Research on Bluetooth AOA-based Indoor Navigation System for Hospitals

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Abstract. Bluetooth 5.1 introduces the direction-finding function which can detect the direction of Bluetooth signal, on this basis, this project combines the actual hospital scenario and uses Bluetooth AOA method and IoT technology to design the implementation of intelligent navigation system in hospital. The project uses WebGL technology to provide real-time cross-floor hybrid spatial guidance navigation for patients by interfacing with the hospital's HIS and realizing in-hospital intelligent navigation with the help of WeChat applets to help patients quickly and accurately locate their consultation locations. The application of the hospital indoor navigation system can shorten patients' in-hospital wayfinding time, reduce the work pressure of front desk staff, improve patients' medical experience, and effectively improve the digital management level of the hospital.

Keywords: Indoor Positioning; Bluetooth; Navigation; Angle-of-Arrival.

1. Introduction

At present, most of the hospitals with relatively good medical resources in China cover a wide area, have a complex layout and cumbersome access processes, making it difficult for patients and their families to easily find the corresponding consultation rooms, departments and other locations[1].Although hospitals have set up directional maps and guidance signs for each floor, according to the survey about 1/3 of outpatients and their families still go to the information desk or seek help from medical staff every day, and more than half of these questions are related to the location or the consultation process[2]. Patients spend most of their time searching for a place to visit. Although the hospital has invested a lot of human, material and financial resources in setting up additional information counters and signage, there are still problems such as understaffed information counters, unmanned counters and unclear signage, especially when many patients come from overseas to visit the hospital for the first time and are unfamiliar with the topography of the hospital and its various departments, and are in a hurry and have precious time to visit the hospital. Then it is difficult for the hospital to improve patient service satisfaction, and there is still a great shortage of patient access.

Along with the boom in technology, a major trend is emerging in hospitals at home and abroad to transform and upgrade hospitals with "smart hospitals". Current trends in the global healthcare industry call for effective ways to provide more personalized services to patients. It has proven necessary to develop tools based on innovation to accelerate the construction of smart hospitals.

Most hospitals in China are still using floor plans and traditional signage to provide guidance services for patients, while similar projects in China are still in their infancy, with only a few hospitals providing patient hospital navigation (such as a Hospital in Guangdong Province), and the functions are not yet perfect, with inaccurate positioning and inconvenient carrying, which does not greatly enhance the efficiency of users in seeking medical treatment, and other convenient functions are also lacking.

The application of intelligent 3D panoramic navigation technology in the medical industry is groundbreaking, and the project development and construction process has encountered a number of technical difficulties and lacked reference to successful cases. As there are fundamental differences between indoor and outdoor positioning in terms of technology implementation, there are still some shortcomings in indoor positioning, such as positioning accuracy, ease of use and real-time steering discrimination, to a certain extent.

2. Research Content and Technical Route

2.1 Research Content

This project is based on the use of Bluetooth indoor positioning to navigate patients within the hospital, and the project team has chosen the mature ecological WeChat app as the carrier. The project is aimed at patients who come to the hospital for the first time or are unfamiliar with the location of the various departments in the hospital. They can turn on the Bluetooth switch through their mobile phones and get the real-time location of the user after interacting with the Bluetooth base station set up by the project team inside the hospital. On the applet, the user can choose their own endpoint and, according to the algorithm, the applet can give the optimal route based on the user's current location. In addition, users can also simulate navigation by setting their own start and end points outside the hospital area to understand the route in advance.

During the research process, the project team first needed to visit the hospital and build a 3D map of the hospital through WebGL technology on the applet, which can be combined with the navigation and positioning system to complete real-time navigation. The app can be combined with the hospital's public number, and through the interaction and docking between the systems, the system can automatically push navigation-related information to the patient's mobile terminal after the patient has successfully registered online with WeChat, and can automatically obtain the navigation path with a single click, helping the patient to easily reach each department and effectively improve the patient's consultation experience. At the same time, the system can provide statistics on the number of patients attending each department in real time according to the background data, so that patients can plan their time and route.

2.2 Technical Route

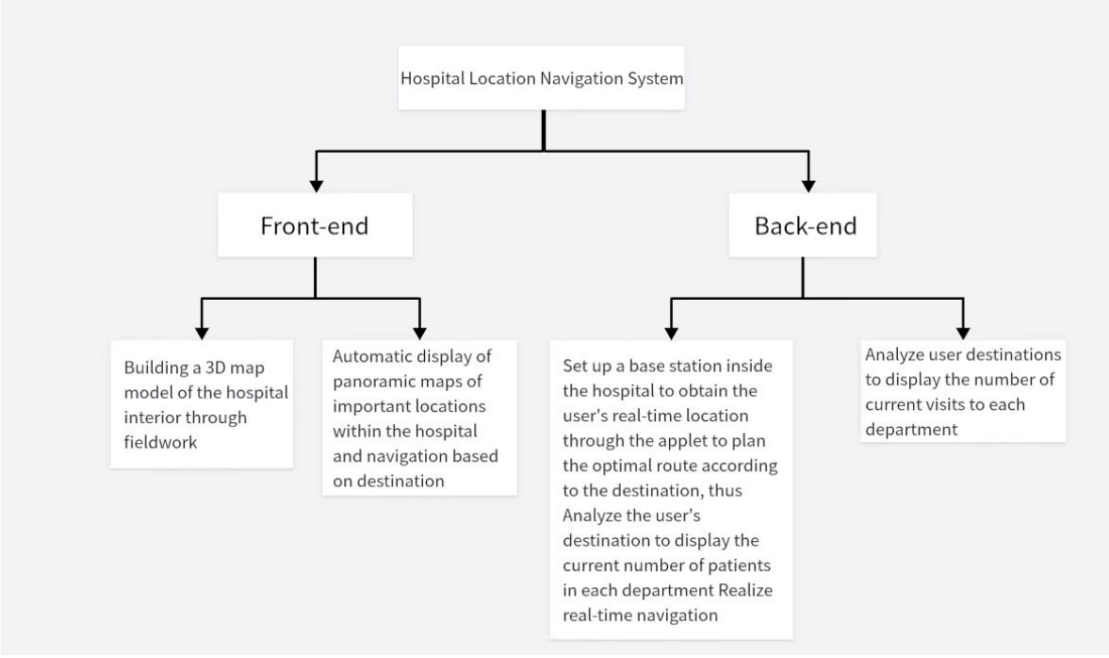


Figure 1. Technical route

After a field trip to A hospital in Inner Mongolia, a 3D map model was constructed, followed by a 3D map of the hospital's interior through WebGL technology on the app, and a number of base stations were set up based on the actual area of the hospital, which interacted with the user's mobile phone signal to determine the user's real-time location. After the project team learns the algorithms related to path planning, the system can calculate the user's current location in the background and finally realise real-time navigation inside the hospital. The technical route is shown in Figure 1.

At the same time, the applet can display the number of people attending each department according to the number of devices in the range and the user's destination. When the number of people attending is too large, the system can automatically triage patients, saving time and effort in management.

3. System Integration

3.1 Navigation Systems

To achieve navigation within a hospital, the user's real-time location must first be determined. Here the project team uses Bluetooth AOA positioning technology, which has emerged in recent years, to ensure that the user's real-time location can be confirmed no matter where they are, by examining the hospital's internal terrain and setting the location of the Bluetooth base station. Secondly, by learning the relevant algorithms, the project team can complete the planning of the optimal path from the user's real-time location to the destination.

3.1.1 Bluetooth AOA Positioning Principle

In early 2019, the Bluetooth Technology Alliance announced the introduction of a new "direction finding" feature in Bluetooth 5.1, which detects the direction of Bluetooth signals and will significantly improve the accuracy of Bluetooth positioning and provide better location services. This ends the history of low-precision fingerprinting by means of RSSI signal strength and provides the foundation for Bluetooth technology to solve the problem of precise positioning and navigation in the Internet of Things [3].

Depending on the upstream and downstream mode of the positioned terminal, Bluetooth high-precision positioning can be divided into two technical principles: the AOA angle of arrival method and the AOD angle of departure method. The AOA angle-of-arrival method is used in this project.

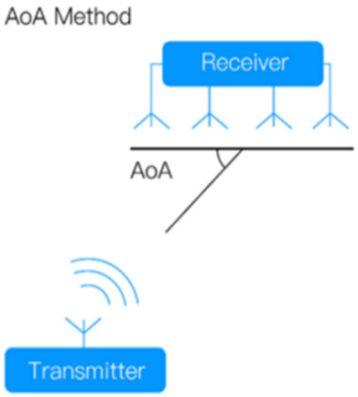


Figure 2. Bluetooth direction finding AOA method

The Angle of Arrival (AOA) method uses a single antenna to transmit a direction-finding signal, while the device at the receiving end has a built-in antenna array. When the signal passes through, it will be received at different distances by the array antennas, resulting in a phase difference, which in turn calculates the direction of the signal [4], as shown in Figure 2.

Whether it is AOA or AOD, the basic principle of angle detection is to obtain the phase difference of the signal on different array elements through the antenna array, and then obtain the incoming wave direction information through the signal angle estimation algorithm. The Bluetooth 5.1 standard protocol has specifically set out the technical requirements for signal IQ sampling and CTE in order to better support AOA/AOD.

3.1.2 Phase Difference of the Signal and IQ Sampling

Taking the two antennas as an example, as shown in Figure 3, when a fixed frequency signal is sent from the transmitter, the electromagnetic wave will arrive at antenna 1 and antenna 2. Due to the

different spatial locations of antenna 1 and antenna 2, the signal will arrive at the two antennas with different wave distances and thus phase differences. Different incoming wave directions will produce different phase differences. The RF chip can obtain the phase information by IQ sampling the signal on each antenna and comparing the phase information on the 2 antennas can obtain the phase difference [5].

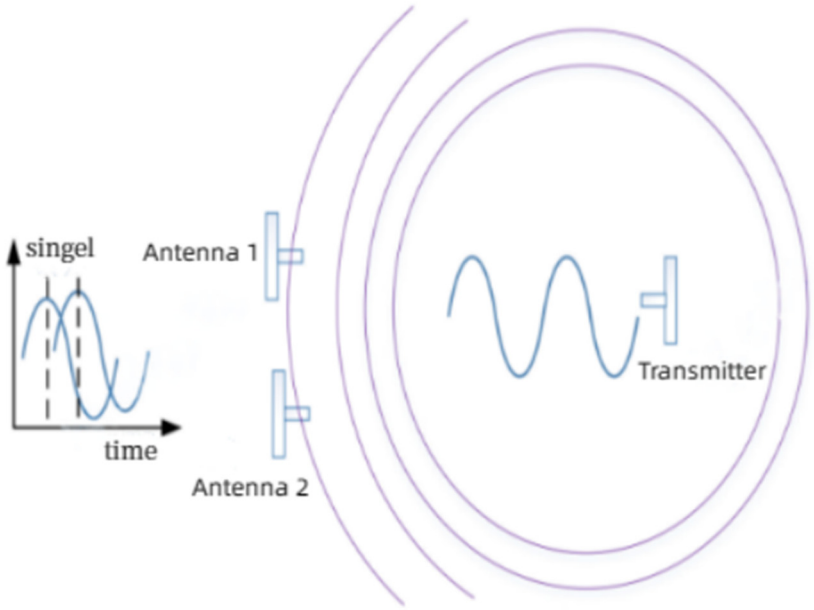


Figure 3. Phase difference of the signal and IQ sampling

3.1.3 Incoming Wave Direction Detection based on Phase Difference

When the two antennas are close enough (less than half a wavelength), the whole-cycle blurring of the phase difference can be eliminated and the direction of the incoming wave can be uniquely determined. As shown in Figure 4, where λ is the wavelength of the transmitted signal, Δφ is the phase difference between antennas 1 and 2 receiving the same signal, θ is the angle of arrival (AOA) of the signal to be sought, and d is the distance between the two antennas [6], from the relationship shown in the figure:

$$\theta = \arcsin\left(\frac{\lambda\Delta\phi}{2\pi d}\right) \tag{1}$$

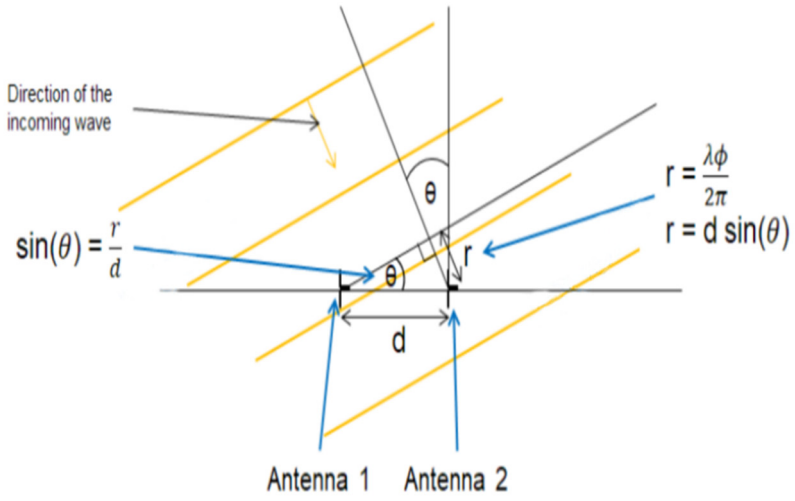


Figure 4. Principle of incoming wave direction detection based on phase difference

3.1.4 Construction of the Positioning System

A common positioning system architecture is shown in Figure 5, which is divided into three parts: positioning sensing, positioning calculation, and positioning application. Positioning sensing includes Bluetooth positioning terminal and positioning base station. According to different positioning requirements, the positioning system can be divided into two-dimensional deployment in multi-slice space, one-dimensional deployment in corridor-type space and zero-position deployment in room-type space. The positioning base station interacts with the positioning engine through the wired network, and the positioning engine performs angle estimation and positioning solution on the signals received by each positioning base station (AOA method), or controls the positioning base station to broadcast the position (AOD method). The positioning application can obtain data from the positioning engine, and the project team needs to build a reasonable solution with the specific situation of the hospital.

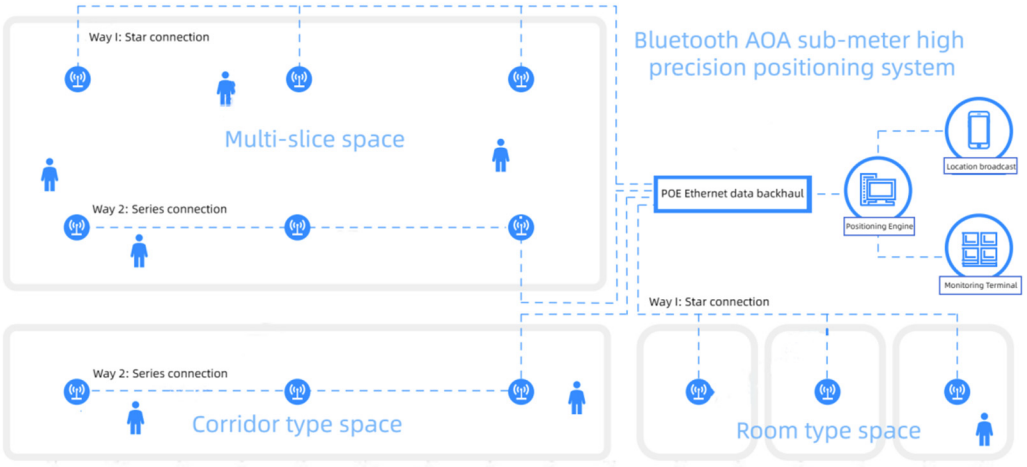


Figure 5. Positioning system architecture

3.1.5 Gaussian and Filtered Indoor Localization Algorithm for Bluetooth Beacons

Due to the presence of severe multipath fading in indoor environments, the measured RSSI values exhibit complex non-Gaussian characteristics. Therefore, the measured RSSI values need to be corrected for BLE beacon localization based on signal fingerprinting. To this end, the Gaussian and filtered Bluetooth beacon indoor localization (GSF-IL) algorithm is proposed. the GSF-IL algorithm first measures the RSSI values in the offline phase to construct a signal fingerprint map; then measures the RSSI values in real time through the online phase, and smoothes the RSSI values measured in real time to filter out some outliers; finally, the user location is estimated by matching.

The GSF-IL algorithm consists of two phases: offline training and online localization. In the offline training phase, the RSSI values of BLE beacons are trained from each training point and a Gaussian mixture (GM) model is built to construct a fingerprint map; in the online localization phase, the RSSI values are first measured online and matched with the fingerprint map, and then the user's location is estimated.

(1) Offline training phase

First collect the data of each BLE beacon RSSI data, such that R_l be the data collected after grid of G_l the RSSI value fromM the RSSI value of each beacon packet, which is defined as in (2)

$$R_l = \begin{bmatrix} RSS^1_{(1,l)} & K & RSSI^1_{(M,l)} \\ M & M & M \\ RSSI^N_{(1,l)} & L & RSSI^N_{(M,l)} \end{bmatrix} \quad (2)$$

where$1 \leqslant \mathrm{l} \leqslant \mathrm{M}$; theR_l The columns in denote the RSSI values received by the same training point from$N$ RSSI values received by the same BLE beacon node.

Then the$\boldsymbol{R}_l$ RSSI values in theGM model, such that$P(\boldsymbol{G}_l)$ denote theGM component. Assuming that theGM model consists ofn_c Gaussian components

$$\mathrm{P}(\mathrm{G_l}) = \sum_{\mathrm{i=1}}^{\mathrm{n_c}} \quad \phi^{(\mathrm{i})}\mathrm{N}(\mu_{\mathrm{l}}^{(\mathrm{i})}, \sigma_{\mathrm{l}}^{(\mathrm{i})}) \tag{3}$$

where$\mathrm{N}(\mu_{\ell}^{(\mathrm{i})}, \sigma_{\mathrm{l}}^{(\mathrm{i})})$ denotes the normal distribution, where$\mu_{\ell}^{(i)}$ is the mean value,$\sigma_l^{(i)}$ is the variance, and$\phi^{(i)}$ denotes the first$i$ weight of the first component.

(2) Online positioning stage

To improve the localization accuracy, the GSF-IL algorithm is iteratively operated. First, the RSSI vector is constructed by observing N BLE beacons, such that$z_k = [Z_k^{(1)}, \cdots, Z_k^{(N)}]^{\mathrm{T}}$ denote the RSSI vector of the kth iteration, and then the Gaussian sum filtering (GSF) algorithm is used toz_k GSF is an effective method to deal with nonlinear filtering problems.

The GSF algorithm assumes that the initial conditional distribution$P(x_0|z_0)$ is equal to the a priori density distribution$P(\boldsymbol{x}_0)$ and assumes that the processing noisew_k is additive white Gaussian noise, and the covariance matrix Q is a known quantity, usingm_c The measurement noise is expressed as a non-Gaussian additive quantity, i.e., the measurement noise is a non-Gaussian additive quantity.

$$P(v_k) = \sum_{i=1}^{m_e} \quad \mu^{(i)}N(v^{(i)}, R^{(i)}) \tag{4}$$

where v_k denotes the measurement noise, and$v^{(i)}$ is the first$i$ measurement noise, and$R^{(i)}$ is the i-th RSSI vector.

First define a state vector$x_k = [y_k, \Delta y_k]^{\mathrm{T}}$, wherey_k denotes the RSSI value, andΔy_k denotes the volatility, andΔy_k depends on the environment and reflects the fluctuation of the RSSI value, the more severe the noise in the environment, the greater the fluctuation.

Invoking the dynamic model of equation (5) to express the process of state vector change

$$\begin{bmatrix} y_k \\ \Delta y_k \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & \Delta t \\ 0 & 1 \end{bmatrix}}_{F_k} \begin{bmatrix} y_{k-1} \\ \Delta y_{k-1} \end{bmatrix} + \begin{bmatrix} w_k^{y} \\ w_k^{\Delta y} \end{bmatrix} \tag{5}$$

Eq.$w_k = N(0, Q)$. The agreement variance is calculated by learning in the offline phase$Q$.

Therefore, the observation model as in equation (6) is established:

$$\mathbf{z}_k = \underbrace{\begin{bmatrix} 1 & 0 \end{bmatrix}}_{\mathbf{H}_k} \begin{bmatrix} \mathbf{y}_k \\ \Delta \mathbf{y}_k \end{bmatrix} + \mathbf{v}_k. \tag{6}$$

Using equation (7) the probability distribution of $\mathbf{v}_k$ can be calculated using the GM approximation likelihood function $P\left(z_k \mid x_k\right)$

$$P\left(z_k \mid \mathbf{x}_k\right) \approx \sum_{i=1}^{m_e} \mathbf{w}_k^{(i)} N\left(\hat{z}_{k|k-1}^{(i)}, S_k^{(i)}\right) \tag{7}$$

Eq.

$$\hat{z}_{k|k-1}^{(i)} = \mathbf{H}_k \hat{\mathbf{x}}_{k|k-1} + \mathbf{v}^{(i)} \tag{8}$$

$$\mathbf{S}_k^{(i)} = \mathbf{H}_k \mathbf{P}_{k|k-1} \mathbf{H}_k^{\mathrm{T}} + \mathbf{R}_k^{(i)} \tag{9}$$

The framework for estimating the user's location is shown in Figure 5: first, the model is trained in the offline phase and the distribution of Eq. (3) is derived; the RSSI values of BLE beacons are collected in the online phase and the probability distribution of Eq. (7) is constructed by combining GSF and WD, then, the BD distance between these two probability distributions is calculated, and finally, the location with the minimum BD distance is selected as the estimated location of the user[7].

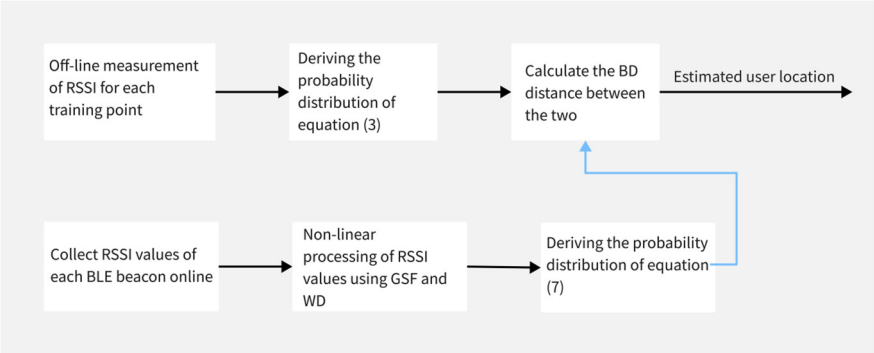


Figure 6. Flow of estimating user location

3.1.6 Optimal Algorithm for Path Recommendation

The path planning recommendation algorithm used in the navigation system in this study is a path planning algorithm based on the idea of segmentation, which has the characteristics of supporting any type of indicator attributes, supporting multiple starting points and multiple endpoints for optimal route queries, response time to meet real-time, fast query road condition updates and customized indicator updates.

Optimal path planning: It will bring users a good navigation experience. The path planning recommendation algorithm adopts the basic idea of CRP algorithm, by distinguishing the topology of the road network and the indicator attributes for processing, in order to achieve the goal of quickly and dynamically adjusting the state of the road network and the recommended solutions. According to the actual geographic information and road conditions of the usage scenario, the recommended route can give priority to the short distance, non-congested, time-saving and energy-saving way of changing floors and buildings while ensuring the overall route rationality[8].

and path planning is divided into the following three cases.

(1) Point of interest (POI) to point of interest (POI) path planning algorithm execution.

(2) Execution of path planning algorithm from coordinate point X,Y to point of interest (POI).

(3) Point-of-interest (POI) navigation in mobile implementation.

3.2 Building of the Applet

First, the project team needed to visit the hospital to complete the construction of the 3D map. In order to adapt to the WeChat environment, the project team could use the official WeChat developer tools provided by WeChat to realize the front-end development and page rendering of the applet using WXML syntax, WXSS style language, WXS scripting language and various supporting components, while using JavaScript code to implement the logic layer and realize geolocation by calling the API provided by WeChat.

3.2.1 3D Map Construction

WebGL is a 3D mapping protocol that makes it possible to display 3D images on the browser. The 3D map engine built based on WebGL technology makes full use of GPU hardware acceleration to substantially improve the rendering performance of large data volumes, and uses Web Worker multi-threading technology to quickly achieve fast data loading and high frame rate operation for complex scenes such as multiple buildings.

3.2.2 Positioning Navigation and HIS System Interfacing

In order to realize the navigation function in the hospital client and achieve humanized service, the navigation module will automatically accept the POIs that HIS pushes to the points of interest that patients may want to go to, such as: payment windows, departments, public facilities, pharmacies, etc. After patients finish registering, they only need to click on the POI list that pops up in mobile applications such as Pocket Hospital APP and WeChat Public, and the program can automatically

guide patients to them, and at the same time, they can also You can also set your own destination[9, 10].

4. Conclusion

Bluetooth AOA positioning technology has unique advantages and broad application prospects in the field of high-precision indoor positioning in the Internet of Things, and its proposed indoor navigation technology provides a guarantee.

In the current period of rapid development of mobile Internet technology, the construction of intelligent navigation system has become an important part of the construction of hospital wisdom, especially the mobile medical applications in the context of the Internet of Things increasingly requires hospitals to be able to export "location capabilities".

In order to allow better patient access and improve the patient experience, the application of intelligent hospital navigation systems has become an irreversible trend in today's era of medical information technology.

Acknowledgments

The authors gratefully acknowledge the financial support from Inner Mongolia University.

Project No. 202210126044, Project Name: Bluetooth AOA-based Indoor Positioning and Navigation System for Hospitals, National Innovation and Entrepreneurship Training Program for College Students, Inner Mongolia University.

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