Accurate Positioning in Extraordinary Circumstances

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Abstract: This paper mainly introduces the indoor and underground closed space. When the GPS cannot meet the user’s requirements for positioning accuracy, the new positioning technology is adopted. SLAM positioning for indoor positioning, and some basic component information used in this technology is at the present stage; In addition, the UWB Ultra-wideband technology used in underground space and some commonly used algorithm models of the technology are presented.

1. Introduction
When it comes to positioning navigation, the first thing that comes to mind is GPS. China has also launched its own navigation system - Beidou. However, satellite positioning, such as GPS, Beidou navigation and even the Galileo plan in Europe, can only be used in places where outdoor space is relatively empty. Once it is indoors or where it is heavily shielded, satellite positioning cannot be used. The main reasons for the failure of satellite positioning in such environments are as follows: first of all, the GPS signal power is very low, the signal acceptance is high, and the antenna cannot be blocked between the sky; Second, since most of the building materials are now reinforced concrete, the GPS signal will be blocked or reflected by the wall and cannot enter the building, resulting in no satellite signal, making the positioning impossible. Therefore, we only discuss the indoor and tunnel or underground space conditions in a special environment.

2. Precise positioning in an indoor environment
Indoor positioning refers to the positional positioning in the indoor environment. At present, the more mature solutions on the market include wireless communication, and various positioning technologies such as base station positioning and inertial positioning are integrated to form a position positioning system. Common indoor wireless positioning technologies include Bluetooth, Wi-Fi, and infrared. Here, the positioning technology currently in the research stage is SLAM positioning.

2.1. Definition of SLAM
SLAM means simultaneous localization and mapping. At the beginning of SLAM, it was mainly used in the field of robotics. With the rise of artificial intelligence, people's interest in robots has grown, but at this time people have encountered bottlenecks in robot development - how to let robots "understand" the surrounding environment. Compared with human beings, because we can understand some of the information that the surrounding environment conveys to us, we can respond to the changes in the surrounding environment. In order to solve this problem, the concept of SLAM technology came into being.
2.2. Type of SLAM
SLAM positioning is mainly based on the camera as the main external sensor. According to the number of cameras, it can be divided into monocular vision SLAM, binocular vision SLAM, and RGBD-SLAM composed of monocular camera and infrared sensor.

2.3. Comparison of various types of SLAM
(1) Single-lens SLAM
   Advantages: The sensor is simple, low cost, and free from environmental influences (both indoor and outdoor).
   Disadvantages: Since the single-lens SLAM relies on triangulation in motion to determine the relative position of the object to itself, the single-lens SLAM cannot know the pixel position at rest.
   For a single-lens SLAM, the robot does not acquire depth data during the stationary process and must move the camera to produce depth[3]. When the camera is moving, the scene has a geometric relationship with the image; the image of the object closer to the camera moves faster, while the image of the object farther from the camera moves slower, so that the distance can be inferred.
(2) Double-lens SLAM
   Advantage: The depth can be estimated both during motion and at rest.
   Disadvantages: Camera configuration and calibration are complex, and calculating the pixel distance is very computationally intensive.
(3) RGBD-SLAM
   Advantages: The distance is directly measured by the infrared structure or the Time-of-Flight principle, and does not require excessive calculation.
   Disadvantages: narrow measurement range, high noise and small field of view.
   RGBD-SLAM calculates the depth by physical methods. The depth camera can directly measure the image and distance of the object to restore the three-dimensional structure.

2.4. Mathematical model of SLAM problem
In determining the position at which a measured point is at a certain moment, we first consider the measurement time and position as random variables and obey the probability distribution.
Discrete time point: T=1,2,3……,i
The position of the SLAM camera: X₁,X₂,X₃,……,Xᵢ
The camera moves from the previous moment to the next moment, so the equation of motion can be written as:
\[ Xᵢ = F(Xᵢ₋₁, Uᵢ, Wᵢ) \]
Road sign: Y₁,Y₂,Y₃……,Yᵢ
Observation equation: \[ Zᵢ = H(Xᵢ₋₁, Yᵢ, Vᵢ) \]
\[ \begin{cases} Xᵢ = F(Xᵢ₋₁, Uᵢ, Wᵢ) \\ Zᵢ = H(Xᵢ₋₁, Yᵢ, Vᵢ) \end{cases} \]

2.5. The basic framework of SLAM technology
(1) Sensor data
   There are two main types of sensors used in SLAM technology:
   ① Sensors installed in the environment, such as: QR code, GPS, rails, etc.
   ② Carry on the robot body, such as: IMU, laser, camera, etc.
   Sensors in the environment limit the application environment, requiring the environment to allow GPS to be used, allowing Marker to be attached. While SLAM emphasizes the location environment, it pays more attention to portable sensors. For portable sensors, laser technology is more mature, but the cost is more expensive. Camera technology is still in development, its cost is low, but it requires a large amount of calculation and a certain working condition[2].
(2) Front visual odometer
The main function is to estimate the motion of the camera based on two adjacent images. Basic form: Calculate motion and structure through two graphs, but inevitably there will be drift. Common methods: feature point method, direct method.

(3) Backend optimization
Estimating the trajectory and map state from the noisy data, and finally estimating the probability. The MAP is represented by EKF in the early stage, and is now represented by graph optimization.

(4) Map construction
Using for navigation, planning, communication, visualization, interaction, etc. Commonly used map construction methods mainly include metric maps (topological maps) and sparse maps (dense maps).

(5) Loop detection
Detect whether the robot returns to the original position; identify the scene that has arrived; calculate the similarity between the figures. Thereby, the quasi-determination and repositioning of the trajectory can be ensured.

(6) The process of SLAM technical data

2.6. Application of SLAM technology in indoor positioning
The SLAM technology can acquire indoor three-dimensional spatial structure information of modern irregular buildings, including three-dimensional point cloud data and panoramic image data. During the SLAM camera travel, the point cloud data of the surrounding environment can be scanned in real time to draw the outline of the indoor space. Provide raw data for map construction to assist in the positioning and navigation of observation objects.

3. Accurate positioning in underground space or tunnel

3.1 Definition
The precise positioning in the underground space or tunnel mainly refers to the positioning technology realized in the relatively closed space where the signal is not received\(^4\). Taking the Qinling Zhongnanshan Highway Tunnel as an example, the entire site is 18 kilometers. Due to the harsh environment in the tunnel, the wireless signal acceptable to the driver of the vehicle exercising in the tunnel is greatly attenuated.

3.2 Ultra-wideband technology (UWB technology)
Ultra-wideband technology is a new type of wireless transmission technology. Unlike previous signal transmission methods, UWB technology does not use carrier form to propagate signals, but uses narrow pulse form as the carrier of signals. UWB uses narrow pulses up to nanoseconds to picoseconds. The Shannon channel capacity formula:

\[
C = \text{Blog}_2 \left(1 + \frac{S}{N}\right)
\]

Among them: C: Maximum channel capacity (bits/s);
B: The bandwidth of the channel (Hz);
S: power of the signal (W);
N: the power of the noise (W);

It can be seen that the channel capacity C is proportional to the channel bandwidth and inversely proportional to S/N; and the duration of the signal is inversely proportional to the bandwidth it occupies. Therefore, when a pulse propagation signal is used, the shorter the pulse action time per unit time, the larger the channel bandwidth, and the greater the amount of information it transmits. Advantages: low power consumption, low cost, multi-path interference and penetration capability. In addition, UWB's wireless communication space capacity is 1Mbit/(s.m^2), which is far superior to other systems; Disadvantages: occupying a large bandwidth, it is easy to cause interference to other radio systems.

3.3 Several typical positioning model algorithms
The wireless positioning algorithm can be divided into a distance-based positioning algorithm and a distance-independent positioning algorithm. Since the distance-independent positioning algorithm generally has low precision, UWB positioning generally adopts a distance-based positioning algorithm.

(1) Arrival angle positioning and the analysis of signal strength
AOA refers to the determination of the position of the measured point to the signal arrival angle of the two signal receivers. It is necessary to configure a more complex antenna system, and the error caused by the angle measurement has a greater impact on the positioning accuracy than the distance measurement. The error caused is large. The relationship between the strength of the received signal and the propagation distance is as follows:

$$RSSI = -\left(10 \times n \times \log d + A\right)$$

Among them: RSSI: the strength of the signal received by the receiver, dbm;
n: the propagation coefficient of the wireless signal;
d: the distance between the receiver and the sender, m;
A: the empirical parameter is obtained by measuring the RSSI value when d=1;

However, this kind of signal transmission model is greatly affected by the environment, and its accuracy is independent of the signal bandwidth, and cannot take advantage of UWB.

(2) Time of arrival (TOA)
The transmitted signal of the measured point reaches the three signal receivers, and the distance between the transmitting point and the signal receiving point machine is obtained by measuring the time taken to reach each signal receiver, and then the signal receiver is taken as the center, and draw a circle with the measured distance as the radius, and the intersection of the three circles is the position of the measured point. as the picture shows:

In the figure, three points R1, R2, and R3 are signal receiver placement points, and point A is the measured point (ie, signal emission point).

(3) Time difference of arrival (TDOA)
It is to determine the position of the measured point by detecting the time difference between the signals arriving at the two base stations, and reducing the synchronization requirement of time. Two TDOAs can be detected using three different base stations, and the measured points are located at the hyperbolic focus determined by the two TDOA.
In the figure, the three points M1, M2, and M3 are the signal receiver placement points, and the B point is the measured point (i.e., the signal issuance point).

TDOA has obvious advantages over AOA and TOA algorithms:

1. The traditional direction finding method requires the use of a phase meter to calculate the angle. In the case of phase counting, the phase uncertainty of the phase is unavoidable, so a signal with a higher frequency is usually used. However, the wavelength of the high-frequency signal is short, and we have to set the distance of the antenna closer, and signal coupling occurs. Since TDOA has only one antenna, the signal coupling phenomenon is effectively avoided.

2. Less complex. The traditional DF antenna is a set of antenna arrays. To achieve accuracy, it is also necessary to ensure the performance of each antenna as much as possible. The TDOA system only needs to configure the monitoring antenna and receiver.

3. High positioning accuracy. For TDOA systems, the accuracy of their positioning depends on the accuracy of the time measurement, up to the nanosecond level after system and algorithm optimization.

3.4 The application of TDOA in tunnel (underground space)

UWB positioning systems mostly use Gaussian pulse signals with extremely narrow bandwidth. The pulse width is usually up to nanoseconds, and the positioning accuracy is greatly improved compared with other positioning methods. Generally, the UWB positioning system sets a number of positioning reference points, accepts a large number of Gaussian pulse signals from the measured points, and each measured point is distinguished by a PN code sequence, and the received pulse sequence can be processed to obtain an acceptance time, thereby obtaining the distance between the measured point and the reference point.

4. Conclusion

With the development of space technology in various countries of the world, positioning technology plays a decisive role in national defense and people's livelihood. In some special environments, GPS is not available. This paper proposes two typical GPS unusable situations, and corresponding solutions are proposed. Although some technologies are still not in the research stage, the research prospects are very bright.

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