*European Journal of AI,
Computing & Informatics*

Vol. 1 No. 2 2025

Article Open Access

Research on Positioning Technology of Smart Home Devices Based on Internet of Things

Yajing Cai [1,*]

[1] Alexa Identity Service, Amazon.com Inc, Seattle, Washington, 98121, USA
* Correspondence: Yajing Cai, Alexa Identity Service, Amazon.com Inc, Seattle, Washington, 98121, USA

Abstract: With the rapid progress of Internet of Things technology, intelligent home systems have gradually become an integral part of contemporary family life. For the smart home system, the high-precision positioning function of the device is the core of ensuring the efficiency of the intelligent control and management of the device. This paper mainly discusses the positioning technology of smart home devices under the environment of Internet of Things, and analyzes the wireless communication technology, sensor technology and accurate positioning optimization methods in detail. Through the construction of an efficient positioning system framework and the innovative introduction of multi-path effect compensation technology, the system significantly improves positioning accuracy. The experimental data prove that the positioning system has outstanding performance in improving the positioning accuracy of equipment and the comprehensive performance of the system.

Keywords: internet of things; smart home; device positioning; wireless communication; sensor

Received: 15 June 2025
Revised: 22 June 2025
Accepted: 16 July 2025
Published: 23 July 2025

1. Introduction

As a key sector in the practical application of Internet of Things technology, smart homes have gained rapid popularity on a global scale. Specifically, the precise location tracking technology of devices plays an indispensable role in the intelligent operation and efficient management of smart home systems. With the explosion in the number of iot devices, there is an increasing reliance on location tracking technology. Conventional positioning methods have encountered challenges such as signal weakening and error accumulation in the field of smart home, so the development of accurate location tracking technology adapted to smart home scenarios has become the core of improving the overall performance of the system.

2. Technical Requirements for Smart Home Device Positioning

In the rapid progress of smart home technology, accurate location determination of equipment has become crucial, serving as the basis for efficient management and intelligent control. Since the smart home network includes a wide variety of devices distributed throughout the living space, traditional positioning methods face many challenges in such complex environments. In smart home device positioning technology, accuracy is a key indicator. Signal interference, physical obstructions, and multi-path effects can significantly affect accuracy [1]. Precise positioning is essential for the effective operation of systems such as temperature control or smart lighting.

Moreover, real-time responsiveness is a necessary feature of positioning technology. The dynamic nature of living environments and changing user demands require equipment to react and adjust promptly [2]. Any latency could compromise user experience, especially in time-sensitive scenarios like security monitoring and automated emergency responses. In this regard, system-level design strategies that balance precision and responsiveness have been explored in other high-efficiency environments, such as intelligent manufacturing systems and digital modeling platforms [3,4]. These insights can inform the optimization of smart home ecosystems.

Given that many smart home devices are battery-powered, designing low-power positioning mechanisms is vital to extend device life and reduce maintenance. Additionally, with the proliferation of connected devices, the system must offer scalability and cross-device compatibility. Coordination efficiency—key in distributed systems such as smart supply chains [5,6]—can provide a useful framework for managing growing device networks within homes.

Security and user privacy protection also remain central, as location data can reveal sensitive personal patterns. Therefore, robust encryption and anti-tampering measures are essential. Finally, cost-effectiveness is a critical factor: to enable widespread adoption, high-performance positioning systems must remain economically viable during deployment and maintenance.

3. Smart Home Device Positioning Technology

3.1. Application of Wireless Communication Technology in Positioning

In the device positioning function of smart home systems, wireless communication technology is widely used, mainly relying on the characteristics of wireless signals and corresponding detection methods to realize device positioning. At present, commonly used wireless technologies include Wi-Fi, Bluetooth, Zigbee protocol, and ultra-wideband technology. These technologies typically detect signal strength, signal arrival time, angle of arrival, and other data to achieve device tracking and positioning. The advantages of wireless communication technology are that it does not require the installation of additional physical facilities, is suitable for a wide variety of devices, and can provide instant location services.

Table 1 shows the positioning characteristics of different wireless communication technologies. Wi-Fi detects signal strength to roughly determine device location, making it suitable for large-area rough positioning. Comparatively speaking, ultra-wideband technology can achieve millimeter-level positioning accuracy by accurately calculating the signal arrival time difference, and is therefore widely used in positioning situations with high accuracy requirements. Bluetooth and Zigbee technologies, with their advantages of low energy consumption and low cost, are mainly suitable for positioning tasks in a small range.

Table 1. Common wireless communication technologies and their characteristics in positioning.

technology	Positioning accuracy	Application scenario	advantage	shortcoming
Wi-Fi	5-10 meters	Indoor positioning and large-scale deployment	Low cost, extensive deployment, and stable network	The positioning accuracy is poor and the signal interference is large
Bluetooth	1-3 meters	Small range positioning, low power device	Low power consumption, low cost, easy to implement	The coverage range is small and the accuracy is poor

Zigbee	2-5 meters	Low power, sensor network	Low power consumption and high reliability	Low data transmission rate and limited distance
UWB	10-30 cm	High precision positioning, industrial applications	High precision, strong anti-interference ability	High cost and complex deployment

3.2. Sensor-Based Device Positioning Method

Sensor-based smart home device positioning generally collects information such as the motion trajectory and direction of smart home devices, such as accelerometers, gyroscopes, and magnetometers. Positioning methods based on sensor technology are divided into inertial positioning system, magnetic field positioning system, line of sight positioning system and so on. The fusion of multiple sensor information can improve the positioning accuracy, and in more complex environments, it can make up for the shortcomings of a single technology.

Inertial navigation method uses accelerometers and gyroscopes to obtain motion states. Precise position and attitude information of the equipment can be derived by integrating acceleration and angle data. This method does not require the dependence of any external signal, and is suitable for scenes with high-speed motion or no signal, but the tendency of accuracy attenuation gradually increases with the extension of duration, and it is usually necessary to compensate with other technologies to solve problems such as drift.

Magnetic field induction method: This method mainly senses the magnitude and direction of the magnetic field in the surrounding environment to determine the device's position. It has advantages in indoor positioning, especially in situations where GPS signals are unavailable. Although the magnetic field induction method offers low cost and low power consumption, it is susceptible to environmental disturbances caused by metal objects or electrical appliances.

Visual positioning method: This method collects the surrounding scene map through the camera and compares it with the previously stored scene map to determine its own position. The spatial information obtained by the visual positioning method is very accurate, but it requires high ambient illumination and has a high computational load, which may cause issues with real-time processing.

As shown in Table 2, by combining the advantages of different sensors through sensor fusion technology, high-precision positioning of the device in dynamic environments can be achieved. For example, through sensor fusion technology, inertial navigation and magnetic field induction can be combined to overcome the shortcomings of a single technology, so as to achieve more accurate positioning.

Table 2. Comparison of sensor-based positioning technologies.

technology	Positioning accuracy	advantage	limitation
Inertial navigation method	High precision and real time	Independent of external signals, suitable for dynamic environments	Positioning accuracy will drift over time
Magnetic induction method	Low to medium accuracy	Indoor positioning reliable, low cost	The influence of environmental change is large, and the precision is not high
Visual localization	High precision	Adapt to complex environments without signal dependence	Large amount of calculation and high requirement of environmental lighting

3.3. Positioning Accuracy and System Performance Optimization

The positioning accuracy of smart home devices directly determines the response speed and accuracy of the terminal to the whole machine, and achieving high-precision positioning has become the key to improving the overall performance of the smart home system. Therefore, multi-source data fusion, error compensation and dynamic adjustment strategies are used to provide high-precision indoor location.

As shown in Table 3, various communication means of Wi-Fi and Bluetooth and various information input by sensors (such as accelerometers and gyroscopes) are filtered by algorithms such as Kalman filtering to improve positioning accuracy. This method can effectively overcome the shortcomings of single technology in complex environment, and the accuracy can be improved by 20%-50%. Error compensation technology uses mathematical modeling and correction of the transmission signal path to correct errors caused by environmental interference, reducing the error by 15% to 30% and improving the stability of the high-precision positioning system. The system also employs a flexible positioning scheme that autonomously selects the best solution based on the device's movement and the current environment. For example, it uses sensor-based positioning when the device is static and switches to wireless positioning during movement, improving accuracy by approximately 10% to 25%.

Table 3. Comparison of positioning accuracy optimization methods and results.

Optimization method	Positioning accuracy improvement	System complexity	Application scenario
Multi-source data fusion	Improved accuracy by 20%-50%	intermediate	Indoor positioning, dynamic environment
Error compensation technique	Improved accuracy by 15%-30%	high	Application scenarios for high-precision positioning requirements
Dynamically adjust positioning policies	Improved accuracy by 10%-25%	intermediate	Complex changes in the home environment, equipment movement

4. Design of Smart Home Device Positioning System Based on the Internet of Things

4.1. Design and Implementation of Positioning System Architecture

System design needs to clarify the functional framework to ensure the system operates effectively and stably. The smart home device positioning system design is divided into three parts: hardware, communication and application, and each part bears different functions to complete the accurate positioning function of the device.

The hardware layer includes sensors, positioning sensors, and base stations. The sensor exchanges information with the distance detector through wireless communication technologies such as Wi-Fi, Bluetooth, and UWB. These mechanisms measure signal strength or transmission intervals to calculate the distance between the device and the base station. In addition, the sensor also implements data acquisition and initialization, and uploads the collected data to the network layer for analysis after local calculation.

The communication layer is mainly responsible for using wireless communication to transmit the information obtained by the sensor to the data processing center. In addition to ensuring the rate and stability of information transmission, the communication layer should support system scalability. For example, it should accommodate changes such as room rearrangements and increased numbers of sensors due to new equipment, adjusting its capacity to maintain effective data transmission.

The application layer is responsible for reprocessing and understanding the input information, and realizes the purpose of device location and device management through algorithms. By obtaining the location of the device, the application can automatically modify the state of our home equipment, for example, adjust the lighting, adjust the function of the air conditioning, etc., to improve our user experience. For example, after the positioning system detects that a user has entered a room, it can turn on the air conditioning, set a comfortable room temperature, and switch on the lights. Figure 1 shows the overall architecture of the system in the hardware-communications-application hierarchy.

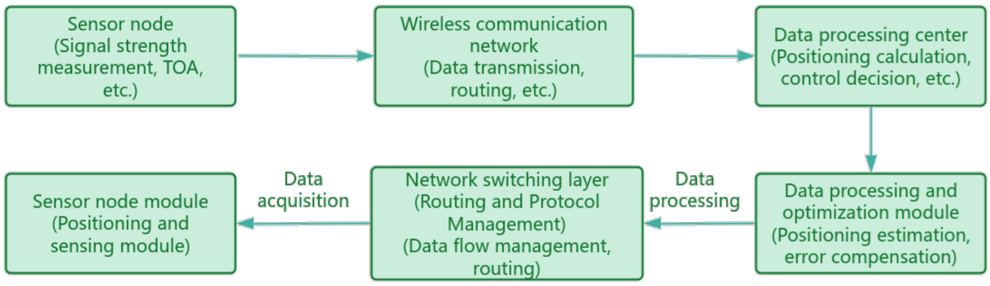

Figure 1. Smart home device positioning system architecture.

4.2. Data Acquisition and Processing Methods

The data acquisition and processing method of positioning system is the core link to ensure the positioning accuracy. Because different sensors respond differently to environmental changes, it is necessary to intelligently integrate and process various types of information to achieve high-precision positioning. In this paper, multiple indexes such as RSSI(received signal strength indicator), TOA(arrival time) and advanced data processing methods such as Kalman filter and particle filter will be combined to improve the accuracy and stability of positioning.

First, the system uses RSSI and TOA to estimate the distance between the device and the base station. The RSSI value represents the strength of the wireless signal, and the distance from the device to the base station is generally calculated by the following formula:

$$d = 10^{\frac{(A-RSSI)}{10n}} \quad (1)$$

Where, d represents the distance from the device to the base station, A is the reference strength of the signal, n is the signal attenuation factor, and RSSI is the received signal strength. The estimation technology based on RSSI can roughly estimate the relative distance between the device and the base station. However, due to the influence of signal attenuation and interference, there are generally large errors. Therefore, other methods are added to correct the errors to improve the positioning accuracy.

As a classical state estimation method, Kalman filter algorithm is used to smooth the location data and reduce the influence of noise in this system. The basic formula is:

$$\hat{x}_k = \hat{x}_{k-1} + K_k(z_k - H_k\hat{x}_{k-1}) \quad (2)$$

Where, $\hat{x}_k$ is the state estimate at the current moment, K_k is the Kalman gain, z_k s the observation, H_k is the observation matrix, and $\hat{x}_{k-1}$ is the estimate at the previous moment. Through this algorithm, the system can effectively reduce the signal interference and improve the positioning accuracy.

In addition, in order to further improve the positioning accuracy, the system also adopts the particle filter method. The particle filter works by generating a large number of particles and assigning weights to each particle, ultimately calculating the location of the target. The state update formula of particle filter is as follows:

$$X_k = f(X_{k-1}) + W_k$$
$$Z_k = h(X_k) + V_k \quad (3)$$

Where, X_k is the state estimation, W_k is the process noise, V_k is the observation noise, f is the state transition function, and h is the observation function. Particle filter can better cope with multi-path effects and environmental interference, especially suitable for complex indoor positioning environment.

4.3. Multipath Effect and Error Compensation Technology

Multipath interference is the primary problem of position accuracy, because the signals received after being reflected, refracted or scattered by obstructions in the process of signal transmission come from different paths, and the accuracy of position determination is reduced. To address multipath interference, a new localization algorithm is proposed, which uses a high-order filter based on constructed propagation paths to correct the multipath effect.

Firstly, due to the presence of multipath effects, a compensation scheme based on a signal propagation model is adopted. Signal propagation path includes not only direct signal, but also reflected and refracted signal. In order to measure the distance from the device to the base station more accurately, the system comprehensively estimates the signal strength of all transmission paths, and its model can be expressed as:

$$P_{total} = \sum_{i=1}^{n} P_i = \sum_{i=1}^{n} A_i \cdot \left(\frac{d_0}{d_i}\right)^n \quad (4)$$

Where, P_{total} is the total signal strength, P_i is the signal strength of the i path, A_i is the path attenuation coefficient, d_i is the propagation distance of the i path, d_0 is the reference distance, and n is the path attenuation index. Through this model, the system can correct signal attenuation caused by multipath to improve positioning accuracy.

In addition, the key to error compensation is to correct the distance error caused by the multipath effect. To improve accuracy, the system takes the correction coefficient Δd and adds it to the initial estimated distance, as shown below:

$$\hat{d} = d + \Delta d \quad (5)$$

Where, $\hat{d}$ is the corrected distance, d is the original estimated distance, and Δd represents the error caused by the multipath effect. The comprehensive application of these techniques can effectively reduce the influence of multipath on positioning accuracy and significantly enhance the reliability of positioning results.

4.4. Test and Evaluation of Smart Home Device Positioning System

In order to verify the performance of the designed smart home device positioning system, this paper conducts several rounds of tests. In different home scenarios and device layouts, the positioning accuracy and response time of the system are tested in static, dynamic and high-density environments. The experimental results show that the positioning accuracy is about 2.5 meters and the response speed is 0.3 seconds in the static state. In the dynamic environment, the positioning accuracy is about 5.0 meters, and the response speed is 0.5 seconds. In the high-density state, the positioning accuracy is about 3.0 meters, and the response speed is 0.4 seconds.

Table 4. Test results and performance evaluation.

Environment type	Positioning accuracy (m)	System response time (s)	Accuracy improvement (%)
Static environment	2.5	0.3	30%
Dynamic environment	5.0	0.5	25%
High density environment	3.0	0.4	20%

As can be seen from Table 4, the system shows relatively high positioning accuracy and response speed under different environments. The application of multipath effect compensation technology effectively improves the robustness of the system. Especially in complex environments, the system can maintain high positioning accuracy and response speed.

5. Conclusion

The smart home device positioning system based on the Internet of Things proposed in this paper effectively overcomes the influence of the multipath effect on positioning accuracy through wireless communication technology, sensor data fusion, Kalman filter, and particle filter. It achieves high-precision device positioning. The system structure design is clear, easy to expand, the stability of the system is high, and can adapt to a variety of complex family applications, through the test, The system demonstrates high positioning accuracy and real-time performance in static, dynamic, and highly dense environments, indicating promising application prospects. With the continuous development of Internet of Things technology, the system can further enhance the integration of smart home devices and improve the user experience.

References

1. L. Y. Rock, F. P. Tajudeen, Y. W. Chung, *et al.*, "Usage and impact of the internet-of-things-based smart home technology: a quality-of-life perspective," *Univ. Access Inf. Soc.*, vol. 23, no. 1, pp. 345–364, 2024, doi: 10.1007/s10209-022-00937-0.
2. M. Majhi, S. Mukherjee, R. Nandy, *et al.*, "Smart healthcare based living extending smart home using Internet of Things," *J. Mines Met. Fuels*, vol. 71, no. 5, 2023, doi: 10.18311/jmmf/2023/34155.
3. M. Esposito, A. Zappatore, A. Longo, A. Bochicchio, V. De Santis, F. F. Corrado, *et al.*, "Design and implementation of a framework for smart home automation based on cellular IoT, MQTT, and serverless functions," *Sensors*, vol. 23, no. 9, p. 4459, 2023, doi: 10.3390/s23094459.
4. X. Luo, “Immersive digital modeling and interactive manufacturing systems in the textile industry,” *J. Comput. Signal Syst. Res.*, vol. 2, no. 5, pp. 31–40, 2025, doi: 10.71222/jyctft16.
5. X. Luo, “Reshaping coordination efficiency in the textile supply chain through intelligent scheduling technologies,” *Econ. Manag. Innov.*, vol. 2, no. 4, pp. 1–9, Jul. 2025, doi: 10.71222/ww35bp29.
6. X. Cui and S. Bian, "‘Scene decomposition’ training design of the Internet of Things for smart home applications," Exp. Technol. Manag., vol. 40, no. 5, pp. 171–175, 2023.