Analysis Of Current Development Status of Global Path Planning for Intelligent Carrier Robots in Warehouse Logistics Scenarios

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Abstract. At present, warehousing and logistics demand has increased greatly, in the face of a large number of parcels that need to be classified, packaged, and shipped, increasing not only the efficiency of the work is uneven and the cost of labor with the growth of workload and growth. However, intelligent robots are not only efficient but also have drastically reduced operating costs. Intelligent robots, as a highly efficient tool, have been gradually improved and applied to various practical scenarios to replace manual labor. In China, a variety of warehouses are needed, such as cargo warehouses, distribution warehouses, pickup warehouses, and so on. To address this situation, intelligent delivery robots, which are specialized in warehouse logistics scenarios, have emerged. The core technology of intelligent delivery robots is the analysis technology of global path planning. This paper analyzes the global path planning algorithm of an intelligent carrier robot in warehouse logistics scenario based on geometric mathematics and bionics. The significance of this paper is to make the intelligent carrier robot work more efficiently, so as to promote the development of the logistics industry.

Keywords: Logistics Robot, Path Planning, Logistics Warehouse.

1. Introduction

As the industry grows, so does the demand for the logistics industry, which in turn leads to a significant increase in the demand for warehousing and logistics. In addition, in China, thanks to the continuous development of e-commerce, the logistics industry is experiencing a daily surge in deliveries, and logistics companies are booming. And there are nine major needs in the logistics warehouse market. They are space, cost, accuracy, talent, smoothness, efficiency, organization, safety, and quality.

In terms of space requirements, the growth of a business may result in a shortage of space, leading to subsequent delays in deliveries, stockpiling and other problems. In terms of cost control, costs are a major test, including labor costs, warehouse rentals, and more. In terms of inventory management accuracy not having an effective inventory management system can lead to low inventory accuracy. In terms of human resource requirements, warehouse management requires hiring skilled professionals. In terms of inventory flow, the absence of good logistics design can lead to backlogs of goods. In terms of efficiency control, there is a need to maximize efficiency. In terms of orderliness of inventory management, goods need to be placed in an orderly manner to prevent theft of goods. In terms of safety needs, warehouses are labor intensive and therefore must pay attention to safety issues. In terms of quality needs, preventing damage to goods is a necessary need.

With the development of technology, robotics has penetrated into all areas of our lives, from small sweeping robots to uncontrolled robotic arms in factories. Robots were first invented in the 1950s. The first robots were used for repetitive manual labor such as automotive manufacturing, plastics manufacturing, etc. The second generation of robots can perform more advanced and complex tasks. Now people have the third generation of robots that can learn and navigate themselves through various environments. Carrier robots are third-generation robots that can navigate themselves in complex and random environments and accomplish certain tasks.

There are two steps in the method of robot navigation in a known environment. In the first step, the known environment is modeled, and the edges of the model are marked to guide the robot to the

marked locations. In the second step, the task is executed according to the given path and obstacles are avoided [1].

Carrier robots are an important branch of intelligent logistics, which can be used to improve material handling capabilities and greatly reduce the time required for work. In the face of a large number of parcels that need to be sorted, packaged, and transported, manual not only the efficiency of the work varies but also the cost of labor with the growth of the workload. Intelligent delivery robots as high-efficiency tools are gradually improved and applied to various practical scenarios to replace manual labor. Various exhibitions for intelligent carrier robots are being organized.

For example, at Ce MAT ASIA 2023, logistics robots were the focus of the show, mostly due to their innovation, both in terms of novel product shapes and operating logic, which are very different from traditional warehouse automation solutions. After years of development, each logistics robot design has its own detailed characteristics, but the overall image is pretty much the same. However, at the Ce MAT ASIA 2023 exhibition site, there is still a robot product with a unique shape fire "out of the circle" - Haitong Elf Mouse, as its name suggests, this AMR in the appearance of the design of smooth lines, the use of A-class curved surface design, surrounded by rounded curvature. According to the staff at the scene, this design can enhance the overall speed, a more dynamic sense, while the obstacle avoidance function is stronger.

In addition, the original design of the aluminum alloy unibody parts, more protection of sensors, and laser radar. In terms of application, it is suitable for more diversified application scenarios as it is more compact on the basis of similar AMR functions [2].

Most of the carrier robots are mechatronic system that mainly has the following parts: an actuator, traveling mechanism, drive system, control system, detection and sensing system. The actuator can grasp the workpiece and send it to a certain position according to a certain speed and trajectory. The traveling mechanism is used to expand the robot's range of motion, and is mostly rail or wheeled, and can also be legged. The drive system is located in each joint and is used to receive signals to control the position of the joints. The control system issues commands to each drive system and also has the function of memorizing the commands. The detection sensing system is mainly used to detect the actuation dynamics and position of the robot and compare it with the set parameters.

Path planning technology is one of the core technology components of the carrier robot. The curve or sequence number that connects the start position and the end position is called a path, and the method of forming a path is called path planning. Intelligent path planning makes the path of the carrier robot more optimized, reduces the delivery cost of logistics, shortens the delivery time, and improves the delivery efficiency.

Therefore, this paper analyzes the current status of the development of global path planning algorithms for intelligent carrier robots in warehouse logistics scenarios. Firstly, in Chapter 2, the scene characteristics of warehouse logistics scenarios are analyzed. Chapter 3 introduces the mainstream perception technology methods. Chapter 4 provides a summary of the whole paper.

2. Perception Technology Analysis

2.1. Geometric Math Based Path Planning

2.1.1 A Start Arithmetic

A start algorithm is based on Dijkstra's algorithm, which is mainly applied to the known and static map model, A start algorithm can quickly delineate an optimal route from the starting point to the goal, the core of A start algorithm lies in the design of the valuation function, $f(n)$ is expressed as in Eq. (1).

$$f(n) = g(n) + h(n) \tag{1}$$

In the above equation, $f(n)$ represents estimated cost from the initial position to the target position via the current position, $g(n)$ and $h(n)$ represents actual cost and estimated cost of the optimal path from the current position to the target position, that is, the lowest cost of all paths. The

total cost from the initial position to the current position and from the current position to the target position constitutes the estimated cost of the path that must pass through the current position. In the A Star algorithm, $g(n)$ is used to represent the actual distance of the movement, and $h(n)$ is used to represent the estimated distance of the movement. the efficiency of the A Star algorithm is often determined by $h(n)$ in the valuation function. Currently, many different distances are more commonly used in the valuation function. In the valuation function shown in (1), if $f(n) = 0$ then you can get $f(n) = g(n)$ at this time is equivalent to the logic of Dijkstra's algorithm, although the use of Dijkstra's algorithm can find the shortest path, but a large number of additional expansion nodes will certainly make the efficiency of the significant decline. In the valuation function, when the selected $h(n)$ is less than the actual cost from the location to the end position, then at this time, through planning, can also find the shortest path. However, this does not mean that $h(n)$ the smaller the better, when the small breakthrough in a certain region, but will increase the need to be searched for nodes, this time relatively speaking, will sacrifice part of the computational efficiency. In the ideal situation, if people directly use the actual cost of the current position to the target position as $h(n)$, so that the optimal path can be found directly, and will not need to be researched, so the efficiency is certainly the highest and best [3].

A* algorithm has the advantages of optimality, speed, adaptability, scalability, and practicality. It will start searching from the node with the smallest valuation function, which saves a lot of time. The A* algorithm is also highly adaptable, it can be adapted to meet the characteristics of the problem by adjusting its own performance, and when a new environment arises, the A* algorithm can be made efficient by increasing the valuation function. The scalability of the A* algorithm is also one of its great strengths, which can be combined with other algorithms.

Combined with the global path task requirements of intelligent carrier robots in warehouse logistics scenarios, many experts and scholars have conducted corresponding improvement studies based on the traditional A Start algorithm. Zhu et al. proposed an improved A start method, the traditional A Star algorithm consists of $f(n), g(n)$ and $h(n)$, which were represented as mentioned earlier. The total cost of the involved path constitutes the estimated cost of the path that must pass through the current location. One of the improvements in this method is the addition of $q(n)$, the reason for adding $q(n)$ is that the carrier robot involves not only the static environment but also the dynamic environment, and if the environment changes, the affected $g(n)$ and $h(n)$ will be updated, at which time $q(n)$ is shown in Eq. (2), and $h(n)$ will be replaced with all $q(n)$. Another improvement is to replace the Euclidean distance with the Manhattan distance [4].

$$q(n) = g(n) + h(n) \tag{2}$$

$q(n)$ denotes the updated valuation function from the start point to the target point; $g(n)$ denotes the updated cost function from the start point to the point that has currently been reached; and $h(n)$ denotes the updated valuation function from the point that has currently been reached to the target point.

2.1.2 Dijkstra's Algorithm

Dijkstra's algorithm is proposed by E.W. Dijkstra in 1959. The principle of Dijkstra's algorithm can be specifically divided into the following five steps, the first step is to carry out an initialization, in the initialization, choose a source node and a graph, you can define the source node as, the graph as, and then initialize the distance value of all the nodes to infinity, except for the source node with a distance value of 0. The second step is to carry out the selection of the nodes, select the node with the smallest distance value as the starting point, and then select one unmarked node at a time, and it needs to be the smallest of the currently known distances. The third step is to do node labeling and set the node of the shortest path so that the distance value of the shorter point can be found by node expansion out to all the nodes. The fourth step is to do a node update and repeat the above steps until all the nodes are labeled as nodes with known shortest paths. The fifth step is to output the result and output the shortest path from every other node. Then backtracking is done to get the shortest path [5].

Dijkstra's algorithm is a global traversal method, which needs to be performed across nodes, thus giving the method a high degree of confidence and avoiding the pitfalls of local optimization. However, Dijkstra's algorithm requires traversing all nodes during computation, which takes a lot of time to traverse meaningless data and reduces the computational efficiency.

In order to solve this problem, Han et al. optimized the traditional Dijkstra method by setting multiple sources and using the influence factors, which greatly improves the addressing speed of the system and reduces the storage space of the computer memory system. The specific optimization of the Dijkstra algorithm is as follows: when planning the minimum path of a single source, only one element is in the set, and all the other nodes are in the set. When planning the minimum path of a single source, there is only one element in the set, and all other nodes are included in an unlabeled set. Multi-source path planning is multiple target sources, under the initial conditions, the set S includes all target sources, all other nodes other than the source are included in the set, and a node that meets the conditions is selected from the set U and added to the set, and then by comparing the distances between each node and the target sources, the nearest source to the node is determined at last. The nearest source point to the node is finally determined by combining the distance between each node and each target source point. In the road network, regarding the selection of the target source point, firstly, the nodes in the network are arranged according to the order from left to right and from top to bottom, and then the node matching the start number and the node matching the end number are selected as the target source point [6].

2.2. Bionic Based Path Planning

2.2.1 Ant Colony Algorithm

The ant colony algorithm is used in path optimization problems to simulate the foraging behavior of ants to find the optimal solution. In this process, the concentration of "pheromone" represents the ant colony's preference for the path, and the path with higher pheromone concentration will attract more ants, and the ant colony algorithm is able to find the optimal path through continuous iteration [6]. The advantages include: the ant colony algorithm has distributed computing characteristics; multiple individuals perform parallel computation. Ant colony algorithm centerless control through indirect communication and positive feedback mechanism, so that the search process is constantly converging, and finally approaching the most excellent route. Ant colony algorithm adopts heuristic probabilistic search method. The ant colony algorithm does not involve complex mathematical operations, and its processing does not require much software and hardware for computers, so it has important theoretical and practical significance [7].

In some complex environments, the traditional ant colony algorithm also has certain shortcomings, such as many bends and slow convergence speed. As the complexity of the environment increases, the requirements of the algorithm will be higher, and a single algorithm often cannot find the optimal path. In this paper, traditional ant colony computation and D* algorithm are combined to improve the computation by optimizing the heuristic function and sub-nodes of the original D* algorithm with the evaluation method of traditional ant colony computation, which enhances the efficiency and adaptability. The ant colony algorithm is the first intelligent simulation algorithm proposed to model the foraging activities of ant colonies, which is easy to be combined with other algorithms and applied to robot path planning due to its robustness and positive feedback. In this paper, it is proposed to integrate the single ant colony algorithm and Dijkstra algorithm with each other, using the fast global query ability of Dijkstra algorithm to process the pheromone of the single ant colony algorithm, and using Dijkstra algorithm to achieve node selection, and then optimizing with the ant colony algorithm. In unknown environments, the ACO and Dijkstra algorithms are fused so that the robot uses the Dijkstra algorithm initially to converge the search goal toward the optimal solution in path planning, and then uses the ACO algorithm to find the optimal path. When the robot encounters an obstacle, the fusion algorithm is utilized to search for the tangent point as a node, select the closest tangent point to the start point, and then translate the tangent point if the tangent point is too close to the

obstacle, followed by updating the pheromone as well as the number of iterations, and outputting the optimal path [8].

2.2.2 RRT Algorithm

La Valle proposed the Rapid Random Tree (RRT) algorithm in 1998. He proposed using a random function to generate random nodes in the robot's workspace. This function takes the initial position of the robot as the starting position of the random tree and uses this position as the parent node of the random tree.

One of the above randomly generated nodes is selected as the parent node by the function, and the generated parent node is used as the starting point, and the above steps are repeated to generate a plurality of nodes until the generated node is close to the target point. When the distance between the generated position point and the target position point meets certain requirements, treating the node as the parent node does not regenerate the termination node. Then connect the generated parent nodes to the starting and target points respectively to obtain the path of the random tree.

The RRT algorithm is able to explore the search space and find feasible paths quickly through random sampling and the establishment of the tree structure. The RRT algorithm is suitable for a wide range of environments and problems. It can be used for robot path planning, UAV trajectory planning, etc. RRT algorithm is relatively simple to implement compared with other path planning algorithms and does not require complex mathematical models and planning algorithms. The advantage of RRT algorithm is that it can still find feasible paths efficiently in the case of complex search space and multiple obstacles. Its stochastic and fast exploration characteristics make the algorithm robust and adaptable.

However, the RRT algorithm is not guaranteed to find the optimal path, but only one feasible path. Since the RRT algorithm is based on random sampling, there is a certain degree of randomness, and it may fall into the local optimal solution and cannot find the global optimal solution. The path found by the RRT algorithm may not be the shortest path because it searches for paths by continuously expanding the tree, rather than by directly calculating the shortest path. The RRT algorithm has a high requirement for the feasibility of the search space, if there are more obstacles in the search space or complex environment, the RRT algorithm may not be able to find a feasible path. Therefore, in some cases, it may be necessary to combine with other path planning algorithms to further optimize the path [9].

To improve the sampling method of the original RRT algorithm, a goal-oriented strategy is proposed to add the starting point repulsive force to the original goal sampling strategy, and an adaptive function is introduced during the expansion process to adaptively regulate each force to accelerate the search efficiency and path generation time of the algorithm. However, collision detection is an indispensable part of the random tree expansion process. The efficiency of the collision detection algorithm will largely determine the efficiency of the whole algorithm. For the improved algorithm has a strong goal orientation, which prompts the rapid growth of the random tree [10].

3. Conclusions

This paper analyzes the current state of development of global path planning algorithms with intelligent carrier robots in warehouse logistics scenarios as the research background. This paper provides a comprehensive overview and analysis of the requirements and characteristics of warehouse logistics scenarios. In addition, this paper divides the global path planning algorithms into two categories to summarize the traditional mathematical algorithms and bionic algorithms and combines the papers in recent years to review the corresponding path planning methods for warehouse logistics scenarios and analyze their advantages and disadvantages. The significance of the research in this paper is to make the intelligent carrier robot work more efficiently, so as to promote the development of the logistics industry.

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