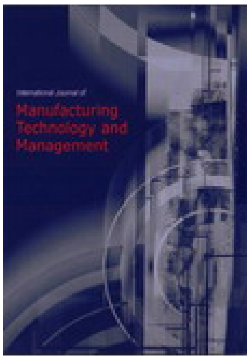

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Path coordination scheduling method of handling robot considering three-dimensional cargo space of intelligent warehouse

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Path coordination scheduling method of handling robot considering three-dimensional cargo space of intelligent warehouse

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Abstract: In order to optimise the path scheduling of the transport robot, shorten the operation time and improve the operation efficiency, a path coordination and scheduling method for the transport robot considering three-dimensional goods are proposed. Firstly, a transport robot path coordination scheduling model considering three-dimensional storage is constructed, and then the improved grey wolf optimisation algorithm is used to solve the path coordination scheduling model, so as to obtain the optimal operation path of the transport robot considering the three-dimensional storage space of the smart warehouse. It is verified by experiments that this method has a good scheduling effect when considering the operation path of the three-dimensional cargo space handling robot in the smart warehouse. When transporting 500 m–2,500 m goods, the time can be shortened by 5–13 min, and the working efficiency of the handling robot can be improved.

Keywords: intelligent warehouse; three-dimensional cargo space; carry; robot; path; coordinated scheduling.

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1 Introduction

Handling robots belong to an industrial robot that can realise autonomous handling operations. These robots are equipped with a variety of actuators at the end and have functions such as items grabbing, accessing, and handling. The emergence of handling robots can replace human beings engaged in heavy manual labour and work fast (Wang and Mao, 2021; Gao et al., 2019). At present, handling robots are often used in warehouse handling work. Since 1980, foreign developed countries have focused on the operation application of handling robots which can reduce labour costs. Handling robots have diversified functions and a high degree of intelligence. They can independently complete many types of handling tasks, but the application cost is also high (Xia et al., 2019).

In the field of warehousing, due to the increasing demand and stricter requirements for the physical flow of physical data, warehousing logistics has become the core issue of the development of various enterprises. Due to the large scale of the warehouse, it is crucial to ensure the efficiency of handling robots when working with them. Therefore, in warehousing operations, it is very important to optimise the path coordination planning of the handling robot. Path planning is to set the most suitable working path for a handling robot in a complex working environment, which is a constrained optimisation problem (Zhang et al., 2020). Good path planning can help effectively avoid collisions between handling robots due to planning errors, shorten the working time of handling robots and improve work efficiency. At present, there are many studies on the path planning of handling robots. Wei et al. (2019) studied a multi-behaviour path scheduling method for robots. This method uses the improved artificial potential field method to track the target point of variable speed, and then switches between various behaviours of the robot in a timely and reasonable manner to ensure its It can avoid obstacles quickly and accurately. For the common U-shaped trap problem in fuzzy obstacle avoidance, a trap escape strategy based on boundary tracking is proposed, so that it can successfully remove the deadlock state. This method has high reliability, but the operating efficiency of the robot needs to be improved after scheduling. Dong et al. (2019) applied the deep reinforcement learning method to the robot path scheduling problem, that is, using the improved DDON network structure to estimate its action value function, estimate the network parameters, and obtain the corresponding Q value through training. The next optimal action of its robot is mainly selected by the combination of Boltzmann distribution and ε-greedy. The feasibility of the method is verified by experiments, but if the method is applied to an environment where multiple robots are running at the same time, the effectiveness of its path scheduling has not been verified.

This paper proposes a path coordination and scheduling method for handling robots that considers the three-dimensional cargo space of the smart warehouse. Firstly, according to the environment in which robots are engaged in handling operations, that is, analyse the smart warehouse, establish a three-dimensional storage grid of the smart warehouse, and then coordinate and schedule according to the path of the handling robot. According to the criterion, a path coordination scheduling model considering three-dimensional cargo space is established, and the improved grey wolf algorithm is used to solve the model to complete the robot path coordination planning. Finally, the value of the method is verified by experiments.

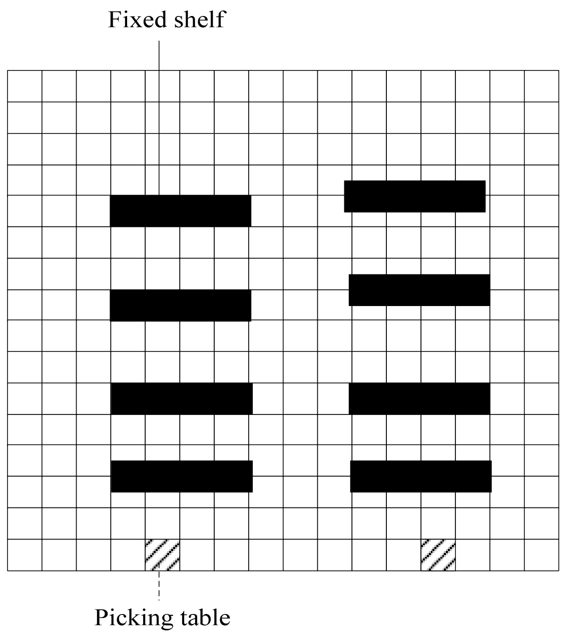
2 Path coordination scheduling method of handling robot considering three-dimensional cargo space of intelligent warehouse

When planning the movement path of the intelligent robot, it is necessary to consider its working environment, that is, first establish the three-dimensional storage grid diagram of the intelligent warehouse, and then use the improved grey wolf algorithm to complete the optimisation of the path planning of the handling robot.

2.1 *The establishment of three-dimensional storage grid map of intelligent warehouse*

The grid map of three-dimensional cargo space in the smart warehouse is shown in Figure 1.

Figure 1 Three-dimensional grid map of intelligent warehouse



To simplify the scheduling difficulty, the following assumptions are made for the handling robot path coordination scheduling problem.

1. In the three-dimensional grid map of intelligent warehouse, the number of handling robots belonging to operation mode in each side is less than the maximum number that can be carried by this side.
2. In the three-dimensional grid map of intelligent warehouse, the speed of each handling robot is uniform during operation. If it meets obstacles, the parking deceleration time is not in the calculation range.
3. In the three-dimensional grid map of intelligent warehouse, if the handling robot works in the same direction, in order to avoid the collision caused by the abnormality of the front handling robot, the setting robot needs to have a fixed distance from the front robot (Xu and Yuan, 2019; Wei et al., 2021; Yu et al., 2020).

Therefore, the assumption of the path coordination and scheduling problem is completed according to the three-dimensional image of the smart warehouse. This paper studies the path planning problem of the handling robot. Because the robot cannot find the optimal route in the process of path planning, it is prone to collision with other robots, or the path is too long. The work efficiency of handling operations is not high, so this research regards engineering problems as mathematical problems, optimises the scheduling model, and completes the optimisation of robot scheduling by finding the optimal solution.

2.2 Path coordination scheduling method of intelligent warehouse handling robot based on improved grey wolf optimisation algorithm

After analysing the working mode of the smart warehouse and the robot, first confirm the path coordination planning criteria of the handling robot, then consider the three-dimensional cargo space to establish the path coordination scheduling model, and finally use the improved grey wolf algorithm to solve the model and complete its scheduling.

2.2.1 Path coordination scheduling criteria for handling robots

1 First-come-first-served

This criterion is one of the basic criteria for the path coordination and scheduling of the handling robot considering the three-dimensional cargo space of the intelligent warehouse. When considering the operation of handling robots in the intelligent warehouse, the task that comes first needs to be placed in the first task in the row.

2 Priority criteria

This criterion is to set priority weight for each handling operation and tasks with large priority weight will be handled first.

3 Minimum operation time

In the case of many batches and few tasks, the handling operations are ranked and priority is given to solving the least time-consuming tasks based on how much time it takes.

4 Joint access guidelines

When considering the three-dimensional cargo space of the intelligent warehouse, the tasks of entering and exiting the warehouse are usually not single. On the premise of meeting relevant requirements, a reasonable combination of handling tasks can be implemented to complete the joint import and export. Which can reduce the operating time and optimise the operational efficiency of the warehouse (Wang et al., 2020a).

5 Priority criteria for outbound tasks

Execute the outbound job first and if there is concurrency in outbound tasks, execute the most urgent task firstly. The inbound job can start only after ensuring that the inbound job does not have a negative impact on the outbound job.

2.2.2 Path coordination scheduling model considering three-dimensional cargo space

After combining multiple inbound and outbound tasks of the intelligent warehouse to the grid map and scheduling criteria mentioned above, the handling robot is used to start the operation (Ma and Mei, 2020).

The mathematical model of joint operation of handling robots is established. If an aisle handling robot acquires a job noted as m_2, which consists of an inbound job noted as m_1 and an outbound job noted as m_2.

The starting and destination points of each handling task are known. When the handling robot starts the joint operation mode, considering the case of a smart warehouse with three-dimensional cargo space, the time consumed by the handling robot to perform a joint task in and out of the warehouse can be expressed as follows:

$$K_C = m_1 K_{OA} + K_{AB} + m_2 K_{BO} + 4K_f + K_a \tag{1}$$

where the time-consuming of the handling robot's warehousing operation, the time-consuming movement of the moving operation, and the time-consuming of the warehousing operation can be expressed as K_{OA}, K_{AB}, K_{BO}. The time it takes for a handling robot to store goods is K_f; the location detection time of the handling robot operation is K_a.

$$K_{OA} = \max\left(\frac{t\left(S_A - 1\right)}{U_z}, \frac{X_{A^Z}}{U_y}\right) K_a \tag{2}$$

$$K_{AB} = \max\left(\frac{t\left|S_A - S_B\right|}{U_z}, \frac{t\left|X_A - X_B\right|}{U_y}\right) K_a \tag{3}$$

$$K_{BO} = \max\left(\frac{t\left(S_B - 1\right)}{U_z}, \frac{tX_B}{U_y}\right) K_a \tag{4}$$

where U_z and U_y are the vertical travel speed and horizontal travel speed of the handling robot respectively. S_A and S_B are the number of layers of the three-dimensional cargo space for the intelligent warehouse. t and z are the height of the three-dimensional cargo space and the length of the cargo space respectively. X_A and X_B are the number of columns of the three-dimensional storage space for the intelligent warehouse.

As mentioned above, under the premise of considering the three-dimensional cargo space of the intelligent warehouse, the path coordination and scheduling model of the handling robot can be written as

$$\min H = \min\left(\sum_{d=1}^{D} K_C K_a + \sum_{r=1}^{R} K_S K_a\right) \tag{5}$$

The task codes and times of joint handling of three-dimensional goods in smart warehouses are d and D respectively. The time consuming for the d^{th} combined transportation is K_C. The number of cycles for a single transfer is R. If m_1 greater than m_2, the time spent on a single handling operation of entering the warehouse can be expressed as K_S. If m_1 less than m_2, the time spent on a single handling operation of exiting the warehouse will be represented as K_S. The value of K_S is equal to zero when m_1 is equal to m_2.

2.2.3 Scheduling model solution based on improved grey wolf optimisation algorithm

In order to obtain the optimal solution, the population reorganisation scheme of the grey wolf algorithm was further improved. The separate flight with *Lévy* was used to update the scheme, and the population reorganisation scheme was improved to optimise the optimisation performance of the grey wolf optimisation algorithm. The operation flow chart of the series algorithm is shown in Figure 2, and the specific operation steps are as follows:

1 The population individual will be initialised firstly and the population is the grey wolf population. The grey wolf population represents the population of path coordination scheduling scheme for handling robots in this paper. The individual represents a grey wolf and the grey wolf individual is a certain solution for the coordinated scheduling of the handling robot path. Which can be determined by $Qeq = \{y_c\}$, where y_c denotes a certain solution for the coordinated scheduling of the handling robot path, *Qeq* denotes the population of handling robot path coordination scheduling scheme population.

2 Initialise all the parameters of the grey wolf optimisation algorithm. The parameters are the coordination coefficient vector, the population's round-up behaviour, the three-dimensional cargo position and the number of iterations.

3 Classify the grey wolf pack into A1, A2, A3 and A4. A1, A2, A3 belong to the leader level.

4 The grey wolf individual updating mode can be improved to update the individual path coordination scheduling of handling robots according to the actual needs of robot handling operations.

5 Mutate the individuals in the grey wolf of A1, A2, and A3 levels to establish a new population all *Qeq*.

6 Update wolf pack levels A1, A2, A3.

7 Analyse whether the number of iterations of the algorithm is the maximum value. If the maximum value is satisfied, the optimal solution of the problem is output. The optimal solution is the path scheme of the head wolf in the wolf pack level A1. This solution is the optimal operation path of the handling robot considering the three-dimensional cargo space of the smart warehouse.

The grey wolf optimisation algorithm can simulate the social level mechanism and predation mode in the natural grey wolf population. The grey wolf population can be decomposed into A1, A2, A3, and A4 levels. A1, A2, and A3 are the best candidate solutions in the population. The remaining individuals will be classified as A4. The core methods of the algorithm are the round-up method and the individual update method.

The hunting behaviour of the grey wolf population can be expressed as,

$$E = \left| F \cdot Y_p(o) - B \cdot Y(o) \right| \tag{6}$$

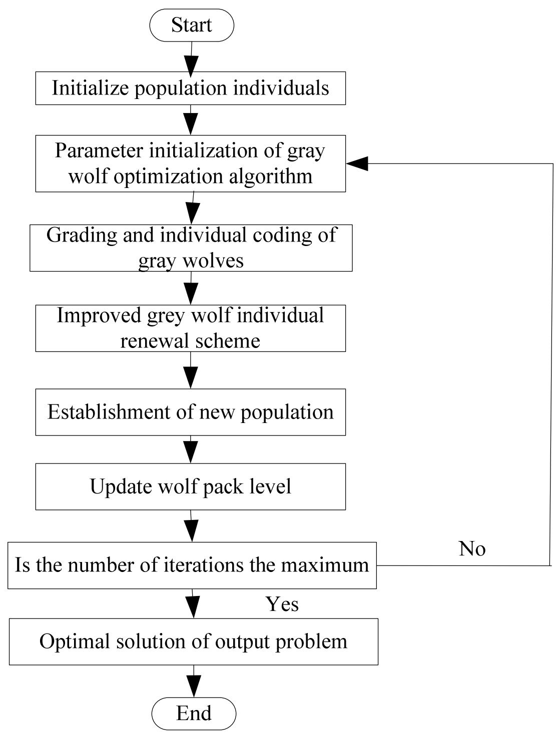
$$Y(o+1) = Y_p(o) - B\left|F \cdot Y_p(o) - B \cdot Y(o)\right| \tag{7}$$

$$B = 2b \cdot \beta_1 - b \tag{8}$$

$$F = 2\beta_2 \tag{9}$$

where o and b are the number of iterations and linearly decreasing parameters respectively, B and F are the coordination coefficient vector. $Y_p(o)$ and $Y(o)$ are the position parameters of the current intelligent warehouse three-dimensional cargo space and handling robot. β_1 and β_2 are random numbers.

Figure 2 Solution flow of scheduling model based on improved grey wolf optimisation



In the A4 level, the path position of the handling robot will be updated with the update of the A1, A2, and A3 positions. Which can be expressed by,

$$E_\alpha = \left|F_1 Y_\alpha - Y\right|; Y_1 = Y_\alpha - B_1 F_\alpha \tag{10}$$

$$E_\beta = \left|F_2 Y_\beta - Y\right|; Y_2 = Y_\beta - B_2 F_\beta \tag{11}$$

$$E_\delta = \left|F_3 Y_\delta - Y\right|; Y_3 = Y_\delta - B_3 F_\delta \tag{12}$$

$$3Y(o+1) = Y_1 + Y_2 + Y_3 \tag{13}$$

where E_α, E_β and E_δ are the update results of the individual positions of A4 level handling robots following the positions of A1, A2, A3. Y_α, Y_β Y_δ are the position parameters of other level handling robots respectively. F_α, F_β and F_δ are the synergy coefficient vectors of A1, A2, and A3 level populations.

The parameter B has a direct impact on the global retrieval and local retrieval performance of the algorithm. If the absolute value of B is greater than one, the global retrieval of the handling robot path coordination scheduling is performed. If the absolute value of B is less than one, the local retrieval of the path coordination scheduling of the handling robot will be performed. The parameter F can manage the distance of the smart warehouse space and the can manage the distance between the intelligent warehouse cargo space and the handling robot (Gao et al., 2021).

Considering the three-dimensional cargo space of the intelligent warehouse, the path coordination and scheduling method of the handling robot needs to take into account the execution sequence of the warehousing operations, the assignment of warehousing operations and the speed of the handling robot. Therefore, the three-stage mixed coding mode is used to realise the coding of the handling robot. In intelligent warehouse management, there is a difference in the number of inbound and outbound operations. Only the number of outbound operations is greater than the number of inbound operations is analysed. Each transfer robot y_c is encoded into a $3E$-dimensional matrix, where E is the total amount of the transfer robot formed. During the encoding process, the code of the handling robot must be corrected by the repair operator, which can be obtained by,

$$f(y_c) = \begin{cases} y_c, & \text{not exceed the number of storage} \\ 0, & \text{else} \end{cases} \tag{14}$$

The position update of the handling robot mainly uses the *Lévy* flight scheme, which can ensure that the grey wolf optimisation algorithm does not fall into local optimum and implements global retrieval. The position update scheme of the individual handling robot is transformed into

$$Y(o+1) = \begin{cases} 0.5Y_1 + 0.5Y_2 + b & |B| > 0.5 \\ (Y_1 + Y_2 + Y_3)/3 & |B| \leq 0.5 \end{cases} \tag{15}$$

This update scheme can use the control amount $|B|$ to manage the position update mode of the handling robot. If the value of $|B|$ is not less than 0.5, the individual position will be updated by the *Lévy* flight scheme. On the contrary, the position update is achieved through the individual position update scheme of the grey wolf optimisation algorithm. Because the path coordination and scheduling of the handling robot itself is a combinatorial optimisation problem, there will be many infeasible solutions to update the individual positions directly through equation (15). Therefore, it is necessary to correct the individual position of the handling robot. The natural number coding mode and the random key coding rule will be used to arrange the coding positions of each handling robot, set it as the transformed coding information of the handling robot.

In order to improve the retrieval efficiency of the grey wolf optimisation algorithm and retrieve outstanding individuals in the feasible region. Based on multiple population reorganisation schemes used in the original algorithm structure (Wan and Peng, 2020; Wang et al., 2020b; Guo and Li, 2019). The population of the original handling robot path coordination scheduling scheme is set as Qeq_{old}, and the population after the handling robot position update is noted as Qeq. A perturbed population noted as Qeq will be added and the number of dominant individuals in the initial population increases in subsequent iterations. Qeq_s is a random selection mode. In the current iteration mode, a single handling robot is selected from the A1, A2, and A3 levels to perform disturbance processing to establish Qeq_s. Transform the pose of the individual encoding vector of the handling robot, the steady-state update of the individual coding of the handling robot is achieved by letting only at most *zes* positions in the entire coding vector change.

Reorganise Qeq_{old}, Qeq and Qeq_s to obtain all Qeq, the incremental objective function of all Qeq is calculated and the individuals with small values will be constructed as Qeq_{new}. The Qeq_{new} is classified again and the first wolf path scheme in the A1 level is the optimal operation path of the handling robot considering the three-dimensional cargo space of the intelligent warehouse.

3 Experiment analysis

A raster map of the intelligent warehouse is constructed by MATLAB and the method of this paper is used to implement the coordinated scheduling of the handling robot paths. As shown in Table 1, three kinds of operations will be set up in the experiment and there are differences in the coordinates of the three-dimensional cargo space of the intelligent warehouse in each job content.

Table 1 Details of operation content setting

Job content	*Start coordinates of handling robot /m*	*Location coordinates /m*
1	(11, 19)	(9, 2)
2	(22, 11)	(17,2)
3	(20, 24)	(25, 2)

The path coordination scheduling of the handling robot after the path diagram is shown in Figure 3.

Under the control of the method in this paper, all three handling robots in the intelligent warehouse can complete their respective handling tasks without any collision. Therefore, the method of this paper proves to be of usable value in scheduling the paths of handling robots considering the three-dimensional cargo space in the intelligent warehouse.

When considering the three-dimensional cargo space in the intelligent warehouse, the distance between the handling robot and the cargo space is 500 m, 1,000 m, 1,500 m, 2,000 m and 2,500 m, respectively. The results are shown in Figure 4 for the time consumed by the handling robot in performing the handling task before and after using the method in this paper.

It can be seen from Figure 4 that when the distance between the handling robot and the cargo space increases gradually, the operation time consumed by the handling robot also increases with the distance, under the premise of considering the three-dimensional cargo space of the intelligent warehouse. After using the scheduling method in this paper, the operation time of intelligent warehouse handling robot is obviously shortened. When transporting 500 m goods, the original time of the robot is 10 min, which is reduced by

5 min after the application of the proposed method. When transporting 2,500 m goods, the original time of the robot is 39 min, which is reduced by 13 min after the application of the proposed method. This further shows that the operation time of intelligent warehouse handling robot still increases with the increase of distance. We can conclude that the method presented in this paper can shorten the operation time of intelligent warehouse handling robot and improve the operation efficiency of intelligent warehouse handling robot.

Figure 3 Path diagram after path coordination and scheduling of handling robot

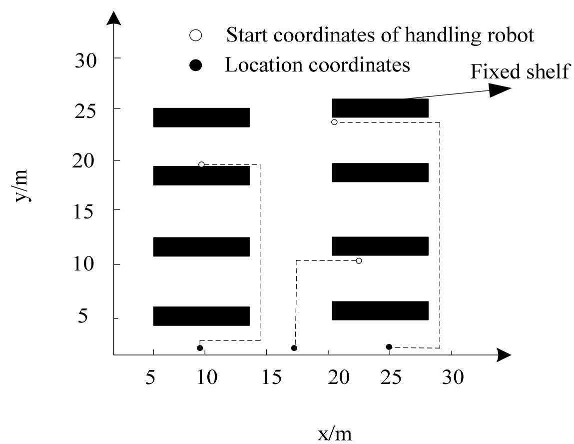
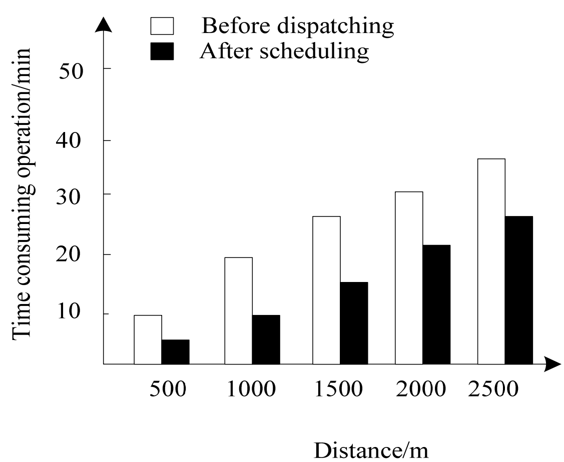
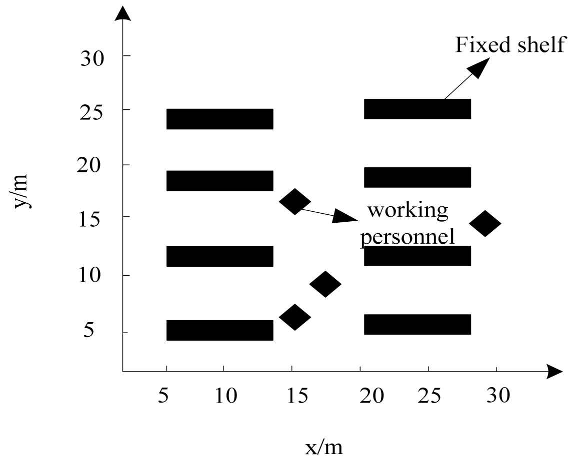


Figure 4 Test results of robot operation time before and after scheduling in this method



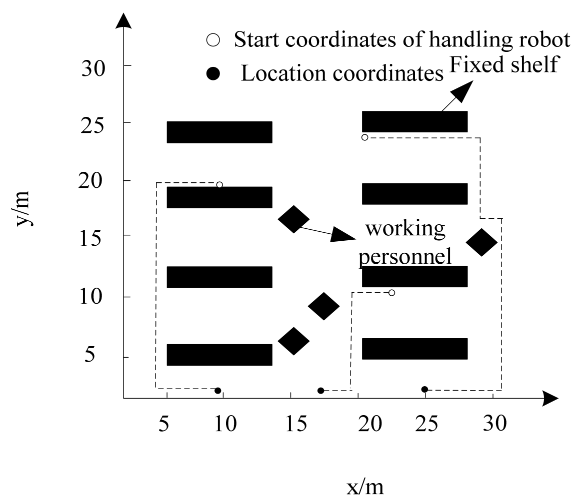
In order to test the anti-interference performance of the method in the paper, several staffs are randomly added in the intelligent warehouse as obstacles to test the coordinated scheduling effect of the method on the path of the handling robot and to judge the obstacle avoidance performance of the handling robot. The distribution of obstacles is shown in Figure 5. The handling path of the handling robot after the scheduling of the method in this paper is shown in Figure 6.

Figure 5 Distribution of intelligent warehouse with obstacles



It can be seen from Figure 6 that after adding several staff members randomly in the intelligent warehouse, the handling robots can complete their respective handling tasks after using this paper's method of scheduling, and no collision has occurred with other handling robots and staff members. This is mainly because the planning method studied in this paper can complete the planning and coordination of the robot path according to the actual situation of the intelligent warehouse. Therefore, it can be seen that the method proposed in this paper has good obstacle avoidance and collision avoidance effect when scheduling the path of the handling robot considering the three-dimensional cargo space of the intelligent warehouse.

Figure 6 Path diagram of multiple handling robots after path coordinated scheduling



4 Conclusions

With the rapid development of industrial production, handling robots are widely used in warehouse cargo handling operations in engineering. Handling robots can not only move goods, but also reduce the workload of manual handling, optimise the efficiency of intelligent warehouse goods handling and reduce the labour cost of enterprises. In this paper, the path planning problem of intelligent warehouse handling robot is studied deeply, a path coordination scheduling method of intelligent warehouse handling robot considering three-dimensional cargo space is proposed, and the intelligent warehouse grid graph is constructed, and the scheduling model is solved by the improved grey wolf algorithm. The application effect of this method is verified by experiments. The work results of this paper are summarised as follows:

1 Regardless of the presence or absence of obstacles in the handling environment, the handling robots controlled by the method in this paper were able to complete their respective handling tasks without any collision with other handling robots or obstacles.

2 After adopting the scheduling method in this paper, the operation time of the handling robot is obviously shortened. When transporting goods 500 m–2,500 m, the robot's operation time is shortened by 5–13 min, but the operation time of the handling robot still increases with the increase of distance. The results show that the proposed method can shorten the working time and improve the working efficiency of the robot.

To sum up, the method presented in this paper can meet the application requirements of path coordination scheduling of handling robots considering three-dimensional cargo space in intelligent warehouse. Experiment was conducted on the computer, but not allowed to test a large number of handling robot operation results, and it's in the study of robot scheduling planning not to consider the goods size and weight on its planning, so this is also the deficiency, will be for the further research in the future, and make use of cloud computing technology for the further optimisation of scheduling.

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