

Indoor Positioning System

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ABSTRACT

In today's smart life, convenient and fast information acquisition greatly enriches our perception of life. People spend most of their time in an indoor environment. In the face of the rapidly increasing indoor environment area, GPS cannot meet our needs for indoor positioning. With more and more urgent demands, indoor positioning technology has attracted great attention in recent years. This article will make a general comparison and analysis of the mainstream indoor positioning technology in recent years, then study its implementation principles and advantages and disadvantages. It is hoped that the most suitable technical system can be accurately selected in different scenarios and put into the specific implementation plan as soon as possible.

KEYWORDS

Indoor Positioning System, WiFi-based Positioning System, RFID, Bluetooth Positioning, IR Positioning System, Ultrasonic Wave Positioning, UWB, Visible Light Positioning.

1 Introduction

An Indoor Positioning System (IPS) is a system which is able to locate one or more people and objects in an indoor environment where GPS and other satellite technologies lack precision or fail entirely. After sending this location to some special applications, the application such as wayfinding, real-time location system, first responder location system and inventory management can make this very useful.

An Indoor Positioning System is usually composed of two different elements: Anchors and location Tags. Anchors are devices placed in the building, while a tag is carried by the person or object whose location is of interest.

Real-time knowledge of the location of people or objects has become essential for the deployment of services in many fields such as retail, logistics, urban planning, leisure activities, etc. (e.g. GPS).

However, GPS is not always able to locate people when they are inside a building. This is because GPS technology uses the signals of satellites in orbit. These signals are seriously degraded when there is no direct visibility, which makes indoor location finding difficult.

Next we will introduce the principles and technologies and then analyze the application areas of the positioning system.

2 Principles

2.1 Positioning recap

Before analyzing the principles of indoor positioning system, it is important to understand how outdoor positioning works. Basically, there are two ways to determine a person's position. The first method is to calculate the exact position at a given time which is called absolute positioning. According to the shape of the earth, we use two angles called latitude and longitude to ensure the location in earth, including height and distance.

In century years, it is a difficult work for the navigator to ensure the position because they need to spend a lot of time to calculate nearly location. They need to use a sextant to measure the latitude while measuring longitude with a precision watch. However, the using of the technique has a limitation that it can only be used in a good weather or even in a certain time.

However, the new technique GPS was emerged since people use it for military and civilian in 1970s. The GPS uses a 32 satellites constellation which can help us easy to know the precious location because people put a very accurate and synchronized atomic clock in each satellite. The clock will send a special radio wave signal. Any equipment can achieve the signal from the different satellite as long as it can work well with GPS. As radio waves across at a known speed, this equipment can receive the signals from several satellites in different time stamps. That is the way how we can calculate the distance between each satellite and the receiver.

We use the algorithm called Trilateration to calculate current position after we distance between satellite and receiver. It is easy for us to know the position of a sphere or a plane with this algorithm which is very significant because it works for all the indoor and outdoor positioning techniques.

The second method to get the position is to calculate speed and direction from the latest point. This is known in the aviation industry as relative positioning, also known as Dead Reckoning in the aviation industry.

This technique relies on a device which is called an inertial measurement unit (IMU). This measurement uses multiple gyroscopes and accelerometers to calculate the distance covered. The measurement can make a contribution to some era such as hips, space rocket, cars and aircraft which need to confirm the current position.

2.2 Indoor positioning

Unlike the outdoor positioning measurement, indoor positioning is a complex matter because the walls and roofs may block the GPS wave. This can lead to important loss of accuracy, even tens of meters. Furthermore, it is completely impossible for GPS to figure out the floor where the receiver is located on. It is especially true that no signal is being received underground. It is impossible to use IMU to ensure the indoor position because there is a limitation indoor. The correlation between the size of the IMU and its accuracy is the less accurate with the smaller the IMU. However, people usually smartphone indoors which cannot embed the large IMU. We need to develop a new product to represent it.

Indoor positioning techniques can divide into four main categories: proximity, trilateration, fingerprinting and motion. In order to achieve the better accurate, we can use these techniques alone or in combination.

Proximity positioning is based on direct contact or proximity between the receiver and the device. Usually, it is used on the client side. In addition to Wi-Fi with server-side detection these are some of the possible technologies:

1. The QR code / NFC tag can be read via a smartphone camera or NFC reader. The QR Code / NFC tag is then attached to a precise location in the building.
2. Bluetooth Low Energy (BLE) devices are also known as beacons. The beacon will send a signal while the smartphone located in the transmitting area. The location will be more accurate if there are more beacons.
3. Visible Light Communication (VLC) devices are also known as Li-Fi. LED sends a invisible signal to the receiver. It is easy to provide an accurate location because each light has a unique ID and this can only be read directly underneath the light,
4. A Wi-Fi access point can link a smartphone, or any kind of device which enabled Wi-Fi.
5. Ultrasound devices are usually used inside shopping center, which is on top of existing audio systems.

Trilateration Is used to calculate the distance between the receiver and several transmitters with the position of the latter. The way to determine the distance is called RSSI and ToF algorithm. First, we talk about the RSSI which represented for Relative Received Signal Strength Indication. Based on the attenuation, RSSI allows distances to be calculate following the physical law of square inverse proportion. Next is Time of flight, also known as time of

flight (ToF). ToF is used to calculate the distance between a transmitter and a device. To compare with RSSI, the results that ToF involves requires a dedicated chipset with round-trip communication and complex signal processing in better accuracy and higher costs. The following techniques use triangulation:

1. Bluetooth Low Energy (BLE) and ultrasound. Based on trilateral measurements, although they are proximity technologies, they can also be used to provide positioning.
2. Wi-Fi using trilateration. This trilateration can be used on some server side expect IOS device.
3. Ultra-wide Band is another emerging technology that can provide very precise location due to the use of ToF to calculate the distance between receiver and transmitter. However, the technology has several drawbacks, for example, a lack of standardization, high costs while resulting in no available smartphones.

Fingerprint positioning technology uses signal measurements between buildings to calculate a person's location. Because we can record the unique signal from every location, so after comparing the received signal with the existing record we can calculate the current position. However, fingerprint recognition also has a negative side. First, it is only effective when in motion. Second, it needs a long-term stable signal. This technique can be used alone or to improve the accuracy of other positioning techniques. In addition, fingerprint recognition technology from multiple sources can be combined to improve accuracy. The following is a list of technologies that can utilize fingerprint technology:

1. The effect of Bluetooth Low Energy (BLE) fingerprinting. Because it can be performed on the client side so it is very good to use. BLE signal has been proven to be stable for a long time.
2. Wi-Fi fingerprints are as easy to use as BLE. However, it cannot be used on iOS devices due to Apple's restrictions. This is the reason why it is only used on Android smartphones.
3. Magnetic field fingerprints use unique changes in the earth's magnetic field. It is unstable because of the multiple factors.
4. Photo fingerprints are based on image analysis inside the building. It can work very well on it because there are difference between floors. However, it will not to be long-term stable if there is no fingerprint can refresh the record frequently which comes from a high-resolution permanent camera.

Locating movement inside and outside buildings is based on the same principles with different technologies. Because conventional IMUs cannot be used, we use smartphone sensors to quantify movement. The problem with these techniques is the poor accuracy. Due to the small size of the sensors and the accumulated errors, this level of accuracy is far below that of IMU. As for fingerprint recognition, it would be better to use motion localization rather than stand-alone techniques to add trilateral measurement localization.

After briefly introducing the categories of indoor positioning system, next we will introduce the technology and application of indoor positioning system in detail

3 Technologies

With the advancement of our country's urbanization process, the face of the city is undergoing tremendous changes. More and more large buildings have become new landmarks in the city, and these modern large buildings have a huge amount of indoor space. As GPS cannot provide reliable location data under indoor conditions, indoor positioning technology is becoming a hotspot for academic research and industry applications.

Commercial indoor positioning systems can generally be divided into four categories based on the positioning technology they rely on:

- Indoor positioning systems based on computer vision technology.
- Indoor positioning systems based on wireless communication technology.
- Indoor positioning systems based on LED visible light technology.
- Indoor positioning technology based on geomagnetic matching.

We gave examples of mainstream indoor positioning technologies in 2020 and compared their advantages and disadvantages:

Tech.	Cost	Advantages	Disadvantages
WiFi	Low	Extensive network, strong communication capabilities.	Easily disturbed by environment.
RFID	Medium	Low cost, high precision.	Tags have not communication ability, short effective distance.
Bluetooth	Low	The equipment is small in size, easy to integrate, and easy to popularize.	Short propagation distance and poor stability.
Infrared	High	High precision.	Straight line of sight, short transmission distance, easy to interfere.
Ultrasonic Wave	High	High precision.	Affected by ambient temperature, short transmission distance.

UWB	High	High precision and strong penetration.	High cost and small coverage.
Visible Light	High	High communication speed, strong anti-interference ability.	Small coverage.

Table 1 Comprehensive comparison of mainstream indoor positioning technologies

In order to analyze specific issues in the implementation process, we need to be able to distinguish the characteristics of different positioning technologies.

3.1 WiFi-based Positioning System

The tags of the WiFi-based system are WiFi transmitters, which can send simple packets to multiple WiFi access points in the facility. These access points report the time and intensity of reading to the backend. The backend uses an algorithm to calculate the location, and then sends the location information to the cloud.

This positioning system usually uses a broadband of 3-5m, so it can achieve quite high accuracy. But the basic requirement is that at least three access points are needed to "hear" each tag transmission. If there is no WiFi access point supporting it, it will be an expensive location technology. WiFi tags are also quite expensive, and also are usually less energy efficient than their alternative products, so the cost performance is not very high in general scenarios.

There are two types of Wi-Fi positioning technologies:

- Through the mobile device and the wireless signal strength of the three wireless network access points, the differential algorithm is used for triangulation method.
- Record the signal strength of a large number of determined location points in advance, then compare with the signal strength of the newly added equipment to have a database of huge amounts of data to determine the location.

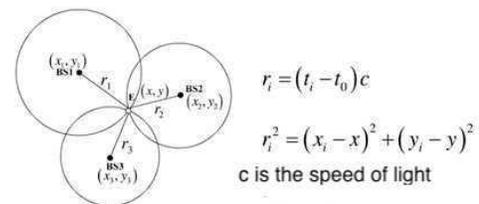


Figure 1 triangulation method

Advantages: high overall accuracy, easy expansion, automatic data update, low hardware cost, and high transmission rate.
Disadvantages: short transmission distance and high power consumption. Due to the complicated indoor space structure, there are shadowing and multipath effects in the propagation of radio waves in the indoor space.

Applicable scenarios: Positioning and navigation of people or vehicles can be used in medical institutions, theme parks, factories, shopping malls and other occasions.

3.2 Radio Frequency Identification (RFID)

RFID refers to the ability to identify specific targets and read and write related data through radio signals. This process does not require the establishment of contact between the identification system and the target.

RFID indoor positioning technology uses radio frequency to fix the antenna and adjust the radio signal into an electromagnetic field. The label attached to the object carries data and needs to be transmitted. The purpose of this is to automatically identify and track the object. After the tag enters the magnetic field, the induced current generated can transmit the data, so no additional battery support is required. This allows multiple pairs of two-way communication to exchange data to achieve the purpose of identification and triangulation.

Advantages: The working distance is very close, but it can get information accurate to the centimeter level within a few milliseconds. The size of the tag is small and the price is low.

Disadvantages: No communication capability, poor anti-interference capability, and not easy to integrate into other systems. And it is not perfect in many details, such as user safety and privacy protection.

Applicable scenario: positioning by the user in a specific area. It can be widely used in emergency rescue, asset management, personnel tracking and other fields.

3.3 Bluetooth Positioning

It is very similar to WiFi-based positioning.

Use several Bluetooth LAN access points installed indoors to maintain the network in a multi-user-based basic network connection mode. And need ensuring that the Bluetooth LAN access points are the main equipment in this micro network area from beginning to end. Then triangulate the newly added blind node by measuring the signal strength. At present, there are two main ways to locate Bluetooth iBeacon: RSSI (Received Signal Strength Indication) and fingerprint-based positioning. There are also many applications that tend to combine the two.

Since Bluetooth positioning relies on the local area network, the distance has a great influence on its positioning effect. There is a challenge based on distance: On the one hand, Bluetooth has a high frequency signal of 2.4GHZ, which is easily interfered due to the complex indoor environment. On the other hand, two different ways of Bluetooth positioning will be discussed.

Based on RSSI: There are many reflection/refraction phenomena in the indoor environment, which will affect the reliability of the RSSI value. In order to improve the positioning accuracy, it is necessary

to obtain the RSSI value multiple times to smooth the result, which will greatly increase the time delay.

Based on Positioning Fingerprints: The cost of obtaining fingerprint data in the early stage is high, and database maintenance is difficult. Assuming that the shopping mall has been transformed and new base stations are added, the original fingerprint data is likely to become useless data. Therefore, the core problem of this technology is how to balance positioning accuracy, delay, and cost.

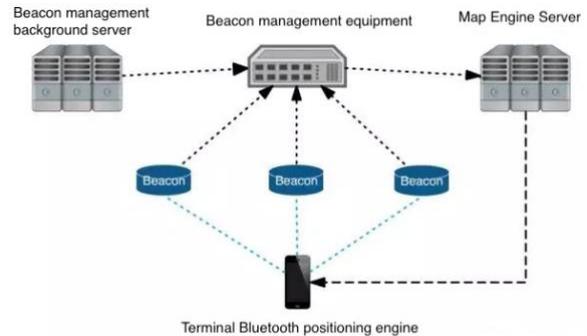


Figure 2 Bluetooth indoor positioning technology

Advantages: Bluetooth low energy devices have low power consumption, no additional power supply, and easy integration.

Disadvantages: For the complex space environment, the stability of the Bluetooth system is poor. And the price of Bluetooth devices is more expensive.

Application: For a small-scale positioning for person. The indoor environment is relatively empty and concise, such as a single-front lobby or a store.

3.4 Infrared-based (IR) Positioning System

Infrared-based indoor positioning systems use infrared light pulses to locate signals in buildings. Infrared receivers are installed in every room inside the building. When infrared tags emit pulses, the infrared receiver device will read it. It is worth mentioning that infrared can easily ensure room-level accuracy. It uses light instead of radio waves that cannot pass through walls, which means that the positioning results are beyond doubt.

There are two realizations of infrared indoor positioning:

- The target to be positioned uses infrared markers as a moving point, and a sensor installed indoors receives light for positioning.
- Multiple pairs of transmitters and receivers are woven into an infrared network, which covers the entire space to be measured and directly locates the moving target.
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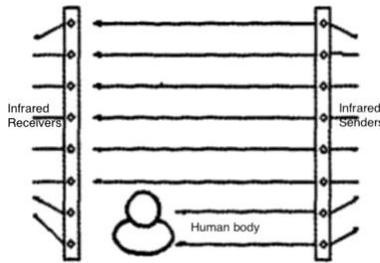


Figure 3 an infrared network

Since the implementation principles of the two are not the same, their desirability is also different. Next, we need to analyze and discuss each situation.

For the first method. **Advantage:** It is easy to achieve higher accuracy in an open room. Passive positioning of infrared radiation sources can also be realized. **Disadvantages:** Because the infrared transmission distance is not long and it is easily blocked by obstacles, a large number of very densely distributed sensors are required, which means that the implementation cost is high. In addition, infrared is easily interfered by heat sources and lights. **Applicable scenarios:** Used in the military, passive positioning of infrared radiation sources such as major weapon facilities. It can also detect the position of an autonomous walking robot indoors.

For the second way. **Advantages:** No need to locate the object to carry tags, strong concealment. **Disadvantages:** Requires dense sensors, which is very costly. **Applicable scenarios:** high-level security.

3.5 Ultrasonic Wave Positioning

Can also be regarded as a acoustic system. It mainly adopts the reflective ranging method, then determines the position of the object through methods such as multilateral positioning. The system consists of a main rangefinder and several receivers. The main rangefinder is placed on the target to be measured, and the receiver is fixed in the indoor environment. When positioning, the signal of the same frequency is transmitted to the receiver, and the receiver reflects and transmits it to the main rangefinder. Then we can calculate according to the time difference between the echo and the transmitted wave, and then we can get the distance and direction to determine the position of the object.

The specific implementation process is as follows: Tags will emit sounds within the ultrasonic range. The receiver (sometimes multiple, sometimes a "smart" receiver) in the room picks up these sounds and locates tags in this way. One benefit of using sound is related to multipath resolution. Assume that we want to send data and make time measurements, we could guess the position based on the speed. If that signal bounced off the wall over there, there would now be multipath. Therefore, the multipath resolution capability is:

$$\text{multipath resolution capability} = \frac{\text{Ultrasonic velocity}}{\text{bandwidth}}$$

Advantages: The positioning accuracy is very high (up to the centimeter level), the structure is relatively simple, there is a certain degree of penetration, and the ultrasound itself has a strong anti-interference ability. **Disadvantages:** The attenuation in the air is large, not suitable for large-scale occasions. Expensive and accurate analysis is required because the reflection ranging is greatly affected by multipath effects and non-line-of-sight propagation.

Applicable scenarios: Mainly used for object positioning in unmanned workshops.

3.6 Ultra-Wideband (UWB) Positioning

UWB positioning technology is a new technology, in fact it is very different from the traditional positioning technology in the past.

It uses the anchor nodes and bridge nodes with known locations that have been arranged to communicate with the newly added blind nodes, then uses triangulation or fingerprint positioning to obtain accurate location information. The entire system requires three or more UWB readers to send very wide pulses on the GHz spectrum, and then the reader can listen to the chips sent by the UWB tags. These tags have a spark gap exciter, which generates a small pulse inside them. These pulses generate a short, coded, very wide pulse train almost instantaneously. Then, the reader reports a very accurate time measurement result from the tag back to the central server.

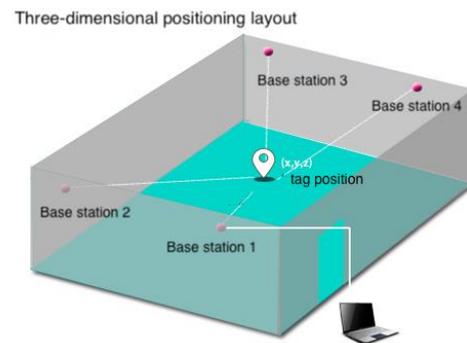


Figure 4 Accurate 3D positioning arrangement: A positioning base station is arranged every 50-100 meters, so that four base stations can receive the pulse sent by the tag at any time.

The whole system is divided into three layers: management layer, service layer and field layer. The scene layer is composed of anchor and tag. The positioning anchor point is used to calculate the distance between the tag and the receiver, and the message is sent back to the position calculation engine through wired or WLAN. The tag is associated with the located person and object, communicates with the Anchor and broadcasts its location. We can clearly see that the system has a clear hierarchy and a clear structure.

Advantage: It may be the most accurate positioning technology at present. It has GHz-level bandwidth, strong penetrating power, good anti-multipath effect and high security. **Disadvantages:** Because the newly added blind nodes also need to actively communicate, the power consumption is high.

Applicable scenes: It can be used for radar detection, as well as indoor precise positioning and navigation in various fields.

3.7 LED Visible Light Positioning

By encoding each LED light, the ID is modulated on the light, the light will continuously emit its own ID, and these codes are recognized by using the front camera of the mobile phone. The obtained identification information will be searched in the map database and its corresponding location information will be determined to complete the positioning process. Since the implementation of this technology does not require additional deployment of infrastructure, the expansion of the number of terminals has no adverse effect on performance, and high accuracy can be achieved.



Figure 5 Visible Light Positioning Technology Design Architecture

Advantages: high distribution density, low cost, rich frequency spectrum, high confidentiality and high speed. **Disadvantages:** The coverage is small and easily blocked.

Applicable scenarios: Used in fields such as airplanes, automobiles and smart life. For example, a user can download related applications. When he arrives in front of a certain shelf in a shopping mall, the application can detect the specific location of the shelf by detecting the lights around the shelf.

4 Applications

Although indoor positioning technology is called the extension of outdoor positioning technology, because of its application scenarios and accuracy requirements, it did not have too much commercial value for a long time. In recent years, because of the development of consumer-level market positioning technology led by Ibeacon, and the marketization of centimeter-level ultra-precision positioning technology led by UWB technology, the

usefulness of indoor positioning technology has become more and more obvious.

The following are the areas where indoor positioning can be applied. The first is a VR theme game park based on 2D or 3D positioning. The game is very demanding on experience. If the accuracy provided by the positioning technology is not high enough, the player will have a strong sense of dizziness during use, which makes the game in this way unable to be recognized by the consumer market at all. However, the previous traditional positioning technologies such as WIFI positioning and Bluetooth positioning, because of the limitations of the accuracy provided by the technology per unit cost, cannot meet the needs of indoor game positioning at all. This is one of the reasons why indoor positioning technology has only recently been used for game positioning.

The second application area is security. For example, firefighters enter the scene to fight the fire. In order to ensure the personal safety of firefighters, they press positioning buttons on their uniforms to visualize the on-site rescue of firefighters. Another example is that due to public places, the back-office command site terrorist attacks or sudden disasters in public places needs to have a better front- and back-office cooperation with on-site personnel. Using indoor positioning system, the back-office commander can understand the movements of on-site personnel in real time, so that on-site personnel can respond timely and effectively.

The third application area is also related to security. For example, the airport. The airport's indoor positioning system should be widely used to track suspicious objects in the future. When airport personnel found a suspicious item but could not confirm whether it was a bomb or something for a while. They were afraid of letting go, and they were also afraid of being complained if they were detained. In this case, stick a soft TAG on the box and use indoor positioning system for tracking. The system will immediately call the police, then this technology is still worthwhile if it finds that the item has entered an area that should not be entered.

The fourth application of indoor positioning technology is drones, and robots will work indoors in the future. Because drones and robots need to know which (X, Y, Z) they are in and which (X, Y, Z) the processing party is in before they can work better. There must be a lot of contribution in the future.

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