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Application of Slam Technology for Autonomous Mobile Robots in Complex Environments

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Abstract: SLAM technology is widely used in many fields, such as whether it is possible to map the environment and determine the direction of progress while placing a robot in an unknown location in an unknown environment. On this basis, this paper studies the use of autonomous movement of robots in complex environments. This article will first introduce vision technology in dynamic environments and camera-based dynamic environmental sensor technology. Additionally, it will discuss parallel research on real time 3D map optimization and algorithm processing based on cameras. Secondly, the map construction and dynamic maintenance of mobile robots and how to improve the application of Road King tracking algorithm in robots are introduced. Finally, the multi-sensor laser mapping technology and algorithm of mobile robot are introduced. This research will significantly contribute to the development and application of mobile robots capable of processing complex information in challenging environments. The integration of these technologies and algorithms paves the way for more robust and adaptable autonomous navigation systems in real-world applications.

Keywords: SLAM, Robots, Complex Environments.

1. Introduction

With the development of the global economy and technology, people's demand for robots is increasing. As they are no longer satisfied with simple fixed robots, the development of autonomous mobile robots has become urgent. Intelligent mobile robots have a variety of functions such as control execution, environmental perception, map construction, dynamic obstacle avoidance, and autonomous navigation, among which autonomous navigation is the most important function of intelligent mobile robots. Smith proposed Simultaneous Localization and Mapping (SLAM) in 1986. This innovative technology revolutionized robot navigation. SLAM refers to an agent loaded with lidar or camera, which is placed into an unknown environment to move, and gradually builds a map of the environment while moving. In this process, the mobile robot relies on its own sensors to perceive the current environment and obtain the information of each frame, and complete simultaneous positioning and mapping by matching the information of the previous frame and the current frame. Currently, the main sensors of SLAM technology are divided into two categories: lidar and camera. Over the past 30 years, SLAM technology has become more mature and widely used: Baidu's Apollo autonomous driving, underwater exploration, coal mine exploration, AR, smart home

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and other fields are all representative application products of SLAM technology. However, our research group found that the application of SLAM technology in complex environments needs to be improved. This study aims to address these challenges and enhance SLAM's performance in diverse and dynamic settings.

2. Slam technology for autonomous mobile robots in complex environments

In the article Research on visual SLAM technology for autonomous mobile robots written by Dawei Zhang and Shuai Su, it examines visual SLAM in a dynamic environment. Firstly, SLAM technology is used to try to remove the feature points and other information of dynamic objects to avoid the trouble of positioning and loop detection, and two parallel computing modules of semantic segmentation and feature point detection are used to remove feature points. The results show that this can segment long-distance dynamic targets and combine multi-view geometry to improve the accuracy of short-range target detection, and can also detect distant targets by deep learning. The second is SLAM technology based on event cameras. Investigate dynamic vision sensors (DVS), which operate independently and asynchronously in event-based cameras in response to changes in intensity by generating events compared to conventional cameras that generate images at a fixed rate. Events are represented by the x, y pixel position, and time t of the change in intensity and its polarity. The polarity indicates whether the pixels darken or lighten. Event-based cameras essentially sample the scene at the same rate as scene dynamics. The result is a display with very high temporal resolution, low latency, very high dynamic range (HDR, 140 dB), and low power consumption and bandwidth requirements, which make it ideal for capturing motion. As a result, event-based cameras can be applied to challenging scenarios that are inaccessible to traditional cameras [1].

In another essay which called a review of Slam technology based on RGB-D series cameras attempts to optimize the visual slam technique. By improving the computing power of GPU hardware and parallel computing technology, the real-time is significantly improved, and the development of visual slam is promoted. Real-time 3D reconstruction on mobile devices faces challengs. While current RGB-D series cameras equipped with SLAM can simplify depth calculation, real-time 3D reconstruction still requires acceleration by high-performance graphics processors. The equipment needed for this process is typically heavy, and energy-intensive, making it unsuitable for mobile devices. Real-time 3D reconstruction is run on low-power mobile devices. The research also aims to enhance the abstraction of the environment map. It attempts to elevate the map from underlying features to a semantic level, providing a more meaningful representation of the environment. Secondly, the RGB-DSLAM series based on the feature point method usually needs to extract and match feature points in the image, which cannot build a dense map, and cannot work in the absence of scene features (such as only one white wall, etc.). In contrast, the RGB-DSLAM series based on the direct method does not rely on the extraction and matching of feature points, but directly estimates the movement of the camera based on the brightness information of the pixels. Therefore, as long as there are light and dark changes in the scene, the direct method will work [2].

Research on SLAM technology in mine intelligence is progressing towards combining deep learning with multi-source heterogeneous data fusion, as shown in the study "Research Status and Application Progress of SLAM Technology in Mine Intelligence". Firstly, deep learning is deeply coupled with SLAM to deeply analyze the mine environment. Deep learning has achieved remarkable results in the field of image recognition and feature extraction, and its combination with SLAM technology can make the SLAM system more targeted to be applied to specific scenarios such as excavation faces, unknown and post-disaster scenarios, and even realize tasks such as accurately identifying dynamic targets and segmenting the mine environment, so as to complete more accurate mapping and positioning tasks. Then, traditional technologies assist SLAM to improve deployment feasibility. In open-pit mines, GPS-assisted SLAM has been used for road network mapping and

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mining truck positioning, and in the mine scenario, traditional technology, especially positioning technology, can be used as an auxiliary means to reduce the pressure of SLAM calculation and deploy high-precision positioning equipment at a lower cost. Third, the 3D reconstruction and visualization of real-time SLAM improves the experience of mine mining operations. With the improvement of the computing power of intelligent devices and the optimization, SLAM technology is expected to integrate with virtual reality (VR) or augmented reality (AR).This integration can help mine personnel better understand the structure and layout of the mine, It also enables safer and more efficient production operations with fewer people on-site. Furthermore, it provides mine personal with a more intuitive and immersive operational experience [3].

In Advanced quaternion unscented Kalman filter based on SLAM of mobile robot pose estimation, it innovative use of temporary local maps to track anomalous observations caused by changes in the position of semi-static objects. The method still assumes environmental static invariance. However, when the environment changes, it establishes a temporary local map to express these changes. This temporary map extends the original prior map. The extended map is then used with a particle filter algorithm to estimate the robot's pose. Experiments show that the robustness of robot positioning can be effectively improved by detecting abnormal observations caused by semi-static objects. Secondly, a dynamic environment composition method based on raster model is proposed. This method defines each raster as an independent Markov chain with two states, and utilizes proximate-factor weights (Recency weighting) of the strategy online learning state transition model parameters. This probability-based raster map can not only represent whether the raster is occupied, but also model the raster dynamics. Building on the probabilistic estimation model, Tipaldi et al. employed an implicit Markov model of a two-dimensional grid. This approach was used to express the dynamic properties of occupied grid cells. This method effectively distinguishes different object types, categorizing them as dynamic, semi-static, or static based on their properties [4].

A study on the application of improved path following algorithm in robot SLAM explores a robot autonomous mapping method based on assisted path tracking. This method first performs raster denoising on the given initial sketch. Then, it improves the fitting of the auxiliary path using multi-segment cubic polynomials. Finally, an improved pure tracking algorithm guides the robot in map building, aiming to reduce the total distance and time of the SLAM mapping process. Experimental results demonstrate that the proposed algorithm outperforms existing V-SLAM and QRCode-SLAM methods in three key aspects: map integrity, accuracy, and mapping efficiency. This improvement enables a visual two-way interaction method for faster and more efficient map construction. In large-scale scenarios, the robot can avoid the inability to quickly build a high-precision complete map due to the accumulation of errors caused by repeated measurements and sweeps at the edge of the region. In addition, the SLAM method of LiDAR SLAM (Simultaneous Localization and Mapping) fuses IMU (Inertial Measurement Unit) data to the 3D point cloud registration process. Reduce the effect of carrier jitter on ground point extraction. The IMU output information serves two purposes: it eliminates point cloud distortion caused by carrier movement and enhances the algorithm's robustness. This dual function significantly improves the overall performance of the SLAM system. The point cloud registration accuracy is improved, and the robustness of the algorithm is enhanced [5].

In RGB-D-based SLAM and path planning for mobile robots, the RGB-D information and ORB-SLAM algorithm were used for autonomous positioning, and the environment raster map was established by combining point cloud data and GMapping algorithm. Based on the quadratic programming method, a smooth and analytic path planning is carried out, and a nonlinear controller is designed, and an autonomous mobile robot system composed of a motion chassis, an RGB-D sensor and a computing platform is realized. A 2D raster map of the environment is established in real time from the laser type data generated by the RGB-D point cloud. The ORB-SLAM system provides real-time pose information with high stability and accuracy. This is achieved through optimizing the

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mapping process and implementing constraints in the closed-loop detection link. Notably, the pose update frequency can reach 20 Hz, meeting the system requirements. At the same time, according to the height constraint of the mobile robot, the RGB-D point cloud in the height range is used for map construction, which is verified by experiments, and the system realizes real-time positioning and mapping, autonomous movement and obstacle avoidance in complex indoor environments. This system offers a comprehensive solution for the popularization and application of mobile robots. Its advantages include a simple hardware structure, good performance, easy scalability, cost-effectiveness, and convenient development and maintenance [6].

The study "Research on SLAM technology for mobile robots" focuses on multi-sensor laser SLAM technology. It explores an optimization framework for vehicle-mounted dual-3D lidar calibration. Additionally, it investigates a loosely coupled multi-sensor diagram approach. In view of the difficulty in finding the constraint relationship between laser points in traditional laser calibration, and the need for additional sensors and artificial markers to assist in the calibration process, the researchers adopt a vehicle-mounted dual-3D lidar calibration approach. They use wall corners as calibration targets and match three linearly independent planes using the least squares method. The external parameter rotation matrix and displacement matrix of the dual lidar system are then obtained using the Kabsch algorithm. The Levenberg-Marquardt (LM) algorithm was used to iteratively optimize the rotation matrix and displacement matrix, and the calibration results were obtained. This paper explores two key aspects: a front-end odometer based on laser point cloud feature descriptor matching, and a loosely coupled multi-sensor map optimization framework. The nonlinear optimization iteration of the odometry motion is carried out, but with the long-term movement time, the information of the lidar alone is not enough to eliminate the cumulative error. Therefore, it is necessary to provide auxiliary information through other sensors to construct the odometer motion pose map and optimize the back-end. Meanwhile, this article also studied cycle detection based on KDTREE search. Set the search radius, search for loopback detection that can build historical constraints with the current frame within the radius, and optimize the map and pose to obtain the optimal pose map and environment map[7].

In Research on SLAM technology of mobile robots in dynamic and complex scenes. This paper introduces an improved SLAM algorithm that combines visual and deep learning techniques. The algorithm addresses the issue of inaccurate positioning in scenes lacking distinct features. Traditional methods using feature points often discard important image information in such scenarios. The proposed approach aims to overcome this limitation. The algorithm replaces the traditional ORB feature extraction method with a deep learning network as a way to extract image feature information. The paper also proposes another improved SLAM algorithm that utilizes fast target detection. This approach aims to address the interference in traditional visual feature point extraction caused by moving objects. The algorithm takes advantage of the advantages of fast target detection algorithms to remove the feature points on movable objects, without affecting the real-time requirements of the algorithm. To further reduce the influence of movable objects on robot positioning, this paper proposes an improved SLAM algorithm based on visual and laser [8].

3. Conclusion

SLAM technology has significantly advanced the capabilities of autonomous robots. Through its application, the movement of autonomous robots in complex environments is no longer limited to basic movement. The research introduced in this paper on visual dynamic processing technology and path algorithms in complex environments has made the movement of robots no longer rigid. With a variety of sensors and optimized algorithms, robots can build 3D maps in real time in complex environments and calculate the optimal movement path. They can also capture, process, and classify various signals from robot vision sensors. Static and dynamic objects are processed and classified by the camera, which helps in the selection of paths.

For example, this article studied how SLAM technology assists autonomous mobile robots in mines. It can not only conduct in-depth analysis of the mine environment through SLAM technology, but also help humans apply it to unknown scenarios such as excavation faces and post-disaster scenarios in the fields of image recognition and feature extraction through deep learning, even accomplishing tasks such as accurate identification of dynamic targets and segmentation of mines.

Moreover, after the optimization research of the path algorithm and the upgrade of the camera discussed in this paper, the robot can avoid the accumulation of map errors caused by repeated measurement areas, and provide a complete map with faster and higher accuracy. In addition, it provides the characteristics of simple hardware structure, good performance, good scalability and good economy for the occasional application of mobile robots. With the continuous breakthrough and development of technology. We believe that SLAM will find more applications in the future. The current robot vacuum cleaner is just one example of its potential. SLAM technology can help robots realize in various civilian robots, so that the trivial things in life can be completed by robots. And can play a certain role in the army.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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