Smart Bluetooth beacon based on LoRa Positioning method and system research

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Abstract. In the era of the Internet of Everything, applications based on real-time location continue to appear in various industries. The indoor and outdoor positioning, analysis and management of personnel and objects can effectively improve the efficiency of production and management, which is of great significance to many industries. The use of Bluetooth beacon positioning has the advantages of low energy consumption, low cost, and fast data transmission speed. However, in real life, there are two obstacles to receiving signals, which are easily affected by the environment and the need for frequent on-site maintenance. This paper designs and implements a new type of LoRa-based smart Bluetooth beacon, which can be quickly connected to LoRa. Online monitoring and remote control can achieve better adaptation to the environment, and can fit a better signal attenuation model in the deployment environment in real time. Traditional signal strength positioning solutions have their own limitations. In order to improve the positioning accuracy of the Bluetooth beacon and the universality of the algorithm, in view of the low deployment density of beacons, the positioning accuracy is not good and the anchor circle has various situations, an optimized weighted centroid positioning scheme integrating greedy strategy is proposed.

1. Introduction
Under the tremendous thrust of the informatization wave, with the rapid development of the mobile Internet and the rapid rise of the Internet of Things, people's demand for smart work, smart life, and smart society is increasing. Circles and missed the opportunity to explore the new world again and again. The GNSS, a global navigation satellite system developed based on satellite technology, has become a leader in the field of outdoor positioning and navigation by virtue of its omni-directional, all-weather, all-time, and high-precision advantages. However, because the satellite signal is seriously attenuated under the obstruction of buildings, GNSS is not satisfactory in indoor positioning applications [1]. After comparing various experimental algorithms, it can be concluded that the Bluetooth indoor positioning solution has the greatest optimization and operability. On the one hand, Bluetooth has the advantages of low cost, low power consumption, small size, easy deployment, and high security. [2] On the other hand, the shortcomings of Bluetooth positioning technology are that the communication distance is short but sufficient, and it also contributes to the obvious difference of Bluetooth signal area, which is beneficial to positioning, while the received signal strength indication (RSSI) of Bluetooth is interfered by the environment. Instability can be optimized by filtering algorithms to reduce errors [3]. How to improve the operability and performance superiority of the Bluetooth beacon application, and how to improve the positioning accuracy and general applicability of the Bluetooth ranging positioning algorithm are
the "winners" of the success or failure of the Bluetooth positioning system. It is of great significance to improve the positioning accuracy and general applicability in the future.

2. Smart Bluetooth beacon system and positioning related technologies
This chapter introduces the LoRa technology, Bluetooth low energy technology and Bluetooth positioning technology involved in smart Bluetooth beacon positioning, and explains and elaborates on LoRa wireless communication, LoRa networking, Bluetooth 4.0 protocol, ranging positioning, non-ranging positioning, etc.

2.1. LoRa technology
Long Range Radio is a special frequency modulation spread spectrum technology, which was developed by Semtech and based on this technology a complete set of Lora communication chip solutions [4]. The most important feature of LoRa is that it not only realizes long-distance secure communication, but also has the advantages of low-power applications.

2.2. Ranging and positioning
In this paper, distance measurement and positioning need to introduce other parameters to estimate the distance from the point to be located to a known Bluetooth node. The RSSI data is converted into the corresponding estimated distances from the point to located to different Bluetooth nodes through the signal attenuation model, and finally the spatial positioning algorithms such as trilateral positioning method, target positioning maximum likelihood estimation method, and weighted centroid positioning method are used to process the target point to be located. Estimate the location.

3. Smart Bluetooth beacon design based on LoRa
Mainly introduces the design and implementation of smart Bluetooth beacon based on LoRa. On the basis of ordinary Bluetooth beacon functions (broadcast, nearby configuration working status), three functional mechanisms are added-fast networking, online monitoring and remote control.

3.1. Research on Smart Bluetooth Beacon System Based on LoRa
This paper studies the practical application of ordinary Bluetooth beacons, such as difficulty in inspection, inconvenience of control, and large signal impact on the environment, and realizes a smart Bluetooth beacon system based on LoRa. The system consists of a beacon node, a beacon gateway, a server and a manager cloud platform. The main functions are: Fast networking, online monitoring and remote control.

4. Research on attenuation model of Bluetooth beacon signal
As a Bluetooth signal generator, the Bluetooth beacon plays an important role in the indoor positioning process. The ranging performance based on the Bluetooth beacon signal directly determines the positioning accuracy to a certain extent. In order to improve the accuracy of RSSI-based ranging, the key lies in the selection of the RSSI acquisition optimization strategy and the Bluetooth signal attenuation model.

4.1. Bluetooth signal attenuation model
There is no absolute free space in the real environment, especially in the indoor environment. Due to the existence of buildings such as walls, ceilings, doors and windows, the transmission of wireless signals will be affected by obstacles, reflection, absorption and other factors [5]. In addition, the wireless signal generator cannot achieve perfect and uniform radiation in all directions. Because of the complexity of the actual scene, the free space model of the signal cannot describe the propagation of the signal in the space well. Ren Weizheng [6] pointed out that the indoor Bluetooth signal attenuation model follows the logarithmic distance path loss model, and The equation (1) is as follows:
\[ RSSI(d) = RSSI(d_0) - 10n\log\left(\frac{d}{d_0}\right) \] 

Hu Binbin\(^7\) studied when \(d_0\) is 1m, the mean value of \(X\) is 0, let \(A=RSSI(1)\), so the logarithmic distance path loss model is transformed into the following equation (2):

\[ RSSI(d) = A - 10n\log d \] 

4.2. Optimization of Bluetooth Smart Beacon Signal Attenuation Model

The signal attenuation model realizes the conversion between received signal strength and distance, and is a key part of indoor Bluetooth positioning. The closer the fitted signal attenuation model is to the real signal attenuation, the smaller the ranging error and the better the subsequent positioning effect. Conversely, the greater the model deviation, the more inaccurate the ranging based on the received signal strength. At present, most Bluetooth beacon signal attenuation models used for positioning are measured and recorded offline in advance. Algorithms are used to make the signal attenuation model as accurate as possible.

4.3. Experimental results and ranging performance analysis

Using the Bluetooth smart beacon as the hardware platform, the smart Bluetooth beacon continuously monitors the surrounding iBeacon, obtains the corresponding RSSI value many times, and performs Gaussian mean filtering on the RSSI, which can achieve real-time fitting of the key environmental parameter \(A\) (distance beacon) of the signal attenuation model. \(1m\) RSSI), \(n\) (environmental attenuation factor), get 10 sets of original \(A\) and original \(n\) continuously fitted, \(A\) and \(n\) obtained by Gaussian mean optimization, and \(A\) and \(n\) obtained by one-dimensional Kalman optimization. In addition, set reference beacons at 0.5m, 1m, 1.5m, 2m, 2.5m, 3m, 3.5m, 4m from the Bluetooth smart beacons. Literature \(^4\) uses Gaussian filtering RSSI and uses the least square method to fit the signal attenuation model segmentally. The corresponding distance is calculated through the fitted signal attenuation model and related optimization model. The experimental results are shown in Table 1.

| Reference point | Actual distance (m) | Original ranging error (m) | Gaussian mean optimization ranging error (m) | One-dimensional Kalman optimized ranging error (m) | Literature \(^4\) Algorithm ranging error (m) |
|-----------------|---------------------|-----------------------------|---------------------------------------------|--------------------------------------------------|------------------------------------------|
| P1              | 0.5                 | 0.12                        | 0.08                                        | 0.10                                             | 0.11                                     |
| P2              | 1.0                 | 0.35                        | 0.21                                        | 0.27                                             | 0.28                                     |
| P3              | 1.5                 | 0.56                        | 0.32                                        | 0.41                                             | 0.43                                     |
| P4              | 2.0                 | 0.81                        | 0.45                                        | 0.58                                             | 0.61                                     |
| P5              | 2.5                 | 1.14                        | 0.61                                        | 0.80                                             | 0.82                                     |
| P6              | 3.0                 | 1.41                        | 0.77                                        | 1.01                                             | 0.86                                     |
| P7              | 3.5                 | 1.67                        | 0.87                                        | 1.18                                             | 1.02                                     |
| P8              | 4.0                 | 1.97                        | 1.03                                        | 1.40                                             | 1.20                                     |
| P9              | 4.5                 | 2.19                        | 1.11                                        | 1.51                                             | 1.31                                     |
| P10             | 5.0                 | 2.45                        | 1.22                                        | 1.67                                             | 1.43                                     |

Analyzing the results of the appeal experiment found that the optimization of Gaussian mean and one-dimensional Kalman optimization for the key environmental parameters \(A, n\) of the signal attenuation model can improve the ranging accuracy of the signal attenuation model.
5. Research on Optimization of Bluetooth Beacon Location Algorithm

This chapter analyzes their limitations by comparing and studying commonly used RSSI positioning algorithms. Combining the characteristics of the current indoor positioning actual application scenarios and service requirements, in view of the problems of the traditional RSSI positioning algorithm in positioning accuracy and algorithm universality, an optimized centroid weighted positioning scheme fused with a greedy strategy is proposed, and the smart Bluetooth beacon is used as an example. The hardware platform verifies the effectiveness of the algorithm.

5.1. Optimization of Bluetooth Smart Beacon Signal Attenuation Model

Aiming at the problem of low positioning accuracy when the weighted object of the weighted centroid positioning algorithm contains too large an area and low anchor node density, although the literature [8] proposes to use the point where the three anchor circles intersect as the weighted object, it can reduce the area where unknown nodes may be located and require anchor nodes. In this paper, an RSSI indoor weighted centroid positioning algorithm with greedy strategy is proposed to adaptively deal with a variety of complex situations of three circles.

5.1.1. Algorithm principle.

Arbitrary selection of two circles can get better weighted points under the decision of fusion greedy strategy. Combine the three circles in pairs, so that you can get three better weighted objects, and then weight these weighted objects with the reciprocal sum of the selected anchor circle distance as the weight, and the result is the estimated position of the unknown node. Take the three-anchor circle example shown in Figure 1 for illustration,

Figure 1. Three-anchor circle example description

The calculation equation (3) is as follows:

\[
X = \frac{X_A \cdot \frac{1}{d_{A3} - d_{A1}} + X_B \cdot \frac{1}{d_{B2} - d_{B1}} + X_C \cdot \frac{1}{d_{C1} - d_{C1}}}{\frac{1}{d_{A3} - d_{A1}} + \frac{1}{d_{B2} - d_{B1}} + \frac{1}{d_{C1} - d_{C1}}},
\]

\[
Y = \frac{Y_A \cdot \frac{1}{d_{A3} - d_{A1}} + Y_B \cdot \frac{1}{d_{B2} - d_{B1}} + Y_C \cdot \frac{1}{d_{C1} - d_{C1}}}{\frac{1}{d_{A3} - d_{A1}} + \frac{1}{d_{B2} - d_{B1}} + \frac{1}{d_{C1} - d_{C1}}},
\]

Among them, \(d_{O1}, d_{O2}, d_{O3}\) are the distances from the anchor node \(O_1, O_2,\) and \(O_3\) to the anchor node \(O_1, O_2,\) and \(O_3\) based on the RSSI measurement; \(A (X_A, Y_A)\) is the weighted object calculated by the combination of circle A and circle O2; \(B (X_B, Y_B)\) is the weighted object calculated by combining circle A and circle O3; \(C (X_C, Y_C)\) is the weighted object calculated by combining circle O2 and circle O3; \(d_{A3}, d_{B2}, d_{C1}\) are the new weighted object points A, B, C to anchor node, respectively. The distances of O3, O2,
and O1; The weights of A, B, and C are $\frac{1}{|d_{A3} - d_{O1}|}, \frac{1}{|d_{B2} - d_{O2}|}, \frac{1}{|d_{C1} - d_{O3}|}$; the estimated position of the point to be located $(X_0, Y_0)$.

5.2. Analysis of results
Through the fitted path loss attenuation model, according to the distance value and anchor node coordinates, the estimated position of each check point is calculated using the classic weighted centroid location algorithm, the weighted centroid location algorithm of literature [9], and the weighted centroid location algorithm improved in this paper. The specific coordinates of the estimated position calculated by the three methods are shown in Table 2.

| Check point number | Measured coordinate value (m) | Classic weighted centroid algorithm positioning value (m) | Literature [9] weighted centroid algorithm positioning value (m) | Positioning value of weighted centroid algorithm fused with greedy strategy (m) |
|--------------------|-------------------------------|--------------------------------------------------------|-------------------------------------------------|-----------------------------------------------|
| P1                 | (2.30,1.20)                   | (2.26,1.02)                                            | (3.30,0.72)                                     | (2.52,1.46)                                  |
| P2                 | (2.70,2.70)                   | (2.36,1.37)                                            | (1.32,1.75)                                     | (2.85,2.83)                                  |
| P3                 | (2.30,4.20)                   | (2.21,3.81)                                            | (2.78,4.23)                                     | (2.42,3.84)                                  |
| P4                 | (3.76,1.12)                   | (4.32,2.06)                                            | (3.96,2.17)                                     | (4.10,1.04)                                  |
| P5                 | (3.80,2.40)                   | (4.37,2.21)                                            | (4.15,2.26)                                     | (4.17,2.33)                                  |
| P6                 | (3.80,3.80)                   | (4.40,3.89)                                            | (4.28,3.86)                                     | (3.67,3.67)                                  |
| P7                 | (5.40,2.80)                   | (5.03,2.38)                                            | (5.06,2.93)                                     | (5.13,2.60)                                  |
| P8                 | (5.43,3.80)                   | (5.02,3.95)                                            | (5.18,3.31)                                     | (5.18,4.13)                                  |
| P9                 | (6.10,2.50)                   | (5.26,1.92)                                            | (5.68,3.06)                                     | (5.95,1.84)                                  |
| P10                | (6.10,1.00)                   | (5.02,4.03)                                            | (5.24,3.34)                                     | (5.69,4.90)                                  |

The weighted centroid positioning algorithm fusion greedy strategy estimates the distance between the two points of the position and the actual position as the judgment standard of the positioning accuracy. The errors of the three positioning algorithms are shown in Figure 2.
Figure 2. Three positioning algorithms positioning error

Compared with the literature \cite{9} weighted centroid positioning algorithm, the algorithm in this paper has improved positioning accuracy under the condition that the algorithm complexity and real-time performance are not much different. It can handle more adaptively. This kind of anchor circle situation is universal.

6. Conclusions
In this paper, based on the LoRa-based smart Bluetooth beacon system designed and implemented, a real-time fitting signal attenuation model is proposed, and the key environmental parameters in the model are optimized by the Gaussian mean method and one-dimensional Kalman method, and the accuracy of the signal attenuation model is improved. Effectively improve the accuracy of Bluetooth beacon based on RSSI ranging. Aiming at the situation where the three-anchor circle intersects multiple areas or no intersecting area in Bluetooth beacon ranging and positioning, an optimized weighted centroid positioning algorithm combining greedy strategy is proposed, which greatly reduces the area where the point to be located may be located and effectively improves the Bluetooth signal. Target positioning accuracy.

Acknowledgments
I would like to sincerely thank the teachers, classmates, relatives and friends who accompany each other along the way. First of all, I would like to thank my mentor, Professor Dai Yawen, for training and teaching me over the years, and urging me to forge ahead and keep making progress. Secondly, I would like to thank the partners in the laboratory for their kind care and selfless help, so that I am not afraid of difficulties in my study and life, and seek steady progress. Finally, I want to thank my family for their silent support and encouragement behind me.

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