Transactions on Computer Science and Intelligent Systems Research
ISSN: 2960-1800, eISSN: 2960-2238 | Volume 5
AIDML 2024

The Application of SLAM Technology in Indoor Navigation in Complex Indoor Environment

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Abstract. This paper describes the application of SLAM in complex indoor environment. Through the joint work of sensor, LiDAR and visual camera, the real-time self-positioning and map construction are realized at the same time. However, in the practical application, there are also many challenges, the layout of the environment, the brightness of the environment, the presence of noise, the presence of dynamic objects and other environmental factors will lead to different degrees of data errors in SLAM technology. The small errors generated by a long time of work will gradually accumulate into potentially dangerous huge errors, and this is one of the biggest challenges for the current SLAM technology. Not only has that, the high configuration conditions required by SLAM technology also become one of the reasons why people do not choose it. However, the advantages of SLAM technology far outweigh the disadvantages. And almost all of these problems have corresponding solutions, SLAM technology is still very reliable, very widely used, the future of a great prospect of a technology.

Keywords: SLAM; Indoor navigation; Map construction.

1. Introduction

SLAM technology is called Simultaneous Localization and Mapping, that is, simultaneous localization and map construction. SLAM technology originated in the early 1980s and 1990s, when the main research was to enable robots to realize positioning and map construction in a static environment. However, with the progress of research, people gradually realized that the difficulty of this research lies in the interdependence of positioning and map construction. So in the initial research work people focused more on LiDAR and sensors. In the 21st century, SLAM technology has been paid attention to because of the progress of algorithms and the improvement of equipment, and began to develop on a large scale, and finally have today's SLAM technology.

The main purpose of this technology is to realize the autonomous positioning and navigation of robots. The basic principle of SLAM technology is to achieve localization and reduce localization errors by using multi-feature matching through probabilistic and statistical methods. Based on sensor data and known map information, the robot estimates its position and attitude by matching feature points and other ways, and updates the map information. Specifically, SLAM technology relies on a variety of sensors, such as cameras, LiDAR, inertial measurement units, etc., to sense the surrounding environment. These sensors provide a stream of data about the environment's geometry, texture, depth, and more. These sensor data are then fused through sophisticated algorithms and data processing techniques to estimate the device's position and orientation [1]. As the robot moves, the map is gradually improved to help the robot better Orient and navigate. Map construction and localization take place simultaneously, hence the name Simultaneous Localization and Map Construction (SLAM). SLAM technology realizes autonomous localization and navigation of robots in unknown environment by alternating these two tasks.

The core of SLAM technology is to obtain real-time environmental information through sensor data (such as LiDAR, visual camera, etc.), which can achieve high-precision positioning with small errors in complex environments. Compared with other technologies, SLAM technology enables robots to navigate autonomously in unknown environments without relying on external infrastructure, making robots or vehicles show a high degree of autonomy in places such as indoor and underground parking lots. Moreover, the applicability of SLAM technology can quickly process and reconstruct maps in case of errors caused by some unexpected events to ensure the accuracy of navigation. With the development of technology, the cost of SLAM technology has decreased, so that it is used in more and more fields, from industrial production to daily life, it has been all over our sight. This paper first introduces the difficulties and obstacles encountered in the technical application of SLAM technology, and give the corresponding solutions. In the second half, some practical applications of SLAM technology including home, automobile, machinery and other fields are described in detail.

2. Difficulties and solutions in complex environments

Although SLAM technology is very mature, there are still some problems when facing a complex indoor environment, which can cause the final result to deviate from the expectation. In indoor environments, especially those with simple decoration or not obvious features, such as white walls, smooth floors, etc., it may be difficult for sensors to extract enough feature points for positioning and mapping. At the same time, some indoor structures may have a large number of repetitive features, such as corridors, stairs, etc., which may cause confusion in SLAM algorithm and affect the accuracy of localization and mapping. There are often dynamic objects in the indoor environment, such as people, pets, furniture, etc. These dynamic objects will cause interference to sensor data, resulting in the failure of SLAM algorithm to accurately extract environmental features, thus affecting the accuracy of localization and mapping. The indoor environment cannot be completely without sound, and some sounds may affect the judgment of the SLAM algorithm, resulting in slightly different results than the actual. Indoor lighting conditions may change with the time of day, the weather, and the switching of lighting equipment. The variation of illumination will lead to the instability of sensor data quality and affect the performance of SLAM algorithm. For example, in low-light or uneven lighting environments, visual SLAM algorithms may not be able to accurately extract feature points.

Although the SLAM algorithm can achieve high-precision positioning and mapping in theory, in practical applications, complex indoor environments and large amounts of sensor data may require high computing resources. Therefore, how to implement efficient SLAM algorithm with limited computing resources is a challenge. In order to solve these problems, In recent years, people have improved and proposed some new methods about SLAM technology, such as IMLS-SLAM algorithm, which is used to represent the map by implicitly moving the least square surface, which can greatly improve the accuracy of positioning, while the disadvantage of LiDAR is low accuracy. Therefore, this will make its LiDAR more effective, so as to achieve the purpose of high-precision robot position. Unfortunately, the disadvantage of this algorithm is that it cannot be executed in real time. This means that it cannot locate the robot's position in real time during localization and map construction [2].By integrating multiple sensor data (such as LiDAR, vision sensors, inertial measurement units, etc.), the advantages of various sensors can be fully utilized to improve the accuracy of SLAM systems. For the interference of dynamic objects, a variety of strategies can be adopted to deal with it. For example, semantic segmentation is used to identify dynamic objects and eliminate their interference. Or add dynamic object detection and tracking mechanism to SLAM algorithm to model and compensate the dynamic object. In order to cope with the influence of illumination changes, illumination invariant feature extraction methods can be adopted, such as feature point extraction based on SIFT. SIFT algorithm is used to analyze the relevant features of images, which can significantly reduce the gray scale mutation and improve the accuracy of SLAM technology. In addition, real-time performance is also satisfied, so the algorithm steps of IFT are simplified, and the strong continuity of SLAM technology is utilized to reduce the required time and improve the accuracy of the trajectory [3]. In addition, you can also consider using deep learning techniques to improve the robustness of feature extraction.

In order to achieve efficient SLAM algorithm while meeting the limitation of computing resources, lightweight SLAM schemes can be adopted, such as visual SLAM algorithm based on feature points or LiDAR SLAM algorithm based on sparse point cloud. The anchor points are adjusted according to the amount of relevant information, and the feature anchor points are iterated into a point cloud by an input-dependent data-driven method. This method can reduce the memory usage, and can be used to analyze more precise and dense details, which can play a better role in the limited configuration space. After being verified by the data, the efficiency and accuracy of this method are higher than the original algorithm [4]. In addition, parallel computing, GPU acceleration and other technologies can be used to improve the efficiency of the algorithm. The above problems and solutions are only a small part, and there are many situations in practical application. However, with the continuous optimization of technology, SLAM technology will encounter fewer and fewer difficulties in complex indoor environments.

3. The application of SLAM technology

SLAM technology is widely used, it is very obvious in daily life, it is everywhere in our lives, the simplest example is to use it in the indoor environment navigation. In indoor navigation, SLAM technology obtains the video stream of the camera or camera in real time, extracts key frames and feature points, and gradually builds the map of the indoor environment. This real-time map-building capability enables a robot or device to move forward in an unknown environment. Using the visual SLAM algorithm, a robot or device can achieve highly accurate positioning through its own camera. In the process of traveling, SLAM algorithm can identify the current location through computer vision technology, and use the indoor map for accurate positioning, to achieve autonomous navigation and obstacle avoidance functions. After building an indoor map and achieving accurate positioning, SLAM technology can also be used for navigation planning. According to the target location and current location, plan the optimal path, and guide the robot or device to navigate according to the path.

SLAM technology can achieve indoor positioning by building a three-dimensional map of the indoor environment, such as shopping malls, museums, airports and other places to provide accurate navigation services. Compared with the Matterport system and NAVIS, the map navigation application produced by SLAM technology can show high accuracy and high efficiency in complex indoor environments and a wide range of buildings. The navigation based on SLAM technology is superior to the other two in both mapping mean error and detecting feature points, which reflects the important position of SLAM technology in indoor navigation field [5]. In the field of smart home, SLAM technology can be used to achieve autonomous navigation and obstacle avoidance of smart home devices. For example, many families have intelligent sweeping robots, which can complete the cleaning task of the ground completely on their own. With the cooperation of sensors, algorithms and other parts, it can achieve positioning, navigation, avoiding obstacles, building maps, detecting clean areas and a series of operations. After completing all tasks, it will return to the original way or stand by. Among them, the navigation and map construction functions of intelligent sweeping robots are the use of SLAM technology. SLAM technology ensures that the intelligent sweeping robot can determine its position in real time, build a map of the entire house, and then clean it, and can calculate the route that has been passed [6]. SLAM technology has a wide range of applications not only indoors, but also in other fields, especially in computer vision and robotics. SLAM technology is the key to realize robot autonomous navigation. By building a three-dimensional map of the environment in real time, the robot can accurately locate and navigate in an unknown environment. Whether it is a domestic robot, an industrial robot or a service robot, SLAM technology plays an important role. Delivery robots are a new application that has emerged in recent years, and people did not have the ability to make such machines at the beginning. However, due to the development of mechanical technology, SLAM algorithm and other fields, the robot can go to the designated place indoors or outdoors to deliver the specified items, and can maintain autonomy, safety and effectiveness throughout. As Fig. 1 shows, Through GPS and SLAM technology, delivery robots can accurately locate in the environment, and can know the terrain of the surrounding environment, the existence of things, and can avoid buildings, people, animals, etc. In the indoor environment, it can be more accurate and safe to complete the delivery task. With the popularity of online shopping and the increasing demand for delivery services, the position of delivery robots is becoming more and more important, which is an indispensable part of reducing the burden of distribution personnel and realizing the automation of service distribution industry [7].

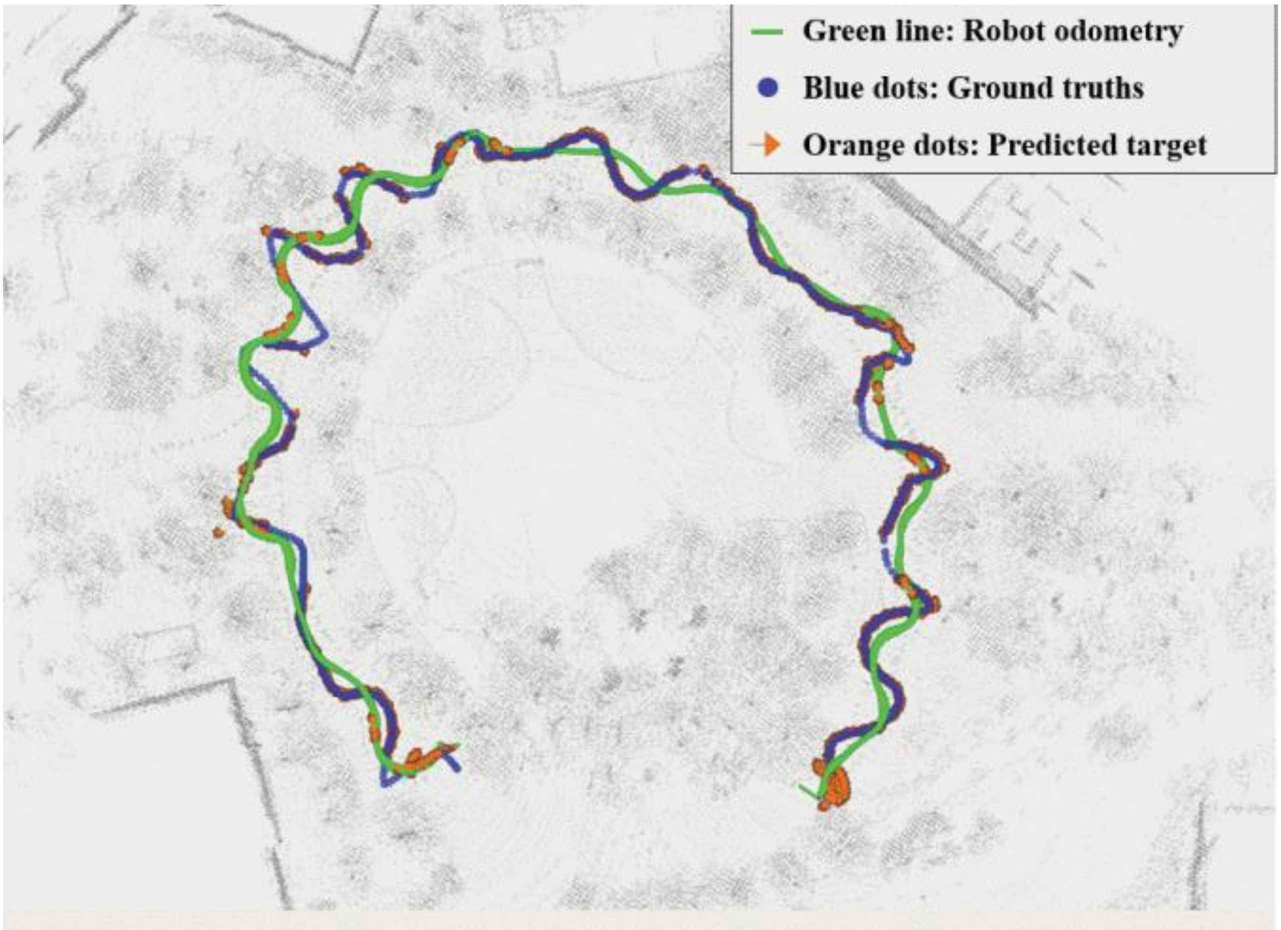

Fig. 1 Comparison of robot route trajectory and predicted trajectory [7].

In autonomous vehicles, SLAM technology is used to achieve precise positioning and navigation of the vehicle on the road. By combining with other sensors on the vehicle, such as radar, cameras, etc., SLAM technology can help autonomous vehicles achieve accurate road recognition, obstacle detection, and obstacle avoidance. Similarly, drones and aircraft need to sense the surrounding environment in real time and conduct accurate positioning during flight. For a few years ago, the UAV is an emerging product, but for now, the UAV may have been known by people, its advantage is dexterous, easy to control. For example, the child in Fig. 2 is piloting a drone in a park. Compared with the helicopter, the UAV does not need to carry people, it can complete most of the operations that the helicopter can complete, it can carry out agricultural irrigation, goods transportation, monitoring and testing, photography and other operations. What is shocking is that it was originally developed for military use. Its navigation mainly relies on the global positioning system, but in some places where the signal is weak or no signal, it will rely on SLAM technology for autonomous positioning and navigation. SLAM technology is also designed to help drones and aircraft achieve accurate indoor and outdoor navigation, as well as autonomous flight and obstacle avoidance [8].

Fig. 2 The child is flying a drone in the park, which proves the advantages of simple operation and low difficulty in getting started [8].

In augmented reality and virtual reality applications, SLAM technology also plays a major role. Using SLAM technology and virtual reality technology, the robot arm can be operated in virtual reality. Fig. 3 shows a trial of the robotic arm. Through the component characteristics of SLAM technology, the user has a better operating experience. Compared with the direct operation of the robot arm in reality, the operation of the robot arm in virtual reality has higher accuracy and lower delay, and the advantage of ignoring the distance operation of the robot arm shows that it has a wide range of application prospects in the future virtual reality field [9].

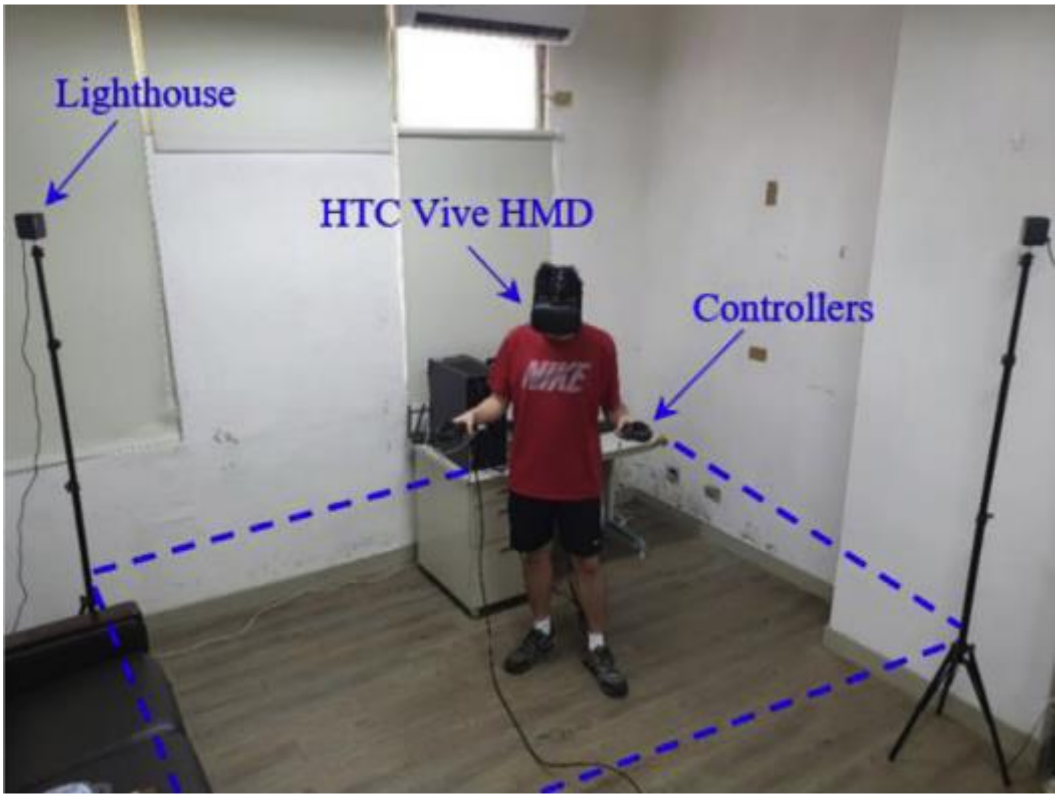

Fig. 3 The crew is testing the tracking area of the robotic arm [9].

4. Conclusion

The advent of SLAM technology has changed the basis of application in many fields, giving developers a wider range of options for developing new applications. This technology is indispensable in the field of indoor navigation. It allows robots or other machines to detect the surrounding environment through sensors and LiDAR without human intervention or input map routes, and at the same time, conduct real-time self-positioning and map construction, and avoid static obstacles in the environment while working. Realized true autonomous work. Especially in complex indoor environments (such as hospitals, companies, supermarkets, warehouses, etc.), navigation robots with SLAM technology are far more efficient than other robots, even in a no-signal environment, robots created with SLAM technology can still carry out barrier-free work, which is difficult for some robots using other programs and software. Although SLAM technology is good enough, but have to admit that it currently has a lot of shortcomings; SLAM technology requires high-performance processors and large memory, which is a difficult for some people who want to use SLAM technology. It may also have performance deviations in areas with poor light or texture. In addition, the accumulation of bias over long periods of time, especially in large environments, can lead to a decrease in the accuracy of self-positioning and mapping. Some of these shortcomings need to be improved, but some of them are urgently needed for SLAM technology. SLAM technology also needs to adapt to more and faster environmental changes in order to navigate complex environments efficiently and accurately. The accumulation of errors due to long running time is one of the biggest challenges for current SLAM technology. With the development of The Times, there are more and more new environments and obstacles, and SLAM technology needs to accurately identify them. However, the functions and effects of SLAM technology in complex indoor environments are enough to make it a stable seat in the current indoor navigation application field.

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