DOI: 10.54254/2755-2721/111/2024.CH17889

Research on Obstacle Avoidance in Automatic Driving Based on SLAM Path Planning

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Abstract. Automatic driving based on SLAM is known as one of the key research topics today. At present, researchers have made progress in some aspects such as EKF-SLAM and Graph SLAM and some even have commercialized attempts. However, the problem of automatic driving obstacle avoidance based on SLAM still lacks a unified cognition. Therefore, the research topic of this paper is the method of obstacle avoidance in automatic driving based on SLAM trajectory planning. This paper summarizes and discusses the relevant research results by integrating relevant literature and further expounds the application of SLAM technology in automatic driving obstacle avoidance: The front-end vision based on feature point method is more mature than other front-end tracking options. EKF-SLAM algorithm is not suitable for complex large-scale maps. Image optimization SLAM is dedicated to obtaining the optimal pose, but it needs to be initialized according to the environment. Through the summary and discussion of the research results, this paper not only shows the application value of SLAM in automatic driving obstacle avoidance, but also gives readers a reference for the choice of SLAM technology

Keywords: SLAM, obstacle avoidance, path planning automatic driving.

1. Introduction

With the rapid development of science and technology, intelligent technology has spread across all walks of life, and the vehicle industry is no exception. Among them, autonomous driving technology has become an important driving force for the change of the global automotive industry. In the construction of intelligent transportation system, automatic obstacle avoidance is adopted to ensure driving safety and the safety of members in the car. In recent years, simultaneous localization and mapping methods that rely on single or multiple sensors to establish high-precision maps of local environments have gradually become a research hotspot in the field of intelligent vehicles, reflecting high value. For example, Zhao Jianwei et al. from China University of Mining and Technology used karto SLAM algorithm to build maps and ROS system to make the chassis pose of four-wheeled robots more accurate and achieve accurate navigation tasks [1]. Radish Fast Run Robotaxi has already begun commercial operation in Wuhan. Through the combination of SLAM related technologies, its fully unmanned autonomous driving has reached L4 level in China. Through continuous research, people can further expand the application field of SLAM. For example, Muhammad Farhan Ahmed et al. pointed out that the application fields of A-SLAM and AC-SLAM include but are not limited to search and rescue, planetary observation, precision agriculture, and underwater autonomous navigation [2].

Therefore, the research on SLAM is of great value in many fields. This paper will focus on the different types of SLAM obstacle avoidance in automatic driving, and give suggestions on this basis

2. The application of path planning in automatic driving obstacle avoidance

Path planning in automatic driving obstacle avoidance first includes the construction of a topological connected graph. The basic idea is to conduct a dismembered discretization of space. The first kind of method emphasizes the complete resolution, but it requires a lot of computation in a complex environment.

The representative methods are grid decomposition, road map, and potential field methods. The second type of method emphasizes probability completeness and can be calculated quickly, but it loses the completeness of the algorithm [3], which is represented by PRM and RRT.

Secondly, it includes the optimal path search algorithm, which can be divided into an exact algorithm and an approximate algorithm from the accuracy point of view. Common accurate algorithms include a depth-first method, a breadth-first method, and a Dijstra algorithm. Accurate algorithms require the generation of optimal solutions. It is often time-consuming to traverse a large number of paths. Although the approximation algorithm is not necessarily the optimal solution, it takes less time, which means that the algorithm has A*, D*, an ant colony algorithm, and so on.

For relatively simple environments or more optimal results, it is recommended to adopt a complete resolution method for constructing topologically connected graphs and a precise algorithm for searching optimal paths. In view of the relatively complex environment or the pursuit of rapid calculation, it is suggested to adopt the probabilistic complete method to construct the topological connected graph, and the approximate algorithm to search the optimal path. In order to adapt to the new environment quickly and change synchronously with the change of the environment, the artificial potential field method can be used to construct the topologically connected graph, and the quasi-heuristic algorithm can be used to search the graph.

In view of the shortcomings of different algorithms, many optimization algorithm schemes have appeared. Among them, it is common to introduce new variable factors or modify them on the basis of the previous algorithm to adapt to the new environment and solve new problems. Xingdong Wang et al. can make path planning more efficient in this environment by introducing factors affecting road conditions and weighting functions [4]. There is also a class that can be called the fusion algorithm, which is characterized by combining different algorithms after adjustment to make up for the shortcomings of a single algorithm. Xiong Yin et al. solved the problem that the trajectory was not consistent with the robot kinematics by combining the TEB algorithm and RRT algorithm [5].

3. The use of SLAM technology in autonomous driving obstacle avoidance

3.1. SLAM Technology Overview

SLAM is a technology that helps a robot to quickly understand its surroundings and map the environment by moving and observing when it enters a strange environment. The basic principle of the SLAM algorithm includes the steps of front-end tracking, back-end optimization and closed-loop detection. Front-end tracking mainly involves the selection and calibration of sensors and tracking feature points in the environment; back-end optimization uses filter theory or optimization theory to optimize the front-end results and get the optimal position estimation; and closed-loop detection corrects the robot's position by detecting repeated feature points in the environment[6].SLAM technology is widely used in the fields of robotics, self-driving cars, and unmanned aerial vehicles. In the field of robotics, SLAM technology enables robots to autonomously navigate and accomplish tasks in unknown environments. In self-driving cars, SLAM technology helps vehicles to localize and plan paths in complex road environments. In addition, SLAM technology is also used in virtual reality (VR) and augmented reality (AR) devices to realize accurate spatial positioning and map construction.

3.2. Front-end tracking algorithms

SLAM algorithms for vision and Infrared LIDAR SLAM are common front-end tracking choices. vision SLAM algorithms can be categorized into direct and feature point methods based on the visual odometry processing from the front end [6]. The direct method does not need to detect feature points and directly uses pixel information to estimate the camera motion position, such as DSO, LSD-SLAM, and other algorithms. The feature point method preprocesses the image to obtain the feature point information and then estimates the camera motion position based on the feature points of the neighboring images.

The front-end visual odometer based on the feature point method is stable and less sensitive to light changes and dynamic objects, which is a more mature navigation algorithm solution in the industry. Infrared LIDAR is a commonly used sensor for vehicle data acquisition and sensing. Infrared LIDAR generates an infrared laser beam through an internal transmitter and faces in a specific direction. When the laser beam encounters an object in the surrounding environment, it will reflect and these reflected laser beams will be received and recorded by the LIDAR receiver [7].

The receiver is located at the other end of the LIDAR and is used to receive the reflected laser beam. The LIDAR converts the captured distance information into point cloud data [7]. By analyzing and processing the sensor data and combining the motion model with the observation model, the SLAM algorithm is used to continuously update the vehicle state estimation for precise vehicle positioning in complex environments [8].

The direct method in vision SLAM is proposed based on the assumption of photometric invariance, and camera position recovery is still difficult in certain scenes with strong instantaneous light changes, such as those frequently switching between light and shade environments in summer. The front-end visual odometry based on the feature point method operates stably and is less sensitive to light changes and dynamic objects, which is a more mature navigation algorithm solution in industry.

With limited LIDAR data and weak scene recognition capability, the traditional laser SLAM system is prone to large positioning errors or even positioning loss in environments with single features. In addition, due to the influence of LiDAR itself and external factors, the scanning is prone to noise points, which will also reduce the positioning accuracy of the system.

3.3. Route planning methods

In practical applications, after acquiring the point cloud map from the vision or laser SLAM system, the A-star algorithm is used for global path planning to improve the navigation efficiency and help the machine to quickly plan the optimal path, and then the temporal elastic band algorithm is introduced to perform real-time path planning according to the changes in the environment and obstacles, which ultimately realizes the detection of the machine's autonomous navigation and obstacle avoidance in the complex scene.

Nowadays, an automatic guided vehicle (AGV) is often used in automatic logistics moving and transferring work, AGV can move autonomously according to the external environment and set the task goal. And Luo Keqi proposed the ORB-SLAM3 algorithm for multi-robot[9], which realizes the collection of surrounding environment information and path planning through the A∗ algorithm, It can be analyzed that although the A∗ algorithm can realize path planning, there are a large number of redundant nodes, which leads to a high collision rate of obstacles.

In order to solve this problem, we propose to delete the nodes in the A∗ algorithm and make up for the problems of the A∗ algorithm by using the Dynamic Window Approach (DWA), which has strong obstacle avoidance dynamics and smooth path planning. Through the above methods, the path planning ability and obstacle avoidance performance of the automatic guided vehicle are improved, and the working efficiency of the vehicle is enhanced.

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3.4. EKF in SLAM

The core idea of the EKF algorithm is an extension of the standard Kalman filter algorithm to nonlinear systems. EKF linearizes nonlinear equations of state and measurements by expanding them through a Taylor expansion neglecting higher-order terms [10]. Estimating the linear Gaussian case using only unimodal (Gaussian) is equivalent to a least squares proof of convergence. The smaller the noise, the better the estimation in the nonlinear case, and the larger the nonlinearity, the deviation occurs [11]. The EKF-based SLAM algorithm due to its difficult algorithmic process complexity, so its not applicable to complex large maps [12]. The EKF-based SLAM algorithm consists of two processes, motion update, and observation update, which are the description of the motion model and observation model of the system, respectively. The motion update process is a predictive estimation of the current position of the robot using the data from each sensor as an input control quantity. Observation update is the process when the mobile robot observes the feature points in the current environment and matches them with the local map, and at the same time updates the robot's position in the map.

3.5. Graph Optimization SLAM

Graph Optimization SLAM is essentially a large-scale nonlinear optimization problem where the estimated poses and observations are used to construct an objective function, which is then nonlinearly optimized to obtain the optimal poses. Graph optimization SLAM is based on graph theory, taking the positions of the mobile robot as the nodes of the graph and the relative position relationships (also called constraints) between the positions as the edges of the graph, using the constraints obtained from the position estimation and the constraints obtained from the observations to construct the minimization objective function, and applying nonlinear optimization methods to optimize multiple nodes at the same time, i.e., solving the position to achieve the minimum value of multiple objective functions [13]. Similar to EKF for large-scale maps and complex sensor data, the arithmetic is large and requires high computational resources; the optimization results may fall into the local optimal solution, resulting in a decrease in the estimation accuracy; for unknown environments, it is necessary to carry out initialization, and the accuracy of the initialization directly affects the subsequent optimization results [14][15].

4. Conclusion

This study focuses on the classification of path planning and SLAM-related technologies in automatic driving obstacle avoidance and introduces how the path planning algorithm and SLAM algorithm should choose the best method to improve efficiency under different environmental conditions or requirements of automatic driving obstacle avoidance. For example, the difference between the two categories of algorithms in path planning and their applicable occasions, the advantages and disadvantages of laser SLAM, EKF-SLAM technology, and their applicable occasions. Some autonomous driving technologies based on SLAM are not mature enough, and they still cannot meet high requirements in the face of complex environments.

In the future, SLAM technology is expected to be selected and optimized, including but not limited to introducing new variables into the existing SLAM technology, modifying it to adapt to the new environment, and combining SLAM with other technologies after adjustment to make up for the shortcomings of single SLAM. It can not only reduce the cost, and popularize the application, but also make SLAM specialized and in-depth in different fields, so as to better promote the development of other fields.

Authors Contribution

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

References

[1] Zhao J Liu S Li J 2022 Research and Implementation of Autonomous Navigation for Mobile Robots Based on SLAM Algorithm under ROS. Sensors (Basel) vol 22 no 11 pp 4172

DOI: 10.54254/2755-2721/111/2024.CH17889

[2] Muhammad F A 2023 Khayyam Masood.Vincent Fremont. Isabelle Fantoni Active SLAM: A Review on Last Decade
[3] Shunqi Q 2024 Review of path planning algorithms in automobile autonomous driving. July Applied and Computational Engineering vol 79 no 1 pp 241-247
[4] Wang X Zhang H Liu S et al 2022 Path planning of scenic spots based on improved A* algorithm. Sci Rep vol 12
[5] Yin X Dong W Wang X et al 2024 Route planning of mobile robot based on improved RRT star and TEB algorithm. Sci Rep vol14 pp8942
[6] Wang X Xi M 2023 Research on SLAM and Path Planning Method of Inspection Robot in Complex Scenarios Electronics vol 12 no10 pp 2178.
[7] Zhang Y 2020 Research on construction and application of intelligent vehicle navigation map based on binocular Visual SLAM Chongqing jiaotong university
[8] Liu X Yang X 2024 Based on near infrared laser radar vehicle collision control system Journal of laser vol 7 pp 215-219
[9] Luo K Xia Y Cai Sh 2022 ORB-SLAM3-based multi-robot map construction algorithm robot map construction algorithm Experimental Technology and Management vol 39 no6 pp82-9.
[10] Qiu Y Liu Y Li J 2024 Application of Mathematical Algorithm in Automotive Automatic Driving System Times Automobile vol 9 pp29-31
[11] Huang Y 2023 SLAM fusion algorithm based on improved EKF laser and vision research University of north
[12] Zhang K 2023 Of autonomous indoor mobile robot localization based on graph optimization SLAM research Hangzhou university of electronic science and technology
[13] Zhu S 2019 Based on automated driving the car interior map generation and navigation and obstacle avoidance research Tianjin university
[14] Shen D Shang G Zhao G et al 2022 Improved EKF - automatic SLAM off car positioning algorithm [J]. Journal of xi 'an engineering university vol 4 no 6 pp 77-85
[15] Hao Y Zhang Y Huang L et al 2024 Research on two-dimensional Laser SLAM algorithm for mobile robots based on Improved graph optimization Laser and optoelectronics pp 1-13