The Application of Bluetooth Technology in Indoor Navigation

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Abstract. In the era of rapid technological advancement, as human activities increasingly extend into indoor spaces, navigation needs have expanded from outdoors to indoors. Due to the limitations of traditional outdoor navigation technology in indoor environments, the demand for indoor navigation technology is increasing. The advantages of Bluetooth technology, such as low power consumption, security, and ease of integration, make it widely applicable in indoor positioning and navigation. Based on current research, common indoor wireless positioning methods were discussed, including ranging-based and distance-free algorithms, and low-power Bluetooth indoor positioning methods such as the geometric method and fingerprint library method were elaborated. In addition, the technical support of Bluetooth systems for indoor navigation, such as the Kalman filtering algorithm in signal processing and the Dijkstra algorithm in path planning, was discussed. On this basis, the article proposes the advantages of Bluetooth positioning in device popularization and deployment, as well as the trend of integrating Bluetooth with other devices or technologies to improve positioning and navigation capabilities.

Keywords: Bluetooth technology; Low power consumption; Kalman filter; Dijkstra's algorithm.

1. Introduction

With the popularization of the Internet of Things and smartphones, indoor navigation technology has a wide range of real-world application needs. Outdoor navigation technologies such as GPS are affected by indoor occlusion, which can't provide accurate localization services and affects navigation efficiency. In large public places (e.g., shopping malls, hospitals, airports, etc.), it is crucial to quickly locate emergency rescue routes or missing persons, and an effective indoor localization system can improve the emergency response speed. Therefore, it is of great practical significance to study navigation techniques applicable indoors. Currently, popular indoor localization technologies on the market include infrared, ultrasonic, radio frequency identification (RFID) and other systems. However, these systems are more complex in realization and have higher deployment costs.

Bluetooth technology is characterized by low power consumption, making it suitable for devices that run for long periods. In addition, Bluetooth technology provides multiple security measures to protect data security and privacy. Bluetooth technology is easy to integrate and highly compatible, allowing it to connect seamlessly with other devices. For example, in complexes such as large shopping malls, Bluetooth technology can be utilized to enable precise navigation at the store level, helping customers quickly locate where the items they are looking for are located. Similarly, in healthcare facilities, Bluetooth location technology can assist healthcare professionals in efficiently locating needed medical equipment and patients, thereby improving the efficiency of medical services and staff. The characteristics of Bluetooth technology, such as low cost, low power consumption, and easy promotion, make it have a wide range of application prospects in the field of indoor positioning and navigation.

This paper mainly introduces the following technologies that are widely used in Bluetooth indoor navigation. In the field of indoor positioning technology research, the scene method (also known as the fingerprint library method) is an effective means of localization. This establishes an exhaustive fingerprint database by collecting and storing the intensity parameters of each key node in the indoor

3D scene in advance. By utilizing this database, high accuracy and high stability localization results can be achieved. In addition, low-power Bluetooth technology, especially iBeacon technology, has been widely used in indoor positioning systems due to its low energy consumption, fast connection, high transmission rate, and stable and secure transmission characteristics. The Kalman filter algorithm, on the other hand, is an optimization estimation technique that provides an accurate estimation of the linear system state through the input and output observations of the system. In terms of navigation, Dijkstra's algorithm is a well-known graph-theoretic algorithm for the problem of finding the single-source shortest path in a weighted graph, i.e., the shortest path from a single source to all other vertices. Combining these techniques can further improve the performance and reliability of indoor localization navigation systems.

2. Bluetooth indoor location technology

2.1. Common Indoor Wireless Location Methods

Indoor wireless location methods can be divided into two kinds according to whether or not to measure distance directly [1].

Among them, there are two localization algorithms based on measuring distance, one is the Angle of Arrival, and the other is the Time of Arrival. AOA, also known as triangulation, requires antenna arrays and advanced signal processing base stations to ensure accurate angle measurements and reliable positioning results [2].

By measuring the angle between the user MS and the base station, the user's position can be determined by the way of forward intersection. Because of the influence of noise and other factors, the accuracy of angle measurement is low, so it is mainly used for auxiliary positioning in engineering. TOA algorithm is a localization algorithm based on arrival time. This method determines its location by the distance between the point to be measured and the reference point. Its essence is the trilateral intersection method. It also requires the point to be measured to be the same time as the reference point equipment, which requires some additional equipment, thus somewhat increasing the cost [3].

2.2. Indoor Location Based on Low-Power Bluetooth

Bluetooth is a wireless transmission technology, the communication specification for Bluetooth protocol stack, running in the 2.4 GHz band, using frequency modulation spread spectrum technology transmission. Maximum transmission distance up to 300 m, maximum transmission rate up to 42 Mbps [4].In terms of precise location, Bluetooth location technology costs only one-tenth to one-tenth of traditional technology. Because the environment has little impact on Bluetooth technology, Bluetooth applications are very common, have low power consumption, and are easy to implement. Therefore, Bluetooth localization technology in indoor localization technology applications is the most widespread [5].

Compared with traditional Bluetooth technology, Bluetooth Low Energy (BLE) has the characteristics of low power consumption, stable signal, low cost and convenient equipment configuration (Table 1). At present, the indoor location method of low-power wireless sensors mainly relies on the wireless signal strength (RSSI) in wireless networks. In recent years, a lot of research has been put forward to realize real-time location indoors by using radio frequency signals (RSSI). At present, there are two main techniques for indoor location based on RSSI values of broadcast signals from BLE base stations: the geometric method and the fingerprint database method.

At present, the indoor location based on BLE RSSI mainly adopts two methods: geometric location and fingerprint location. The geometric method is to calculate the spatial position of an object by using the principle of geometry. Using the relation of angle and distance between the undetermined node and three anchor nodes, the centre and radius of three intersecting undetermined nodes are calculated [6]. To improve the accuracy of fingerprint location, it is necessary to build a fingerprint database with high accuracy. The geometric law highly depends on the stability of the RSSI value

and the accuracy of the distance model. Therefore, this method has the advantages of simplicity, low cost and high speed [7].

Table 1. Comparison of geometric method and fingerprint database method.

Indicators	Geometric method	Fingerprint library method
BLE base station calibration	Need	Partially required
Matching Database Making and Online Matching	No need	Need
Ranging model	Need	No need
Implementation difficulty and cost	Low	Higher
Stability	Lower	Higher

3. Technical support of Bluetooth systems for indoor navigation

3.1. Signal Processing

Bluetooth indoor navigation system mainly relies on receiving Bluetooth signals to obtain positioning information, the use of Bluetooth signals for positioning and communication, is an important part of different indoor navigation systems. In the actual design, the signal processing technology is a key link and needs to use different algorithms for a series of signal processing to reduce the error.

3.2. Kalman Filtering Algorithm

Kalman filtering algorithm is an optimised recursive filter for linear dynamic systems and linear observation models, capable of optimally estimating the system state in the presence of noise [8]. In the field of wireless communication, Bluetooth technology is widely used for data transmission, in which Received Signal Strength Indication (RSSI) is a key parameter for assessing the quality of Bluetooth signals. The RSSI value reflects the degree of attenuation of the signals during the transmission process, but it is susceptible to the influence of noise resulting in fluctuation of the data. The Kalman filtering algorithm can smooth the RSSI value by calculating the noise variance, providing a more stable estimate, and continuously adjusting the estimate to reduce the effect of noise [9]. Compared to simple filtering techniques such as Gaussian and mean filtering methods, the Kalman filtering algorithm has a significant advantage in dealing with fluctuations and errors as it takes into account the dynamic properties of the system and past observations to provide more accurate and stable estimates. The Kalman filtering algorithm is as follows [10]:

$$\mathrm{GAUSS} = \sqrt{\mathrm{pdelt}^2 + \mathrm{mdelt}^2} + \mathrm{Q} \tag{1}$$

$$\mathrm{K} = \sqrt{\frac{\mathrm{GAUSS}^2}{\mathrm{GAUSS}^2 + \mathrm{pdelt}^2}} + \mathrm{R} \tag{2}$$

$$\mathrm{RSSI} = \mathrm{K} \times (\mathrm{current} - \mathrm{predict}) + \mathrm{predict} \tag{3}$$

$$\mathrm{mdelt} = \sqrt{(1 - \mathrm{k}) \times \mathrm{GAUSS}^2} \tag{4}$$

3.3. Route Planning

Path planning is another key technique in indoor navigation systems. Its main purpose is to find an optimal path given a start point and an endpoint. Common path planning algorithms include Dijkstra's algorithm, A* algorithm, genetic algorithm, etc., and different algorithms have their different advantages.

3.4. DIJKSTRA Algorithm

Dijkstra's algorithm is a search algorithm for calculating the shortest path between two points in a graph, named after Dutch computer scientist Edsger Dijkstra. The algorithm employs a greedy

strategy that selects the current shortest path extension each time to ensure that the global shortest path is found, which is important for path planning. Compared to the A* algorithm, Dijkstra's algorithm does not require a heuristic function is suitable for a wide variety of terrains, and is especially advantageous in complex environments such as robot navigation and network routing. For example, in Fig. 3-2, in an environment full of obstacles, Dijkstra's algorithm can efficiently find a path from the start point to the endpoint, and even when the environment changes or there are multiple obstacles, it can quickly adjust the path and find a new shortest path, which makes it highly valuable in practical applications.

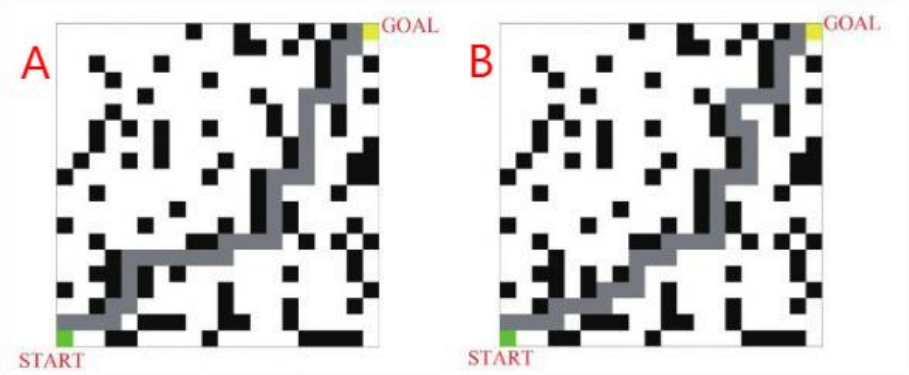

Figure 1. Complex Scene Simulation: (A) DIJKSA algorithm simulation diagram (B) A*algorithm simulation diagram [13].

4. Application of Bluetooth in indoor navigation

Since most smart devices are equipped with Bluetooth modules, the advantage of Bluetooth positioning is that it is easy to popularize and transfer devices on a large scale. The low-power Bluetooth technology (iBeacon technology) of Bluetooth 4.0 enables secure information transmission based on low power consumption, high transmission speed and stable signal, but it is not widely used because of the high density of Bluetooth beacon deployment and high software cost. [15] In different application scenarios, the research on the number of Bluetooth devices deployed is helpful to keep the cost within the appropriate price. For example, in the literature [16], through a small range of indoor, Bluetooth 5 to 6 in a linear arrangement, you can obtain high-precision positioning. At present, both at home and abroad intend to adopt Bluetooth 5.0 to improve the accuracy of Bluetooth positioning and reduce the cost, and the signal coverage of a single Bluetooth 5.0 beacon will be 16 times that of 4.0, and there will be an increase in communication speed, power consumption and capacity (the amount of data information that can be carried in a single broadcast).

In the application of Bluetooth localization, the stability of Bluetooth is often combined with other devices or technologies to obtain more accurate localization and navigation. In the study [17], it is proposed to integrate Bluetooth and AR to fill the gap in the current 2-D navigation based on GPS and to provide users with a better navigation experience and better-addressing effect [18]. Traditional indoor location methods include radio-frequency signal-based location, but because of the instability of radio-frequency signal, signal filtering is often needed; But through real-time Bluetooth signal and image matching algorithm stability, as well as the powerful image acquisition ability of AR technology, wireless signal and visual signal are combined to achieve high accuracy. However, when the dataset is large, the computation time is prolonged and the sensor delay is different for different devices. Another example is the accuracy of sensors. Conventional indoor navigation techniques, such as cameras and IMUs (inertial measurement units), use sensors to locate and navigate but often face the effects of environmental factors such as lighting, occlusion and scene similarity, as well as the low accuracy of the sensors themselves. Bluetooth and SLAM indoor positioning and navigation devices based on the use of Bluetooth are not affected by light and skid [19], and combined with multiple sensors, complement each other.

With the improvement of Bluetooth beacon performance and cost reduction, indoor navigation applications will be more and more but also face many challenges. Location data and privacy issues are important factors and effective means must be taken to provide security for users [20]. Indoor positioning systems are equipped with many devices, such as communication networks, data analysis and signal detection, which necessarily consume a large amount of electricity and increase the operating costs of the system [21].

5. Conclusion

Today, indoor navigation technology has been widely used in a variety of scenarios such as shopping malls, hospitals, schools, airports, and so on, thanks to its accuracy and practicality. Especially through the integration of Bluetooth technology, the accuracy and efficiency of indoor navigation have been significantly improved. In this paper, the mainstream Bluetooth indoor navigation technologies at home and abroad are introduced in detail, and their application scenarios and methods are summarised systematically, revealing the long-term prospects for the use of Bluetooth technology in the field of indoor navigation.

With the continuous development and improvement of Bluetooth technology, its advantages of low power consumption, long-distance transmission and high data transmission rate make indoor navigation systems more efficient and stable. Driven by the new technology, indoor navigation systems show great potential. Firstly, Bluetooth indoor navigation technology is widely used in many fields, such as retail, healthcare and education. Secondly, the application scenarios and methods of Bluetooth indoor navigation technology are also being enriched. In addition, the long-term use of Bluetooth indoor navigation technology is very promising. With the introduction of new standards such as Bluetooth 5.0, the transmission distance and data transmission rate of indoor navigation systems will be further improved. In terms of cost, as technology continues to advance, the cost of Bluetooth indoor navigation systems is gradually decreasing, making them affordable for small businesses and individual users. At the same time, the ease of use and maintenance costs of the system are also being reduced with the development of the technology, improving the overall efficiency of the system.

In conclusion, the application of Bluetooth technology in the field of indoor navigation is very promising. With the continuous progress and innovation of the technology, the indoor navigation system will become more accurate and efficient, bringing more convenience to all walks of life and promoting the development of indoor navigation technology to a higher level.

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All the authors contributed equally, and their names were listed in alphabetical order.

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