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Research on mechanical structure and collaboration of AGVs

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Abstract:

With the entry of intelligence and automation into our world, automated guided vehicles (AGVs) have become more and more significant in logistics, warehousing, transportation, and other industries, making transportation more convenient and fast under the system algorithm's command, which can save a lot of labor costs and greatly improve production efficiency. This paper mainly introduces the individual structure of AGV and the research status of the ant colony algorithm among cooperative algorithms. They determine whether AGVs can adapt to complex dynamic environments and complete tasks reliably and safely, which is a major, current concern in the AGV industry. This paper analyzes the individual structure's chassis, sensor technology, and navigation mode and introduces their advantages and disadvantages, application scope, working principle, etc. For the ant colony algorithm, this paper first introduces the traditional ant colony algorithm. Then it divides current improved methods into the improved methods based on the principle of ant colony algorithm and the improved methods integrated with other algorithms and compares with the traditional algorithms to introduce their improved advantages. This article aims to provide readers with a more profound comprehension of how AGVs work and their role in modern industrial automation, explain key technical points for the future, and provide directions for future research.

Keywords: Automated Guided Vehicle; chassis; sensor; navigation mode; Ant colony algorithm.

1. Introduction

An automated guided vehicle (AGV) is a transport vehicle that has optical or electromagnetic automatic guidance equipment that allows it to follow a predetermined guiding course. It has safety protection and various load-shifting functions[1]. With the arrival of the new technological revolution, smart logistics appears in people's vision. It is the use of integrated intelligent technology so that the distribution of goods automation, information, and AGV is a key component of smart logistics. AGV can replace manual

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transfer, loading and unloading, and handling of goods, effectively reduce manual labor intensity, improve work efficiency, and improve the safety of working in some dangerous and complex environments, and is frequently utilized in logistics, machinery, electronics, chemical, and other industries[2]. At present, the construction of factories and warehouses requires digitalization and intelligence. The market competition is becoming more and more fierce, which requires not only low manufacturing costs but also the pursuit of better and better performance of AGVs. Agvs must adapt to different working environments and independently plan moving routes, improving safety, accuracy, and reliability. This paper summarizes the popular mechanical structures and cooperative algorithms of current AGV robots. The aim is to give readers a better understanding of how AGV robots work.

The individual mechanical structure of an AGV is the key to the AGV's ability to perform different tasks efficiently and safely in different working environments, including chassis, sensors, and navigation technologies. The chassis determines the flexibility of AGV movement, and the selection of different chassis for different terrain and space can accelerate the intelligent transportation efficiency of AGV. Sensor technology is important for AGV to measure the external environment and obtain information. The multi-sensor fusion algorithm integrates and analyzes the measured data of sensors to provide data support. The navigation technology is based on sensor technology to realize the accurate positioning and movement of AGV in different scenarios. Common ones include electromagnetic navigation [3], laser navigation [4], inertial navigation [5], and natural navigation (based on SLAM technology) [6]. In some repetitive or high-precision tasks, AGV robots need to adopt different navigation methods, sensors, and chassis styles to adapt to this work and complete tasks stably and accurately.

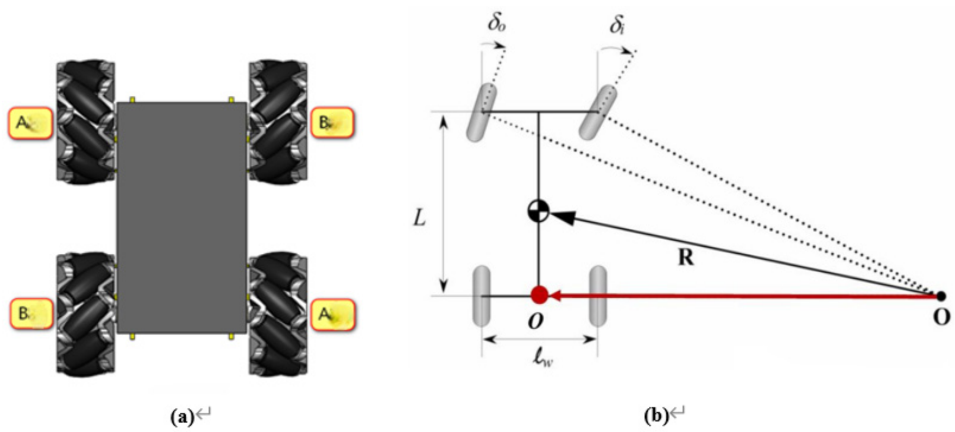
The paths of AGV operations are long and short, and the paths of multi-AGV operations are complicated and the path problem is related to work efficiency and operation cost. Therefore, path routing is the key to the implementation of AGV tasks and the main challenge in its engineering application, which has attracted extensive attention from scholars at home and abroad[7]. The path planning and obstacle avoidance algorithm used in the coordination is also an important technology in the field of AGV. This paper focuses on the ant colony algorithm, an intelligent path planning algorithm, and summarizes some improvements to the traditional ant colony algorithm, including optimizing the parameters of the traditional algorithm and integrating other algorithms such as genetic algorithm. Using better coordination algorithms can avoid collision and wait, complete the transportation of packages and materials independently, and make transportation more convenient and fast under the command of the system algorithm, which can save a lot of labor costs and greatly improve production efficiency.

Finally, the current technical bottlenecks and future research hotspots of AGV are summarized and prospected to further promote the research progress of AGV and provide directions for future research.

2. Mechanical structure

The chapter mainly introduces the working ways of AGV, aiming to let readers understand its working principles deeply. Firstly, the chassis structures used in motion are suggested. The chassis is the foundation of the AGV, carrying its various functional modules and ensuring its stability and flexibility. Secondly, the key sensors used to acquire data in the environment are listed, including IMU, Gyroscope, and so on, which provide accurate position information and motion status by monitoring the AGV's attitude, velocity, and acceleration in real-time. The data is crucial for the balance and navigation of the AGV. Finally, some navigation methods used in the AGV movement are introduced. In modern logistics and industrial applications, the choice of navigation system directly affects the efficiency and safety of the AGV. The chapter will cover several navigation techniques, including electromagnetic and laser navigation.

2.1



Chassis Style

Fig.1 Two chassis styles: (a) the McNamee wheel, (b) the Ackermann wheel

The structure of the McNamee wheel is in Fig.1 (a). The McNamee wheel is an omnidirectional wheel that can move in all directions. On the rim of the hub are diagonally distributed several small wheels, or rollers, which are small, unpowered slave rollers.

The McNamee wheel is a very effective all-around wheel with a small construction and fluid action.

It has the advantages of flexible operation, convenient control, high efficiency, strong carrying capacity, etc. Proper control of the steering and speed of each wheel can realize accurate positioning and track tracking, usually applied in space that needs better flexibility. The structure of the Ackermann wheel is in Fig.1 (b). Ackermann wheel control is a drive method for controlling robots or vehicles that enables good turning radius control and can address the issue of distinct steering angles on the left and right wheels, which arise from their respective steering radii when the vehicle is turning. The Ackermann wheel is freely movable without changing the attitude of the vehicle body, which reduces the complexity of AGV trajectory tracking and path planning, allowing the robot to complete the task well in a narrow working environment.[8]

2.2 Sensors

LIDAR is a radar system that emits a laser beam. The principle of operation is to focus the beam of light on an object, and then the laser light reflected from the target is signalized with the eyes of AGV to detect the position, speed, and other characteristic quantities of a target.

The Inertial Measurement Unit (IMU) contains three single-axis accelerometers, three single-axis gyroscopes, and a three-axis magnetometer. The accelerometers measure angular velocity. In the IMU, Gyroscopes detect angular velocity. Its working principle is based on the principle of Coriolis force. The principle of the magnetometer is based on the law of magnetic induction and emitted laser light. LIDAR is usually adopted to detect the environment around AGV, working as Faraday's law of electromagnetic induction. Then they together solve for the attitude of the object.

The depth camera is also an irreplaceable sensor for AGV. It depends on the parallax principle and uses imaging technology to capture two views of the item under measurement, one from each angle. It obtains the object`s three-dimensional geometric information by calculating the position deviation between the corresponding points of the image.

Using these sensors, AGV uses sensor fusion algorithms, such as Monte Carlo Localization and Extended Kalman Filter, to solve AGV`s image recognition and path planning problems. [9]

At present, the technical bottleneck of sensors focuses on multi-sensor fusion. Since AGVs need to use different sensors in different environments, and the accuracy, data, and format of these sensors are not the same, some better algorithms are needed to adapt to these situations. In addition, the higher the sensor`s accuracy, the stronger the route planning and obstacle avoidance ability, but it is followed by higher use and maintenance costs, which is also an issue with sensor utilization that has to be resolved.

2.3 The ways of guiding

Electromagnetic navigation works by burying a metal wire on the AGV driving route and using low frequency and low voltage current to create a magnetic field around the wire. By detecting and monitoring the intensity of the navigation magnetic field, the AGV's induction coil provides guidance. Advantages include concealed lead, not easy to pollute and damage, simple and reliable guiding principles, manageable control and communication, and low manufacturing cost. The disadvantage is that the path change flexibility is poor, the adjustment process is cum-

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bersome, and the induction coil is more susceptible to the ferromagnetic material around it.

The principle of laser navigation is that The AGV uses a laser beam to identify its current position and direction, then simultaneously collects the reflected laser beam, and realizes the AGV's navigation through continuous triangular geometric operations. In contrast, the laser can be replaced by infrared and ultrasonic. Advantages include accurate positioning, the ability to adjust to challenging working conditions and path conditions, and the ability to quickly change driving paths and modify operating parameters. The disadvantage is that the laser positioning device has a high cost and relatively high environmental requirements (such as external light, ground requirements, visibility requirements, etc.).

Inertial navigation is accomplished by installing a positioning block on the ground in the driving area and a gyroscope on the AGV. To achieve automated guiding, the AGV calculates the tractor's deviation signal (angular rate) and gathers the ground positioning block's signal to establish its position and direction. Advantages include precise positioning, minimal ground handling, and flexible routing. The disadvantage is that the manufacturing cost is high and the gyroscope's manufacturing accuracy and subsequent signal processing have a direct impact on the navigation's accuracy and dependability.

Natural navigation is the navigation mode based on SLAM technology. First, the AGV equipped with environmental sensing sensors starts from a specific location in an unknown environment and self-locates according to the perceptual information obtained by internal and external sensors during its movement. At the same time, a continuous environmental map is gradually established, that is the SLAM process. Then, based on this map, we can realize the precise positioning and path planning of AGV and complete the navigation task. Advantages include no need to install markers or reflectors, reduced plant retrofit costs, and improved plant flexibility and device portability. The disadvantage is that the accuracy of map establishment during SLAM significantly impacts the accuracy of later localization and navigation.

3. AGV Collaboration

This chapter mainly introduces the cooperative algorithm of AGV in the work. Firstly, the traditional ant colony algorithm, which is mainly adopted in collaborative work, is introduced. This algorithm simulates the behavior of ants foraging in nature, realizes path optimization and resource allocation through the accumulation and volatilization of pheromones, and is widely used in AGV scheduling and path routing. Next, we propose two optimization schemes of the ant colony algorithm to further improve its performance. The first scheme is to improve the algorithm's parameters by adjusting the influence weights of pheromones, heuristic information, and other parameters. The second scheme integrates the ant colony algorithm with the genetic algorithm. This hybrid method can take advantage of the advantages of different algorithms to enhance the overall optimization effect. In addition, we will compare the data performance of the improved algorithm with that of the original algorithm in practical applications. The effectiveness of the optimization method is verified by comparative analysis.

3.1 Traditional ant colony algorithm

Ant Colony Algorithm is an algorithm that simulates the phenomenon of ant colonies in nature pursuing the target food according to the odor emitted by the food. In the algorithm, the ants will release pheromones in the process of searching for the target to make it easier for other ants to choose the direction. Meanwhile, the concentration of the pheromone will be volatilized with time, and as they hunt for the goal, the ants will determine the path's orientation based on the pheromone concentration. [10] Therefore, the more ants passed along a path, the higher the pheromone concentration on the path, and the later ants would prefer this path. Problems with path planning, task scheduling, and network design are frequently solved with the ant colony method. The algorithm flow chart is in Fig. 2.

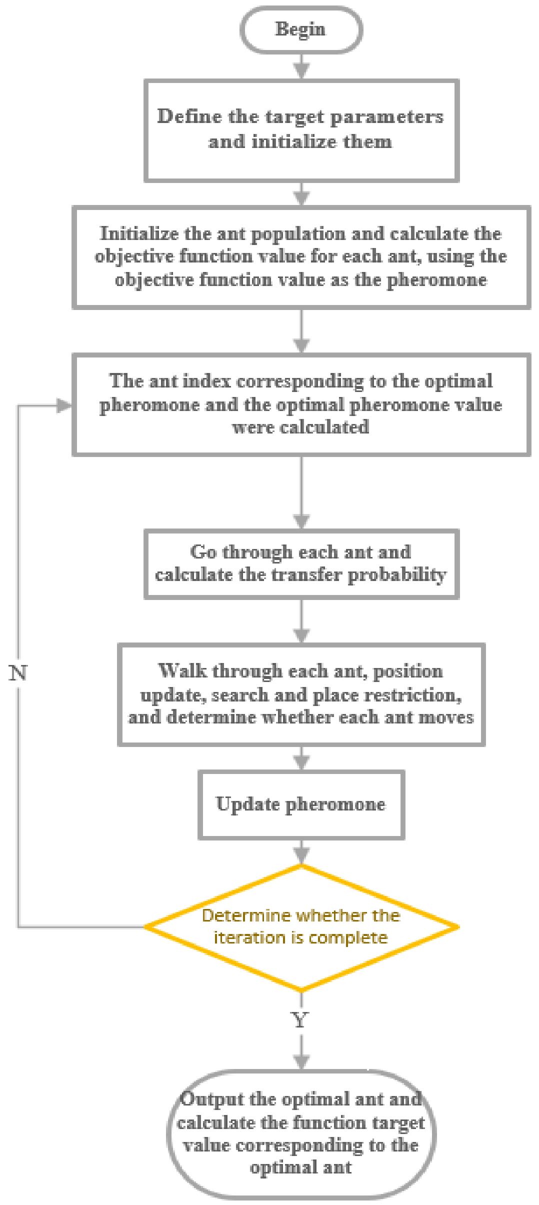

Fig.2 Flow chart of traditional algorithm

The advantages of the ant colony algorithm include the following: the search process of each ant is relatively independent, only through pheromone communication, improving the reliability and global search ability; High robustness; With fewer parameters, the setting is relatively simple. The disadvantage is that the convergence speed is slow. In the ant colony algorithm, the next node is selected at random, and the pheromone's initial value is the same. Random selection takes a long time to play the role of positive feedback, which causes the algorithm to converge slowly at first, even if it can explore a broader problem space and aid in locating the possible global optimal solution.

3.2 Improve the parameters in the ant colony algorithm.

3.2.1 Planting multiple heuristic factors.

The traditional ACO algorithm only has a distance heuristic factor, i.e., it can only optimize the path length. To achieve multiple optimization objectives, this section proposes the multi-heuristic factor idea. This idea mainly includes adding two factors: one is the distance heuristic factor, and the other is the path smoothing heuristic factor. Setting distance heuristic factor is aimed at achieving the goal of optimizing the path length and being defined as $\eta_{ij}(t)$. Path smoothing heuristic factor is defined as μ_{ij}, where μ_{ij} is the path-smoothing heuristic information for the position j, θ_{ij} is the robot corner of the position j.

Substituting the above factors to the original ant colony algorithm, the novel position selection probability of the multi-heuristic ant colony algorithm is obtained:

$$P_{ij}^{k} = \begin{cases} \dfrac{\tau_{ij}^{k}(t)\eta_{ij}^{k}(t)\mu_{ij}^{\gamma}(t)}{\sum_{k\in D}\tau_{ik}^{\alpha}(t)\eta_{ik}^{\beta}(t)\mu_{ij}^{\gamma}(t)}, j \in D \\ 0, j \notin D \end{cases}$$

where γ is the smooth factor.

In terms of this idea's advantages, the essay's author tests this idea. In the 30x30 grid environment, the planning performance of the multi-inspired ant colony algorithm was verified, and the traditional ant colony algorithm and the multi-inspired ant colony algorithm were used for path planning, respectively. The shortest path planned by the traditional algorithm and the new algorithm are compared, and the results are in Fig.3:

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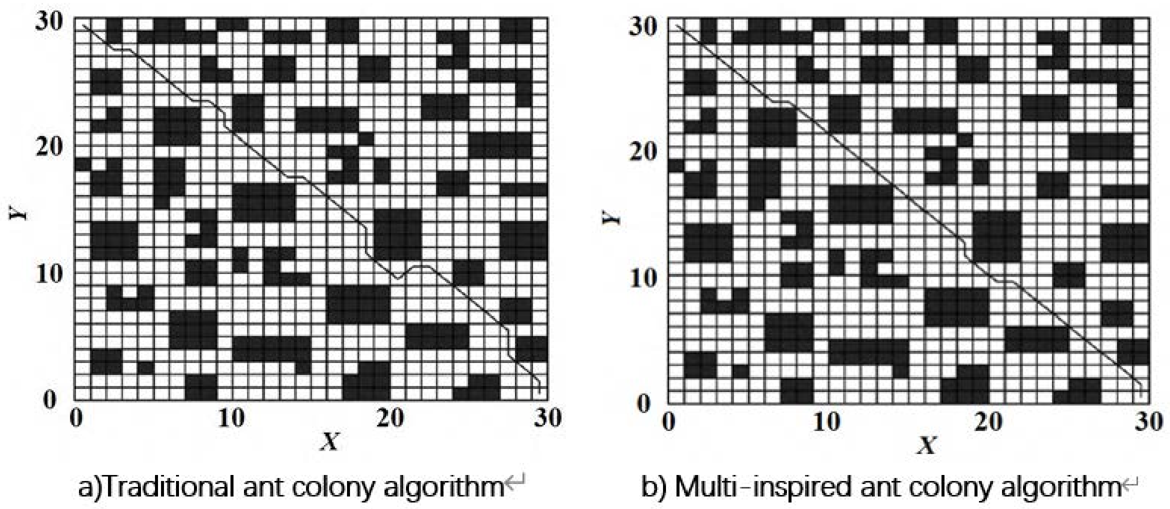


Fig.3 The comparison between tranditional and multi-inspired ant colony algorithms

Table 1 presents the experimental results of the comparison between the first enhanced method and the traditional approach.

Table 1. Experimental Data of Different Algorithms

Types of algorithms	Path length	Scheme 2	The number of iterations
Traditional	45.36	16	71
Improved	42.18	7	34

3.2.2 Optimizing the parameters of the ant colony algorithm.

The heuristic function of the traditional ant colony algorithm is based on the distance between two positions, which greatly affects the search efficiency. It is difficult to find the optimal path among many grids. This section will quote the adaptive heuristic function applied to improve the optimization ability of the algorithm.

In the traditional ant colony algorithm, if one ant finds the shortest path by chance, while most ants are stuck on the suboptimal path, it will soon cause the pheromone increment on the suboptimal path to exceed that on the optimal road, causing the best path to be disregarded. To avoid the above situation, the author introduces a new way of updating pheromone concentrations, the new strategy is as follows:

$$\eta_{ij} = \frac{\varphi_{ij}}{\lambda d_{ij} + \left(1 - \lambda d_{je}\right)}$$

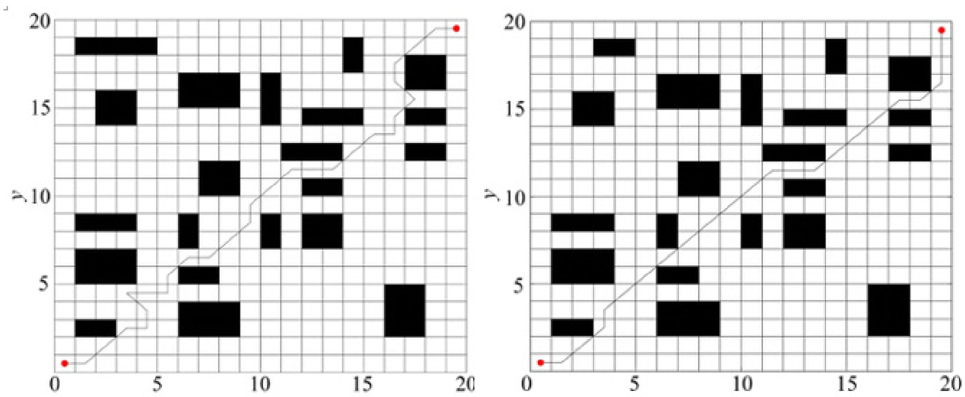
$$\varphi_{ij} = \frac{D_{max} - d_{ij}}{D_{max} - D_{min}}$$

Meanwhile, in the traditional approach, the pheromone volatilization coefficient is a fixed value, which affects the global search capability and convergence speed of the algorithm. The author modifies ρ as follows:

$$\rho = \begin{cases} \rho_{max} - \dfrac{\rho_{max} - \rho_{min}}{N}(i-1), i < N \\ \rho_{min}, i \geqslant N \end{cases}$$

where i is the current iteration number; N is the iteration period demarcation line; ρ_{max} is the starting pheromone volatilization coefficient; ρ_{min} is the minimum pheromone volatilization coefficient. [11]

In the 20x20 grid environment, Fig. 4 compares the shortest paths predicted by the new method versus the conventional algorithm.



a)Traditional ant colony algorithm   b)Improved ant colony algorithm

Fig. 4 The comparision between tranditional and improved ant colony algorithms

Table 2 presents the experimental results of the comparison between the first enhanced method and the traditional approach.

Table 2. Experimental Data of Different Algorithms

Types of algorithms	Path length	Scheme 2	The number of iterations
Traditional	33.80	20	69
Improved	29.79	8	11

3.3 Combine other algorithms with the ant colony algorithm

(1) Combine with genetic algorithm

The Ant Colony algorithm and the Genetic Algorithm are fused using the parallel fusion mechanism, i.e., firstly, the individuals of the population are randomly and equally divided into the improved Adaptive Genetic Algorithm and Ant Colony Algorithm and initialized with the relevant parameters, and then the two algorithms are iterated simultaneously for the search of the best. At the end of each iteration, the 50% of individuals with optimal fitness values among the two algorithms are selected to form a new population for the next iteration of searching for the best. [12] The specific fusion algorithm flow is shown in Fig.5.

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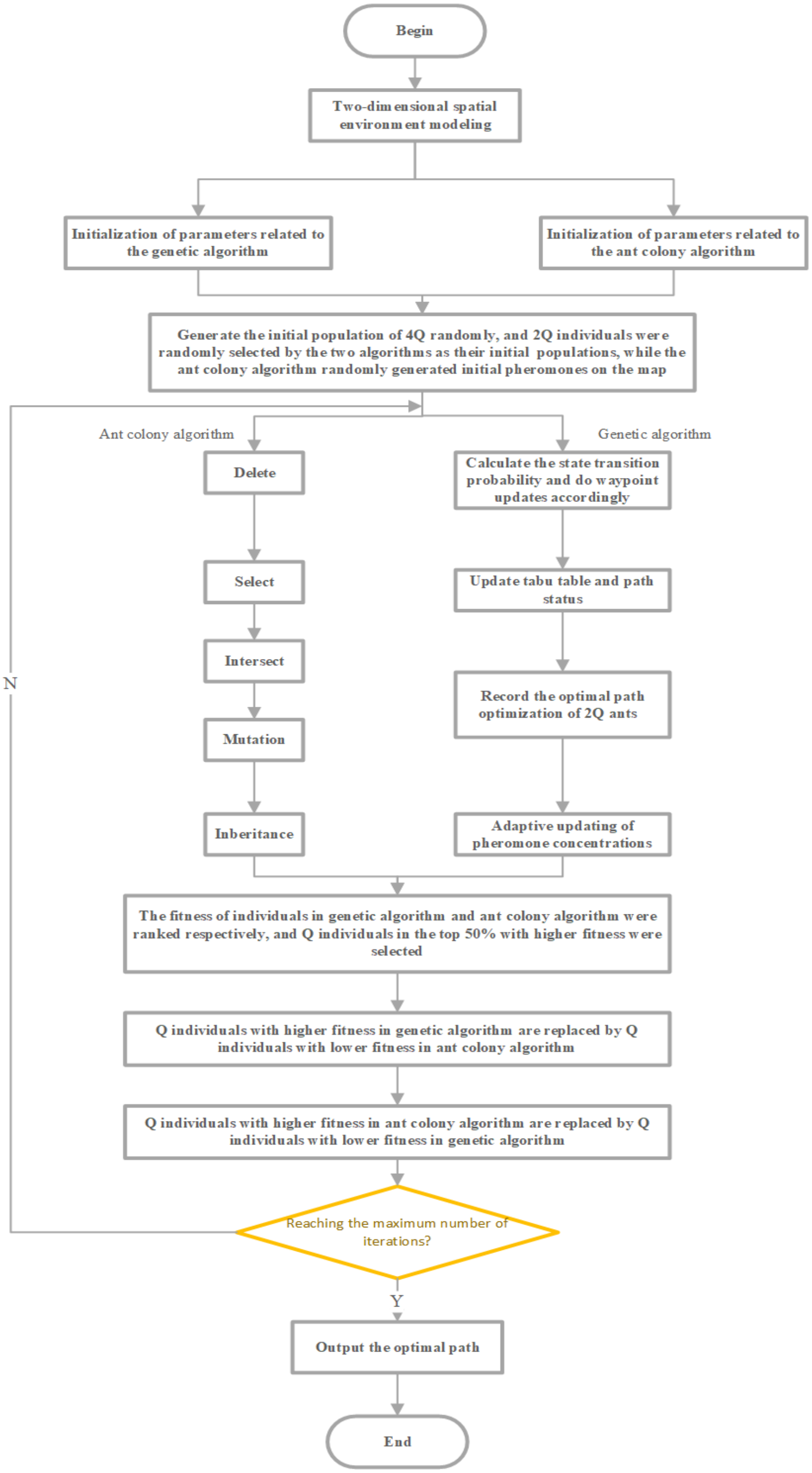

Fig.5 Algorithm combined with genetic algorithm

This combination can not only retain the excellent individuals in the path search process of the two algorithms simultaneously, but also improve the population diversity and local search ability of a single algorithm, and reduce the premature maturity of the algorithm.

(2) Combine with Dynamic window algorithm

Dynamic window algorithm DWA is a local path planning algorithm that fully considers the motion characteristics of AGV. The principle is to predict the robot's motion trajectory in time by sampling and analyzing multiple groups of velocities, and then select the optimal velocity group to drive the robot motion according to the evaluation function. Combining the two algorithms and local path planning for some key nodes can optimize the AGV performance of path length and rotation smoothness. Unlike the traditional ant colony algorithm, this fusion algorithm takes the critical nodes in the path as local sub-targets, uses DWA for speed sampling and trajectory prediction, and finally uses the evaluation function to give the optimal path of local sub-targets, achieving the purpose of optimization [13]. Through this integration, the quality of the planned path is improved, and the coordination and local obstacle avoidance of AGVs are better.

(3) Combine with improved artificial potential field algorithm

In the process of AGV moving, obstacles will be encountered, so it is necessary to introduce an improved artificial potential field method for path planning and obstacle avoidance. The artificial potential field method was proposed by Oussama Khatib in 1985, which describes the opposing potential fields produced by the obstacle at a specific location and the gravitational potential field produced by the target point. The main idea of improving the artificial potential field is to introduce the gravitational and repulsive potential fields existing in the original artificial potential field into the “relative”. This fusion method uses the sensor carried by the AGV to understand the environmental data in front of it and can predict the collision and issue the corresponding obstacle avoidance instructions before moving to the next node. It has good safety, effectiveness, and traceability and enhances the robot's adaptability to environmental uncertainties to better operate in a dynamic environment.[14]

4. Limitations and future outlooks

Since technology is developing so quickly, AGVs play more and more roles in intelligent logistics while some problems need to be tackled such as inefficient and unreasonable routing, high cost, and so on. The interactivity and adaptability of AGVs also need to be enhanced to better adapt to different scenarios and customer needs.

Future research hotspots should focus on the following aspects:

(1) Integration of perception and control. Integrate sensor perception and control strategies to achieve a more comprehensive. Accurate and real-time environment perception and control decisions to achieve higher AGV path planning and obstacle avoidance effects.

(2) Multi-agent cooperation. The multi-agent system can realize the collaboration and cooperation among multiple AGVs to further improve the efficiency and robustness of the system.

(3) Requirements of specific application scenarios. The application scenarios of AGV will gradually expand from the industrial field to logistics, medical, warehousing, aerospace, smart home, and other fields, and different application fields and scenarios will pose new challenges for planning an AGV's route and avoiding obstacles.[2]

It is worth mentioning that the continuous development of artificial intelligence, machine learning, and other technologies will also bring new challenges, such as machine security, privacy protection, ethics, and other issues that require experts, scholars, and decision-makers in related fields to work together to solve.

5. Summary

In the context of intelligent warehousing and logistics, with the advent of new technologies like artificial intelligence and the Internet of Things, AGVs are becoming more and more significant. In the automation field. Therefore, the performance of AGVs needs to be continuously improved to meet the increasing application requirements, including the use of different structures to complete high-precision, high-demand tasks. Improving the ant colony algorithm, an intelligent planning algorithm, such as changing parameters and merging with other algorithms, makes the collaboration between AGVs more efficient. This paper can let readers understand the structure and working principle of AGV, reveal future research hotspots, and inject new vitality into the research of AGV. In the future, with the expansion of the application scale of AGV, the research on the principle and function of AGV will be gradually deepened, and the research methods will be constantly innovated. AGV will not only be applied in warehousing and logistics but also be widely used in other industries.

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