DESIGN AND IMPLEMENTATION OF INDOOR POSITIONING SYSTEM BASED ON IBEACON

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ABSTRACT

With the rapid increase in data and multimedia services, demand for positioning has increased especially in complex indoor environment which often needs to determine the location information of the mobile terminal. There is a lack of accuracy and robustness in current indoor positioning system. This paper designs and implements an indoor positioning system based on iBeacon. We adopt Gaussian filter and Unscented Kalman filter method to robustly extract strong signals from iBeacon device. With the extracted signals, we compared them with-in database. The goal of this paper is to design and implement a mobile-based indoor location system which has the mobile applications with the Bluetooth Low Energy technology based on the iBeacon. Using a mobile terminal our system can show position results. Moreover, our system can run on both Android systems and IOS ones. Our method has better performance compared with WiFi method. The experimental results demonstrates that the error is only within 4 meters and our system can achieve accurate and robust positioning.

***Index Terms*—**Indoor positioning, iBeacon, Unscented Kalman filter, Euclidean distance

1. INTRODUCTION

With the development of mobile Internet of things, the urban population and its location is closely interrelated. The outdoor positioning system based on satellite position (GPS) has matured enough that it provide users with the needs of high-precision positioning. However, GPS positioning satellite signals can only be received in outdoor environment, it difficult to meet the needs of indoor positioning. So, there is an urgent demand for indoor positioning technology.

In recent years, various types of emerging short-range wireless communication protocol and related products are presented in the market, where the standards of short-range wireless data communication includes ZigBee, WIFI, Bluetooth, RFID and Ultra Wideband (UWB) and other types of technology. These technologies play an important role in their respective areas as they meet current application requirements.

Among them, the targeting of Bluetooth has major advantages because of its high efficiency [1] [2]. As long as the Bluetooth device remains turned on the user's position can be determine by the Bluetooth indoor positioning system by using Bluetooth-enabled mobile terminal equipment.

Apple's iBeacon is an indoor positioning technology that is meant to be used with the BLE enabled beacons [3], it uses latest BLE4.0 technology, with low power consumption, low latency and transmission distance characteristics. The requirement of high-precision indoor positioning technology was best to meet with combination of software and hardware [4]. As compared to previous Bluetooth technology, iBeacon periodically transmits a broadcast signal that accurately determine user's current location by using positioning algorithm.

2. RELATED WORK

Now, many popular indoor positioning technology are presented in the market that's can be classified in many ways. According to the location algorithm, it can be divided into terminal-based positioning technology and server-based positioning technology. According to the targeting method, it can be divided into active positioning technology and passive positioning technology and according to location information, it can be divided into absolute positioning technology and relative positioning technology. In this paper, we introduced the indoor positioning technology about the short-range wireless communication [5].

The indoor positioning technology can be divided into the following categories by depending on frequency and positioning mechanisms for indoor signals.

2. 1. Bluetooth

Bluetooth is a radio technology which supports short distance communication from each other, the positioning of Bluetooth technology is the measuring of radio wave signal intensity values for targeting. The wireless technology specification of Bluetooth is used worldwide, which uses the 2. 4GHz band and this band is free to use. Therefore, the use of Bluetooth technology does not require any additional costs in addition to the cost of purchasing the desired Bluetooth device. The prime advantage of Bluetooth indoor positioning technology is that, Bluetooth chips are small, low power consumption, easy to integrate in mobile phones and even in smaller devices. When, there is a Bluetooth network access point at indoor, then the network is set to multi-user infrastructure network interconnection model, it will be able to get position information by obtaining the radio signal measurements in Bluetooth chip, so that it can achieve the purpose of Bluetooth positioning.

On the other hand, the shortcomings of Bluetooth technology are; more expensive equipment and lack of stability when the system in complex space environment [6].

2. 2. Wi-Fi

Wi-Fi applications are very broad and covering almost all areas, it is considered one of the most promising nominal fields of wireless communications in the 21st century.

The main advantages of Wi-Fi are as follows: 1. The coverage of radio wave is very wide, it can reach 100 meters, and achieve coverage with comprehensive; 2. The speed of network transmission is higher, it's very auspicious for real-time interactive facet of the application; 3. The network construction has a low cost, easy to maintain and very suitable for use in mobile phones. The core drawbacks are data security and performance slightly less compared to Bluetooth [7].

2. 3. IBeacon

The communication protocol used in iBeacon was the Bluetooth Low Energy (BLE), maximum Bluetooth version 4. 0 devices supports Bluetooth BLE version. IBeacon communication frequency consumption opened to the public to use the 2.4GHz band, which is a typical application scenario, was location services at the public service establishments. We use the attenuation characteristics of the radio frequency signal, the user of the distance from the base station by near to far was divided into three areas: close (d <50 cm), near (50 cm <d <2 m), far (2 m <d <30 m). In daily life as an example of the store, IBeacon can cooperate with back-office systems to provide location-aware services. IBeacon has proximity sensing technology of BLE, it can transfer Uniform Code of unique ID (UUID), APP intelligent terminal obtained the information about UUID and RSSI, and it can be converted into a physical location, which triggers location-aware applications.

3. SYSTEM ARCHITECTURE AND LOCATION ALGORITHM

3. 1. The Introduction of System

In this paper, the indoor location algorithm is based on iBeacon which gets broadcast signal through real-time positioning algorithm and query these results in SQLite database, and then displays the current position in unity3D to accomplish the positioning process. The system structure is represented in Figure 1.

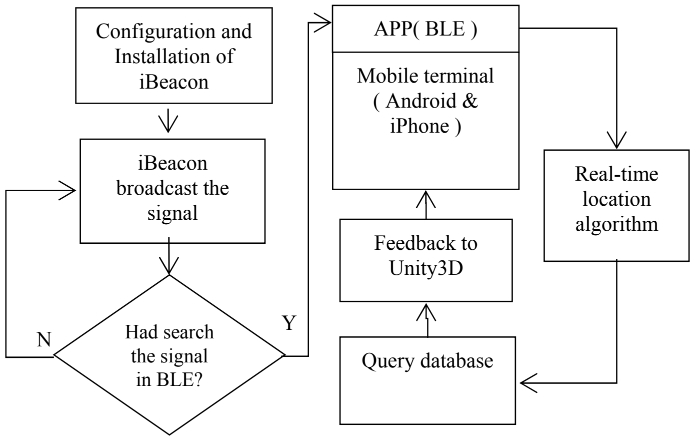

Fig. 1. The structure of system

3. 2. The algorithm of location

The rate of signal strength will be unstable because of the volatility of RF signal in actual data collection method. So there was no longer accurate correspondence between the RSSI and distance. Consequently, we need to purify the sample data in order to reduce the relevant positioning errors. The flow chart of Specific targeting algorithm is shown in Figure 2.

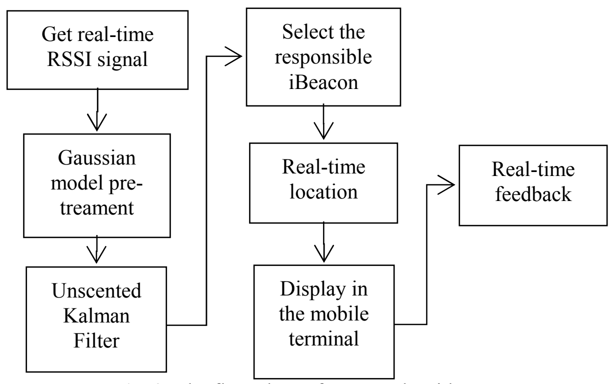

Fig. 2. The flow chart of system algorithm

We need place iBeacon at some fixed position in the test environment before positioning, the mobile terminal detects the response of iBeacon signal strength, and we build RSSI vector set based on it, this set represents the RSSI vector is $R = (R_1, R_2. \ldots . R_i. \ldots . R_P)$, where i is the signal strength of i-node RSSI, P is the total number of iBeacon.

The common approach is to repeatedly measured RSSI and averaging the values, the average value as the iBeacon characteristic value $r = (r_1, r_2, \ldots, r_i, \ldots, r_m)$, the formula is as follows:

$$RSSI = \frac{1}{m}\sum_{i=1}^{m} RSSI_i \qquad (1)$$

Where m is the total number of collected RSSI vector at the coordinate points.

In practice, however, the use of the averaging method does not reflect the real environment characteristic of RSSI because the results are not ideal when the indoor environment had random disturbances. However, before the processing phase, we are using the Gaussian model to determine the maximum value at the RSSI, it can efficiently solve the problem of signal propagation, affected by interference.

The specific distribution density function of Gaussian model is as follows:

$$f(x)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(x-m)^2}{2\sigma^2}} \tag{2}$$

$$\mathrm{m}=\frac{1}{\mathrm{n}}\sum_{i=1}^{n}X_i \tag{3}$$

$$\sigma^2=\frac{1}{\mathrm{n}-1}\sum_{i=1}^{n}(X_i-\mathrm{m})^2 \tag{4}$$

Where Xi is the value of received RSSI, n is the number of signals.

According to the study of actual situation [8], this paper choose 0. 6 as the critical point, when the Gaussian distribution function is greater than 0. 6 and less than 1, this is high probability event; when it less than 0. 6, this is a low probability event, then the RSSI values are filtered.

$$0.6\le\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{(x-m)^2}{2\sigma^2}}\le 1 \tag{5}$$

After making Gaussian filtering, extreme shake of individual signal still exists. In this case, we used the unscented Kalman filtering for further processing of the signal. British scholar Julier S J, Ullman J K, etc. Designed UKF filter based on Kalman Filter framework [9], it can be seen as technology-based UT Kalman filter. The specific UKF transformation algorithm as follows [10]:

1) Set the nonlinear system equation is:

$$X_{k+1}=F_k(X_k,U_k,V_k) \tag{6}$$

$$Y_k=H_k(X_k,N_k) \tag{7}$$

Where X_{k+1} is system state measurement until k+1 time, Y_k is one set of observation systematic values in k time. V_k is system noise, N_k is the observation noise in system. Suppose the covariance matrix is P_n.

2) This system may contain noise, so we set the system noise, observation noise and state variable as follows:

$$X^{a}=[X^T,Z^T,W^T]^T \tag{8}$$

3) The system initialization state and augmented as follows:

$$\hat{x}_0^a=E(x_0^a)[\hat{x}_0,0,0] \tag{9}$$

$$P_0^{a}=E((x_0^a-\hat{x}_0^a)(x_0^a-\hat{x}_0^a)^T)=\begin{bmatrix}P_0 & 0 & 0\\ 0 & Q & 0\\ 0 & 0 & R\end{bmatrix} \tag{10}$$

4) Select sigma points around the initial point which use sampling strategy:

It can be simplified algorithm of UKF when the system processes and measurement noises are additive noise. Simplified UKF algorithm is sampled sigma state, and proposed treatment the process noises and measurement noises [11]. Calculates the sampling point as follows:

$$\chi_{k-1}=[\hat{x}_{k-1}\quad \hat{x}_{k-1}+\gamma\sqrt{P_{k-1}}\quad \hat{x}_{k-1}-\gamma\sqrt{P_{k-1}}] \tag{11}$$

Where $\gamma=\sqrt{(L+\lambda)}$ is scale factor.

Or obtained the sampling point which used of the equation of state:

$$X_i^x(k+1|k)=f[X_i^k(k|k),u(k),X_i^v] \tag{12}$$

5) Some of the Equations used to prediction the status of system:

$$\chi_i^x(k+1|k)=f[\chi_i^x(k|k),u(k),\chi_i^w(k)] \tag{13}$$

$$\hat{x}(k+1|k)=\sum_{i=0}^{L-1}\varpi_i^m\chi_i^x(k+1|k) \tag{14}$$

$$\hat{z}(k+1|k)=\sum_{i=0}^{L-1}\varpi_i^m z_i(k+1|k) \tag{15}$$

6) Some of observations the system and update:

$$W(K+1)=P_{xz}(k+1|k)P_{vv}^{-1}(k+1|k) \tag{16}$$

$$\begin{aligned}\bar{x}(k+1|k+1)&=\bar{x}(k+1|k)+\\ W(k+1)&(z(k+1)-\bar{z}(k+1|k))\end{aligned} \tag{17}$$

Seen from the above process of algorithm, UKF is the posterior probability density which approximates the system state and it determined by a series of samples. This algorithm is applied to nonlinear models, we don't need to calculate the Jacobian matrix and hessian matrix, this process quite easy to achieve. When the system noise and measurement noise is additive noise, it can be simplified algorithm of UKF, and then simplified algorithm only samples the state of system.

3. 3. The positioning in real-time

In this paper, we structure the testing venues model with proportional used Unity 3D software, and development the software which could acquire the iBeacon signal and positioning in the mobile terminals. First, we could get relatively accurate RSSI data at the end of the Gaussian filtering and the Unscented Kalman filter. Then, we calculate the Euclidean distance between RSSI sample vector and RSSI mean vector corresponding real-time in database. Thirdly, we only search iBeacon within the Euclidean distance. We can find the average coordinate position corresponding with iBeacon at the end of queried the location coordinates in SQLite database, and the display can be positioned in the mobile terminal. The Euclidean distance is calculated as follows:

$$D=\sqrt{\sum_{j=1}^{m}(RSSI_{\mathrm{j}}-\overline{RSSI})^2} \tag{18}$$

Where $RSSI_{\mathrm{j}}$ is the real-time measurement of the RSSI value, $\overline{RSSI}$ is the mean of received RSSI, m is the number of iBeacon.

4. EXPERIMENT AND ANALYSIS

4. 1. Experimental site and data collection

In our experiment, we are using android phone as the fingerprint test and positioning terminal, the experimental site is in the Institute of Smart City at Shanghai University. The statistical analysis shows that the installation of 36 internal iBeacon in this site, in the course of the experiment, we select 15 different test points in test feature, and ensure that the spatial position of iBeacon should be fixed.

4. 2. Experimental results and analysis

In the experiment, we have larger number of iBeacon, so the experiments conducted three times in order to observe the effects of iBeacon to positioning results, and statistical comparison to the results of indoor positioning. Among these, the ratio between the drawings and the actual distance, the actual average error is 2.5 times then average measurement error, the localization error is between 1 and 4 meters, this result might be affected by the walls and barriers in the tracking surroundings.In Fig.5, The red dot represent the actual position and the blue dot represent average test position.

The results of experiment are as follows:

Table 1. Experimental results

Test point	Actual coordinates	Test coordinates in average	Actual error in average /m
1	(5. 50, 8. 00)	(6. 00, 9. 25)	3. 38
2	(6. 25, 12. 50)	(6. 88, 11. 50)	2. 95
3	(9. 50, 1. 75)	(9. 95, 3. 20)	3. 80
4	(9. 25, 5. 25)	(9. 50, 6. 50)	3. 18
5	(9. 50, 9. 50)	(9. 17, 9. 00)	1. 50
6	(14. 00, 8. 50)	(14. 88, 9. 38)	3. 10
7	(18. 25, 5. 25)	(19. 71, 4. 63)	3. 98
8	(20. 50, 2. 50)	(19. 00, 3. 00)	3. 95
9	(20. 50, 9. 00)	(21. 08, 8. 67)	1. 68
10	(26. 25, 8. 75)	(26. 33, 9. 56)	2. 03
11	(32. 25, 9. 25)	(31. 30, 9. 85)	2. 80
12	(38. 25, 9. 00)	(39. 45, 9. 05)	3. 00
13	(43. 50, 8. 75)	(43. 85, 9. 50)	2. 08
14	(46. 50, 5. 00)	(47. 25, 4. 63)	2. 10
15	(48. 75, 8. 75)	(47. 25, 8. 23)	3. 97

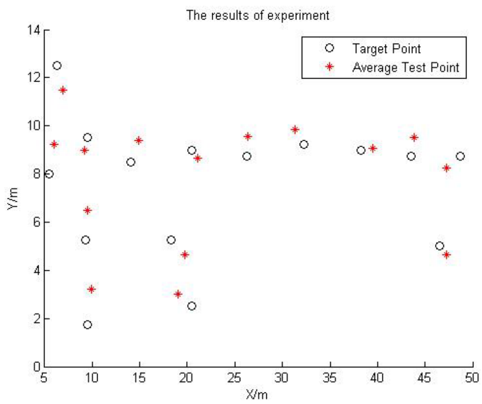

Fig. 3. The results of experiment

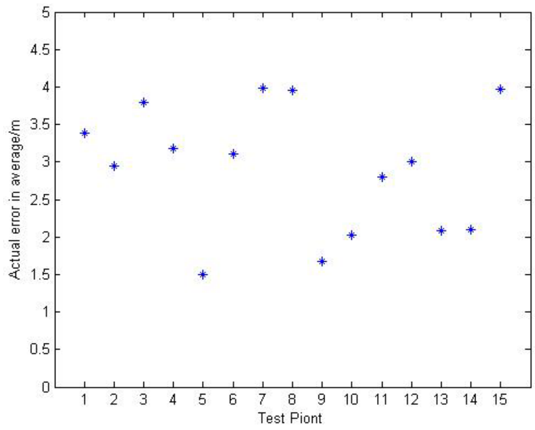

Fig. 4. Actual error in average

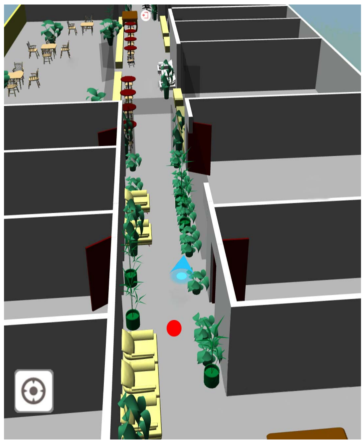

Fig. 5. Actual position (red point) and average of test position (blue point)

5. CONCLUSION AND OUTLOOK

In this paper, we implemented an indoor location algorithm based on iBeacon. The algorithm based on Euclidean geometry distance, and combined with Gaussian function and Unscented Kalman filter. We could displays the current position in the mobile terminal. As the result, the average location error of the indoor location algorithm was only within 4 meters, it can accurately determine the current location of the user, our system is dependable enough to overcome the constraints indoor positioning environment and the algorithm has strong real-time positioning and robustness.

In addition, you can try the different layout program about iBeacon at the research work in the future, and combined with WIFI positioning and research on the positioning accuracy with the multi-mode convergence. Finally, you can combined with different weights optimization algorithm for positioning result of further analysis and summary.

6. ACKNOWLEDGMENTS

This research was partially supported by the National Nature Science Foundation of China (No.61373084) and the Innovation Program of Shanghai Municipal Education Commission (No.14YZ011).

7. REFERENCES

[1] M. Altini, D. Brunelli, E. Farella, and L. Benini, "Bluetooth indoor localization with multiple neural networks, " 51h International Symposium on Wireless Pervasive Computing, 2010, pp. 295-300.

[2] Sheng Zhou and J. K. Pollard, "Position measurement using Bluetooth. " IEEE Transactions on Consumer Electronics. vol. 52. no. 2. pp. 555-558, May 2006.

[3] iBeacon for developers. https://developer. apple. com/iBeacon/.

[4] H. K. Fard ,Wireless Networking and Mobile Computing Laboratory, Memorial University of Newfoundland, St. John's, NL, Canada , Y. Chen and K. K. Son, "Indoor Positioning of Mobile Devices with Agile iBeacon Deployment ". Proceeding of the IEEE 28th Canadian Conference on Electrical and Computer Engineering Halifax, Canada, May 3-6, 2015.

[5] Shuming Nie, "The processing and application of the urban geographical basic data" IEEE Remote Sensing, Environment and Transportation Engineering (RSETE), 2011 International Conference on, 24-26 June 2011.

[6] Jinsong Xu, Xiaochun Lu. "Design and Simulation of Indoor Positioning System Based on UWB"[C]. E-Business and E-Government (ICEE), 2010:3872-3875.

[7] Kietlinski Zaleski J. , Yamazato T. UWB, "positioning using known indoor features-environment comparison"[C]. Indoor Positioning and Indoor Navigation (IPIN), 2010:1-9.

[8] Zhang Xinghui, Zhang Zhihui, Deng Zhidong. "Area summation of triangle location algorithm based on RSSI technique"[J]. Electronic Measurement Technology, 2008, 31(11):92-94(in Chinese).

[9] S. Julier, IDAK Ind. , Jefferson City, MO, USA, J. Uhlmann and H. F. Durrant-Whyte, "A new method for the nonlinear transformation of means and covariances in filters and estimators"[J]. IEEE Transactions on Automatic Control, 2000, 45(3):477-482.

[10] H. M. T. Menegaz , Dept. of Electr. Eng. , Univ. of Brasilia, Brasilia, Brazil , J. Y. Ishihara , G. A. Borges and A. N. Vargas, "A Systematization of the Unscented Kalman Filter Theory", IEEE Transactions on automatic control, Vol. 60, no. 10, October 2015.

[11] JULERSJ. "The Scaled Unscented Transformation"[M]. Proceedings of the American Control Conference Anchorage, AK, 2002:4555-455.