Research and prospect of intelligent workshop AGV path planning algorithm

Abstract: Path planning algorithm is one of the core algorithms for automatic guided vehicle （AGV）to complete the autonomous task of intelligent workshop.The research status of grid method and Viewable method in environment modeling at home and abroad is described.The research results of traditional path search algorithms such as artificial potential field method, Dijstra algorithm and A* algorithm are analyzed and compared with intelligent algorithms such as particle swarm optimization algorithm, ant colony algorithm and genetic algorithm.The analysis finds that in the face of complex workshop environment, multi-factor influence and complex obstacles, some tasks are not completed or work overtime depending on the traditional algorithm.Therefore, starting from the algorithm improvement, in order to improve the operational efficiency and efficient obstacle avoidance of AGV, the fusion of intelligent algorithm and traditional algorithm will become the focus of research.Finally, combined with the existing problems in the current AGV path planning research, the research trend of intelligent development and integrated development is prospected.In future research, improvements in algorithm efficiency and integration with emerging technologies such as artificial intelligence can be considered.

Key words: path planning,automatic guided vehicle（AGV）,algorithm improvement

1.INTRODUCTION:

At present, with the continuous progress of human science and technology, factories in the traditional sense consume too much manpower and material resources, and the corresponding work cost of enterprises has also increased. This traditional work mode is no longer applicable in the face of a large number of complex work tasks.With the introduction of intelligent machines in medical, catering, logistics and other fields, their work efficiency is greatly improved compared with human labor, such as medical robots, catering robots, transportation robots and so on. In order to ensure the safety of staff, many high-risk operations are also replaced by intelligent machines. Therefore, AGV has become an indispensable part of many smart factories, and AGV is currently being more combined with the Internet and big data technology, so that the perception ability and independent decision-making ability of the logistics system can be improved. The first AGV was born in 1953, it was a simple AGC product tractor modified, its cargo needs to be transported through the air wire, then AGV-related research began[1]. The United Kingdom was the first to develop electromagnetic induction guided AGV, soon Europe installed a variety of forms, different levels of AGV, early AGV as shown in Figure 1, by the mid-1970s, due to the popularity of microprocessor and computer technology, servo drive technology mature design more flexible AGV.

Fig. 1. Agvs for early factory applications

The paths of AGV operations are long and short, and the paths of multi-AGV operations are complicated, and the path problem is related to work efficiency and operation cost. Therefore,path planning is the key to the implementation of AGV tasks, and also the main challenge in its engineering application, which has attracted extensive attention from scholars at home and abroad[2]. In this paper, AGV path planning algorithms are divided into two categories: environment modeling and path search. Reasonable environment modeling method is helpful to reduce the number of path search, and different path search algorithms are based on different environment models. The common environment modeling methods are: grid method, Viewable method and so on. Path search algorithms mainly include artificial potential field method, genetic algorithm, particle swarm optimization algorithm, ant colony algorithm and so on. The core of AGV path planning technology is the design of algorithm.The optimization of AGV job paths by different algorithms can be adapted to a wider range of scenarios. Zhu Mingzhe and Sun Bingyu[3] studied the global search ability of genetic algorithm and the conflict prediction ability of time window algorithm. They solved the congestion problem, but did not pay attention to the operation path. This paper reviews how to optimize AGV path, speed up algorithm convergence and improve AGV efficiency by improving intelligent algorithm or combining intelligent algorithm with traditional algorithm in recent years.

2.Path planning algorithm based on environment modeling

For the processing of environmental information, through the construction of effective mathematical models, environmental information can be better understood, effective analysis and optimization of the environment can be realized, environmental problems can be modeled and solved by mathematical optimization methods, and paths can be searched and optimized. When solving the problem, the corresponding modeling method is helpful to reduce the calculation amount of path planning and speed up the calculation.

2.1Grid method

Grid-based Method (Grid-based Method) is a commonly used mathematical modeling method, which was first proposed by W.E. Bowden in 1968, and is generally used as an environmental modeling technique for path planning. Especially suitable for processing spatial information and geographic information. In environmental information processing, the grid method divides the space area into regular grids or cells, and stores the corresponding information in each grid or cell, which is to simulate the obstacles into a collection of small squares, equivalent to the binary substitution of all things in the scene, with obstacles as 1 and non-obstacles as 0. The modeling of intelligent workshop environment is shown in Figure 2. This method can be used in map making, geographic information system (GIS), environmental simulation and other fields. In the raster method, each grid or cell usually represents a specific region of space with a certain size and properties. By storing environmental information in each grid or cell, the discrete representation and processing of spatial information can be realized. If the grid is small, the environmental information represented by the grid map will be very clear, but because more information needs to be stored, consider the storage cost will increase, reducing the planning speed and compromising real-time performance.On the contrary, due to the small amount of information storage, the planning speed is increased, but the division of environmental information will become fuzzy, which is not conducive to the effective path planning. Jiang L[4] et al. built raster maps, randomly set obstacle information to simulate the actual working environment, and designed a full-coverage path planning method based on neuron excitation network method, which can realize large-scale coverage of farmland plots and achieve independent optimal path planning for obstacle maps of different complexity. Qiu T[5] et al. divided the map by grid, and divided the threat level of grid according to the obstacle area in the grid, and then used different sampling strategies to connect sampling points, no longer traversed all points, but only connected with nearby grids. The results showed that the operation time was reduced and the success rate was increased. As a common AGV path planning algorithm, raster method is difficult to solve the complex environment information problem directly, and generally needs to be combined with other path search algorithms for path planning.

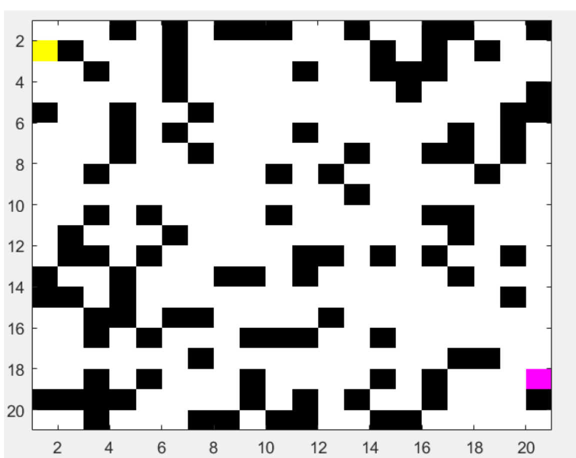

Fig. 2. Smart workshop environment map

2.2Viewable method

Viewable method, proposed by Lozano-Perez and Wesley in 1979, is a classical algorithm for robot global motion planning. In Viewable method, robots are described by points and obstacles by polygons. The starting point S, the target point G and the vertices of the polygon obstacle are combined and connected, requiring that the lines between the starting point and the vertices of the obstacle, between the target point and the vertices of the obstacle, and between the vertices of the obstacle can not cross the obstacle, that is, the straight line is "visible". The Viewable method is shown in Figure 3. However, if the starting point and the target point change, the Viewable method must be reconstructed, and the complexity of the algorithm is proportional to the number of obstacles, Viewable method is usually suitable for polygonal obstacles, for circular obstacles failure, can be improved by tangential graph method and Voronoi diagram method. Chen C[6] et al. realized accurate positioning through the joint application of UHF radio frequency identification system and low frequency radio frequency identification system, and combined Viewablemethod and A* algorithm to improve the search efficiency and ensure the feasibility of the planned path. Liu Y[7] combined theViewable method with the convex point method to optimize the initial path, generate the optimized path for the shortcomings, and then perform the secondary optimization. Each node in the path generated for the first optimization is sequentially selected as the new starting point and end point to generate a sub-optimized path to get a better path.

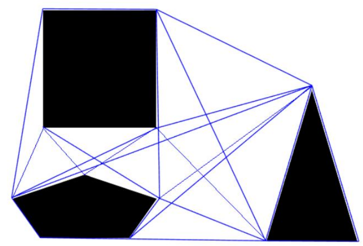

Fig.3. Viewable method

With the increase of AGV computing speed and the need for the integrity of shop environment information, 3D environment modeling will become one of the focuses of AGV path planning algorithm research. The advantages and disadvantages of the above common environmental modeling methods are shown in Table 1.

Table 1.Comparison of common environment modeling methods

method	advantage	shortcoming	reference	Scope of application
Grid method	Simple and effective, with scalability, visualization and interpretability, simple modeling process	The space and calculation cost are large, the accuracy is limited, the data update is difficult, and it is not suitable for large-scale spatial search	[2][3]	Autonomous driving, robot positioning and path planning, building the geographic layout of the game world
Viewable method	Intuitive concept, Simpleimplementation, easy to find the shortest path	Long search time, lack of flexibility, local path planning ability is poor	[4][5]	Geographical scenario prediction of outdoor environment, Marine environment modeling

3.Path planning algorithm based on path search

The path search algorithm is based on the established environment model to obtain a shortest path between the beginning and the end of the search path. There are a lot of path search algorithms, according to their own characteristics, the application field is also different. Traditional optimization algorithms are generally aimed at structured problems, with more clear descriptions of problems and conditions.Many traditional optimization algorithms belong to the category of convex optimization, and have the unique and clear global best advantage. For path planning, there are two parts, local and global, most of the research directions include avoiding local minimum or searching global optimal. A local minimum is a minimum in a region rather than a global minimum. Global optimum is the optimal solution obtained under global research.With the progress of science and technology, traditional path search methods no longer meet the increasingly sophisticated work requirements. Although the theory is relatively perfect, there are shortcomings such as poor search ability, etc., while intelligent optimization algorithms are mostly targeted at multi-extremum problems. How to avoid falling into local optimal and find global optimal as much as possible, traditional algorithms are often combined with intelligent algorithms. Or on the basis of the original algorithm to improve to adapt to the specific scene of the work.

3.1Traditional path search algorithm

The traditional path search algorithm is simple and easy to implement, but it also has some problems such as poor path optimization effect (poor feasibility), slow processing speed and insufficient dynamic obstacle avoidance ability. The traditional path search algorithms commonly used in AGV include artificial potential field method, Dijkstra algorithm, A* algorithm and so on.

3.1.1Artificial potential field method

Artificial potential field method is a virtual force method proposed by Khatib for robot motion planning. The basic idea is to concretize the effect of objects and obstacles on the robot's motion. Low potential energy at the target, high potential energy at the obstacle. This kind of potential difference produces the attraction of the target to the robot and the repulsion of the obstacle to the robot, which together control the robot to move towards the target point along the negative gradient of the potential field. The artificial potential field method is easy to calculate, and the obtained path is safe and smooth, but the complex potential field environment may produce local minima outside the target point, causing the robot to fail to reach the target.In order to solve the local minimum point problem of artificial potential field method, scholars have proposed various improved methods. It is divided into two directions: one is to construct a suitable potential function to reduce or avoid the occurrence of local minima; The other is to combine other methods to make the robot leave the local minimum after the robot encounters the local minimum.Saravanakumar[8] et al. introduced a directed search method on the basis of the traditional APF algorithm to sample the potential field. By determining the point where the minimum potential energy exists, the vehicle can be moved to the point in three-dimensional space to analyze the local minimum problem. By reducing the proportional factor of the fine-tuning potential function, the burden of the local minimum is avoided. Local minima in three-dimensional space can therefore be avoided.Yan[9] et al. proposed a dynamic formation model in a complex underwater environment to further improve the artificial potential field method and combine it with the variable dimension particle swarm optimization algorithm to find an optimal path by dynamically adjusting the number and distribution of path nodes.Zhang G[10]et al. proposed an improved artificial potential field algorithm based on fuzzy control and virtual target points to solve the local minimum trap and path redundancy problems existing in robot local path planning. The improved APF algorithm can quickly get rid of the trap, reduce redundant paths, improve path smoothness and reduce planning time.

3.1.2Dijkstraalgorithm

Dijkstra algorithm was proposed by E.W. Djkstra in 1959.The algorithm adopts a greedy mode, which can calculate the shortest path from one vertex to the other vertices, and solve the shortest path problem in the power graph. The main feature is to start from the starting point, adopt the greedy algorithm strategy, and traverse the adjacent nodes of the closest and unvisited vertices to the starting point every time until extended to the end point.The algorithm is optimal for graphs with non-negative weights.Due to the shortcomings of traditional algorithms such as less than ideal time complexity, Huang Y and Yu Y[11] proposed an improved algorithm of Dijkstra algorithm to find the shortest anti-conflict route for multi-UAV. The shortest route was obtained by introducing variable length backtracking array and time window conflict judgment model, and then feasible non-conflicting routes were found from the shortest route.Sun N[12] et al. proposed an optimized scheduling scheme based on the enhanced Dijkstra algorithm to solve the problem of long waiting time and low traffic efficiency when vehicles pass through the intersection without signal lights.Wang X[13] et al. improved the traditional Dijkstra algorithm by using the adjacency list and binary sort tree structure, which enabled the emergency command vehicle to solve all kinds of emergencies in a timely and effective manner on crowded urban roads.

3.1.3A* algorithm

The A* algorithm, originally published in 1968 by Peter Hart, Nils Nilsson and Bertram Raphael at Stanford Research Institute, is an efficient search algorithm for solving the shortest path in static networks.A* algorithm heavily depends on the accuracy of the heuristic function used.A* is optimal and complete if the heuristic is admissible and consistent.In order to better solve the problems of large extended search range and easy path collision in global path planning, Zhang W, Zhang Zand Wang W[14] proposed an improved A* algorithm with adaptive search distance. In the process of path extended search, the original fixed search distance is replaced by an adaptive adjustment of search distance mechanism in eight directions, so as to reduce the number of extended search nodes and reduce search time.Shi X[15] et al. proposed A robot navigation method based on the improved A* algorithm, which uses the nth-order Bessel curve to smooth the path twists caused by the small-range A* algorithm, and only uses the small-range A* programming.The cost of the heuristic path obtained by using A* algorithm is low, and its advantage is that it can be interrupted and restored in time during the planning process.

The research on the above commonly used traditional search methods is shown in Table 2

Table 2. Comparison of traditional search methods

Traditional algorithm	advantage	shortcoming	reference	Research characteristics	Research problem
Artificial potential field	It has good robustness , simple	There is the problem of unreachable	[6]	Potential field sampling to avoid local minima	Overcoming local optimality

method	and intuitive, and good real-time performance	target, which is easy to fall into local optimal and local minimum	[7]	In combination with particle swarm optimization, the path nodes are dynamically adjusted	Optimal path
			[8]	Fuzzy control combined with virtual target points to improve APF	Local path planning
Dijkstra algorithm	The algorithm is simple and suitable for most scenarios	The time complexity is not ideal and there are negative loops. Fails with negative edge weights	[9]	Variable length traceback array	Anti-conflict, Shortest path
			[10]	Dynamic grid weight assignment, shortest path global search	Shortest travel time
			[11]	Improved by adjacency list and binary sort tree structure	Shortest path
A* algorithm	High efficiency, enlightening and expandable	The evaluation function is not accurate and the space complexity is high	[12]	Adaptive search, global path planning	Search efficiency, anti-collision
			[13]	Euclidean distance, Bessel curve	Path real-time

3.2Intelligent path search algorithm

Because the traditional path search algorithm has some problems, such as poor path optimization effect and slow processing speed, intelligent bionics path search algorithm has gradually become the mainstream algorithm when dealing with the path planning problem under complex dynamic environment information. At present, the commonly used intelligent bionics path search algorithms include particle swarm optimization algorithm, ant colony optimization algorithm, genetic algorithm, etc., but intelligent algorithms also have some problems such as slow convergence speed, too long calculation time and easy to fall into local optimality.

3.2.1Particle swarm optimization algorithm

Particle swarm optimization (PSO), originally proposed by Kennedy and Eberhart, is a parallel algorithm. Based on the observation of the activity behavior of animal clusters, it makes use of the information sharing of individuals in the group to make the movement of the whole group evolve from disorder to order in the problem solving space, so as to obtain the optimal solution[16].PSO can be parallelized for concurrent processing, enhancing its efficiency.From the perspective of quantum mechanics, Sun J[17] et al. proposed an improved particle swarm optimization algorithm with quantum behavior combined with the idea of quantum physics, and focused on the current local optimal position information and global optimal position information of each particle when updating particle positions.Biswas S[18] et al. proposed a path planning algorithm for multi-agent systems based on particle swarm optimization algorithm for collision avoidance in dynamic environments, and obtained a high-quality solution with fast computing speed. The traditional particle swarm optimization algorithm has some defects, such as low precision and local optimum. In order to improve the performance of the algorithm, it is necessary to improve the particle swarm optimization in different aspects.

3.2.2Ant colony optimization algorithm

Ant colony optimization(ACO)algorithm is a meta-heuristic algorithm proposed by Italian scholar Dorigo inspired by the foraging behavior of ant colonies. ACO benefits from positive feedback, which accounts for the rapid discovery of good solutions.ACO is particularly efficient in solving problems like the Traveling Salesman problem.In recent years, many scholars have studied the path planning problem based on ant colony algorithm, and improved ant colony algorithm from many aspects.In consideration of path smoothness, Zeng Y[19] et al. introduced a smoothing function into the state transition probability, and proposed a segmental pheromone update method based on entropy weight to improve the convergence speed of the algorithm. The improved ant colony algorithm planned a shorter, smoother path and a faster convergence speed.As the ant colony algorithm has problems such as poor global search ability, few initial pheromones and weak optimization ability, etc., and can not well meet the purpose of path optimization, Zhou J[20] et al proposed a multi-factor improved ant colony algorithm. By changing the initial pheromone concentration distribution and changing the heuristic function, the improved algorithm has better path and fewer iterations. Robustness and optimization are also improved.

3.2.3Genetic algorithm

Genetic algorithm(GA)[21] is a heuristic random search algorithm based on the concepts of biology, genetics and evolution. Through the process of biological evolution in nature, genetic algorithm has evolved into a solution that is more and more adaptable to the environment.Genetic algorithms can provide high-quality solutions to a variety of problems involving search, optimization, and learning, and they are similar to natural evolution, so they can overcome some of the obstacles encountered by traditional search and optimization algorithms. Addressing the issue of parameter tuning, which is crucial for the performance of the Genetic Algorithm (G.A.). G.A.s do not guarantee finding the global optimum due to their probabilistic nature.Genetic algorithm has some defects, such as premature convergence and low computational efficiency. In order to improve the performance of genetic algorithm in path planning, researchers have improved the algorithm.Chen L[22] et al. proposed to improve it by using a variety of grid selection models and priority heuristic search algorithm to find the shortest path and reduce the number of turns. Sun B[23] et al. proposed an improved adaptive genetic algorithm, which introduced the idea of simulated annealing into the selection operation of genetic algorithm, and improved the self-adjusting strategy of crossover and mutation operators, so as to improve the global search ability and convergence speed of the algorithm.In order to solve the problem of reducing the proportion of infeasible paths when the initial population is generated by random method, Wu M[24] proposed an obstacle avoidance strategy based on Cost-Gain algorithm to improve the genetic algorithm, and the obtained path length is shorter and the convergence speed is faster.

The research pairs of the above commonly used intelligent algorithms are shown in Table 3.

Table 3. Research comparison of intelligent algorithms

Intelligent algorithm	advantage	shortcoming	reference	Research characteristics
PSO	Simple and easy to implement, Fast convergence, It is insensitive to the scaling of design variables and is derivative-free.	Easily fall into local optimality	[15]	Quantum physical thought
			[16]	Dynamic environment reprogramming
ACO	Good robustness, Low implementation cost	The convergence speed is slow, and it is easy to fall into local optimal	[17]	Secondary optimization, path smoothing processing
			[18]	Multi-factor optimization
GA	Strong adaptability, global search ability and scalability	Premature convergence, low computational efficiency, easy to fall into local optimal	[20]	Full cover path
			[21]	Anti-collision, smooth path processing
			[22]	Anti-collision, Cost-Gain algorithm

3.2.4Other algorithms

In recent years, with the continuous exploration and development of AGV, some new algorithms have been widely applied to the AGV path planning problem because of their excellent characteristics, and have achieved good results. These algorithms generally have strong path search ability, such as D* algorithm, pigeon colony algorithm, gray Wolf algorithm, artificial bee colony algorithm, etc.

4.Conclusion and prospect

AGV path planning algorithm plays an important role in intelligent workshop. In this paper, common AGV path planning algorithms are divided into two categories: environment modeling method and path search algorithm. This paper introduces the research status of AGV path planning algorithms in detail, analyzes the advantages and disadvantages of each algorithm, and compares their real-time performance, algorithm complexity, environment adaptability and planning path stationarity. It is found that in the face of complex workshop dynamic environment, how to improve the practicability of the algorithm in 3D environment, so as to achieve efficient obstacle avoidance and energy saving is the most important thing in AGV path planning. Traditional path planning methods are difficult to meet today's complex shop operations, and AGV's own dynamic model and environmental information are difficult to describe accurately. Therefore, applying emerging artificial intelligence algorithms to AGV path planning and further improving the intelligence level of AGV will become the focus of future development.

At present, the research of AGV path planning algorithm has made great progress, but there are still some shortcomings in each specific planning algorithm, so the focus of the path planning field is still the research of new and efficient path planning algorithm and fusion algorithm. Or consider potential improvements in algorithmic efficiency, real-time adaptability or integration with emerging technologies such as the Internet of Things and artificial intelligence.In recent years, with the gradual application of some new algorithms (technologies) to path planning, this complementary algorithm fusion has also promoted the development of algorithms, through learning from each other, resulting in a series of more excellent algorithms. For example, the dynamic window method is combined with A* algorithm, or the intelligent algorithm is integrated into a hybrid algorithm, and the potential problems of path planning are analyzed and solutions are proposed, which makes the application prospect of AGV more broad.

FUNDING: Henan 2023Research and development of key technologies forintelligent distribution of ready-mixed concretematerials and cloud platform system (232102220089)

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REFERENCES:

[1] Jiao Jian. Research on Investment Prospect of AGV Robot Product Market [J]. Vitality, 2024, 42 (09): 166-168.

[2] Aggarwal S ,Kumar N . Path planning techniques for unmanned aerial vehicles: A review, solutions, and challenges [J]. Computer Communications, 2020, 149 270-299.

[3] Zhu Mingzhe, Sun Bingyu. Research on Multi-AGV scheduling strategy of factory Storage System based on Genetic Algorithm [J]. Electronic Technology, 2021, 50 (01): 33-37.

[4] Jiang Longteng, ChiRuijuan, Ma Yuqi, et al. Research on path planning method of agricultural robot based on grid method [J]. Journal of Agricultural Mechanization Research, 2024, 46 (06): 19-24.

[5] Qiu Tian, Zhang Zhi-An, WangHailong. Path Planning of Mobile Robot Based on Raster Probability Path Diagram [J]. Machine Tool & Hydraulics, 2022, 50 (21): 14-19.

[6] Chen Chao, Tang Jian, JinZuguang, et al. Path Planning of a Guide Robot based on Viewable Method [J]. Mechanical Science and Technology for Aerospace Engineering, 2014, 33 (04): 490-495.

[7] LIU Ya. Obstacle Avoidance Path Generation and Optimization based on Viewable Method [D]. Kunming University of Science and Technology, 2012.

[8] Saravanakumar S, Asokan T. Multipoint potential field methodfor path planning of

autonomous underwater vehicles in 3Dspace[J]. Intelligent Service Robotics, 2013, 6(4):211-224.
[9] Yan X F, Gu F, Song C, et al. Dynamic formation controlfor autonomous underwater vehicles[J]. Journal of CentralSouth University, 2014, 21(1): 113-123.
[10]Zhang Guosheng, Li Caihong, Zhang Yaoyu, et al. Robot local path Planning based on improved Artificial Potential Field Method [J/OL]. Computer Engineering, 1-9[2024-04-22].
[11] Huang Yihu, Yu Yanan. Research on anti-conflict shortest path Planning based on improved Dijkstra Algorithm [J]. Computer and Modernization, 2022, (08): 20-24.
[12] Sun Ning, Wu Weihao, ZhaoFengcai, et al. Research on Intelligent Vehicle Scheduling at no-signal Intersection Based on Enhanced Dijkstra Algorithm [J]. Applied Research of Computers, 2022, 39 (01): 188-193.
[13] Wang Xianquan, et al. Research on the Shortest Path Algorithm of Emergency Command Vehicle Timely Rescue based on improved Dijkstra [J]. Computer Knowledge and Technology, 2021, 17 (14): 1-3+10.
[14]Zhang Wei, Zhang Zezhou, Wang Wei. Research on Improved A * Algorithm for Adaptive Search Distance [J/OL]. Machine Design & Manufacture, 1-5[2024-04-23].
[15] Shi Xun, Yang Genghuang, Chen Qingbin. Research on robot navigation based on improved A* algorithm [J]. Journal of Tianjin Vocational and Technical Normal University, 2024, 34 (01): 44-48.
[16] Xue M, Xu H C, Wang S. Path planning of unmannedvehicle based on particle swarmoptimization algorithm[J].China Science and Technology Information, 2018(24): 69-70.
[17] Sun J, Feng B, Xu W B. Particle swarm optimization withparticles having quantumbehavior[C].Proceedings of the2004 IEEE Congress on Evolutionary Computation, Portland,Jun 19-23, 2004.Piscataway: IEEE, 2004: 325-331.
[18] Biswas S, Anavatti S G, Garratt M A. Particle swarmoptimization based co-operative task assignment and pathplanning for multi-agent system[C]. IEEE SymposiumSeries onComputational Intelligence (SSCI). Honolulu,2017: 1-6.
[19] Zeng Yuji, Chen Bo, Qu Rui, et al. Research on Path planning of Mobile Robot based on improved Ant Colony Algorithm [J]. Modern Manufacturing Engineering, 2023, (10): 57-63+119.
[20] ZhouJingdong, Gao Weizhou, Yang Wenguang, et al. Path planning of mobile robot based on improved ant colony algorithm [J]. Science Technology and Engineering, 2022, 22 (28): 12484-12490.
[21] Nikolos I K, Valavanis K P, Tsourveloudis N C, et al.Evolutionary algorithm based o□ine/online path plannerfor UAV navigation[J]. IEEE Transactions on Systems,Man, and Cybernetics — Part B: Cybernetics, 2003,33(6): 898-912.
[22]Chen Long, ZHENG Xiangpan, TANG Xiaoteng. Research on full coverage path planning of mobile robot based on Genetic algorithm [J]. Journal of Minjiang University, 2023, 44 (05): 18-27.
[23]Sun Bo, Jiang Ping, Zhou Genrong, et al. Application of Improved Genetic Algorithm in Path Planning of Mobile Robot [J]. Computer Engineering and Applications,2019,55(17):162-168.
[24]Wu Meihua. Research on path planning of Mobile Robot based on improved Genetic Algorithm [J]. Electronic Products World, 2023, 30 (08): 34-37.