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Robot Navigation and Map Construction Based on SLAM Technology

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Abstract: ***SLAM (Simultaneous Localization and Mapping) technology plays a crucial role in the field of robotics, which realizes the autonomous navigation of robots in unknown environments through real-time positioning, mapping and path planning. This paper first introduces the basic principle and workflow of SLAM technology, including sensor data fusion, state estimation and map construction. Then, by comparing and analyzing the map construction methods of traditional raster map and visual SLAM technology, the advantages and disadvantages of different map representations are shown. Finally, combined with the practical application scenario, the wide application of SLAM technology in logistics, intelligent manufacturing and other fields is discussed, and its future development direction is prospected.***

Keywords: SLAM technology; Map construction; Visual SLAM; Application scenario

1. INTRODUCTION

In the burgeoning landscape of robotics, the quest for autonomy stands as a paramount aspiration. At the heart of this endeavor lies Simultaneous Localization and Mapping (SLAM) technology, a cornerstone poised to underpin the infrastructure of the impending "robotic era." In essence, SLAM embodies the quintessential process through which robots navigate uncharted territories, seamlessly achieving localization, mapping, and path planning in real-time. As the crux of autonomous mobility, [1-4]SLAM tackles the intricate challenge of guiding robots from point A to point B, a task deceptively simple yet laden with complexity. Within the realm of unknown indoor environments, SLAM emerges as a beacon of innovation, enabling robots to construct meticulous maps of their surroundings and navigate autonomously. With decades of relentless research and development, the industry has forged a path toward realizing robot autonomy, with SLAM technology at its forefront, heralding a new frontier in navigation for autonomous mobile robots.

At present, autonomous mobile applications supported by SLAM navigation technology have been very extensive, covering many fields such as aerospace, military, special operations, industrial production, intelligent transportation, consumer entertainment and so on. [5]Typical applications include the application of SLAM autonomous navigation technology to logistics robots, which can ensure that the robot is highly intelligent and strong environmental adaptability, so as to effectively improve the logistics efficiency of enterprises and reduce production costs. SLAM navigation has strong adaptability, and changes in the surrounding environment have no impact on navigation, [6]fully demonstrating the flexibility and scalability of the vehicle, and various connection schemes can be customized according to the requirements of working conditions.

SLAM technology relies entirely on rich natural features in the environment for autonomous localization and navigation. The logistics and warehousing environment is relatively complex, and the robot needs to complete more work, so its location information will constantly change[7]. SLAM technology can complete the autonomous positioning of the robot, effectively track and operate the target, realize autonomous path planning and navigation, automatically avoid obstacles and other operations, which can greatly improve the intelligence and autonomy of the warehousing system. Improve the breadth and depth of mobile handling robot applications.

2. RELATED WORK

2.1 SLAM technology

Early SLAM research almost all used Lidar as a sensor, which has the advantage of high accuracy and relatively mature solutions. [8]But the disadvantages are also very obvious, such as expensive, large volume, less information is not intuitive enough. Visual SLAM uses the camera as the main sensor and the captured video stream as the input to achieve simultaneous positioning and mapping. [9-11]Visual SLAM is widely used in AR, autonomous driving, intelligent robots, drones and other frontier fields.

Among them, autonomous navigation requires determining the location of the machine in the environment, while generating a map of that environment. Meeting these conditions is difficult because the machine needs a map of the environment in order to estimate its own position. And the machine can only generate a map if it knows where it is.

2.2 How SLAM works

Here's a very simplified definition of SLAM: When the machine is powered up, SLAM technology fuses data from onboard sensors and processes it using computer vision algorithms to "recognize" features of the surrounding environment. This allows SLAM to build a rough map and make a preliminary estimate of the machine's location. SLAM calculates the machine's initial position as it moves, collects new data from the system's onboard sensors, and makes a new (and improved) position assessment[12]. Once the machine has a new location assessment, it updates the map in turn, thus completing a cycle. By repeating the above steps consecutively, SLAM can track the path of the machine as it moves through the asset. It also produces detailed maps.

Lidar can scan for obstacles in the environment, generate a map of the environment with landmark information through the SLAM process, and provide it to the robot. Because the laser radar has high accuracy, high output efficiency, and does not require too much calculation process, it is widely used[13]. But lidar is not cheap, and Lidar does not detect transparent obstacles such as glass, nor can it be used underwater, because water will hinder the transmission of light, so Lidar also has certain application limits.

Visual SLAM is computatively intensive and is easily affected by illuminance. However, with the improvement of hardware performance in recent years, visual SLAM has also been rapidly developed and applied. In the process of large-scale outdoor unmanned driving, multi-sensor combinations such as vision sensors, millimeter-wave radar, multi-line Lidar, [14]IMU and [15]GPS are generally selected at the same time, and multiple sensors of the same type are equipped around the body to realize the automatic perception of the surrounding environment.

2.3 SLAM procedure

The SLAM process is done in several steps, and its main purpose is to use the environment to update the robot's location information. The general process includes landmark extraction, data association, state estimation, state updating and landmark updating.

Relying solely on the motion of the robot to estimate its position is not accurate, because robot odometers usually have some error. [16-18]Usually, the environment information is obtained by means of ranging equipment such as LiDAR and then fused with the odometer information to obtain the robot's position more accurately. There are usually many ways to achieve this, and EKF is a common SLAM implementation. EKF is the core of SLAM, which continuously estimates the position of the robot and the surrounding environment information, and more accurately estimates the position of the robot through iterative calculation.

When the robot moves, its position changes, and the robot associates the information observed by the odometer with the landmark information obtained by the [19]liDAR. EKF performs a comprehensive calculation of the current observed position and the robot's moving position to estimate the accurate position information of the robot.

SLAM technology With the development of AI technology is gradually known by people, 2D Lidar SLAM technology is relatively mature at present, there are many practical applications. There are still many questions in the field of visual SLAM, and there is still a lot of room for research and improvement. For example, multi-sensor data fusion in unmanned driving, optimization of data association, loop detection mechanism and relocation accuracy. Visual SLAM may be a key research area and development direction in the future.

2.4 SLAM Framework

Sensor data: mainly used to collect various types of original data in the actual environment. Including laser scanning data, video image data, point cloud data and so on. - [20][21]Explore UWB perceived distance and Angle as sensing inputs;

Odometer: mainly used to estimate the relative position of moving targets at different times. Including feature matching, direct registration and other algorithms. - Distance calculation with video, IMU and UWB range + Angle measurement;

Back end: Mainly used to optimize the cumulative error caused by the odometer. Including filter, graph optimization algorithm applications.

Map building: Used to build two-dimensional or three-dimensional maps.

Loop detection: It is mainly used to eliminate cumulative spatial errors.

2.5 Positioning and sensor selection

When you open the navigation app on your phone, what's the first action you have to take before choosing the best route to your destination? Yeah, it's positioning. We need to know our position in the map before we can carry out subsequent path planning. In the real time robot location problem, because the robot position information obtained by the robot motion estimation usually has a large error, we also need to use the surrounding environment information obtained by the ranging unit to correct the robot position.

At present, the common ranging units include laser ranging, ultrasonic ranging and image ranging. Among them, with the laser's good directivity and high focusing, Lidar has become the core sensor of mobile robots, and it is also the most reliable and stable positioning technology.

Since it was proposed in 1988, the theoretical research of SLAM has developed rapidly. In practical application, in addition to equipped with LiDAR, the robot also needs to have IMU (inertial measurement unit) and odometer to provide auxiliary data for LiDAR, the calculation consumption of this process is huge, and traditionally requires a PC-level processor, which has become one of the bottlenecks limiting the wide application of SLAM.

3. Financial decision realization path of generative AI

3.1 Build map

Just as humans draw maps, the process of describing and understanding the environment of robots mainly relies on maps. It uses environment map to describe its current environment information, and adopts different map description forms with the difference of algorithms and sensors used. There are four kinds of map representation methods in robotics: raster map, feature map, direct representation and topological map.

The most common way robots describe an environment map is [22-23]Grid map or Occupancy Map. A grid map divides the environment into a series of grids, each of which is given a possible value representing the probability that the grid will be occupied.

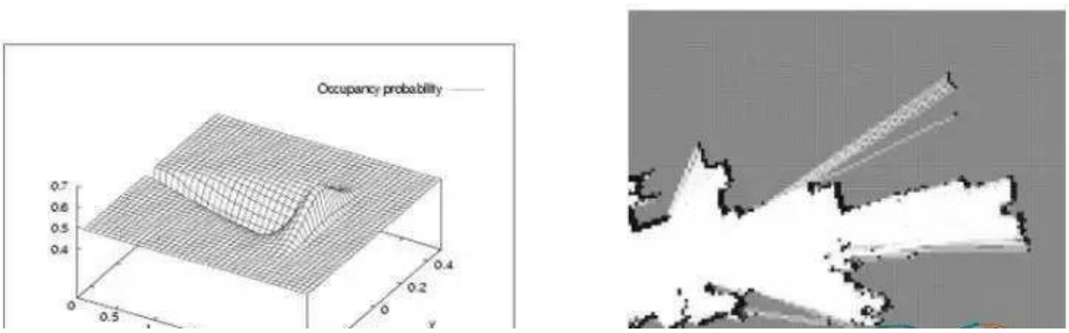

Figure 1. Grid map

The map, which looks much like a familiar map, was first proposed by NASA's Alberto Elfes in 1989 and has been used on Mars rovers. It is essentially a bitmap image, but each "pixel" represents the probability distribution of obstacles in the actual environment.

In general, the map can be used when performing SLAM with sensors such as lidar, depth cameras, and ultrasonic sensors that can directly measure distance data. Such maps can also be made using range-measuring sensors, ultrasound (in the early days)[24], and LiDAR (now).

3.2 Feature point map

Feature point maps, which represent the environment with relevant geometric features (such as points, lines, and surfaces), are commonly used in vSLAM (Visual SLAM) technology.

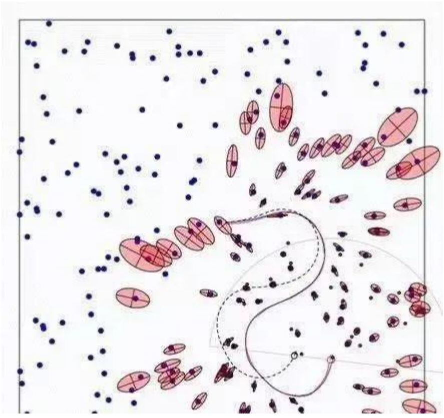

Figure 2. Schematic diagram of feature point map

While grid maps offer a straightforward representation of environments by dividing them into evenly spaced cells, alternative mapping techniques like visual Simultaneous Localization and Mapping (vSLAM) produce maps that might seem less intuitive at first glance. These maps are generated through the integration of various sensor technologies, including GPS, [25-27]Ultra-Wideband (UWB), and cameras, combined with sophisticated algorithms.

The vSLAM approach relies on sparse data points extracted from sensor readings to infer the robot's location and surroundings. Unlike grid maps, which store information for every grid cell, vSLAM maps are constructed using only essential features or landmarks detected by the sensors. This sparse representation results in maps that are more memory and computationally efficient, making them particularly suitable for resource-constrained robotic systems.

Furthermore, the use of visual data from cameras in vSLAM algorithms adds another dimension to mapping, as it enables robots to perceive and navigate based on visual cues similar to human vision. This capability allows robots to operate in dynamic and complex environments where traditional grid-based mapping techniques may struggle to adapt.

3.3 Topological map

A more abstract form of map, it represents the indoor environment as a topological structure diagram with nodes and related connecting lines, where nodes represent important points in the environment (corners, doors, elevators, stairs, etc.), and edges represent connections between nodes, such as corridors[28], etc.

This method only records the topological link relationship of the environment, and this kind of map is generally extracted by the previous types of maps through relevant algorithms.

For example, when the sweeping robot wants to clean the room, it will establish such a topological map:

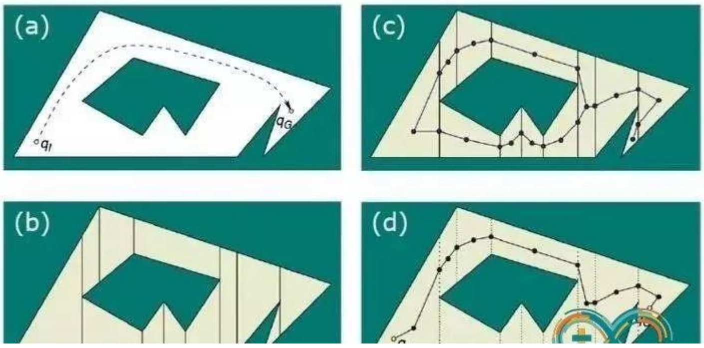

Figure 3. Robot and topological map

In robotics, map building in SLAM usually refers to building a map that is geometrically consistent with the environment.

The topological maps established in the general algorithm only reflect the connection relationship of various points in the environment, and cannot build a geometrically consistent map. Therefore, these topological algorithms cannot be used in SLAM[29].

Direct representation is similar to satellite maps in that it is built directly from sensors (usually image sensors). This method has the largest redundancy of information, which is a great challenge for data storage, and at the same time, it takes a lot of trouble for robots to extract useful data from it, so it is rarely used in practical applications. Feature map is the other extreme, although the amount of data is small, but it often can not reflect some of the necessary information of the environment, such as the location of obstacles in the environment. [30-31]In vSLAM technology, this kind of map is often used to solve the robot localization problem. If you want the robot to carry out autonomous obstacle avoidance and path planning, you also need to configure additional distance sensors, such as lidar and ultrasonic to complete.

Raster maps, or Occupancy maps, fit right in. On the one hand, it can represent many features of a spatial environment and robots can use it for path planning, while on the other hand, it does not directly record raw data from sensors, achieving the relative optimization of space and time consumption. Therefore, raster map is a map storage method widely used by robots.

4. CONCLUSION

The wide application and continuous development of SLAM technology opens up new possibilities for the advancement of robotics. By continuously optimizing SLAM algorithms and map building technologies, we can expect smarter and more flexible robot systems to further promote the application of robots in various fields. With the continuous evolution of SLAM technology, robots will be able to achieve a higher level of autonomous navigation and task execution capabilities in more complex environments, thus playing a greater role in industrial production, intelligent logistics, medical care and other fields. In addition, with the increasing application of SLAM technology in the consumer goods industry and entertainment fields, we will also witness the emergence of more interesting and practical robot products and services, bringing more convenience and fun to human life and work. In the future, SLAM technology will continue to be an important engine for the development of robotics technology, driving the robotics industry towards a more intelligent, autonomous and humane future.

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