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AUTONOMOUS MOBILE ROBOT NAVIGATION AND MOTION CONTROL PROBLEMS AND ANALYSIS OF EXISTING METHODS

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Abstract. This paper briefly introduces the characteristics of the current mobile robots , sorts out the current robot navigation problems, introduces the robot positioning and navigation algorithms, and then introduces the grid, topology and geometric feature maps that describe the environment model. Map-based further research for subsequent autonomous navigation.

Keywords: mobile robot, motion control, navigation, SLAM, LiDAR.

Introduction. In recent years, human beings are constantly pursuing to free their hands and replace human work with robots to improve production efficiency or quality of life. As the jobs being replaced become more and more complex, the degree of robot automation and intelligence is getting higher and higher. Both academia and industry have set off an upsurge in robot intelligence research. Intelligence requires robots to be able to complete established tasks with as little human intervention as possible. At present, intelligent robot technology is widely used in various fields of production and life, such as production robot arms for industrial production, sweeping robots for household cleaning, auxiliary robots for medical care, and storage robots for logistics. UAVs for aerial photography, underwater robots for deep-sea scientific research and exploration and other practical applications.

For intelligent mobile robots such as storage robots, drones, and underwater robots, they usually have functions such as environment perception, positioning and navigation, path planning, autonomous movement, and task operations. Among them, environmental perception is an important step in realizing intelligence. Obtaining important state information such as its own position, speed, attitude, and obstacle position through the monitoring of the environmental state by the sensor is the prerequisite for the mobile robot to independently perform complex tasks in an unknown environment.

The exploration of mobile robots originated in the late 1950s. In 1959, two scientists in the United States, Ingeberg and DeVore, developed the world's first mobile robot. This robot mainly identifies underground routes for simple exploration. Path planning [1] from 1966 to 1972, the Stanford Research Institute for International Studies successfully developed the Shakey mobile robot, which is mainly used indoors and can be controlled in real time in complex environments. With the continuous breakthrough of robot research technology and the continuous expansion of application fields, foreign defense researchers began to invest in robots and conduct research in the military field. Since the 1980s, the United States began to carry out the ALV program. At the same time, Japan Carry out robot research programs working in complex environments, and the EU launches underwater robot programs, etc. Since the 21st century, the development of mobile robots has advanced by leaps and bounds. In 2005, the American adept company researched the PatrolBot mobile robot, which is now used in shopping malls, factories and other occasions. It can accurately locate and navigate autonomously in complex environments, basically replacing manual services; Kiva systems The mobile robot developed by the company scans the QR code for autonomous navigation, helps warehouse personnel to process orders, and greatly improves the efficiency of inventory processing.

With the rapid development of science and technology brought about by informatization and intelligence, the demand for robots in society is also gradually increasing. replace. According to the Internet Data Center [2], by the end of 2020, the world's industrial and application expenses related to robots exceeded 188 billion US dollars, and the huge amount promoted the continuous expansion of the robot market. Since robots can help us solve many problems, the government has introduced policies to help the robot industry to flourish, making the society pay more and more attention to robots, which has broad development prospects, so its research is of great significance. At the same time, robots are a sunrise industry, and has also been favored and invested by the market and entrepreneurs.

Mobile robot is a comprehensive system, which integrates multiple functions such as environment perception, dynamic decision-making, behavior control and execution. In various fields, mobile robots have been widely used. For example, in the military, they can replace humans in dangerous areas to complete dangerous tasks such as reconnaissance and mine clearance; in industrial production, they can replace humans in harsh environments to complete equipment testing, Cargo handling and other tasks; in civilian use, as a blind guide vehicle, it can provide assistance in daily life for the blind; in scientific research, it can assist humans in mineral exploration or alien planet exploration and other activities. Mobile robots are closely related to many disciplines, such as computer science, communication, signal processing, pattern recognition, control theory, and artificial intelligence.

With the development of computer and robot technology, the development of robots has gone through three generations of evolution [3]: the first generation is a robot that works in a «teaching-reproduction» mode. This generation of robots has been widely used at present. It is a system that relies on people to give programs and repeatedly perform various operations. However, this generation of robots does not have sensor feedback information, so it cannot improve its own movement quality by continuously obtaining external information during the operation process, which greatly limits its application range. The second generation is an off-line programming robot, which has a certain ability of self-adaptation and perception of the external environment.

This kind of robot is equipped with simple internal and external sensors, which have sensing capabilities such as «vision», «tactile» and «auditory», and can detect the external environment, obtain information such as its actual position and direction, and then Under the algorithm and program instructions, the feedback information is used to adjust the action process. This generation of robots is closely related to research fields such as sensors, bionics, microcomputer technology, and control theory that have developed rapidly in recent years, and a few have been practically applied so far. The third-generation robot is an intelligent robot, which can perceive external objects and the environment, and has the ability to accurately process complex information and make autonomous decisions about its own behavior. This kind of robot is equipped with a variety of sensors, and can «fusion» the information detected by multiple sensors (multi-sensor information fusion) [4], and then make corresponding autonomous decisions to complete specific tasks. It has a strong self-adaptive ability, can effectively adapt to environmental changes, and is an intelligent robot with autonomy (autonomous decision-making) and learning functions. At present, robots are developing toward autonomy, complexity, and intelligence. In human life, robots are more and more closely connected with us.

Navigation problems for mobile robots. In the research of mobile robot related technologies, navigation technology is the core of its research. Common navigation methods for mobile robots include electromagnetic navigation, map model matching navigation based on environmental information, landmark navigation based on various navigation signals, taste navigation, sound navigation, visual navigation, etc. A commonly used navigation method at present is «following the path guidance», that is, the mobile robot navigates by responding to certain external continuous path reference information that can be perceived. The path-following guidance method differs according to the sensor used to identify the guidance line: embedded guidance based on the principle of electromagnetic induction, track in the mechanical method, magnetic strip in the magnetic guidance method, reflective tape in the optical guidance method, and Guidance methods based on computer vision. For example, magnetic guidance is to lay magnetic nails or metal wires on the moving path of the mobile robot, and determine the position and posture of the mobile robot by detecting the characteristic information generated by them. From the perspective of mobile robot navigation, the advantages of traditional navigation methods such as magnetic guidance are high reliability, but at the same time there are disadvantages such as single function, poor flexibility, weak adaptability to the environment, and high maintenance costs. Recognizing target features while moving, and also unable to detect obstacles, limits the application of these methods in mobile robot navigation. Visual navigation has the characteristics of high level of intelligence and rich information, and has been widely used in the autonomous navigation of mobile robots in recent years. Visual navigation is a navigation method based on local vision. The main function is to use the camera installed on the mobile robot to obtain video or images, simulate the visual function of the human eye through computer technology, and drive the mobile robot from the image or image sequence. The information of the road area is extracted, so that the mobile robot can observe and understand the world through vision like a human being, and has the ability to adapt to the environment autonomously. This is also the ultimate research goal of the visual navigation of the mobile robot.

For humans, more than 90% of the information comes from visual perception of the environment, and human vision provides humans with the most detailed and reliable information about the surrounding environment. Therefore, the use of computer vision to realize the navigation of mobile robots has some advantages that other navigation methods do not have [5]. First of all, for navigation, visual information not only provides distance information of objects in the field of view, but also provides characteristic information such as color and shape of objects in the field of view, which cannot be obtained when other active sensors are used for navigation. These unique information can make mobile robots have higher intelligence and become more intelligent. Secondly, for navigation, road direction and edge features can also be learned from visual information, which enables mobile robots to make high-level path planning that is more in line with human traffic rules. In addition, the two advantages of computer vision technology in terms of information volume and acquisition speed determine that it plays a vital role in the development of mobile robots. In recent years, a series of research results in the field of visual navigation have fully reflected the great potential of visual navigation technology. The continuous progress of visual navigation technology is very positive for the realization of highly intelligent mobile robots and the improvement of the current level of technology. impetus. Road detection technology is one of the key technologies in the visual navigation of mobile robots. It mainly recognizes information such as color and edges from road images to understand the road environment and obtain location information for mobile robots to navigate autonomously. In this paper, the monocular vision system is used to realize the visual navigation of the mobile robot. By detecting the color and edge information in the road image, the position of the road guide line is determined, and then the navigation information of the mobile robot is obtained through the camera calibration model to realize its autonomous movement. Laying metal wires, magnetic nails and multi-eye visual navigation, etc. This method enhances the flexibility of the system and reduces maintenance costs. On the other hand, the quality of road detection and tracking directly affects the quality of mobile robot visual navigation. accuracy. Therefore, the research on road detection technology in mobile robot visual navigation has extensive application value and great theoretical significance.

Methods for Perceiving Mobile Robots Moving in Urban Environments. Simultaneous localization and mapping (SLAM) is a method that enables mobile robots to autonomously carry out environmental perception analysis and obtain the state of themselves and the environment in an unknown environment. In the field of robotics research [6], SLAM has always been the focus of research. Due to the complexity and unknownness of the environment, the complexity of the sensor hardware system, the diversity of measurement methods, and the inevitable errors in measurement results, how to obtain more accurate and robust state estimation and establish higher precision through sensor measurement The map can achieve precise control of the robot while reducing the hardware cost. These problems are still not well resolved and need further breakthroughs in sensor hardware technology, data acquisition technology, software and hardware integration technology, data processing technology, map construction and algorithm technology. and improvements. This paper conducts research on the simultaneous positioning and map construction related issues such as the acquisition method of the internal parameters of the lidar, the selection optimization algorithm of the occupancy grid map parameters, and the independent system design of the robot map construction. Methods for precision maps.

SLAM research overview, SLAM includes two parts of positioning and map construction, which means that the robot moves from one position to another in a completely unknown environment. In this process, the robot uses the information obtained by the sensor to estimate the change of its position And build the map incrementally according to the obtained innovation. In fact, the two are inextricably linked. On the one hand, in order to obtain the precise positioning of the robot in the environment, a correct map is required; on the other hand, in order to build a good map by adding the scanned elements to the map, the correct positioning of the robot is required. SLAM can be widely used in robot positioning and navigation, drones, unmanned driving, VR/AR and other fields.

The SLAM algorithm was first proposed at the ICRA (IEEE Robotics and Automation Conference) in 1986, and people began to use probabilistic methods to think about robot perception problems.

So far, the development of SLAM has roughly gone through three stages [7]. The first stage (1986-2004) is called the budding development period. During this period, some important probability methods were proposed, such as Extended Kalman Filter (EKF), Particle Filter (PF), Maximum Likelihood Estimation (MLE), and related issues of data association. The second stage (2004-2015) is called the algorithm analysis period. At this stage, a lot of research has been done on the characteristics of SLAM algorithms, including observability, convergence, and continuity. At the same time, a large number of SLAM algorithms were proposed during this period. The third stage (2015-present), known as the robust perception period, people began to pursue the robustness of the SLAM algorithm, and expected the algorithm to perceive the surrounding environment more intelligently. From the type of sensor used, SLAM is mainly divided into lidar-based SLAM algorithm and computer vision-based visual SLAM algorithm.

At present, commonly used sensors for mobile robot SLAM include: single-line lidar, multi-line lidar, monocular camera, binocular camera, RGB-D camera, etc. They are the RplidarA3 laser radar from Silan Technology, the Pandar64-line mechanical laser radar from Hesai Technology, the DS-2CD7T47DWD-IZ camera from Hikvision, and the binocular camera from Xiaomi Smart.

A review of lidar SLAM algorithms. The research on lidar-based SLAM technology started relatively early, but due to the high cost of lidar, it is not widely used. However, in recent years, with the development of lidar technology, the cost has dropped rapidly, and unmanned driving has gradually become popular. Radar has the incomparable superiority of visual technology. It is believed that in the near future, radar SLAM will be irreplaceable in autonomous driving technology important part of Grisetti G. et al. proposed Gmapping, a particle filter-based SLAM algorithm, which maintains maps and pose estimates for each particle [8], and obtained considerable results by improving the proposed distribution and resampling methods, but this method relies on The odometer does not have a loop detection algorithm. Kohlbrecher S et al. proposed HectorSLAM, which is based on the occupancy grid map, overcomes the discontinuity of the occupancy grid map through linear interpolation, uses the Gauss-Newton method to optimize scan matching, and uses multi-resolution maps to avoid getting trapped when optimizing poses. local minimum. This method can fuse information from other sensors (such as inertial sensors) through the method of Extended Kalman Filter (EKF). KartoSLAM is a SLAM method based on graph optimization [9] , which uses window traversal to find the optimal scan match, and uses sparse point adjustment (Spare Pose Adjustment) or g2o for optimization estimation .

A review of visual SLAM algorithms, visual SLAM is the focus of current research. Compared with lidar, vision sensor camera is favored by the industry because of its low price. But at the same time, visual sensors usually introduce larger errors, so a good SLAM algorithm is very important. Andrew Davison brought the EKF-SLAM in the lidar into the monocular vision SLAM, and established the MonoSLAM algorithm, which is fast and can model the uncertainty of features [10], but the algorithm only extracts a very small number of features Points count, and the tracking is not very stable. Nister uses efficient corner point feature extraction and matching to implement visual odometry (VO, Visual Odometry), and improves accuracy through bundle adjustment, but cannot eliminate offsets and cannot track relocation after loss. Georg Klein and David Murray proposed the PTAM (Parallel Tracking and Mapping) algorithm, which is a Keyframe-based algorithm that pioneered the separation of tracking and mapping into two The independent thread can be optimized in the drawing thread to improve the real-time performance and accuracy of the algorithm. Richard Newcombe and others proposed DTAM (Dense Tracking and Mapping), which uses denser image information and image features, which greatly improves the robustness and accuracy of the algorithm. The ORB-SLAM proposed by Raul Mur-Artal has improved the map initialization. On the basis of the tracking and mapping threads, the loop detection thread is added, and the loop closure and relocation are performed through the bag of words method, which achieves a better algorithm effect. DSO (Direct Sparse Odometry) was proposed by Jakob Engel. It is a visual odometry calculation method with high precision, good robustness and small drift. The Hong Kong University of Science and Technology Shen Shaojie and others proposed the Vins-mono algorithm in 2018. This algorithm is an algorithm that combines inertial measurement units and monocular vision SLAM, and is applied to drones. The algorithm effect is relatively ideal.

SLAM algorithm framework. In terms of framework, the mainstream SLAM algorithm framework mainly includes five steps [11] . (1) Sensor data acquisition and processing, such as laser (sonar) SLAM, visual SLAM (monocular, binocular, depth); (2) matching algorithms, such as feature matching, ICP matching, correlation matching, etc.; (3) Back-end processing, such as filter algorithm, graph optimization algorithm, etc.; (4) map construction algorithm, such as feature map, occupancy grid map, point cloud map, etc.; (5) loop detection, such as bag of words algorithm, etc. It can be seen that the current research on SLAM algorithms focuses on positioning algorithms and pose estimation, and the research on the accuracy of sensors and map construction is relatively good.

An overview of robot map construction. Maps are an important part of robotics. For a fully autonomous robot, a good map model plays a vital role in each step of perception positioning, path planning, and navigation. Up to now, map models mainly include scale map, feature map, topological map and semantic map.

Scale maps are the most common and intuitive form of maps. These maps are proportional to the real environment and are the most easily understood map models for humans. For example, park maps and world maps are all maps drawn according to the real environment through scaling. According to the dimension of scale information [12] , it can be divided into planar map (2D map) and stereo map (3D map).

Grid map. In robotics, the most common form of scale map is grid map. Because the creation and maintenance of grid maps are very simple, and the corresponding relationship with the real environment is simple and clear, it is often used in map construction based on sensors such as lidar and ultrasonic ranging. However, when the grid size of the grid map is constant, the number of grids will grow quadratically (planar map) or cubically (spatial map) as the area of the described environment grows, which causes the time complexity of updating the map to be the same as that of The space complexity of storing maps grows rapidly, so raster maps are often used in small environments or by approximating the global map with local submaps.

Feature map, the feature map does not store the information of the entire environment, but stores some iconic features. This is similar to the way humans remember maps. People tend to describe the environment and their location through distinctive landmarks in the environment (such as typical buildings, intersections, etc.). In robotics, there are various forms of features in feature maps. It can be features extracted from sensor data, such as point, line, surface and other corner features obtained from lidar, or operator features such as SIFT, SURF, ORB obtained from images, or artificial in the environment. Feature signpost added.

Feature maps are suitable for structured environments, where specific feature descriptions are more precise. For unstructured environments, it is difficult to describe with standard features. Another problem with using feature maps is the problem of data association. When maintaining the map, it is necessary to compare the obtained features with those of the current global map, and associate the corresponding feature data, so that a consistent map can be updated and maintained. How to efficiently match and correlate a large amount of feature data becomes another problem.

Topological map, topological map is usually used to describe the connection relationship of each part of the map, such as a city subway map. Unlike grid maps and feature maps that correspond to the real environment in scale, topological maps use nodes and connections between nodes to represent the environment. In the topological map, nodes are used to represent a certain location in the environment, and links are used to represent path information between nodes. The map model describes the topological relationship of various places in the environment, making path planning more efficient

Semantic map, semantic map not only contains the basic information of the environment, but also contains a high-level understanding of the environment, such as the location of the door, the purpose of the building, etc. Semantic maps play an extremely important role in realizing more intelligent robotic systems. The sequence of different types of maps are shown in Figure 1.

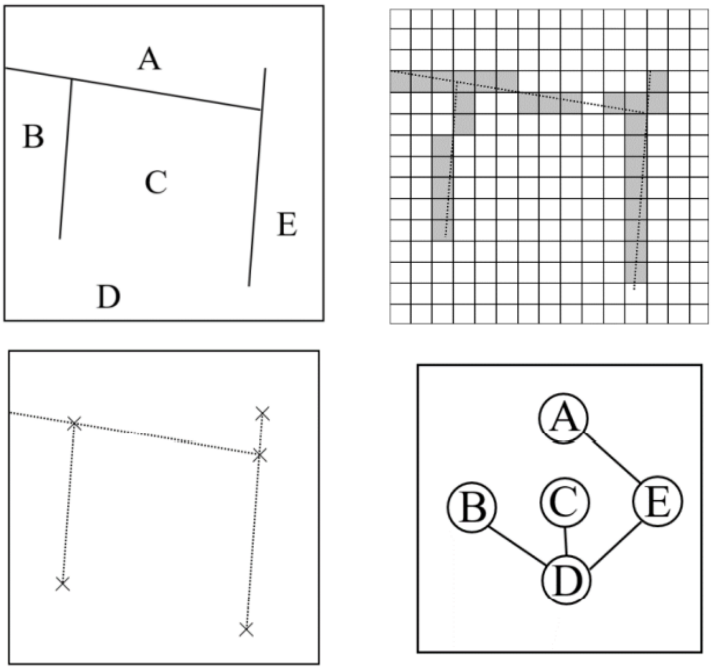

Figure 1. Different types of maps

Lidar point cloud scan matching, scan matching is a very important algorithm step in map construction. The purpose of scan matching is to match and correlate the data measured by the sensor with the existing map data, estimate the position and attitude of the current system, so as to update the position and attitude of the robot incrementally through the sensor data, and further realize the mapping of the map renew. There are three main types of scan matching methods based on lidar point cloud data.

Point-based scan matching. This type of method directly operates on the data points obtained by the sensor, and the most widely used and researched is the ICP algorithm (Iterative Closest Point). In the standard ICP algorithm, scan matching is achieved through continuous iterative optimization to minimize the Euclidean distance between two frames of point clouds. At present, there are various ICP improved algorithms, such as ICL (Iterative Closest Line) algorithm.

Feature-based scan matching. This kind of method considers the problem of noise and error in the sensor data measurement, so the point cloud data is processed first, the salient features are extracted, and the scan matching is realized through the correlation between the features. Therefore, good features become an important factor for the accuracy of the algorithm. Features include point features (such as corner points, intersections, etc.), line features (such as Split-and-Merge method), surface features, etc.

Methods based on mathematical characteristics, such as NDT method (Normal Distribution Transform) and correlation-based algorithms. The NDT method converts the discrete points in the scan into a probability density, and completes scan matching by optimizing the score of another frame of point cloud data on this probability density distribution. Correlation scan matching is based on the defined correlation description function, and optimizes the score of the point cloud of the second frame to achieve scan matching.

Problem Analysis of Solving Navigation Problems Based on Laser Range Finder Data. Navigation corresponds to several basic questions: «Where am I now?», «Where am I going?», «How will I get there?». The first problem corresponds to the positioning of the mobile robot. Based on the robot's own observations and historical poses, the current location is judged. The second and third problems are path planning problems for a given goal and planning a feasible route. Only when the positioning is completed can the starting point be established for subsequent path planning. Therefore, it can be said that the first question determines whether the follow-up question can be answered more accurately. For a robot system with comprehensive exploration capabilities, positioning, mapping, and navigation are indispensable.

In order to solve the above three problems of the mobile robot, it is necessary to use the sensors carried by it for external perception to realize the feature recognition and path planning of the environment map. At present, the two most common types of sensors on the market are laser-based and vision-based. Among them, laser-based mapping and navigation solutions are widely used in industry and service due to their high precision and good work in dark environments. Industry and military, such as factory inspection robots, express logistics vehicles, etc.

For the positioning and mapping of robots, the current mainstream solutions include graph-based optimization and filtering-based solutions. Among them, the graph-based optimization can construct maps with high consistency, but due to the large resource consumption, it is more suitable for Applies to larger or more complex maps. In contrast, the filtering-based mapping scheme has higher real-time performance and performs better in small-scale indoor environments. As for the path planning algorithm, there are currently three schemes based on sampling, nodes, and models. For static scenarios, the node algorithm can more effectively solve the optimal path.

Existing methods for solving the local navigation problem. Navigation methods have been developed to the present, and there are many methods including a series of solutions such as sound, light, electricity, and machinery, but their essence is to use a series of historical moments in the past as the current unknown calculation standard for the robot. Common navigation methods include inertial navigation, magnetic navigation, visual navigation and lidar navigation.

Inertial navigation. The development of inertial navigation has gone through several generations, and it is one of the most basic navigation methods. Inertial navigation uses decoders, gyroscopes, etc. to predict the next trajectory of the mobile robot. This navigation method is similar to the Markov transfer process, that is, the current attitude depends only on the previous attitude and is not related to other historical moments. However, this characteristic lead to accumulation of errors. The ball bearing gyroscope in 1852 belongs to the first generation of inertial navigation sensors, because it cannot be associated with electronic signals, so it cannot complete the navigation task of the robot system; the second generation of floating liquid gyroscope was invented in 1942 and is widely used in In terms of military affairs, such as missiles, aircraft or early military robots, their advantages mainly lie in high navigation accuracy; third-generation laser gyroscopes, micro-electric accelerometers, etc. are widely used in the field of robots. At present, the relatively mature strapdown inertial navigation system uses a unified package of gyroscope and accelerometer.

Magnetic navigation. Magnetic navigation is mainly linked with the signal acquisition system of the robot. Using the landmark signal, collision rubber signal, infrared signal, etc. collected by the robot, after calculation and processing, the mechanical drive structure of the robot is comprehensively controlled to realize the real-time guidance of the mobile robot. Compared with other navigation schemes, this scheme has significant advantages: easy to control, cost saving, etc. Widely used in warehousing logistics, industrial production and other specific fields. However, the disadvantages exposed in the application of magnetic navigation are also very obvious: the magnetic strip embedded in the ground may be damaged, once the path is changed, the magnetic strip track can only be rebuilt, and dynamic obstacles cannot be avoided.

Satellite navigation, satellite navigation must first measure the distance between the current user receiver (mobile phone, radio, etc.) and the satellite, and then integrate the distance information of a series of satellites to calculate the current specific position of the receiver. In order to calculate the longitude and latitude altitude position of the user on the earth, the real-time position and the distance to the receiver of at least 4 satellites are required. The receiver clock can measure the approximate distance between the current user and the satellite. The satellite obtains the current position information through autonomous positioning, and uses the obtained four distance information and the current relative position of the satellite to construct an equation to solve the specific three-dimensional position of the user receiver. The advantage of this navigation method lies in its universality and the practicability of global positioning, but the disadvantage is that indoor positioning is prone to signal interference, which leads to positioning failure.

Visual navigation, visual navigation is similar to humans using binoculars to identify and locate the surrounding environment. A common visual navigation solution generally uses a depth camera to scan the surrounding environment to obtain a series of point cloud information, and then constructs a two-dimensional or three-dimensional environmental map through feature extraction and distance calculation. Its application was first used in 1993. Atiya and Hager proposed a method of extracting static feature points in a dynamic environment to locate the robot in real time. At present, this method is still used in interstellar exploration. Foreign scholars and the National Space Administration of the United States have carried out a large number of experiments based on visual navigation; domestic visual navigation research focuses on extracting a series of images taken during the robot's movement to measure the robot's For example, Wang Yanli et al. have studied the autonomous operation mobile platform in the greenhouse environment. In addition, visual navigation technology has also participated in my country's space exploration plan. For example, Shao Wei et al. have studied the visual navigation algorithm of small celestial body landers.

LiDAR navigation. Lidar is the sensor with the highest accuracy and the fastest response in the current robot navigation ranging solution, but it is also the sensor with the highest price. Its navigation principle and ranging effect are shown in Figure 2.

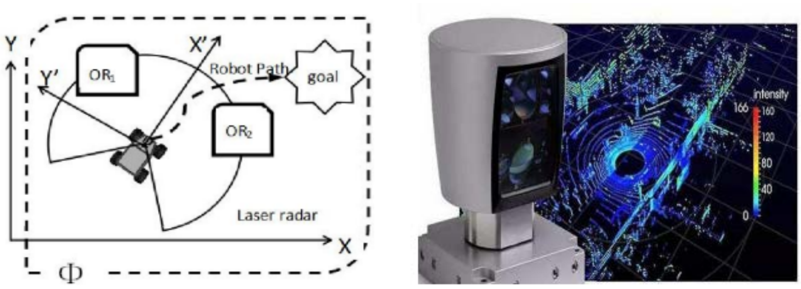

Figure 2. Navigation principle and ranging effect

According to the use scenarios of lidar, it can be divided into ground-based lidar, airborne lidar, and space-borne lidar. The accuracy of airborne and space-borne lidar is slightly worse, but its perception range can reach hundreds of meters. , in contrast, ground-based lidar has the highest accuracy, but has a shorter measurement range. Xia Jing et al. measured the measurement accuracy of the airborne lidar linearly with the increase of the height of the carrier. As for the spaceborne lidar, foreign research on it was earlier, and NASA applied it to the lunar probe when it landed. Aspects such as finding a safe landing spot and automatic navigation. At present, lidar is mainly used in the construction of 3D map reconstruction and detection in a closed environment. In specific environments such as rescue and underground exploration, lidar can take advantage of its high accuracy.

Existing approaches to solving global navigation problems. The method to solve the global navigation problem is satellite navigation . Satellite navigation first needs to measure the distance between the current user receiver (mobile phone, radio, etc.) Location. In order to calculate the longitude and latitude altitude position of the user on the earth, the real-time position and the distance to the receiver of at least 4 satellites are required. The receiver clock can measure the approximate distance between the current user and the satellite. The satellite obtains the current position information through autonomous positioning, and uses the obtained four distance information and the current relative position of the satellite to construct an equation to solve the specific three-dimensional position of the user receiver. The advantage of this navigation method lies in its universality and the practicability of global positioning, but the disadvantage is that indoor positioning is prone to signal interference, which leads to positioning failure.

Conclusion. To sum up, the path of magnetic navigation is relatively fixed and lacks flexibility; inertial navigation has a large drift after long-term use; satellite navigation cannot be used directly under indoor conditions; visual navigation has too much calculation and is easily affected by light; and LiDAR navigation is less affected by environmental factors and has good measurement characteristics. Therefore, this paper uses LiDAR to realize the navigation system of mobile robots in various environments.

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ПРОБЛЕМЫ НАВИГАЦИИ И УПРАВЛЕНИЯ ДВИЖЕНИЕМ АВТОНОМНОГО МОБИЛЬНОГО РОБОТА: АНАЛИЗ СУЩЕСТВУЮЩИХ МЕТОДОВ

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Аннотация. В данной статье кратко представлены характеристики современных мобильных роботов, разбираются текущие проблемы навигации роботов, представлены алгоритмы позиционирования и навигации роботов, а затем представлены карты сетки, топологии и геометрические характеристики, которые описывают модель окружающей среды. Дальнейшие исследования на основе карт необходимы для последующей автономной навигации.

Ключевые слова: мобильный робот, управление движением, навигация, SLAM, LiDAR.