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Circular Multiple RGV Path Planning based on Improved A* Algorithm

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Abstract: Aiming at the problems that traditional A* algorithm has many unnecessary turns and the collision between multiple Rail Guided vehicles (RGV) in orbit at the same time, an algorithm with the minimum total cost of combining "8" type track and improved A* algorithm was proposed. An improved algorithm is applied to circular multi-RGV path planning. The traditional cost function is improved and new influencing factors are introduced, which makes the estimated cost closer to the actual cost. The experimental results show that compared with the traditional A* algorithm, the length of the path planned by the improved A* algorithm combined with the minimum total cost of the priority strategy is reduced by 8.1% and 8.6%, the turning rate is reduced by 0% and 33.3%, the conflict rate is reduced to 0%, and the total cost is reduced by 73.6% and 77.5%, respectively. The improved method can effectively improve the transfer efficiency of the automatic workshop.

Keywords: Improved A* Algorithm; Path Planning; Priority Strategy; Ring Multiple RGV.

1. Introduction

In recent years, with the development of science and technology, there are more and more automated warehouses. rail guided vehicle (RGV) is a tool for transporting materials along the track in automated warehouses. With the wide application of automation system in tobacco, medicine, logistics and other industries, the demand for conveying equipment is increasing.

In order to improve the efficiency of material transportation, modern RGV material handling tools are introduced into the automated warehouse. In order to improve the handling efficiency of RGV, RGV moves from the initial linear reciprocating motion to the circular 2-RGV motion. Aiming at the problem that RGV may collide with each other in the process of automatic warehouse delivery, the RGV conflict avoidance constraint is put forward, and the queuing theory is put forward to Xiang Wang [1] and Yang Shaohua [2], which effectively solves the problem that RGV waiting is time in a specific scene, improves the transfer efficiency, and establishes the mathematical model of this problem under the given delivery sequence, with the goal of minimizing the total delivery time of materials.

At present, there are many researches on RGV algorithms. People such as Zhang Guiqin [3] and Chen Hua [4] have studied the linear reciprocating track automatic guided vehicles, and solved the intelligent scheduling algorithm and collision avoidance algorithm of two linear reciprocating track automatic guided vehicles on a single track, which solved the problems of two RGVs colliding in the opposite direction and rear-end collision in the same direction, and improved the transportation efficiency. Chen Haijun [5] and others combined the advantages of linear reciprocating RGV, circular rail RGV and AGV, and developed the RGV with automatic rail changing. Some scholars [6-8] have studied the scheduling problem of linear reciprocating 2-RGV system. Gu Hong [9] studied the ring RGV, and considered the influence of start-stop, waiting and compound operation of RGV on handling capacity, and solved the multi-objective optimal scheduling mathematical model of RGV handling operation by using the real-time scheduling algorithm of ring RGV based on self-learning and improved genetic algorithm. Jiang Wei [10] studied the scheduling problem of ring RGV. Dotoli [11,12] studied the deadlock avoidance problem of RGV and proposed the corresponding RGV scheduling strategy. Martina [13] through the simulation analysis of the ring RGV system, the number of RGVs required by the handling system is determined according to the cargo transshipment volume. Tian Shuaihui [14] and Shen Keyu [15] proposed an improved A* algorithm for path planning, which solved the problem of too many turns in the traditional algorithm in a specific scene. Wang Tianhao [16] studied the warehousing scheduling model of ring 2-RGV system, which effectively reduced the warehousing time of goods and improved warehousing efficiency. Tian Guohui [17] put forward the modeling and control research of automatic warehouse scheduling problem.

To sum up, at present, the research on RGV mostly stays in the path planning and task scheduling of linear reciprocating 2-RGV or circular 2-RGV. Due to the limitation of traditional orbit, the research on multiple RGVs in orbit at the same time is very scarce, and a lot of time is wasted when two RGV paths conflict.

Aiming at the "8"-shaped orbital ring-shaped multi-RGV system, the improved A* algorithm is combined with the path planning with the minimum total cost of the priority strategy, which increases the number of RGVs in orbit at the same time and reduces the path repetition between RGVs, thus avoiding the possibility of conflicts and collisions and greatly improving the transport efficiency of the whole system.

2. Problem Description and Model Building

This research is based on the automatic transshipment system, because the weight of the goods to be transported is 6T, and RGV is adopted for transshipment due to safety and other reasons. On the circular track, many RGVs work at the same time. In view of the fact that there are many platforms (loading and unloading ports) and many tasks, and many RGVs need to work at the same time, the ordinary circular track scheduling efficiency is low and it is easy to lock up. In view of this situation, this paper adopts the "8" circular track to improve the emulsion transfer efficiency.

2.1. Problem Description

Description of the research problem as shown in Figure 1, the intelligent transfer system consists of a "Japanese"-shaped track, 3 RGVs, 15 discharge ports of reaction kettle, 9 discharge ports and 1 cleaning port. Each reactor reacts with three batches of materials every day, discharging once every 8 hours, and discharging three at the same time, so there are three emulsion tankers running in orbit at the same time.

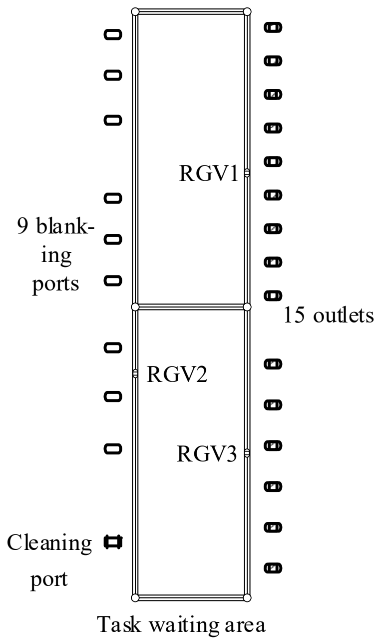


Figure 1. Workshop planning and layout

The operation flow is as follows: firstly, the discharge port of the reaction kettle sends out a discharge request instruction, then the dispatching system carries out path planning for all idle RGV vehicles in the task waiting area to find out the nearest RGV vehicle, then sends a dispatching instruction to the RGV, and then goes to the target discharge port to receive materials. After receiving materials, the dispatching system will plan the path of the RGV to the discharge port, and the RGV will go to the discharge port to discharge materials, then go to the cleaning port to finish cleaning, and finally return to the task waiting area to wait for the next task.

The path planning of multi-RGVs seeks an unobstructed and shortest driving path for multiple RGVs to reach the target point from their current positions. All path planning can be summarized as the following three questions:

1. Is there a path from the starting point to the target?
2. The planned route must be feasible, and there are no other vehicles between the routes and there is no conflict with other vehicles.
3. The planned path makes all RGVs add up to the shortest, that is, the RGV operation of the whole system is optimal.

Compared with ordinary circular track and straight track, the 8-shaped circular track has the following advantages:

1. It has higher transfer efficiency.
2. To realize more RGV running in orbit at the same time.
3. It has higher flexibility in scheduling.

2.2. Model Building

Common map methods in path planning include grid method, visibility method, topological graph method, etc. The grid method has the advantages of simplifying the environment and being easy to realize, so it has been favored by many researchers in the process of path planning research. In the later research of this paper, the whole emulsion transfer workshop is simplified into a two-dimensional plane grid map. In the grid map, all grids are divided into two types: feasible grid (RGV can pass freely) and obstacle grid (RGV cannot pass), which are white and black respectively. As shown in Figure 2.

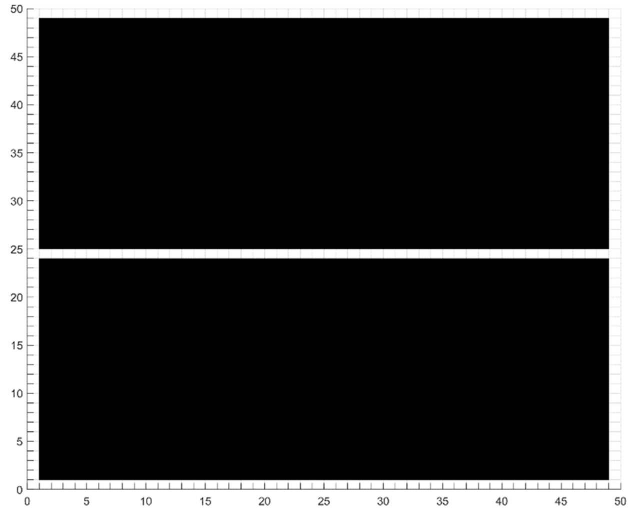


Figure 2. Grid map

3. Algorithm Description

There are Floyd algorithm, Dijkstra algorithm, A* algorithm, simulated annealing algorithm, artificial potential field method, ant colony algorithm, neural network algorithm, genetic algorithm and related improved algorithms in the path planning of mobile robots. Based on the background of this research, the path planning of circular RGV is adopted, and the electric turntable is used at the turn of circular track to realize 90 turns. Therefore, considering the comprehensive factors in RGV path planning, A* algorithm is adopted to realize RGV path planning.

3.1. Traditional A* Algorithm and Shortcomings

The traditional A* algorithm is improved on the basis of Dijkstra algorithm. Its core idea is to plan a path with the lowest cost from the starting point to the end point on the created map. The cost function f(n) is:

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

Where: n represents the current node in the process of path search, g(n) represents the actual cost and driving distance from the starting node to the current node, and h(n) represents the estimated cost from the current node to the target node. The flow chart of the A* algorithm is shown in Figure 3.

In the cost function, if g(n) is much greater than h(n) and f(n) is about equal to g(n), then A* algorithm is similar to Dijkstra algorithm, which will lead to an increase in node traversal and a decrease in search efficiency. If g(n) is far less than h(n) and f(n) is about equal to h(n), A* algorithm is similar to the best priority search algorithm, although the speed of path planning becomes faster, but it is easy to fall into the local optimal result. Therefore, the quality of A* algorithm will be determined by the heuristic function h(n). Usually, the prediction method of the heuristic function h(n) is Manhattan Distance (Manhattan distance).

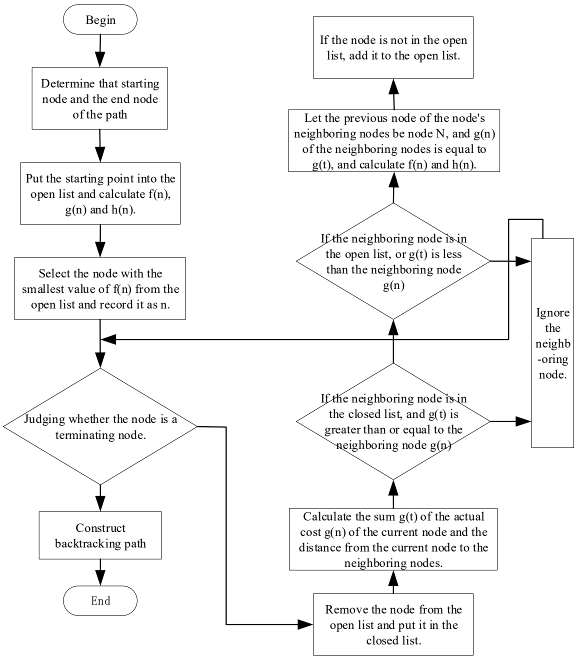


Figure 3. A* algorithm flow chart

In path planning, if the starting point coordinates are (x1, y1) and the ending point coordinates are (x2, y2), then the estimates of the above two heuristic functions h(n) are:

Manhattan distance heuristic function is:

$$h(x) = |x2 - x1| + |y2 - y1| \tag{2}$$

Euclidean distance heuristic function is:

$$h(x) = \sqrt{(x2 - x1)^2 + (y2 - y1)^2} \tag{3}$$

Shortcomings of traditional A* algorithm: The traditional A* algorithm will produce many unnecessary turns in model simulation and practical application, and will fall into local optimum in severe cases, so that the global optimal solution (shortest path) cannot be found. When transferring emulsion, the electric turntable is used to turn, and the electric turntable needs to carry a 6T emulsion tanker to rotate, which will consume huge energy and use more time. In order to reduce the number of turns, this paper improves the traditional A* algorithm and introduces new cost factors when expanding nodes, so as to reduce the number of turns.

3.2. Improved A* Algorithm

The traditional A* algorithm can find the shortest path in most cases, but the shortest path is not necessarily the highest efficiency. In the process of emulsion tanker transportation, because the consigned emulsion is very heavy, it will be very difficult and consume a lot of energy when turning, and the emulsion tanker will rotate when turning, which may cause the emulsion in the tanker to splash out, thus leading to safety hazards. In order to reduce the number of turns of RGV, the traditional cost function f(n) is improved, and a new influence factor is introduced. The expression is as follows:

$$f(n) = g(n) + h(n) + k(n) \tag{4}$$

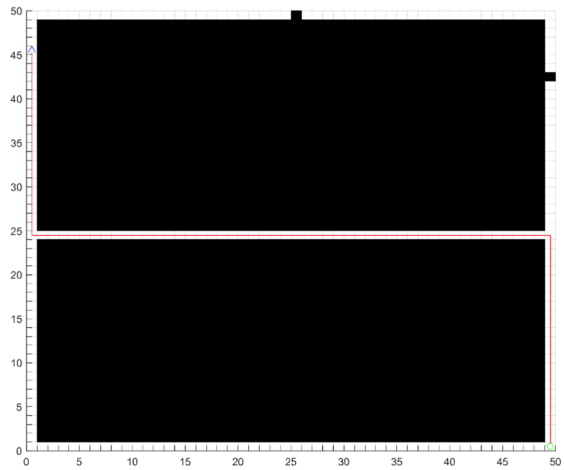
Where f(n) is the total cost of the current node, g(n) is the actual cost from the starting point to the current node, h(n) is the estimated cost from the current node to the target node, and k(n) is the introduced new cost factor. The expression of k(n) is as follows:

$$k(n) = \begin{cases} 0, (x_m - x_n) * (y_m - y_n) = 0 \\ \delta, (x_m - x_n) * (y_m - y_n) \neq 0 \end{cases} \tag{5}$$

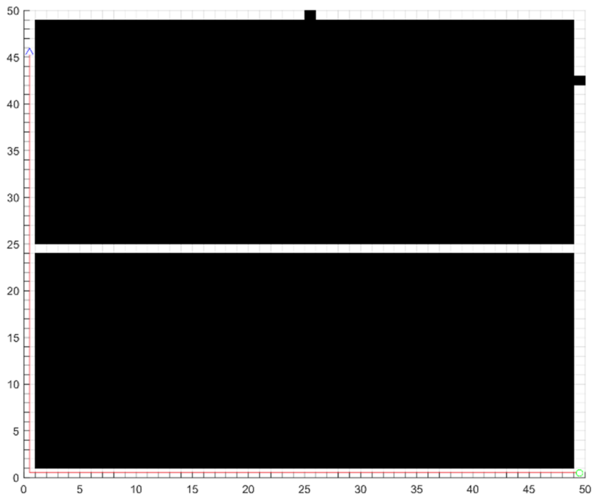
Where x_n is the x coordinate of the current node, y_n is the y coordinate of the current node, x_m is the x coordinate of the extended node, and y_m is the y coordinate of the extended node, $\delta \in (0,1)$, Because the cost of adjacent grids is set to 1, in order to ensure that the introduced cost factor does not affect the search for the optimal path and can reduce the number of turns at the same time, the simulation later in this paper chooses δ as 0.5, and the estimated cost $h(n)$ adopts Manhattan distance, and the expression is as follows:

$$h(n) = |x_m - x_n| + |y_m - y_n| \tag{6}$$

In order to verify that the improved A* algorithm can effectively find the shortest path and reduce the number of turns after introducing a new cost factor, it is verified on MATLAB R2019b software, and the path planning of three groups of comparative experiments is carried out by using the traditional A* algorithm and the improved A* algorithm respectively, as shown in Figure 4, Figure 5 and Figure 6 respectively.

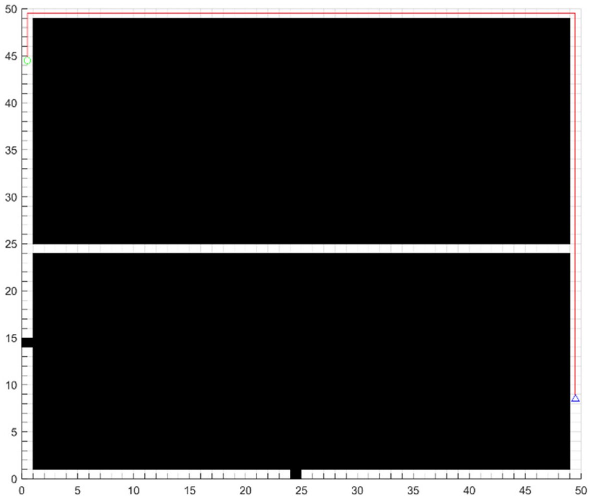


(a) Traditional A* algorithm

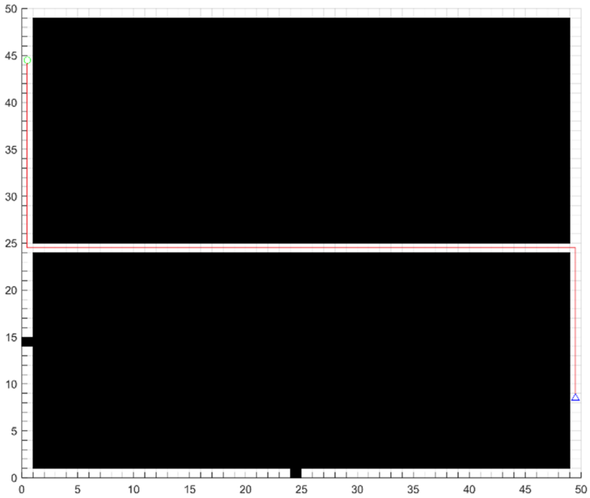


(b) Improved A* algorithm

Figure 4. Comparison of Path Planning for Task 1



(a) Traditional A* algorithm



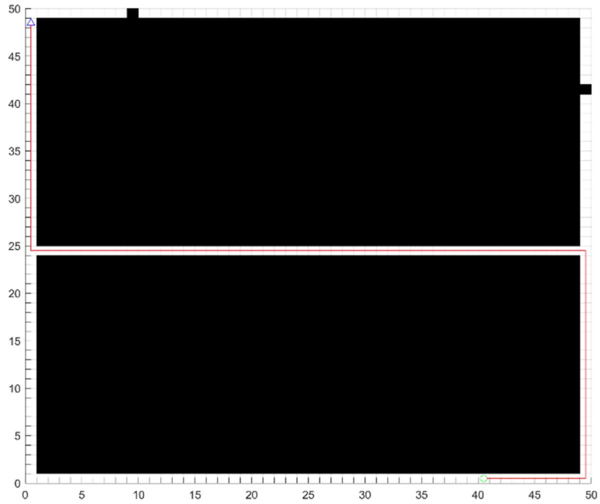
(b) Improved A* algorithm

Figure 5. Comparison of Path Planning for Task 2

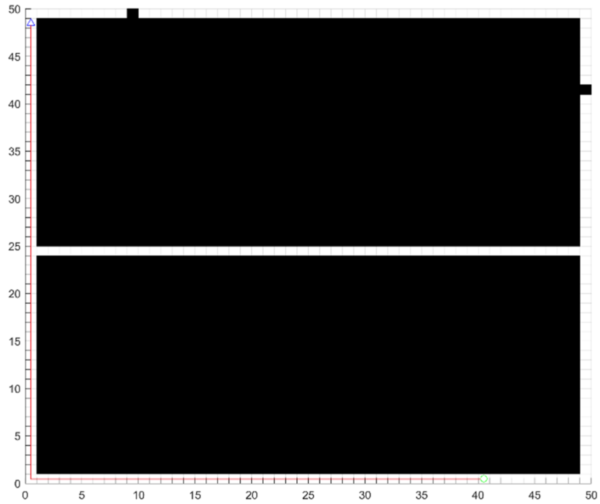
In the above three comparison charts, (a) is the path planning result of the traditional A* algorithm, and (b) is the path planning result of the improved A* algorithm. In the grid chart, the blue triangle is the starting point, the small green circle is the end point, and two black squares in the track are obstacles (the other two RGV cars). As can be seen from Figure 4, the path length planned by the improved A* algorithm is the same as that of the traditional A* algorithm, which is the shortest path. From Figure 5, it can be seen that the traditional A* algorithm is the same as the improved A* algorithm in the number of turns, but it falls into a local optimal solution, and its planned path is longer, and the optimal path cannot be found, but the improved A* algorithm finds the optimal path; As can be seen from Figure 6, the traditional A* algorithm falls into the local optimal solution, which leads to the failure to find the global optimal path, resulting in the planned path being longer than that planned by the improved A* algorithm, and the number of turns is three times that of the improved A* algorithm.

3.3. Conflict Type

In the transfer system of emulsion tanker, in order to improve the transfer efficiency and productivity, there will be many RGVs running on the circular track at the same time, so it is easy to cause path conflicts between RGVs. In order to solve this problem, the possible conflicts are classified, and each conflict is solved accordingly. Several common types of conflicts in multi-RGV operation system are: intersection conflict, opposite conflict and occupation conflict.



(a) Traditional A* algorithm



(b) Improved A* algorithm

Figure 6. Comparison of Path Planning for Task 2

(1) Intersection conflict: At the corner, two RGVs traveling in opposite directions arrive at the corner at the same time, and then both will turn to the same track, or two RGVs from different directions will travel in the same direction after passing through the intersection, which will lead to corresponding conflicts, as shown in Figure 7.

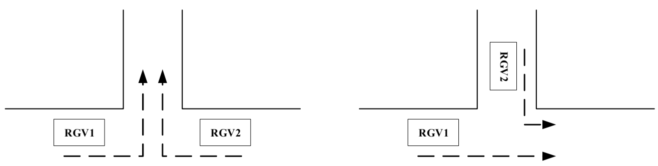


Figure 7. Intersection conflict

Figure 8. Opposing conflicts

(2) Conflict in opposite directions: When two RGVs are

driving in opposite directions, or two RGVs arrive at the corner at the same time, and then turn in opposite directions, it will lead to conflict in opposite directions, as shown in Figure 8.

(3) Occupancy conflict: On the track, RGV may stop on the track because of loading, unloading, cleaning the tank car or no task for the time being, which will lead to occupation conflict when other RGV operations pass by. As shown in fig. 9.

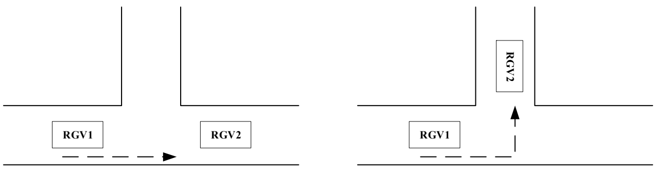


Figure 9. Occupation conflict

In the process of emulsion transportation, the strategy to solve various conflicts will greatly improve the safety and efficiency of the whole transportation system. In the traditional solution to various conflict problems, waiting is adopted, that is, the following RGV waits at the node before the conflict node, and then continues to run after another RGV successfully passes through the conflict node. However, this kind of waiting strategy can only effectively solve the intersection conflict, and in the face of the opposite conflict and occupation conflict, the waiting strategy will be locked up, and even the whole system may fail. Therefore, in order to effectively solve various conflicts, different obstacle avoidance strategies will be formulated.

When the paths conflict, the decision can be continued by priority, that is, when the paths conflict, the RGV path with high task priority remains unchanged, and the RGV with low task priority changes the path. In view of the above three kinds of conflicts, the corresponding strategies are as follows:

(1) Intersection conflict: RGV with high priority runs normally according to the route, while RGV with low priority stops and waits before entering the intersection, and continues to run after RGV with high priority passes.

(2) Conflict in opposite directions: RGV with high priority runs normally according to the route, RGV with low priority re-plans the route or stops and waits before entering the repeated route, and then continues running after RGV with high priority passes smoothly.

(3) Occupation conflict: the static RGV is regarded as a static obstacle, and the task RGV is re-planned.

3.4. Priority Strategy and Objectives

Priority strategy has been widely used in solving the problem of path conflict. The target points of RGV are set to four categories: discharge area, blanking area, cleaning area and waiting area. Because the emulsion transported by RGV is very heavy, it will consume a lot of electricity during transportation, so whether the power of RGV is lower than the set threshold should be given priority. Then there is the repetition length of RGV path. The longer the repetition, the higher the probability of collision or locking. Then, for the sake of safety, the emulsion should be transported from the discharge area to the blanking area as soon as possible to complete the emulsion transportation; Then RGV receives the transfer task command and goes to the discharge area to receive the emulsion; Then RGV needs to go to the cleaning area to complete the cleaning of the tank car after completing the emulsion transportation; Then RGV completes the cleaning demand and runs to the waiting area to wait for the new transfer task.

To sum up, in order to improve the efficiency of multi-RGV emulsion transfer system, the priority is set as follows: whether the RGV power is lower than the set threshold >> RGV path repetition length >> whether the RGV target point is in the discharge area >> whether the RGV target point is in the cleaning area >> whether the RGV target point is in the waiting area.

The priority model of the i-th RGV when performing tasks is as follows:

$$Y^i = 100X_1^i + 80X_2^i + 60X_3^i + 50X_4^i + 40X_5^i - S_i \quad (7)$$

$$X_1^i = \begin{cases} 1, & \text{The power is below the threshold.} \\ 0, & \text{The power is above the threshold.} \end{cases} \quad (8)$$

$$X_2^i = \begin{cases} 1, & \text{It's a blanking hole} \\ 0, & \text{It's not a blanking hole} \end{cases} \quad (9)$$

$$X_3^i = \begin{cases} 1, & \text{Discharge area} \\ 0, & \text{Not a discharge area} \end{cases} \quad (10)$$

$$X_4^i = \begin{cases} 1, & \text{Cleaning area} \\ 0, & \text{Not a cleaning area} \end{cases} \quad (11)$$

$$X_5^i = \begin{cases} 1, & \text{Waiting area} \\ 0, & \text{Not a waiting area} \end{cases} \quad (12)$$

$$S_i = \alpha X_6^i + \beta X_7^i + \gamma X_8^i \quad (13)$$

Among them, X_1^i is a decision variable with 0-1 distribution, which represents the result of comparing the current power of the i-th RGV with the set threshold; X_2^i is a decision variable with 0-1 distribution, indicating whether the current target area of the i-th RGV is a blanking area; X_3^i obeys the decision variable of 0-1 distribution, indicating whether the current target area of the i-th RGV is the feeding area; X_4^i is a decision variable with 0-1 distribution, indicating whether the current target area of the i-th RGV is a cleaning area; X_5^i is a decision variable with 0-1 distribution, indicating whether the current target area of the i-th RGV is a waiting area; X_6^i is a decision variable with a distribution of 0-1, indicating the planned path length of the i-th RGV; X_7^i indicates the number of turns in the planned path of the i-th RGV; X_8^i represents the repeated path length in the i-th RGV planned path; α、β、λ is a constant; If there is a conflict between RGVs with the same priority, the RGV closest to the conflict point will be adopted to pass first.

Objective: The ultimate goal of circular multi-RGV path planning is to improve emulsion transport efficiency and reduce energy consumption. Common optimization methods include shortest path repetition, shortest path and the least number of turns. In this paper, the shortest path repetition, the shortest path length and the number of turns is combined, and the final goal is to find the optimal path and improve the transshipment efficiency.

$$\min S=\sum_{i=1}^{3}(\lambda_1 n_i+\lambda_2 s_i+\lambda_3 m_i) \tag{14}$$

Where S is the total cost of three RGVs, n_i is the repeated path length of the i-th RGV and other RGVs, s_i is the path length of the first RGV, m_i is the number of turns of the i-th RGV, and λ_1、λ_2、λ_3 are constant coefficients.

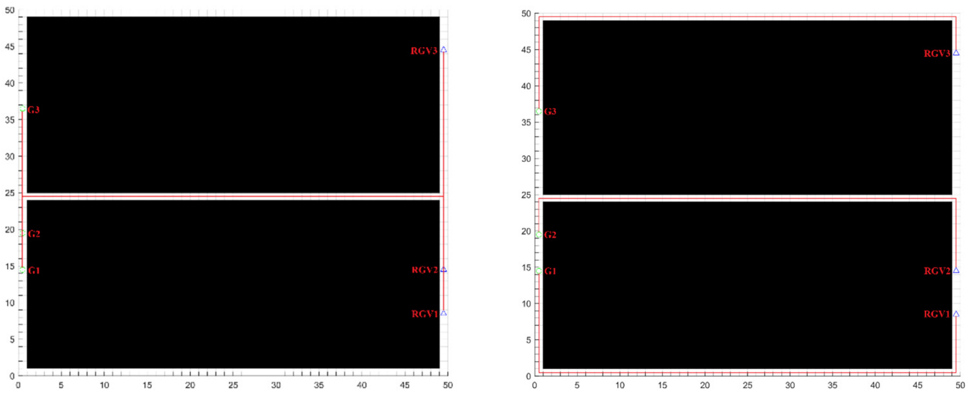
4. Simulation Experiment

In order to verify that the improved A* algorithm is effective for the path planning of ring multi-RGV with minimum total cost of fusion priority strategy. Taking emulsion transfer in an intelligent workshop as the research object, considering that there are multiple outlets and discharge outlets, and there are three outlets discharging at the same time, and three RGVs are needed to pick up and drop off the materials, this algorithm is now applied to an "8"-shaped track formed by adding a track on the basis of the circular track. The following two groups of control experiments are conducted, and three starting points and three ending points are randomly generated in each experiment. In Formula (14), the value is $\lambda_1=2$、$\lambda_2=0.5$、$\lambda_3=5$.

The results of experiment 1, the comparison of experimental information of traditional A* algorithm and improved A* algorithm is shown in Table 1, and the experimental comparison results are shown in Figure 10.

Table 1. Experiment 1 Comparative information table

	Vehicle	Starting point	Destination	Path length	Conflict length	Number of turns	Conflict rate	Total cost S
Traditional A* algorithm	RGV1	(50,9)	(1,15)	76	65	2	86%	501.5
	RGV2	(50,15)	(1,20)	65	65	2	100%	
	RGV3	(50,45)	(1,37)	82	50	2	61%	
Improved A* algorithm	RGV1	(50,9)	(1,15)	72	0	2	0%	132.5
	RGV2	(50,15)	(1,20)	65	0	2	0%	
	RGV3	(50,45)	(1,37)	68	0	2	0%	



(a) Traditional A* algorithm (b) Improved A* algorithm

Figure 10. Experiment 1 comparison result chart

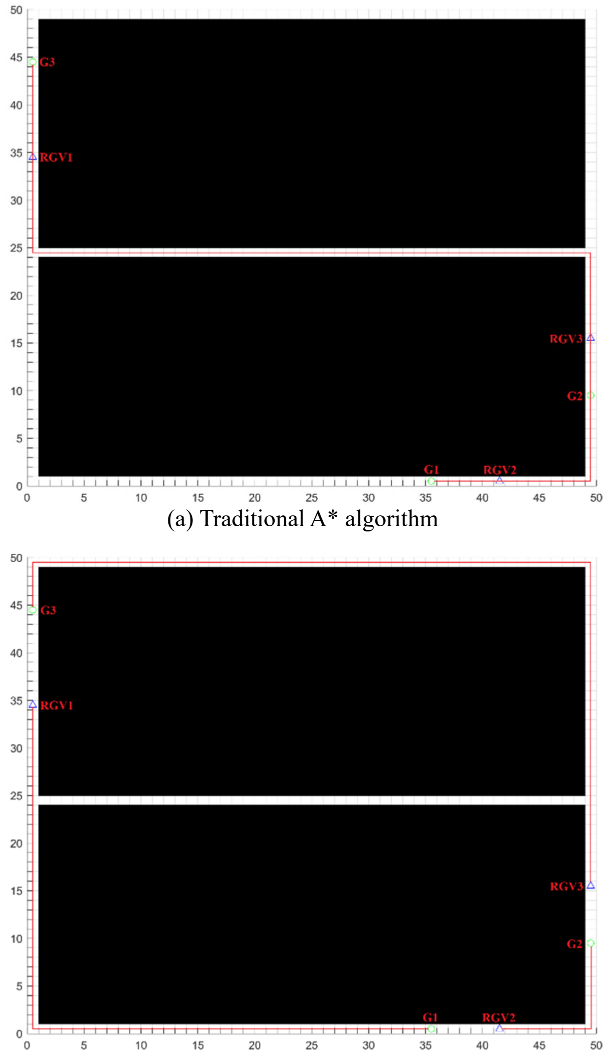
Table 2. Experiment 2 Comparative information table

	Vehicle	Starting point	Destination	Path length	Conflict length	Number of turns	Conflict rate	Total cost S
Traditional A* algorithm	RGV1	(1,35)	(36,1)	98	92	3	94%	485.5
	RGV2	(42,1)	(50,10)	18	18	1	100%	
	RGV3	(50,16)	(1,45)	79	69	2	87%	
Improved A* algorithm	RGV1	(1,35)	(36,1)	70	0	1	0%	109
	RGV2	(42,1)	(50,10)	18	0	1	0%	
	RGV3	(50,16)	(1,45)	90	0	2	0%	

In figure 10, (a) path planning for traditional A* algorithm, and (b) path planning for improved A * algorithm with priority strategy. RGV1, RGV2 and RGV3 are the starting points of three vehicles, and G1, G2 and G3 are the corresponding target points. As can be seen from Table 1, when the traditional A* algorithm is used for path planning, the path repetition between RGVs is very high, and some even reach 100%. The improved algorithm can effectively avoid the possibility of collision caused by repeated paths, and the path length of RGV3 is shorter, the total path sum is reduced, and the total cost S is reduced. As can be seen from Figure 10, compared with the path planned by the traditional algorithm, the path planned by the improved algorithm can effectively avoid the possibility of collision.

The results of experiment 2, such as the comparison of experimental information of traditional A* algorithm and improved A* algorithm, are shown in Table 2, and the experimental comparison results are shown in Figure 11.

In figure 11, (a) path planning for traditional A* algorithm, and (b) path planning for improved A * algorithm with priority strategy. RGV1, RGV2 and RGV3 are the starting points of three vehicles, and G1, G2 and G3 are the corresponding target points. From Table 2, the improved algorithm can effectively avoid the possibility of conflict, and at the same time, the total planned path, the number of turns and the total cost S are reduced.



(a) Traditional A* algorithm

(b) Improved A* algorithm

Figure 11. Experiment 2 comparison result chart

5. Conclusion

In this study, aiming at the path planning of multiple RGVs in the circular "8" track, the improved A* algorithm combined with the minimum total cost in the priority strategy is proposed to solve the possibility of path duplication and conflict between RGVs. The experimental results show that in three groups of static path planning experiments, compared with the traditional A* algorithm, the improved A* algorithm reduces the path length by 0%, 9.5% and 16.8% respectively, and the turning rate by 50%, 0% and 50% respectively. In two experiments of ring multi-RGV path planning, compared with the traditional A* algorithm, the minimum total cost of the improved A* algorithm combined with priority strategy is reduced by 8.1% and 8.6% respectively, the turning rate is reduced by 0% and 33.3% respectively, the collision rate is all reduced to 0%, and the total cost is reduced by 73.6% and 77.5% respectively. Therefore, the improved algorithm can effectively avoid the possibility of collision, reduce the total path length and reduce the number of turns.

References

[1] Xiang Wang, Wu Shuang, Zhang Keyi, et.al. Analysis of Operation Parameters of Ring Shuttle System Based on Queuing Theory. Manufacturing Automation, 2018, 40 (06): 151-153.

[2] Yang Shaohua, Zhang Jiayi, Zhao Li. Analysis of the number and capacity of multiple cars on the ring track based on queuing theory. Manufacturing Automation, 2011,33(16):102-104.

[3] Zhang Guiqin, Zhang Yangsen. Intelligent Scheduling Algorithm for Linear Reciprocating Automatic Guided Vehicle. Computer Engineering, 2009,35(15):176-178+181.

[4] Chen Hua, Sun Qiyuan. Research on scheduling of linear reciprocating 2-RGV system based on TS algorithm. Industrial Engineering and Management, 2015,20(5):80-88.

[5] Chen Haijun, Yang Zhongwen. Technical Highlights of New Type Automatic Track-changing Shuttle Car. Logistics Technology and Application, 2009,14(06):82-84.

[6] Ma Changpu, Zhang Yichun. 2-RGV scheduling optimization model of automatic cargo handling system in logistics center. System Engineering, 2019,37(05):109-116.

[7] Hu W, Mao J, Wei K. Energy-efficient rail guided vehicle routing for two-sided loading/unloading automated freight handling system. European Journal of Operational Research, 2017, 258(3): 943-957.

[8] DING C, HE H, WANG W, et al. Optimal strategy for intelligent rail guided vehicle dynamic scheduling. Computers & Electrical Engineering, 2020, 87:106750.

[9] Gu Hong, Zou Ping, Xu Weihua. Self-learning algorithm for optimal scheduling of circular shuttle . System Engineering Theory and Practice, 2013,33(12):3223-3230.

[10] Jiang Wei, He Fei, Tong Yifei, et al. Research on scheduling optimization of circular orbit RGV system based on hybrid algorithm. Computer Engineering and Application, 2016, 52(22):242-247.

[11] DOTOLI M, FANTI M P. A colored Petri net model for automated storage and retrieval systems serviced by rail-guided vehicles: a control perspective. International Journal of Computer Integrated Manufacturing,2005,18(2-3):122-136.

[12] DOTOLI M, FANTI M P. Deadlock Detection and Avoidance Strategies for Automated Storage and Retrieval Systems. IEEE transactions on systems, man and cybernetics. Part C, Applications and reviews,2007,37(4): p.541-552.

[13] MARTINA C, ALESSANDRO P, FABIO S. Modelling of Rail Guided Vehicles serving an automated parts-to-picker system[J].2018,51(11):1476-1481.

[14] Tian Shuaihui, Fan Lue. Multi-AGV Path Planning of Express Distribution Center under Dynamic Priority Strategy. Computer Engineering and Application: 1-14[2022-11-09].

[15] Shen Keyu, You Zhiyu, Liu Yongxin, Tao Huang. Path Planning of Mobile Robot Based on Improved A* Algorithm. Computer Application Research: 1-6[2022-11-09].

[16] Wang Tianhao, Chen Hua, Wang Xinping. AS/RS warehousing scheduling model and solving algorithm of ring 2-RGV system. Computer integrated manufacturing system: 1-19.

[17] Tian Guohui. Research on modeling and control of automatic warehouse transportation scheduling problem. Control and decision, 2001(04):447-451.