localization, there is still not a mature indoor positioning technology that has been widely used to date. On the other side, since people spend most of their time on indoor activities, the indoor localization is an essential part of location-based service, the application of which could not be ignored. After years of research and development, some techniques related to indoor localization have been put forward and developed. For instance, infrared-based localization [3], ultrasonic-based localization [4], Bluetooth positioning [5], wireless WLAN-based positioning [6], Ultra Wideband (UWB)-based positioning [7], each of which has its own advantages and disadvantages in the accuracy, efficiency and cost of localization. According to the types of information measured, the existing indoor localization technologies could be classified into: Received Signal Strength Indication (RSSI)-based; Time of Arrival (TOA)-based; Time Difference of Arrival (TDOA)-based; Angle of Arrival (AOA)-based [8].

Recently, the localization technology based on RSSI (Received Signal Strength Indicator) has gradually become a hot topic in the research field of indoor localization technology, because of its relatively low cost, easy measurement, stable signal strength and other advantages [9]. ZigBee technology is an emerging wireless sensor network technology, in recent years, whose application in the short distance indoor localization has gradually attracted researchers' attention and interest due to its characteristics of low power consumption and low cost [10]. Inspired by this, based on the ZigBee wireless sensor network, a set of indoor localization system is studied and designed in this paper. In the processing of received signal strength, the maximum errors in RSSI are removed and k-Nearest Neighbor (kNN) algorithm is utilized in this study to make sure the validity of the data in the established fingerprint database, thus improving the positioning accuracy.

## 2. Fingerprint-based Localization Systems

The fingerprint-based indoor localization system mainly uses the average signal strength indication received from each reference point as the data to be stored in the fingerprint database and makes use of the reference algorithm to estimate the location of the measured points, thus achieving the final goal of localization [11].

### 2.1 Characteristics of Received Signal Strength

The received signal strength is equal to the intensity of the transmitted signal, which can be expressed as:

$$P_R = \frac{1}{d_n} P_T \tag{1}$$

In formula (1): $P_R$ stands for the received signal strength, $P_T$ represents the transmitted signal strength, $d$ stands for the distance of signal transmission and $n$ means the path attenuation coefficient. Because of the low intensity of the signal emission, the above formula could be displayed as the following logarithmic formula:

$$P_R = P_T - 10n\log(d) \tag{2}$$

Form the above formula, it is not hard to find out that, although the received signal strength does not absolutely varies linearly with the signal transmission distance, there is a certain regularity in the changing of the two. That is, the received signal strength generally decreases with the increase of the signal transmission distance. It is this characteristics in received signal strength that provides an ideal theoretical basis for the fingerprint localization technology [12].

### 2.2 Implementation Phases of Fingerprint-based Localization

The implementation of the fingerprint-based localization system is divided into two phases: an off-line collection phase and an online localization phase[13].

The first phase is mainly used to collect data of fingerprint from different pre-known locations and then to store them in the fingerprint database. In addition, in order to ensure the accuracy of the data, before stored into the fingerprint database, the data is needed to be filtered, such as the removal of large errors in the collection phase.

The second phase refers to such a localization process that, by exploiting the fingerprint matching algorithm to match each signal strength indication collected from the reference point with its corresponding record in the fingerprint database, to find out one or several records which demonstrate the maximum matching with the collected signal strength. Based on these records, the actual position could be estimated.

## 3. Design and Implementation of Localization System

This Zigbee-based localization system designed in this paper includes a host computer and a lower computer. The lower computer is responsible for the data collection, and the host computer is used to do the processing and analysis of the collected data. A rectangular region with a maximum length of eight meters and a maximum width of five meters in a laboratory is selected as the experimental scene in this paper to carry out this study.

### 3.1 The Lower Computer

By utilizing the CC2530 chip and ZigBee protocol stack researched and developed by TI (Instruments Texas) company, it is easy to set up a ZigBee wireless sensor network. In this network, there are three kinds of nodes, which are coordinator node, router node and terminal node, whose corresponding functions are the network setting up, data routing and data collection respectively. The lower computer designed in this experiment mainly depends on the protocol stack. There are one coordinator node, one router node and four terminal nodes included in the lower computer. The process of signal strength collection deigned in this study is explained in detail as follows:

Firstly, four terminal nodes are used as the transmitter of the signal, which are scattered in the selected laboratory. In order to cover the entire experimental scene as much as possible, these four terminal nodes are placed in relatively higher locations of the laboratory. To be more specific, one is placed on the top of the air conditioning, one on the top of the cabinet, and the other two on the top of the desk.

Secondly, the router node serves as the positioning node, which is responsible for reading the signal strength received from each terminal node and for sending the corresponding data to the coordinator.

Thirdly, the coordinator is fixed in a certain position and connects to host computer through the serial port, which is used to set up network and transfer data to the host computer.

The program of the lower computer runs in the integrated development environment IAR Embedded Workbench. The operation interface and project directory structure are shown in Fig. 1:

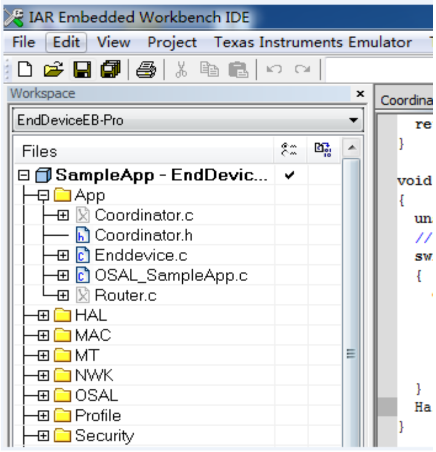


Fig. 1 Project directory structure of lower computer

### 3.2 The Host Computer

The host computer is responsible for receiving, filtering, processing, accessing and matching data, and for displaying the operation interface and positioning results. Its software development environment is Visual Studio 2012, the database is Sql Server 2008, and the interface is realized by using the Microsoft Foundation Classes (MFC), which is shown in Figure 2.

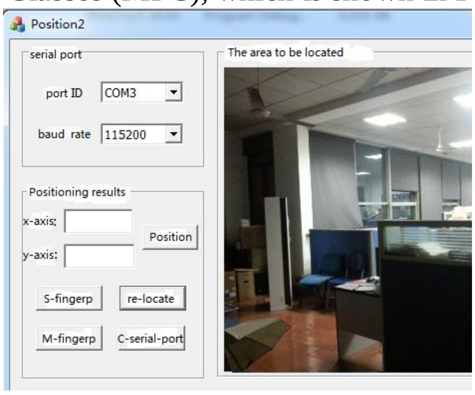


Fig. 2 Localization interface

### 3.3 The Establishment of Fingerprint Database

The fingerprint database is established through the process of storing signal strength and position information received from each reference point in a Table after the data have been processed, mainly including collection, processing and storage of the received signal strength.

#### 3.3.1 RSSI Collection

According to the measurement results, the magnitude of the signal strength is not stable, and the signal strength will have a small amplitude of fluctuation at the same period. In order to make sure the validity of the data in fingerprint database, as many as possible RSSI of each reference point should be collected. Therefore, in this experiment, 120 RSSI of each transmitting node are collected by the router at the reference point. However, considering the limited storage capacity of CC2530 chip, 30 RSSI could be collected at one time. The router is responsible for sending the data of the collected 30 RSSI to the coordinator, and then to the host computer through the serial port. To get total 120 RSSI collected from each transmitting node, it is needed for the router to forward four times. And the distance between the two adjacent reference nodes is one meter.

#### 3.3.2 RSSI Filtering

For those collected RSSI, what is not sure is that every RSSI is expected, since in addition to the instability of the signals, the results of indoor localization will be influenced by those factors, such as signal reflection, diffraction and multipath effects. Consequently, it is necessary to filter those collected RSSI.

Firstly, the collected 120 RSSI are sorted by small to large, among which those significantly too small and too large data are removed to ensure the validity of the data used in this study. In this experiment, according to the order, both of the top 10 minimum RSSI and top 10 maximum RSSI are removed, and the mean scores of those remaining 100 RSSI are calculated, which is demonstrated in the following calculating formula:

$$\overline{RSSI} = \frac{1}{n}\sum_{i=1}^{n} RSSI_i \tag{3}$$

In this formula, $\overline{RSSI}$ stands for the calculation result of the mean score of RSSI, $n$ represents the total number of RSSI, $RSSI_i$ stands for the value of the $i_{th}$ RSSI.

By the above calculation, the RSSI from each transmitting node at each reference point will be acquired. In this experiment, there are total four transmitting nodes, so each fingerprint in the fingerprint database is displayed as follows[14]:

$$(\overline{RSSI}_1, \overline{RSSI}_2, \overline{RSSI}_3, \overline{RSSI}_4, x, y) \tag{4}$$

In the above format, $\overline{RSSI}_1, \overline{RSSI}_2, \overline{RSSI}_3, \overline{RSSI}_4$ stands for its corresponding mean score of the signal strength of the transmitting node, and $x$, $y$ stands for the coordinate axes of the reference point.

Since whether the data collected in the fingerprint database is representative or not determines the accuracy of the indoor localization results, the filtering of the data in the fingerprint database is an essential part in the design of the indoor localization system. In order to improve the positioning accuracy, the fingerprint data of the adjacent nodes are further dealt with.

In theory, when there is no other items placed between the adjacent reference points, the RSSI value will follow the principle of adjacent similarity, and the signal strength will be decreased with the increase of the distance between the nodes. As shown in the following Figure 3, the reference point 1 and reference point 2 are adjacent in location and no matter the router is placed in the reference point 1 or reference point 2 will receive the data transmitted by the node T1. As the reference point 1 is significantly closer to the T1, the RSSI value of the reference point 1 theoretically should be greater than or equal to the RSSI value of the reference point 2. Even though the results do not meet the above hypothesis, the gap between the results from two different reference points will not be too large.

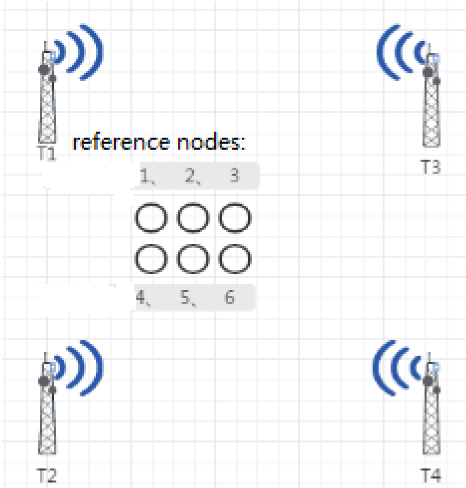


Fig. 3 A diagram of the adjacent reference points

However, as it is mentioned before, in the actual process of data collection, due to those uncertain factors such as multipath effect, articles occlusion, the movement of people, the measuring errors and instability of the signal strength, which will bring out inaccurate localization results, it is needed to do the comparison and contrast between two adjacent points in the process of the data collection. Specifically, when the difference on the results measured between the two adjacent reference points is too remarkable, the data will be removed and the fingerprints of this reference point will be re-measured and stored in the fingerprint database. The data collection from each reference point will be processed like the above process and then stored in the fingerprint database, until the fingerprint database is finally built.

### 3.4 Data Matching in Localization Stage

After the establishment of the fingerprint database, it goes to the online localization stage. In the localization stage, first of all, it is needed to decide the similarity between the current measurement points and the reference points in the fingerprint database. In this paper, Euclidean distance is utilized to calculate the similarity, the calculation formula of which is shown as follows:

$$D(e) = \sqrt{\sum_{i=1}^{m} (S_i - RSSI_i)^2} \quad (5)$$

In the above formula, $D(e)$ stands for the calculation result of Euclidean distance, $m$ represents the number of transmitting nodes, $S_i$ meas at the current measurement point the signal strength value of the $i_{th}$ transmitting node, $RSSI_i$ stands for the the signal strength indication of the $i_{th}$ transmitting node at the reference point selected in the fingerprint database. Moreover, a proper matching algorithm is required in this study to determine the reference point in the fingerprint database, which has the maximum matching with the current measurement point. Therefore, K-Nearest Neighbor (KNN) algorithm[15] is chosen in this paper. Namely, those k points which show the maximum matching possibility are selected, the weights of which are calculated according to the Euclidean distance, thus estimating the position of the measuring points. The calculation formula is demonstrated as follows:

$$\left(\bar{x}, \bar{y}\right) = \frac{\sum_{i=1}^{k} \frac{1}{D(e)_i}(x_i, y_i)}{\sum_{i=1}^{k} \frac{1}{D(e)i}} \quad (6)$$

In the above formula, $(\bar{x}, \bar{y})$ is the coordinate of the final estimation, $\frac{1}{D(e)_i}$ stands for the weight value of the nearest points, $(x_i, y_i)$ is the corresponding coordinates of the nearest point, $k$ means the number of selected nearest nodes.

# 4. Experimental Results and Data Analysis

## 4.1 Measurement Results

In this experiment, five sets of data with k=1, k=3 and k=5 respectively, are collected. And for the convenience of comparison between the numerical values, the same measuring location is selected for each k-value. Their actual values and measured values are shown in the following Table 1, Table 2 and Table 3:

Table 1. Measurement results for k=1

| | | | | | |
|---|---|---|---|---|---|
| Actual values | X=1.0 Y=1.0 | X=1.0 Y=0.5 | X=3.0 Y=2.0 | X=1.5 Y=3.5 | X=5.0 Y=2.0 |
| Measured values | X=1.0 Y=1.0 | X=1.0 Y=0.0 | X=3.0 Y=2.0 | X=3.0 Y=3.0 | X=2.0 Y=1.0 |

Table 2. Measurement results for k=3

| | | | | | |
|---|---|---|---|---|---|
| Actual values | X=1.0 Y=1.0 | X=1.0 Y=0.5 | X=3.0 Y=2.0 | X=1.5 Y=3.5 | X=5.0 Y=2.0 |
| Measured values | X=1.08 Y=0.53 | X=0.71 Y=0.67 | X=2.77 Y=3.69 | X=3.0 Y=2.33 | X=2.84 Y=3.0 |

Table 3. Measurement results for k=5

| | | | | | |
|---|---|---|---|---|---|
| Actual values | X=1.0 Y=1.0 | X=1.0 Y=0.5 | X=3.0 Y=2.0 | X=1.5 Y=3.5 | X=5.0 Y=2.0 |
| Measured values | X=1.14 Y=0.93 | X=1.12 Y=0.91 | X=2.41 Y=2.26 | X=1.78 Y=1.77 | X=4.47 Y=2.84 |

From the above tables, it can be found that, when the k-value changes, the localization accuracy becomes different as well, which could be clearly described as follows:

When k=1, errors for x, y coordinate axes are (0,3) meters and (0,1) meters respectively, the median errors of which are 0 meter and 0.5 meter correspondingly.

When k=3, errors for x, y coordinate axes are (0.08,2.16) meters and (0.17,1.69) meters respectively, the median errors of which are 0.29 meter and 1.0 meter correspondingly.

When k=5, errors for x, y coordinate axes are (0.12,0.59) meters and (0.07,1.73) meters respectively, the median errors of which are 0.28 meter and 0.41 meter correspondingly.

## 4.2 Error Contrast of Different K-values

For ease of observation, the absolute error values of x, y coordinate axes errors are summed up, that is, to be processed as follows:

$$dev = |x - x_0| + |y - y_0| \tag{7}$$

In formula (7), $x$, $y$ stands for the actual position of the localization point, $x_0$, $y_0$ represents the measured position, and $dev$ means the processed results of the errors. After processing the data in the above three tables, a line chart could be drawn as follows:

The combination of the above tables and figure reveals that when k=1, the measurement results are relatively accurate, while sometimes the measurement errors are too large, generally lacking of stability. However, with the increase of k-value, the change of the result of measurement error tends to be more and more stable. Among the three values of k, namely, k=1, k=3 and k=5, when k=5, the measurement error is the smallest and the measurement result is the most stable.

From the data analysis of the experimental results, it could be seen that mainly based on the establishment of fingerprint database in the Zigbee network, the indoor localization system designed in this paper, which relies on the received signal strength and k-Nearest Neighbor (kNN) algorithm is feasible to some extend. The experimental results demonstrate that the positioning accuracy and stability is effected by the k-value in kNN algorithm. To be more specific, within a certain range, with the increase of the k-value, the positioning accuracy and stability will be improved accordingly. Meanwhile, the k-value should not be too large. If the k-value is too large, on one hand, the localization proficiency will be influenced, on the other hand, those reference points with little relevance will be chosen, which will create negative effects on the localization accuracy. Therefore, the selection of k-value should be determined according to the actual measurement.

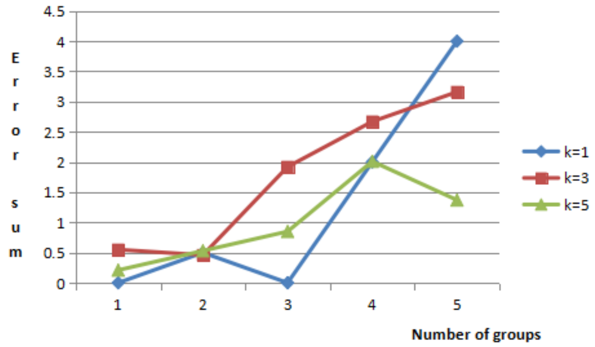


Fig. 4 Measurement error contrast of different k-values

## 5. Conclusion

Since the ZigBee wireless sensor network utilized in this study has the characteristics of low power consumption, the indoor localization system designed in this paper is energy saving. In terms of the hardware devices in this indoor localization system, the ordinary PC and the CC2530 chip whose price is moderate are needed, so the overall cost of this designed localization system is relatively not high. And from the above description, it can be noticed that the localization process is not complicated. Taking these advantages into consideration, this indoor localization system has a promising prospects for application. On the other hand, in this study, there is still room for further improvement. For instance, the positioning accuracy and stability can be improved, and both the matching of the fingerprint data and the establishment of fingerprint database are time-consuming and energy-demanding.

In addition to above problems, there will be more challenges in the practical application of indoor localization system. For example, when the indoor items and personnel move, how to deal with this situation? And when the positioning objects is moving or the localization range is too large, how to deal with this situation? These questions certainly need further and deeper explorations. At the same time, it is confirmed that these problems will be solved in the near future, so that indoor positioning technology will have a profound impact on people's production and life.

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## References

[1] X.K. Liu, H. Guo: Fingerprint database optimization algorithm based on Zigbee indoor positioning system, Computer Engineering, Vol.40 (2014) No.2, p.193-198. (In Chinese)

[2] X. Song: *Multi-sensory Fusing Localization Techniques in Indoor Environment* (MS., Shanghai Jiaotong University, China 2013). (In Chinese)

[3] Y. Yu, K.F. Zhao, J. Shen: Application, research and outlook for indoor localization, Telecommunications Network Techonology, (2014) No.5, p.46-49. (In Chinese)

[4] H. Yang, J.H. Xiao, Z. Liu, J.F. Cui, D. Liu, L.Y. Han: Indoor three-dimensional positioning system based on ultrasonic, Journal of Jilin University (Information Science Edition), Vol.30 (2012) No.3, p.267-271. (In Chinese)
[5] M.W. Liu, T.J. Liu, Y. Ye, L. Wu: The application research of indoor positioning based on low-power Bluetooth technology, Wireless Communication Technology, Vol.24 (2015) No.3, p.19-23. (In Chinese)
[6] H.Y. Wang, N.L. Zhang, H. Feng, Y.J. Liu, T. Lv: , The application and implementation of indoor positioning system based on wireless WLAN, Journal of Chifeng University (Natural Science Edition), Vol.30 (2014) No.6, p.23-25. (In Chinese)
[7] D. Yang, X.M. Tang, B.Y. Li, F.X. Wang: A review of Ultra Wideband based indoor localization technology, GNSS World of China, Vol.40 (2015) No.5, p.34-40. (In Chinese)
[8] Q. Wan, X.S. Guo, Z.X. Chen: *Indoor Localization Theory, Method and Application* (Publishing Houses of Electronics Industry, China, 2012), p.25. (In Chinese)
[9] B.T. Chen, R.R. Liu, Y.Q. Chen, J.F. Liu, X.L. Jiang, D.J. Liu: WiFi fingerprint based self-adaptive indoor localization in the dynamic environment, Chinese Journal of Sensors and Actuators, Vol.28 (2015) No.5, p.729-738. (In Chinese)
[10] M. Gao, X. Ji, Y. Liu, H. Lv: Application of ZigBee technology in indoor localization, Journal of Xi'an Technological University, Vol.30 (2010) No.1, p.9-12. (In Chinese)
[11] Z.H. Cai, X. Xia, B. Hu, D.M. Fan: Improvement of indoor signal strength fingerprint location algorithm, Computer Science, Vol.41 (2014) No.11, p.178-181. (In Chinese)
[12] F. Li: Research on Indoor Positioning Technologies of Location Fingerprint Method Based on Zigbee (Ph.D., Harbin Institute of Technology, China 2012), p.34-35. (In Chinese)
[13] J.W. Niu, B.W. Wang, S. Lei, et al.ZIL: An energy-efficient indoor localization system using zigbee radio to detect wifi fingerprint, IEEE Journal on Selected Areas in Communications, Vol.33 (2015) No.7, p.1431-1442.
[14] X. Zhang: Research on Indoor Positioning Technology Based on ZigBee Sensor Network (Ph.D., Nanchang University, China 2014). (In Chinese)
[15] Z.M. Wang, Z. Chen, C.H. Pan: Improved fingerprinting algorithm for smart phone indoor positioning, Journal of Xi'an University of Posts and Telecommunications, Vol.19 (2014) No.1, p.17-20. (In Chinese)