Robot Navigation Technology and Its Application

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Abstract: In this paper, robot navigation technology is comprehensively reviewed. This paper introduces the basic concepts and key technologies of robot navigation, including location, map construction, path planning, classification and application scenarios of navigation algorithms. This study analyzes the advantages and disadvantages of different positioning technologies. It evaluates the strengths and limitations of various map construction technologies. The research compares the performance of different path planning technologies. It examines the effectiveness of different robot navigation algorithms. The paper forecasts future trends in intelligent robot navigation technology. Miniaturization is predicted to become a key development direction. Low-cost solutions are expected to gain prominence in research and applications. Cooperative navigation technologies are anticipated to advance significantly. The findings aim to provide references for robot navigation research. The results offer practical guidance for real-world applications of intelligent robots. This systematic analysis of core robot navigation technologies provides critical insights for technology selection, algorithm optimization, and system development. The predictions of future trends will help accelerate the industrialization of intelligent robotics and advance collaborative navigation systems.

1 INTRODUCTION

With the continuous development of science and technology, robots are increasingly widely used in various fields, such as industrial production, logistics distribution, medical services, family services. Robot navigation technology is the key to realize the autonomous movement of robots and complete tasks. It enables robots to determine their own position in a complex environment, perceive the surrounding environment and plan a reasonable path to reach the target location (Thrun, Burgard, Fox,2005).

The research of robot navigation technology began in the 1960s, and it was mainly applied to industrial robots at first. With advances in technologies such as computer vision, sensor fusion and artificial intelligence, robot navigation has gradually expanded from structured environments to industrial unstructured environments. In the 1990s, the proposal of simultaneous localization and Map Construction (SLAM) technology brought a revolutionary breakthrough for robot navigation. In the 21st century, the rise of artificial intelligence technologies such as deep learning has further promoted the development of robot navigation technology, making its performance better in complex and dynamic environments.

Previous studies have achieved important results in every key link of robot navigation. In terms of localization and map construction, researchers have proposed filter-based SLAM (such as EKF-SLAM) and Graph-SLAM (such as Graph-SLAM). In path planning, global planning methods such as A* algorithm and Dijkstra algorithm, as well as local planning methods such as dynamic window method (DWA) and artificial potential field method are widely used. Obstacle avoidance technology has developed from a simple ultrasonic sensor to a complex multi-sensor fusion system. In recent years, the application of deep reinforcement learning in navigation decision making has also made remarkable progress.

This paper aims to comprehensively review the research status of robot navigation technology, analyze the advantages and disadvantages of key technologies, discuss the existing problems and challenges of robot navigation technology, and put

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forward the future development trend of the technology.

In the first place, the key technologies in robot navigation must be systematically sorted out, and their advantages and disadvantages must be analyzed. The second step summarizes the role of robot navigation technology in different application scenarios. The third step is to discuss the existing problems and challenges of robot navigation technology. Finally, summarize the future development trend of robot navigation technology.

2 MAP CONSTRUCTION TECHNOLOGY

First, raster maps. Raster maps divide the environment into equal-sized grids, each indicating whether it is occupied by obstacles, simple and intuitive, easy-to-implement path planning algorithms, but there needs to be a balance between map resolution and storage (Elfes,1989). Next is the topological map. Topological maps use nodes and edges to represent key positions and connection relationships in the environment. With a small amount of data, topological maps are suitable for navigation in large-scale environments, but their adaptability to environmental changes is relatively weak (Choset, Nagatani,2017). Finally, there are semantic maps. A semantic map refers to integrating the semantic information of the environment into the map, such as the category and function of the object, so that the robot can better understand the environment and provide support for advanced task planning (Galindo, Fernandez-Madrigal, Gonzalez,2017).

3 PATH PLANNING TECHNIQUES

3.1 Global Path Planning

The first is the A* algorithm, the principle of the A* algorithm can be divided into the following steps.

The first is initialization. Place the starting node into the OPEN list, which is used to store nodes awaiting evaluation. At the same time, create a CLOSED list to store the evaluated nodes.

The second step is the node evaluation. Take the node with the lowest value of the valuation function f(n) from the open list as the current node and move it to the closed list. Then, calculate f(n) values for all neighbors of the current node. If the neighbor node is not already in the open list, add it to the open list and set the current node as its parent. If the neighbor node is already in the open list and the path to that neighbor node through the current node is shorter, update the parent and f(n) values for that neighbor node.

The third step is the path lookup. Repeat the process until the open list is empty or the target node is added to the open list. If the target node is added to the open list, then start at the target node and trace back along the parent node of each node until you reach the starting node to get the shortest path. If the open list is empty, there is no path from the start node to the destination node.

Finally, the heuristic function is selected. The key to the A* algorithm is the choice of the heuristic function h(n). A good heuristic function should be able to accurately predict the cost from the current node to the destination node so that the algorithm can search more efficiently. Common heuristic functions include Manhattan distance, Euclidean distance, and diagonal distance, among others

A* algorithm uses heuristic search to find the optimal path from the starting point to the target point, which has high search efficiency, but may fall into local optimality in complex environments (Hart, Nilsson, Raphael,1968).

A* algorithm is mainly used to solve path planning problem and multi-objective navigation problem in robot navigation technology.

A* algorithm is widely used in the following aspects.

3.1.1 Industrial Robots

In automated factories, the A* algorithm is used for the path planning of material handling robots. The robots can efficiently handle materials between shelves, production lines and warehouses. They can avoid collisions with equipment and personnel. All of these can improve the efficiency of production logistics.

3.1.2 Service Robots

The restaurant service robot uses the A* algorithm. It plans the optimal delivery path from the kitchen to the table. It does this according to the restaurant layout and table position. The robot can also flexibly avoid obstacles. It does so when it encounters customers or other obstacles. This ensures efficient and accurate service.

3.1.3 Driverless Vehicles

Driverless vehicles are driving on urban roads. The A* algorithm is used. It combines map data and real - time road condition information. It plans the optimal route from the current location to the destination. It also takes into account traffic lights, pedestrians, other vehicles and other factors. This ensures safe and smooth driving.

3.1.4 Drone

When the drone is conducting surveying and mapping, inspection and other tasks, the A* algorithm can use information such as terrain, buildings and no-fly areas. It can plan a safe and efficient flight path so that it can complete the task as required.

3.2 Dijkstra's Algorithm

Dijkstra's algorithm is an algorithm used to find the shortest path between nodes in a graph. The basic principle is to use the greedy strategy, each time selecting the node with the shortest distance from the current node to the starting point as the next intermediate node, and updating the other nodes with the shortest distance from the starting point.

The specific steps of Dijkstra's algorithm are as follows

First is initialization. Set the distance from the starting point to itself to 0. Set the distance from the other nodes to the starting point to infinity.

The second step is to select the current node. Select the node with the shortest distance from the starting point from the unvisited node as the current node.

The last step is to update the distance. For nodes adjacent to the current node, update its shortest distance to the starting point. If the path to the adjacent node through the current node is shorter than the previously calculated path, update the path value. Dijkstra's algorithm can guarantee to find the global optimal path: however, the calculation complexity is higher, and it is suitable for small-scale maps.

In robot navigation technology, Dijkstra's algorithm is mainly used to solve the path search problem and the dynamic environment adaptation problem.

3.2.1 Warehouse Logistics Robots

In large warehouses, logistics robots need to move goods between shelves quickly and accurately.

The Dijkstra algorithm can plan the optimal driving path for the robot based on information such as the layout of the warehouse, the location of the shelves and the storage points of the goods, improving the efficiency of cargo handling and reducing transportation time and cost.

3.2.2 Rescue Robot

Detected obstacles, dangerous areas and possible channels, and other information, planned a safe search and rescue path, quickly reached the location of trapped people, improve the success rate of rescue. In earthquake, fire, and other disaster sites, the environment is complex and dangerous, the rescue robot uses the Dijkstra algorithm, according to real-time.

3.2.3 Agricultural Robot

When the agricultural robot carries out sowing, fertilizing, weeding, and other operations in the field. The Dijkstra algorithm can plan the optimal operation path for the robot according to the terrain of the field, crop distribution and obstacles, so as to ensure that the robot can complete the task efficiently and avoid damage to crops.

The basic principle of the artificial potential field method is to regard the robot as a particle moving in the potential field, the target point generates gravity, and the obstacle generates repulsion, thus guiding the robot to avoid the obstacle and reach the target, but there is a local minimum problem.

By considering the robot's velocity, acceleration, and other dynamic constraints, the dynamic window method searches feasible paths in the velocity space with good real-time performance and can adapt to a dynamic environment (Fox, Burgard, Thrun, 1997)

Classification and characteristics of robot navigation algorithm:

3.3.1 Reaction-based Navigation Algorithm

The robot makes decisions directly. It makes decisions according to the perception information of the current environment. It responds quickly. It can respond to emergencies quickly. However, it lacks consideration of the global environment. This lack of consideration may lead to a sub-optimal path (Brooks, 1986).

3.3.2 Planning-based Navigation Algorithm

environment modeling and path planning are carried out first, and then execution is carried out according to the planned path. The optimal path can be obtained, but the computational complexity is high, and the adaptability to environmental changes is relatively slow (LaValle, 2006).

3.3.3 Learning-based Navigation Algorithms

Such as reinforcement learning, deep learning, and other methods, which automatically optimize navigation strategies by letting robots learn and train continuously in the environment, have strong adaptability and flexibility, but need a lot of training data and computing resources (Sutton, Barto, 2018).

4 APPLICATION SCENARIOS

4.1 Industrial Sector

Industrial robots are on the production line. They carry out material handling tasks. They also carry out assembly tasks. Precise navigation technology is important. It ensures that the robots can complete the work efficiently. It also ensures that the robots can complete the work accurately. As a result, production efficiency is improved. Production quality is also improved (Groover, 2013).

Robot navigation technology in the industrial field is mainly used in manufacturing and assembly, quality testing and monitoring, industrial cleaning and maintenance.

In the industrial field, robot navigation technology is playing an irreplaceable role, becoming a key force in promoting industrial intelligent upgrading. Taking warehousing and logistics as an example, the automated guided vehicle (AGV) realizes intelligent material handling by relying on advanced navigation technology. Laser navigation AGV in the process of operation, by emitting a laser beam and receiving reflected signals, can accurately determine its own position, and then in the warehouse full of shelves and goods flexible shuttle, efficient completion of goods transportation tasks. In the industrial production line, the collaborative robot can sense the surrounding environment and the location information of parts in real-time with the help of visual navigation technology to achieve high-precision assembly operations. For example, in the assembly line of auto parts, after the use of visual navigation cooperative robots, the assembly efficiency is increased by 40%, and the product defect rate is reduced by 15%, which significantly improves the production quality and efficiency.

4.2 Logistics and Warehousing

Automated guided vehicles (AGV) and mobile robots realize automatic storage, retrieval and transportation of goods in warehouses, optimize logistics processes and reduce labor costs (Vis, 2006).

Robot navigation technology in logistics warehouses is mainly used in inventory and management, sorting and distribution, intelligent storage layout optimization and so on.

In the field of logistics and warehousing, the application of robot navigation technology is profoundly changing the traditional operation mode and becoming a key factor in improving logistics efficiency and management level. For example, with the help of laser navigation technology, an automatic guided vehicle (AGV) can send laser beams through lidar and receive reflected signals to build environmental maps and determine its own position, so as to accurately travel along the preset path in the complex warehouse environment and realize the efficient handling of goods. Using laser navigation AGV large logistics warehouse, cargo handling efficiency is improved by 35%, and due to accurate positioning, the cargo placement error rate is reduced to less than 1%. For example, the composite robot uses visual navigation and SLAM navigation technology, which can not only autonomically navigate and accurately position the goods from the entrance to the storage area and from the storage area to the exit of the storage area, but also automatically sort the goods by scanning the two-dimensional code or RFID tag on the goods, and seamlessly update the inventory information with the warehouse management system.

4.3 Service Robot

Home service robots can autonomously navigate indoors and complete tasks such as cleaning and companionship; Medical service robots can assist medical staff in medicine distribution and patient care in hospitals to improve service quality and efficiency (Siciliano, Khatib ,2016).

Robot navigation technology in the service robot is mainly used in catering service, hotel service, medical services, family services and so on.

In the field of service robots, robot navigation technology plays a crucial role, which greatly improves the quality and efficiency of services. In the hotel scene, with the help of laser navigation and visual navigation integration technology, the delivery service robot can accurately identify the hotel's corridor, room number, and other information and quickly deliver items to the designated room. The hotel distribution robot using this kind of navigation technology has improved the distribution efficiency by about 40% compared with manual labor, and can also effectively reduce the error rate. In the hospital, the guide robot uses SLAM navigation technology to build a hospital map, combined with voice interaction and visual recognition. To provide patients with accurate department guidance services. The guidance robot has been introduced. It has reduced the average time of patients searching for departments. The reduction is by more than 50%. This has greatly improved the medical experience of patients. In the shopping mall, there is a shopping guide robot. It uses multi-sensor fusion navigation technology. It can sense the surrounding environment in real time. It can also sense the flow of people in real time. It plans the optimal path. Then it provides shopping guide services for customers. This effectively improves the shopping efficiency of customers. It also improves the satisfaction of customers.

5 EXISTING PROBLEMS AND CHALLENGES

The first is the problem of adaptability to complex environments. In complex, dynamic and unknown environments, such as crowded public places and outdoor unstructured terrain, the accuracy and reliability of robot navigation still need to be improved (Himmelsbach, Wuensche, 2018). Secondly, there is the problem of multi-sensor fusion. Fusing the data of multiple sensors, giving full play to the advantages of each sensor, and reducing data redundancy and conflict are key issues (Khaleghi, Khamis, Karray, 2013). Real-time performance is important. Computing resources are important, too. They ensure the accuracy of navigation. They meet the needs of real-time decision-making of robots. They also reduce the dependence on hardware computing resources. This is of great significance for some resource-limited robot platforms (Chen, Liu, Zhang, 2017).

6 FUTURE DEVELOPMENT TREND

Intelligence: With the development of artificial intelligence technology, robot navigation will be more intelligent, able to independently learn and adapt to complex and changing environments, and achieve more advanced task planning and decision-making.

Miniaturization and low cost: Develop smaller and lower-cost navigation sensors and devices to promote the popularization of robots in more fields.

Collaborative navigation: Multiple robots can work and navigate together to complete complex tasks and improve work efficiency and overall system performance.

7 CONCLUSION

Robot navigation technology has made remarkable progress after years of development, but it still faces many challenges. Key technologies such as positioning, map construction and path planning are continuously improved and innovated. This is combined with the development of emerging technologies like artificial intelligence. The robot navigation system will become more intelligent. It will become more efficient. It will also become more reliable. It provides strong support for the wide application of robots in various fields. It promotes the development of the era of intelligent robots.

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