



WHITEPAPER

Introduction to the Basic Principles of Positioning Technology

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Abstract

Nowadays, one parameter is missing from many scenarios, car rental, assets in warehouses, packages and containers in logistics, hospital personnel, and people who are injured but cannot be reached (chemical factory, mining site). This parameter connects and automates many processes that fell apart before, improves efficiency and safety, and lowers the cost of the total flow, which in turn improves the competitiveness of the organization, customer satisfaction, and comfort of employees. It can be widely used in industry, agriculture, logistics, consumer electronics, and aerospace.

It is the **POSITION**, the purpose of asset and people tracking.

Actually, the requirements for the position were there. The new technologies make them possible now. The technologies are listed on the right figure.

Communication



LPWAN (LoRa and NB-IoT, .etc.), CAT-M, and CAT-1 offer low-power, long-distance communication coverage from a small building to worldwide. BLE with iBeacon and Eddystone protocol, UWB, and AoA enables a short-distance positioning method.

Cloud Computing



AWS, Azure, AliCloud, and SaaS providers enable us to meet almost any clients' software needs.

Semiconductor



The new technology, lowers IC cost, power consumption, and reduces chip dimension.

Sensors



Especially MEMS sensors, enable us to measure temperature, humidity, air pressure, accelerated speed, angular velocity, heart rate, etc.

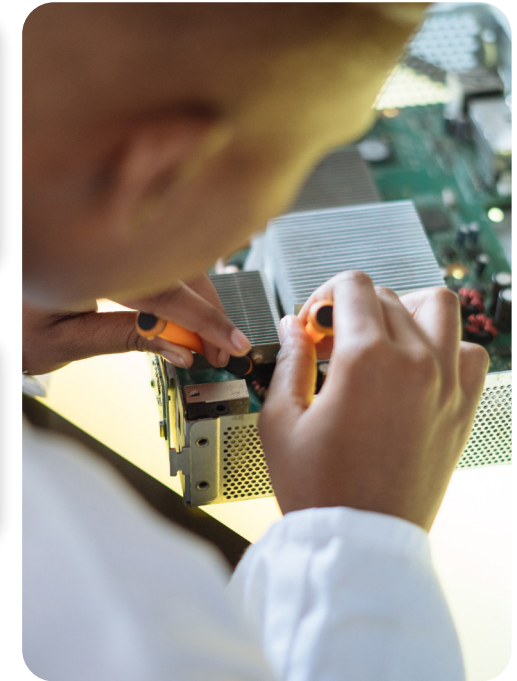
Battery



MnNiCo ternary battery, LiFePO4 ternary battery, LiMn2O4 ternary battery, Li/SOCl2 (lithium thionyl chloride) battery, etc. We have vast battery options for different use cases with different requirements on temperature range, battery life, product size, and safety.

Tracking products and solutions combine the above features with positioning technologies. The typical positioning technologies are based on sound, light, electricity, magnet, and inertia.

Even though there are varieties of derived technologies based on these theories, no one technology is the best because each use case has different requirements. This paper briefly introduces the basic principles, the pros, and the cons of each principle. It mainly introduces wireless technologies and uses to help readers select the most appropriate positioning technology and solution for industrial use.



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1. Sound Source Localization

What is Sound Source Localization (SSL) technology? Sound Source Localization technology means using multiple microphones at different points in the environment, and measuring the acoustic signal. The sound arrives at the microphones at different times. An algorithm is applied to process the received acoustic signal, thus gaining the relative direction (including azimuth and pitching angle), distance, and other information of the source point.

Human Ear Localization

When it comes to sound source localization, it is easy to think of how the human ears work. Human ears have monaural and bilateral localization ability.

In the case of monaural localization, the received sound wave is reflected by various parts of the auricle and then enters the ear canal. Since the phase of the direct sound wave varies when reaching the ear, they interfere in the auricular and produce a special auditory effect, which is called the auricle effect. Combined with the rotation of the head, the location of sound source location can be perceived.

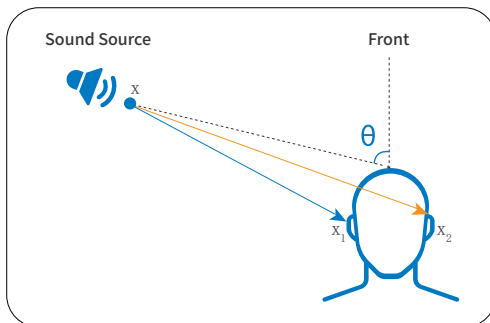


Figure 1. Human ear sound source localization

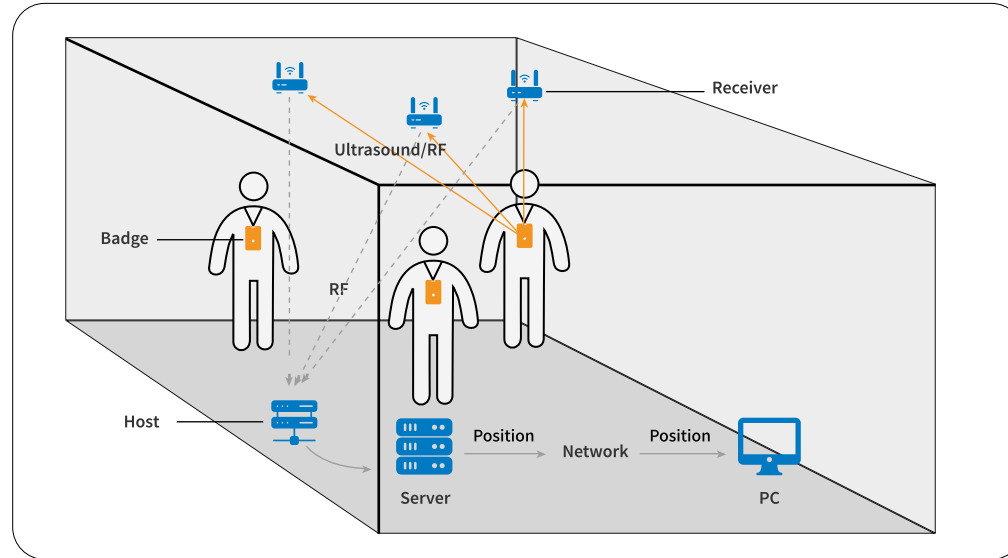


Figure 2. Ultrasonic positioning method

In binaural localization, the signal received in the left ear and the right ear will have the Interaural Time Difference (ITD) and the Interaural Level Difference (ILD). Positioning is based on the ITD and ILD for specific sound localization. The determination of horizontal azimuth can be mathematically expressed as a two-dimensional acoustic direction estimation problem, as shown in Figure 1 on the right.

The ITD information has a better effect on azimuth estimation at mid and low frequencies, while the ILD information has a better effect on azimuth estimation at high frequencies. Combined with the auricle effect, head rotation, and priority effect, we will have further and more accurate cognition of angle, distance, and other sound information.

Ultrasonic Positioning

Ultrasonic positioning mainly adopts the reflective ranging methods and determines the position of the object through multilateral positioning and other methodologies. The system consists of a host and several receivers. The host is placed on the target to be measured. The receivers are placed at fixed indoor locations. To establish the position, the host transmits signals of the same frequency to the receiver. After received by the receiver, The signal is then reflected back to the host. The distance is calculated according to the time difference between the echo and the transmitted wave to determine the position.

Sound source localization can be used for ship and vehicle detection, locating the major noise sources in machines (such as engines, automobiles, and aircraft), target selection, interference suppression in communication equipment or speech recognition, and monitoring the state of mechanical systems.

In addition, due to the ability to estimate source intensity and sound field information, sound source localization methods have been widely used in the acoustic design of audio equipment and theater systems, non-contact measurement of vibration, and virtual reality audio systems. With the development of the metaverse, machine learning, cloud computing, and on-chip electronics, sound source location technology has ever-wider application prospects.

Ultrasonic Positioning Overview

Advantages:

- high accuracy, to within a centimeter
- relatively simple structure, with certain penetrability
- strong anti-interference ability

Disadvantages:

- large attenuation, not suitable for large-scale situations
- reflection range is greatly affected by the multi-path effect and line-of-sight limitations
- heavy investment in hardware facilities

Applications:

- widely integrated into digital pens
- offshore mining and military purposes
- indoor positioning: object positioning in unsupervised workshops

2. Optical Positioning

In theory, if the distance can be measured, then the location can be determined. Visible light, infrared light, laser, and other light sources that can measure the distance between the light source and the receivers, can also be used for positioning purposes. They have a variety of applications in practical scenarios.

2.1 Visible light positioning

Visible light communication technology (VLC) can realize Internet information transmission. Generally speaking, the Light Fidelity technology is taking all kinds of the visible light as the signal source. The controller turns the light on and off, to control the communication between the light source and the terminal receiver.

Among them, visible light positioning technology based on LEDs is widely used:

- LED-ID positioning method
- TOF (Time of Flight) positioning method
- RSSI (Received Signal Strength Indication) positioning method

The LED-ID positioning method assigns a fixed ID to each LED. Then the receiver determines its position by obtaining the ID information in the signal. The accuracy of this positioning method mainly depends on the layout of the LEDs. Increasing the number of LEDs can effectively increase the accuracy, but the complexity of the corresponding algorithm will also increase. It can be used for presence location, like checking whether a receiver is in a room.

TOF location method uses LED time information sent to a receiver, and the information time difference allows the measurement the distance,



which then uses triangulation and other methods for positioning. The main difficulty of this method is that the chronometers of the transmitter and receiver must strictly align. The accuracy can be within a centimeter.

The RSSI positioning method measures the distance between the detection point and LED by receiving the received signal strength. It can achieve a more accurate positioning effect without any requirements of sender and receiver chronometers. It has a simple structure and is easy to realize. It is a widely used indoor visible light positioning method.

The main problem with visible light positioning is that the light can easily be blocked, and there are many limitations in practical use.

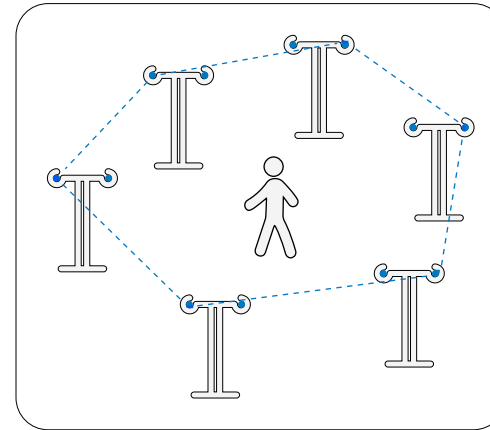


Figure 3. Infrared positioning

2.2 Infrared positioning

There are two kinds of infrared positioning:

The first is that the target to be located uses an IR Locator, which emits a modulated infrared ray. The infrared ray is received by a positioning sensor installed in the room.

The second is to cover the space to be measured by several pairs of transmitters and receivers. The transmitters and receivers weave an infrared net to locate a moving target.

At present, it is only suitable for the accurate positioning and recording of the trajectory of simple objects in the laboratory and the tracking of indoor self-propelled robots.

2.3 Computer Visual Positioning

The visual positioning system is divided into two categories. One is to determine the position of the sensor by collecting images of moving sensors. Based on the selection of different reference points, it can be divided into referencing a 3D building model, image, pre-deployed target, target projection, referencing other sensors, and no reference, which is called SLAM (Simultaneous Localization and Mapping). It can also be used to determine the position of a target in an image with a fixed position sensor.

Referencing 3D building models and images means comparing them with the existing building structure database and pre-calibrated images. To improve the robustness, referencing the pre-deployed target uses a specific image sign (such as a QR code) arranged as a reference point. Referencing the projection target is to project the reference point in the indoor environment based on the reference to the pre-deployment target. Referencing other sensors allows for the combination of other sensor data to improve accuracy, coverage, or robustness.

The other category is to use image recognition to compare the real-time image information with the database and then perform positioning. The disadvantage is that image processing is time-consuming and has poor real-time performance.

SLAM technology is widely used in autonomous driving and robot control.

Infrared Positioning Overview

Advantages:

- relatively high accuracy
- locate moving target

Disadvantages:

- short transmission distance
- poor penetration ability
- complex layout
- high cost

3. Magnetic Field Positioning

The earth itself is a giant magnet that forms a fundamental magnetic field between the geographic north and south poles. However, the earth's magnetic field is disturbed by metal objects, especially when passing through buildings with reinforced concrete structures. The original magnetic field is disturbed and distorted by the building materials (metal structures), which gives each building a unique 'magnetic pattern'.



Accurate location information can be obtained by collecting the magnetic field information in the venue in advance and then comparing it with the information collected by the magnetometer in the locator (such as a mobile phone). Theoretically, the differences in geomagnetic fields at different locations are slight, and cannot be measured by ordinary metering tools.

However, this 'indoor geomagnetic field' distorted by the disturbance of the building widens the difference of geomagnetic signals, making it possible to obtain indoor geomagnetic data. It thus indirectly improves the positioning accuracy.

The magnetic field pattern of each small space in the room is unique. When the mobile phone obtains the magnetic field characteristics of the area, it performs accurate positioning by matching the magnetic field database in the system. The accuracy may be limited to about 2 meters. But if the layout of nearby buildings changes, such as the vehicle moves, the magnetic field changes with it. Hence, it will be more difficult to guarantee accuracy. This method requires frequent calibration of the magnetic field.

Magnetic Field Positioning Overview

Advantages:

- does not rely on hardware
- no cumulative error
- low cost

Disadvantages:

- geomagnetic data collection
- signal interference
- initial position needs to be calibrated

Advantages:

1) No hardware required

The positioning environment does not need to deploy additional hardware. There is no construction cost and no additional terminals are required are its advantages.

With mobile phones that have built-in geomagnetic sensors, the whole positioning system is complete to deploy and experience, regardless of scenario and time. The whole system is free of power supply and on-site maintenance issues, which makes it convenient for users to carry out large-scale deployment and applications.

2) No cumulative error

As a matching positioning algorithm, the errors of geomagnetic navigation do not produce a cumulative effect over time. Therefore it is ideal for information integrated with the inertial navigation system, to form an integrated navigation system and calibrate the accumulated errors caused by inertial devices in real time.

3) Low cost

With no hardware cost, the overall cost of the indoor geomagnetic positioning system will be significantly reduced.

Disadvantages:

1) Geomagnetic data collection

The use of geomagnetic positioning technology begins from the collection of field geomagnetic data. Whenever there is an obvious change in the indoor environment, such as renovation, it is necessary to collect and update the field geomagnetic data, which raises a serious workload for the users.

2) Signal interference

The geomagnetic signal itself is prone to interference from metal objects. The indoor environment is difficult to remain unchanged as well. If a car suddenly passes the user, the field magnetic field will have interfered. Situations like this will inevitably impact the acquisition of its position, so the stability of geomagnetic positioning is worth discussing.

3) Obtaining the initial position

Geomagnetic positioning is a relative position. It is impossible to obtain an initial position immediately. To obtain the initial position, many schemes require users to walk 5 to 8 meters indoors prior to use.

4. Electromagnetic Wave Related Positioning Technology

The principle of positioning using electromagnetic waves is divided into methods such as Signal Strength, Angle of Arrival/Angle of Departure, and Time of Flight. The positioning accuracy increases in turn.

4.1 Signal Strength

The typical technologies that use signal strength for ranging and positioning are BLE and Wi-Fi positioning. For example, the Bluetooth tag broadcasts information and the Bluetooth gateway receives it. Then the gateway sends the data back to the server, which calculates the position of the beacon or the tracker. The method can be point location (presence detection) or triangulation. It can also send a signal via a Bluetooth tag, which is received and forwarded by a tracker.

Our company's B-Mobile and B-Fixed systems adopt this scheme. The Bluetooth gateway can be LoRa Bluetooth gateway, NB-IoT Bluetooth

gateway, or CAT-M Bluetooth gateway. You can also use a LoRa tracker, NB-IoT tracker, or CAT-M tracker with Bluetooth beacons and satellite positioning (such as GPS) for indoor positioning.

The accuracy of Wi-Fi positioning largely depends on the number of nearby APs. Therefore its accuracy is relatively poor and its power consumption is higher than BLE positioning.

The advantages of using signal strength for positioning are low cost and easy deployment. The accuracy is within 2 to 3 meters. This method is mainly used for the presence detection of assets and personnel.

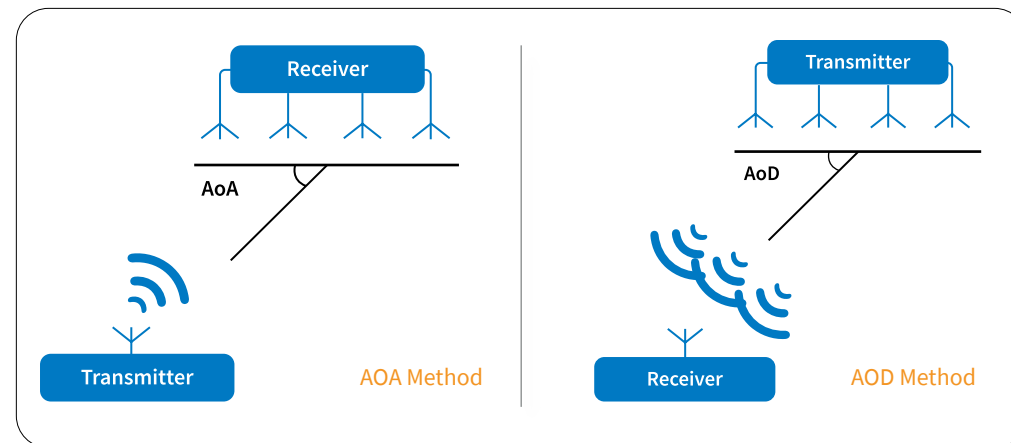


Figure 5. AOA & AOD method principles

4.2 AOA & AOD

According to the differences between uplink and downlink modes of the terminal to be located, high-precision Bluetooth positioning can be divided into two technical principles, namely the AoA (Angle of Arrival) and the AoD (Angle of Departure). The technical principle is the AoA uses a single antenna to transmit a direction-finding signal, and the receiving device has a built-in antenna array. When the signal passes through, a phase difference will be generated due to the different distances received in the array. Then the relative signal direction is calculated.

AoD is the opposite of the former. The device with an antenna array is installed in a fixed position. It transmits a signal to a single-antenna terminal. Then the single-antenna terminal can detect the signal direction and then calculate the location.

AoA & AoD Overview

Advantages:

- low terminal cost
- only one gateway required to achieve sub-meter level accuracy

Disadvantages:

- limited coverage range
- gateway needs to be accurately fixed at a location, not subjected to vibrate
- gateway needs to be powered and connected to the network

Technology	Accuracy	Distance	Power Consumption
BLE	1~3m	<150m	5mA
Wi-Fi	10~15m	<100m	100~200mA

Figure 4. BLE and Wi-Fi Positioning Technology Performance Comparison

For details, please refer to our company's product brochure:

<B-Mobile® PERSONNEL & ASSET TRACKING SOLUTION> & <B-Fixed® PERSONNEL & ASSET TRACKING SOLUTION>.

4.3 TOF (time-of-flight)

TOF positioning is performed by separately measuring the propagation time of the signal between the mobile terminal and three or more base stations, and it adopts triangulation positioning. If the straight-line distance from the mobile terminal to the base station is R (radius), then using geometrical principles, the position of the mobile terminal must be on a circle with the position of the base station i as the center and R as the radius. In the same way, the common intersection of multiple circles gives the position of the mobile terminal.

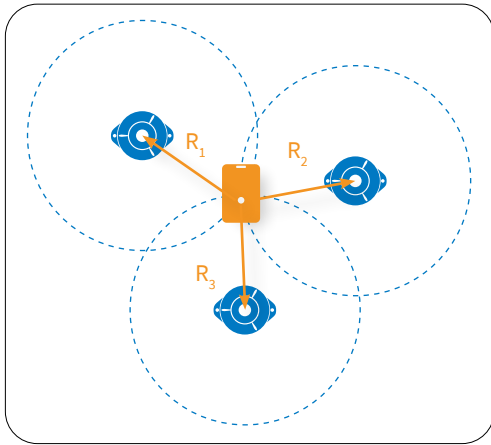


Figure 6. TOF positioning method

The typical TOF positioning is satellite positioning. In addition, Carriers can also locate phones in this way or by measuring signal strength, known as LBS (Location Based Service).

LoRaWAN also supports time-of-flight positioning, but three or more LoRa gateways need to be installed. The positioning accuracy is from tens of meters to hundreds of meters depending on the gateway distance and the number of surrounding buildings.

4.4 UWB Technology

Ultra-Wide Band (UWB) technology is a wireless communication technology that uses frequency band above 1GHz. Instead of a sinusoidal wave, UWB uses a narrow pulse of the non-sinusoidal wave at the nanosecond level to transmit data. Therefore, it occupies a wide frequency spectrum.

UWB technology has the advantages of low system complexity, low power spectral density of transmitted signal, and not being sensitive to fading channels. It also has low interception ability and high positioning accuracy, making it especially suitable for high-speed wireless access in dense areas such as indoors. Since it covers a large spectrum, by using wireless communication, it can transmit data at rates of hundreds of megabits per second or more. UWB can transmit signals over an ultra wide bandwidth. According to Federal Communications Commission (FCC), UWB occupies more than 500MHz bandwidth in the 3.1 to 10.6GHz band.

UWB Positioning Overview

Advantages:

- strong penetration capability
- low power consumption
- good anti-multipath effect
- very secure and simple system
- high accuracy

Disadvantages:

- high deployment cost
- limited coverage range

Applicability:

- trace still or moving objects indoors
- people tracking and navigation

4.4.1 Single-sided Two-way Ranging

The basic principle of Single-sided Two-way Ranging is shown in Figure 8:

SS-TWR ranging principle: device A sends a pulse to device B, and after a period of time t_{roundA} receives the pulse returned by device B. Let the flight time be t_p , then it can be roughly calculated:

$$2t_p = t_{roundA} - t_{replyB}$$

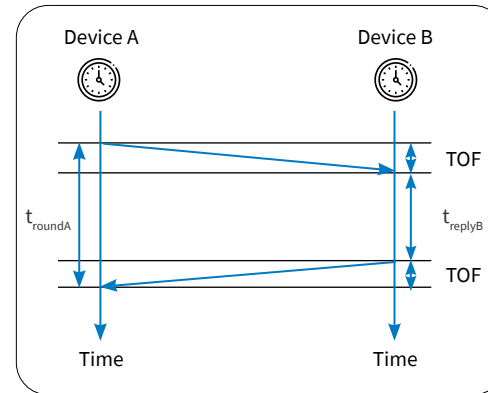


Figure 7. SS-TWR ranging principle

The two time differences are calculated based on the local chronometer. The local clock error can be offset, but there will be a slight clock offset between different devices.

With the increase of T_{replyB} and clock offset, the error of flight time is increased simultaneously.

4.4.2 Double-sided Two-way Ranging

Double-sided two-way Ranging is an extended distance measuring method that records timestamps for 2 round trips, to calculate the time of flight. Although it increases response time, it reduces measurement error. If you are interested in this solution, please contact us and we will give you a detailed introduction.

UWB positioning accuracy is up to 30cm or even higher. Its power consumption is relatively low. UWB is widely implemented in unmanned vehicles in mining businesses, valuable cargo positioning, and other fields. Currently, the anchor of the mainstream UWB positioning scheme requires a clock channel and power supply, resulting in high construction complexity.

We have high precision positioning system and anti-collision system based on LoRa and UWB technologies. The system has the advantages of high precision, low power consumption, and no wiring requirements.

4.5 RFID

The radio-frequency-identification positioning system is deployed in parking lots, ski resorts, golf courses, wharves, and other places. Users can deploy the system in a specific area for positioning. After RFID tag readers are placed at specific locations, such as key entrances and exits in these areas, the system can then detect the location of objects with RFID devices in real time.

RFID indoor positioning technology works over a short distance, but it can obtain the information within a meter of positioning accuracy in milliseconds. Moreover, due to the advantages of a non-line-of-sight electromagnetic field, the transmission range is large. The size of the tag is relatively small, with low cost.

RFID indoor positioning has been widely used in warehouses, factories, and shopping malls for obtaining the position of commodity circulation. At present, there are a large number of mature commercial positioning solutions based on RFID technology. It is also widely used in emergency rescue, asset management, personnel tracking, and other fields.

The RFID tag is passive communication. Its anti-interference ability is poor.

5. Inertial Navigation System

INS (Inertial Navigation System), also called inertial reference system, is an autonomous navigation system that does not rely on external information, nor radiates energy to the outside (such as radio navigation).

Its working environment includes not only in the air, and on the ground, but also underwater. Inertial navigation is to measure the acceleration of the carrier in the inertial reference system, integrate it against time, and then transform it into the navigation coordinate system. Therefore, the information on speed, yaw angle, and position in the navigation coordinate system can be obtained.

The inertial navigation system belongs to the dead-reckoning navigation mode. Departing from a known point, the position of the next point is calculated by continuously measuring the heading angle and velocity of the object. Then, the real-time position of the object can be measured continuously.

The gyroscope in the inertial navigation system is used to establish a navigation coordinate system, which makes the measurement axis of the accelerometer stable in the coordinate system, and gives the heading and attitude angle. The velocity can be obtained by integrating time once, and then the distance can be obtained by integrating the time again.

6. Positioning System Comparison

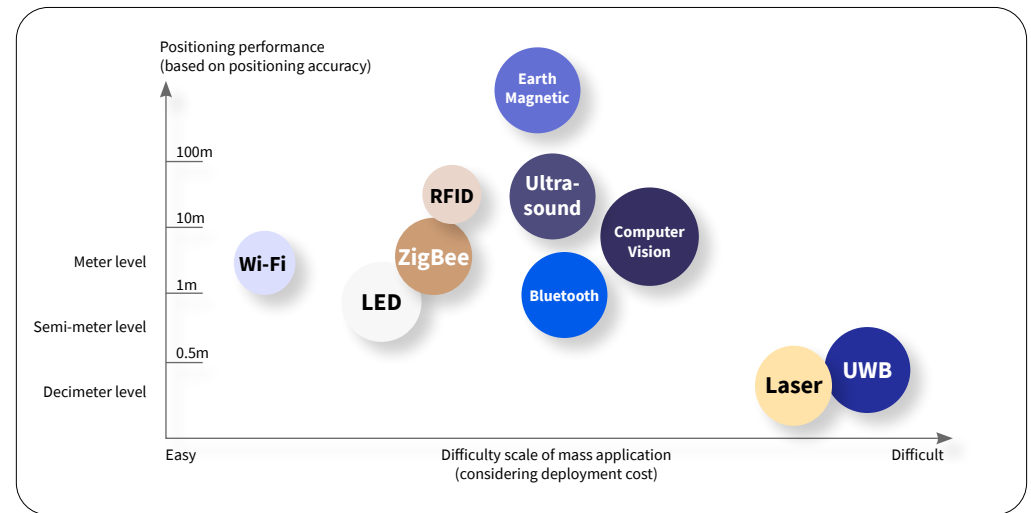


Figure 8. Positioning system comparison

Inertial Navigation System Overview

Advantages:

- autonomous system, good concealment, not affected by external interference
- operable in all conditions & full-time
- navigation info is generated continuously and has low noise
- high data refresh rate
- good short-term accuracy
- high stability

Disadvantages:

- poor long-term accuracy
- long initial alignment time is required
- high cost, expensive equipment
- time info unavailable

The technologies above are widely used in indoor scenarios. Currently, dozens or even hundreds of technologies exist in this field. Each positioning technology has its own unique advantages and disadvantages, and is suitable in particular application scenarios.

The above diagram compares the positioning performance and deployment difficulty of the mainstream indoor positioning technologies.

Many applications require a combination of fundamental concepts or hybrid technologies. For example, BLE+GNSS+LoRa is used for indoor and outdoor tracking. UWB+BLE is used for accurate positioning and asset management.

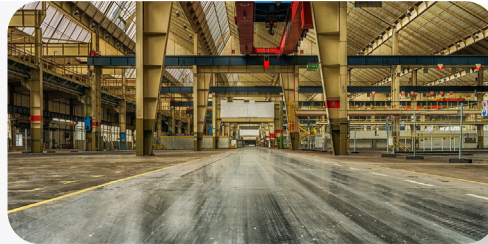
When choosing a positioning technology, data transfer method, power supply, and installation method should be taken into consideration. The data transfer methods include ethernet, 4G, 5G, LPWAN (LoRa and NB-IoT). Lansitec has a full range of LPWAN-based Bluetooth gateways, Macro Bluetooth Gateway, Solar Bluetooth Gateway, Compact Bluetooth Gateway, indoor Bluetooth Gateway, NB-IoT Bluetooth Gateway, and other options.

Sensors can also help improve accuracy in specific applications, such as a barometer that can help to measure the attitude of tracker. The accelerometer can judge the motion state of the tracker to save power on electricity costs.

Use Cases

Factory

Factory personnel positioning adopts satellite positioning + Bluetooth indoor positioning method.



Logistics

Logistics container positioning adopts satellite positioning and uses 2G, 4G, and NB-IoT mobile networks provided by operators for data transfer.



Parking lot

Parking lot vehicle positioning uses the method of Bluetooth beacon + Bluetooth gateway. It can also use infrared to detect whether the vehicle is present or SLAM technology to recognize the license plate.



Metal tools

Metal tool positioning: As shown in the picture, there is no appropriate position to attach the tracker or label on the tools. The metal tools are also used in various scenarios. Hence, no active positioning technology is available for this situation. Laser printing QR codes on tools can be considered.



About Lansitec

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With our tracking products, solutions, and related algorithm and services.

Lansitec Technology Co., LTD, located in Nanjing, China, has been helping clients to improve workers' safety, asset management efficiency, and vehicle status since 2016.

We offer tailored products and services to our clients, system integrators, and software platforms to interact with our products to provide exactly what you need. We are dedicated to enabling your success.

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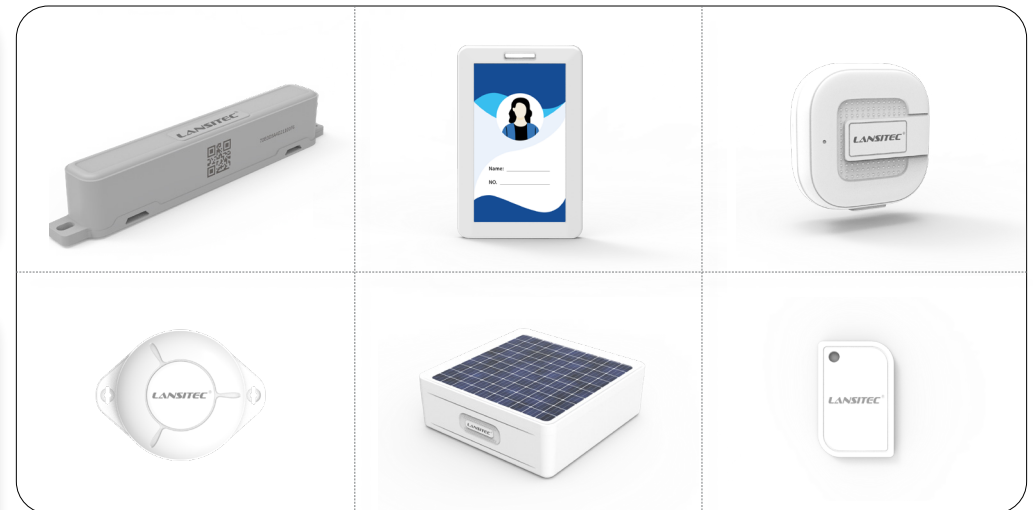


Figure 9. Lansitec product display