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The Research Overview of Simultaneous Localization and Mapping

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Abstract

Since entering the 21st century, more and more attention has been paid to the development of autonomous navigation technology at home and abroad, and it has become one of the most active fields of cutting-edge high-tech research. Localization and map creation are the key problems to be solved for mobile robot to realize autonomous navigation, which has important theoretical and application value. Simultaneous localization and mapping (SLAM) combines map creation and location into an estimation problem to establish a more reliable environment map. Taking the SLAM of mobile robot as the research object, this paper introduces the research progress of SLAM algorithm.

Keywords

Mobile Robot; Autonomous Navigation; Simultaneous Localization and Mapping (SLAM); Particle Filter; Extended Kalman Filter (EKF).

1. Introduction

As an important branch of robotics, mobile robot is a comprehensive system that can perceive the environment and has the functions of decision-making, planning, behavior control and execution [1-2]. With the continuous progress of science and technology, the performance of mobile robot has been gradually improved and has been widely used in military, industry, exploration, medical and other fields. The research on mobile robot has also developed to a new stage and has become one of the biggest hotspots in the field of robot.

Whether it is unmanned vehicle, unmanned ship or UAV, there are four core and fundamental problems, namely localization technology, tracking technology, path planning technology and control technology. In the first three of these four questions, autonomous navigation plays the most core function, and its significance, for example, is the same as the significance of WIFI and 4/ 5G data transmission technology to mobile phones in the era of mobile Internet, playing the most core and indispensable role. If the mobile phone leaves WIFI and data network, it is like unmanned car and robot leaving autonomous navigation. Autonomous navigation technology is deeply applied in various fields, and all fields regard it as the future.

Simultaneous localization and mapping (SLAM) is also called concurrent mapping and localization (CML) [3-4]. SLAM was first proposed by Smith, Self and Cheeseman in 1988. Because of its important theoretical and application value, SLAM is considered by many scholars as the key to the realization of fully autonomous mobile robot. SLAM has been widely used in mobile robots, unmanned vehicles, unmanned underwater vehicles, UAVs, augmented reality (AR)and other fields. However, SLAM technology still faces many challenges, such as complex environment, reliable data fusion, nonlinear and unknown prior knowledge [4].

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2. SLAM Problem Description

SLAM can be described as a mobile robot moving from an unknown position in an unknown environment, positioning itself according to control information and sensor observation, and building an incremental map. Positioning and incremental map construction are integrated, rather than two independent stages. Because the control information and sensor observation will be disturbed by noise, SLAM is essentially the problem of the whole path probability estimation of mobile robot. The main goal of SLAM is to obtain the best estimation of the pose and map information of the mobile robot based on a set of control data u1:t and observation data z1:t with errors from the beginning to t. The SLAM problem can be described as the following a posteriori probability.

$$p(x_t, \Theta | z_{1:t}, u_{1:t}) \tag{1}$$

Where xt is the pose of the current robot and Θ is the environment map. xt can be represented by the probability function of the pose xt-1 at the previous time and the motion ut at the current time. This function not only describes the motion model of the robot, but also explains how the noise caused by motion affects the estimation of the pose of the robot. The motion model is as follows.

$$x_t = g(x_{t-1}, u_t) + \varepsilon_t \tag{2}$$

Where ε_t is the motion model noise obeying Gaussian distribution. The observation data obtained by sensors can also be expressed by probability function, which is generally called observation model. The observation model is expressed as:

$$z_t = h(x_t, \Theta) + \delta_t \tag{3}$$

Where δ_t is the observation model noise obeying Gaussian distribution.

3. SLAM Solution

SLAM research methods are mainly divided into online and offline methods. The off-line method was proposed by Milioset al. In 1997. This method is to construct the complete path and map after the mobile robot has collected all the sensing data. Sam (smoothing and mapping) and graphSLAM are two typical offline processing methods. Sam estimates not only the current position of the robot, but the complete path of the robot so far [5]. GraphSLAM converts the posterior probability of the robot into a graph, which represents the maximum likelihood function of the data [6].

The online method is to estimate the pose of the mobile robot and create a map in real time. Common online methods include extended Kalman filter SLAM (EKF-SLAM) algorithm, particle filter SLAM (pf-SLAM) algorithm and visual SLAM [7].

4. SLAM Technology Development

4.1. Hybrid Algorithm

At present, SLAM technology generally uses a single observation sensor for environmental observation, combined with inertial measurement unit to realize mobile robot positioning and map creation. SLAM Based on single observation source has some problems, such as low

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accuracy, easy interference and insufficient reliability. In recent years, with the continuous reduction of sensor cost and the continuous development of multi-sensor data fusion technology, SLAM application and Algorithm Research Based on multi-source sensor data fusion has become one of the hot research fields, promoting map construction The development of positioning and autonomous navigation.

Gerasimos et al. [8] combined odometer and sonar sensor measurement, analyzed the signal with Gaussian noise distribution, and developed into a famous case of mobile robot state vector estimation. Tungadi et al. [9] used the complementary characteristics of sonar and laser data to integrate sonar and laser data to realize two-dimensional map creation and improve the accuracy of SLAM estimation. Santos et al. [10] applied sonar and laser data fusion technology to the environment with low visibility to reduce the impact of such environment on SLAM. In recent years, the rapid development of machine vision technology provides a good development opportunity for map construction. However, due to the restriction of the generation quality of parallax map, many studies are still in the stage of laboratory concept experiment. Literature [11] integrates visual technology and lidar observation data to achieve SLAM, and has achieved some research results, but its map reconstruction effect still needs to be improved, and visual environment modeling still faces technical challenges in terms of accuracy and reliability.

4.2. RGB-D SLAM

In recent years, with the popularity of cheap and high availability sensors, rgb-d cameras for recording color and depth images have been preliminarily applied in the field of SLAM. Henry of the University of Washington first proposed SLAM algorithm based on rgb-d camera [12]. Kinectfusion [13] proposed by RA ú l et al. Is the first SLAM algorithm based on Kinect depth camera, which can build dense 3D environment map in real time on GPU. Mur Artal et al. Added support for binocular and rgb-d cameras on the basis of orb-SLAM and proposed the open source algorithm of orb-SLAM2 [14]. Scholars at home and abroad also began to try to integrate rgb-d camera and lidar sensor for simultaneous positioning and map creation, so as to realize the complementary advantages of sensors to improve the SLAM estimation accuracy [15].

4.3. Deep Learning Applied in SLAM

The combination of deep learning and SLAM is one of the research hotspots of SLAM in recent years. Deep learning combined with SLAM is mainly used in feature extraction, depth estimation, pose estimation, relocation, image semantic segmentation and so on. For example, literature [16] uses the depth generated by depth neural network to create a map. Detone et al. used the point tracking system of two deep convolution neural networks to realize feature extraction in SLAM [17]. The combination of deep learning and SLAM is one of the research hotspots of SLAM in recent years. Deep learning combined with SLAM is mainly used in feature extraction, depth estimation, pose estimation, relocation, image semantic segmentation and so on.

4.4. Cloud SLAM

The traditional SLAM method completely relies on the local computing resources of mobile robot to solve in real time, and the execution speed is slow, which can not meet the SLAM under multi-source heterogeneous data fusion. Benefiting from the rapid growth of network data transmission rate, cloud computing technology began to be applied in the field of robotics. There is a new solution to the SLAM problem, that is, the SLAM process is divided into two stages: front-end acquisition and cloud computing. The front end is responsible for acquiring sensor data, and the SLAM computing intensive part is put into the cloud for execution. The front end is responsible for acquiring sensor data, and the SLAM computing intensive part is put into the cloud for execution. Based on DaVinci platform, arumugam et al. adopted Hadoop

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distributed system architecture Map/Reduce cluster to implement SLAM algorithm, improved the efficiency of map construction and execution, and shared data with other robots through software as a service (SaaS) model[18]. Because Hadoop is disk level computing with poor real-time performance, it is more suitable for batch processing, which limits the application of DaVinci platform in real-time SLAM environment. At the same time, this method transmits messages through ROS message mechanism to restrict the scalability of the platform. The server receiving ROS messages has also become the bottleneck of the system. Kamburugamuve et al. Implemented GMapping algorithm on IOT cloud platform [19] using distributed processing framework. Lidar and inertial sensor data are sent to the cloud as stream events. The cloud performs SLAM processing and returns positioning and map results to the robot. IOT cloud aims to connect IOT devices to the cloud. Its application in mobile robot real-time SLAM needs to be verified. At the same time, this method does not consider how to implement SLAM under multi-source heterogeneous data fusion in the cloud. C2tam framework is based on roboearth cloud platform and uses parallel tracking and mapping (PTAM) algorithm to realize multi robot cooperative tracking and map creation tasks [20]. The advantage of c2tam architecture is to make full use of the advantages of the cloud and use the PTAM method in 3D mapping to propose a more successful Cloud + Robot architecture.

4.5. Semantic SLAM

Semantic SLAM means that in the process of mapping, the SLAM system can not only obtain the geometric structure information in the environment, but also identify the independent individuals in the environment and obtain the semantic information such as their position, posture and functional attributes, so as to deal with complex scenes and complete more intelligent service tasks. The knowledge representation of similar objects in semantic SLAM can be shared, and the scalability and storage efficiency of SLAM system can be improved by maintaining the shared knowledge base.

Semantic SLAM can realize intelligent path planning. For example, the robot can move the movable objects in the path, so the path is better. The key of semantic SLAM lies in the accurate recognition of object targets in the environment, and the emerging deep learning in recent years happens to be the most potential and advantageous object recognition method. Therefore, the combination of deep learning and semantic SLAM has attracted extensive attention of researchers in the field. Map semantic generation and SLAM process are two parts that can promote each other. On the one hand, accurate map construction is conducive to the learning and classification of target model, on the other hand, accurate target recognition and classification is conducive to the accurate construction of map, such as accurate closed-loop detection, so the two complement each other. The challenge of semantic information generation lies in accurate object target level or pixel level classification.

4.6. Multi-Robot SLAM

The early research of SLAM is generally based on a single agent. By the beginning of the 21st century, the research on multi robot cooperative SLAM (cSLAM) began to appear. At present, multi robot cooperative SLAM methods can be divided into the following two types of solutions: distributed, each robot establishes its own map according to its own observation, and in the later stage, a public map is formed by integrating the independent maps of robot team members. Centralized, a central management module is responsible for evaluating the running tracks of all robots, using the observations of all robots to complete the generation of complete maps at the same time. Reference [21] proposed a method for cooperative localization, named collective localization. A group of robots is regarded as a single system. Multiple robots carry different sensors and have different positioning capabilities. Only one Kalman filter is used to estimate the pose of all members. The centralized mode can fuse sensor information from different robots. In order to carry out distributed processing, the central Kalman filter is decomposed

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into m modified filters, which run on each robot. This centralized method is not suitable for large-scale multi robot systems.

Generally speaking, the research on multi robot cooperative SLAM is still in the primary stage. There are many theoretical discussions but few implementations, which limits the scale of robots and is far from reaching the degree of application. The research of collaborative SLAM can not be applied to the application of multi unmanned vehicle collaborative exploration in large-scale environment. It is necessary to combine the advantages of centralized and distributed system and unify the SLAM environment model to improve the scope, accuracy and reliability of map environment exploration. Therefore, the research of multi robot SLAM is an important research direction in the field of SLAM in the future.

5. Conclusion

Mobile robots are widely used in military, aerospace, deep-sea, medical, disaster relief, service and other fields, and the requirements for the accuracy and reliability of their autonomous navigation are becoming higher and higher. Since the 21st century, more and more attention has been paid to the development of robot technology at home and abroad, and it has become one of the most active fields of cutting-edge high-tech research. Simultaneous localization and mapping (SLAM) is the key for mobile robot to explore in unknown environment, and plays an important role in robot autonomous application. Today, intelligent mobile robot technology is listed as a priority development field by various scientific and technological powers, SLAM problem is still facing severe challenges. If SLAM technology can not keep up with the needs of application and can not match the development of the overall technology of mobile robot, it will seriously restrict the intelligent level of robot, make it "developed limbs and simple mind", and affect the technology transformation and promotion. With more and more scholars carrying out research on SLAM, the efficiency, quality and adaptability of SLAM are continuously improved. In the research in this field, we should not only expand vertically and deeply, but also horizontally combine other technologies in autonomous navigation, and finally continuously promote the development of path planning technology.

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