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Study on scheduling and path planning problems of multi-AGVs based on a heuristic algorithm in intelligent manufacturing workshop

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ABSTRACT

In order to solve the scheduling and path planning problems of multi-AGVs in an intelligent manufacturing workshop, it is necessary to consider loading, unloading, and transporting the workpiece of each AGV at the same time. A step task scheduling and path optimization mode of AGV is proposed. The process is as follows: Firstly, a mathematical model algorithm and a material transportation task allocation algorithm based on the urgency degree of workpiece processing were established for the optimization objective, and all workpiece transportation task sequences between shelves and processing equipment were assigned to the corresponding AGV to generate the initial feasible path of each AGV. Then, the AGV collision detection and anti-collision algorithm are designed to plan the global collision-free walking path of multi-AGVs in the workshop, and the path can be dynamically adjusted according to the delivery task. The model is solved by a heuristic algorithm ant colony algorithm and MATLAB coding. Finally, an example is given to verify the effectiveness of the method, which can effectively solve the task allocation of multi-AGVs and avoid collision path planning based on the transportation task sequence, and improve the work efficiency of AGV. This research can provide a theoretical basis and practical reference for realizing multi AGVs collaborative scheduling by using AGV automated material transport system in an intelligent production workshop.

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1. Introduction

With the rapid development of artificial intelligence, the Internet of Things, 5G, and other innovative technologies, the main direction of the future development of China's manufacturing industry is intelligent manufacturing. The digital workshop of intelligent manufacturing is highly integrated with mechanical equipment, sensor equipment, and other hardware, control, data acquisition, and data processing systems. Automated Guided Vehicle (AGV) is applied to intelligent production workshops, and with its high flexibility and stability, it can help the workshop to realize flexible automatic production [1]. Automatic call, information sensing, and production tempo control functions of AGV can improve workshop efficiency. However, How to design An optimization algorithm for AGV workpiece transportation task scheduling in an intelligent manufacturing workshop and plan the route of AGV for workpiece transportation in the workplace, and AGV can accurately and timely execute and complete the production material transport task, it is an urgent problem to be solved in AGV work of intelligent manufacturing workshop.

In the intelligent production workshop based on Manufacturing Execution System (MES), the work of AGV is mainly to load, unload and transport the workpiece, and ensure that the workpiece is delivered to the equipment workbench or the finished workpiece is delivered to the shelf in time, and cooperate with the vehicle equipment to avoid idle mechanical equipment or production delay, and ensure the working efficiency of the equipment. The task scheduling of AGV is aimed at minimizing the total AGV workpiece transportation time, determining the task execution sequence and travel path, and preventing conflicts and collisions in the process of multiple AGVs.

There has been much research on AGV scheduling and path planning. Ma *et al*. [2] applied a tabu search algorithm to solve the vehicle slash-and-drop transportation problem and carried out path planning. Yin *et al*. [3] applied a tabu search algorithm to solve the path planning problem and solved the problem of excessive energy consumption in the process of vehicle movement. Wang *et al*. [4] proposed an improved A* algorithm, which solved the problems of redundant points and unsmooth in path planning. Sun *et al*. [5] proposed a neural network algorithm based on directional constraints, which improved the speed of path planning. Li *et al*. [6] applied BP neural network to study the path planning and obstacle avoidance problems of robots. Corpuz *et al*. [7] proposed an improved neural network to solve the problem of slow convergence speed in intelligent vehicle path planning. Sunet *et al.* [8] solved the problem of complex traps in path navigation based on an adaptive fuzzy neural network. S. Hitam *et al*. [9] applied an improved genetic algorithm to improve the quality of path planning solutions. Li *et al*. [10] integrated AGV environmental safety information into a grid map and applied a genetic algorithm to solve the path planning problem. Mousavi *et al*. [11] applied genetic algorithm and particle swarm optimization algorithm to the AGV task scheduling model. Deepak *et al*. [12] combined decision theory with stochastic time path planning to schedule and control the optimal path under dynamic and uncertain conditions. Yue *et al*. [13] proposed a hybrid PSO-GA algorithm to complete the scheduling and planning problem of AGV. Rugalska [14] proposed a new control strategy for cooperative AGVs, in which two AGVs cooperate to achieve specific task objectives. Antakly[15] *et al.* proposed a task scheduling method based on temporal logic, adding appropriate delay to AGV to avoid collisions between multiple vehicles. Yan *et al.* [16] proposed an algorithm based on co-evolution to conduct scheduling research on AGV. Shi *et al.* [17] proposed a multi-objective scheduling model based on total driving distance and waiting time, and used the A* path planning algorithm to search the shortest path of AGV. Zou *et al.* [18] proposed a multi-objective mixed-integer linear programming model to solve a new automatic guided vehicle scheduling problem with pickup and delivery from the goods handling process in a matrix manufacturing workshop with multi-variety and small-batch production. Yin *et al.* [19] proposed a decentralized framework of multi-task allocation with attention (MTAA) in deep reinforcement learning.

To sum up, most of the literature on AGV path planning focuses on planning AGV anti-collision strategies in static environments with known obstacles, which does not apply to intelligent production workshops where multiple AGVs work together. The scheduling algorithm in the existing literature does not apply to intelligent workshops. AGV is necessary equipment for an intelligent workshop to realize intelligent production, but there is little research literature on AGV path planning and collision prevention in an intelligent workshop. Therefore, the problems of workpiece transportation task allocation, task sequencing, path planning, and collision prevention in the multi-AGV system are studied in the intelligent workshop.

The paper is organized as follows. The AGV scheduling and path optimization framework is constructed in Section 2. AGV Initial feasible path and AGV collision detection and anti-collision algorithm are described in this section. The case analysis and discussion are reported in Section 3. Finally, in Section 4, the conclusions are reported.

2. AGV scheduling and path optimization framework

In the actual production process of the workshop, multiple stations are requiring multiple AGVs to transport the workpiece to each station at the same time. It is necessary to allocate the AGV delivery sequence and optimize the AGV delivery path to make the AGV perform the task of the total transport path shorter, at the same time, to complete the delivery of workpieces for all stations or shelves. Because of AGV path planning and task allocation problems, combined with the manufacturing production line process, a step optimization algorithm model is proposed, as shown in Fig. 1.

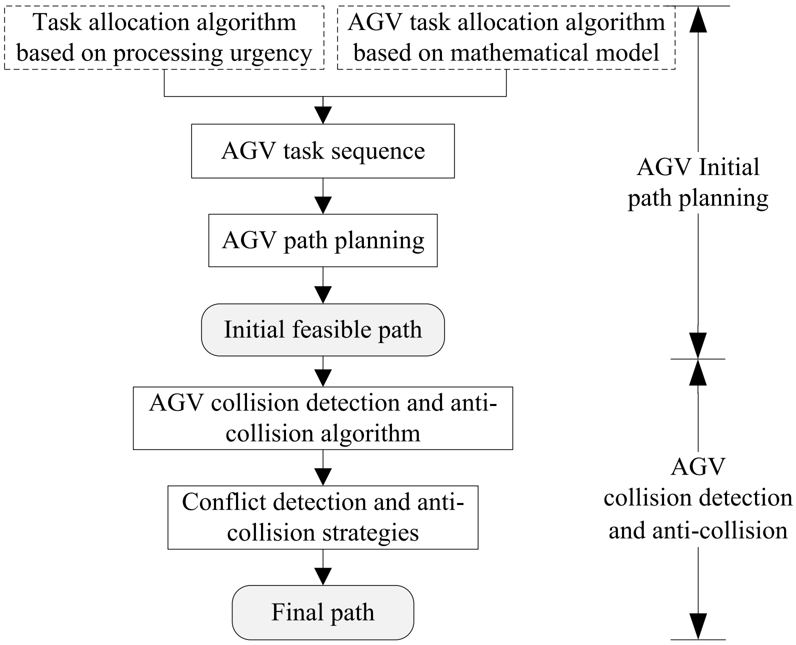

Fig. 1 AGV scheduling and path step optimization mode

First, using the mathematical model of the algorithm based on minimizing the total delivery time, or the materials transportation task allocation algorithm based on the emergency degree of workpiece processing, all workpiece transport tasks within the planned time between the shelves and the processing equipment shall be assigned to the AGV currently in the idle state according to rules. The current AGV task sequence is dynamically updated, and the initial feasible task transport path for each AGV is generated. Then, the algorithm of AGV collision detection and anti-collision is designed, and the global collision-free walking path of multiple AGVs in the intelligent workshop is planned, and the path can be dynamically adjusted.

2.1 AGV initial feasible path

2.1.1 Generation of AGV transportation task sequence

Two algorithms can be used to generate AGV transportation task sequences.

(1) AGV task allocation algorithm based on time minimization mathematical model

According to the production plan, the workpiece delivery task is assigned to the appropriate AGV, and the task execution sequence is determined. The mathematical model is established with the goal of the shortest time for the AGV to complete all delivery tasks. The relevant settings and assumptions are as follows:

- All AGVs are the same, and the transport speed is the same and uniform.
- Keep a safe distance during driving, and the waiting time is short and ignored.
- Ignore equipment start time.

- Each AGV can perform one transportation task at a time. Similarly, only one AGV can perform a transportation task.
- No more than two AGVs in each direction on the driving channel to avoid congestion and conflict, and re-plan the route when the capacity exceeds.
- AGV runs along the grid, one grid per second, and the statistical distance is calculated according to the broken line distance travelled
- When the AGV works, it is powered on continuously and will not fail.
- AGV returns to berth after delivery.

The notations used for modelling are described below.

P represents the transportation set of the workpiece to the equipment for processing and is $\{1,2,\ldots,n\}$.

D represents the task set of transporting the finished workpiece back to the shelf and is $\{n+1, n+2, \ldots, 2n\}$.

N is the set of transporting workpiece, $N = P \cup D$.

K is the set of AGVs, represented as $\{1,2,\ldots,m\}$, 0 indicates the docking position.

A is the set of workshop location points, $A = N \cup 0$.

B_i^k and E_i^k are the start time and finish time of AGV k, $i \in N, k \in K$.

(X_i, Y_i) represents the position coordinates. The AGV travels one grid per second, so $X_i + Y_i$ can represent the travel time.

X_{ij}^k is the 0-1 variable. When the value is 1, AGV k performs the transport task i and then the task j, a value of 0 indicates other cases, $i \in N, j \in N, k \in K$.

t_i is the minimum travel time for task i.

T_{ij}^k represents the minimum travel time from the completion position of task i to the start position of task j.

Pt_i represents the workpiece processing time.

e_i represents the planned processing time or planned completion time of the workpiece in the production plan.

The mathematical model is constructed to determine the delivery task and execution sequence of AGV.

$$min\, Z = \max_{k \in K, j \in A} E_i^k + (X_i + Y_i) \tag{1}$$

$$\sum_{j \in N} X_{0j}^k = 1, \sum_{i \in N} X_{i0}^k = 1 \qquad \forall k \in K \tag{2}$$

$$\sum_{k \in K} \sum_{j \in A, j \neq i} X_{ij}^k = 1 \qquad \forall i \in N \tag{3}$$

$$\sum_{k \in K} \sum_{i \in A, i \neq j} X_{ij}^k = 1 \qquad \forall j \in N \tag{4}$$

$$E_i^k \geq Z_i^k (B_i^k + t_i) \qquad \forall i \in A, k \in K \tag{5}$$

$$E_i^k \geq e_i \qquad \forall i \in P, k \in K \tag{6}$$

$$B_{n+i}^k \geq E_i^k + Pt_i \qquad i \in P, \forall k \in K \tag{7}$$

$$B_{n+i}^k \geq e_i \qquad \forall i \in D, k \in K \tag{8}$$

$$B_j^k \geq X_{ij}^k (E_i^k + T_{ij}^k) \qquad \forall i,j \in N, k \in K \tag{9}$$

$$X_{ij}^k, Z_{ij}^k \in \{0,1\} \qquad i,j \in A, \forall k \in K \tag{10}$$

$$B_i^k, E_i^k \geq 0 \qquad \forall k \in K, i \in A \tag{11}$$

Eq. 1 is the objective function. The objective is to minimize the maximum AGV transportation time. Others are constraint conditions.

Eq. 2 indicates that AGV starts from the docking position and returns to the docking position after the workpiece arrives. Eqs. 3 and 4 ensure that all delivery tasks are performed. Eqs. 5 and 6 ensure that the execution time of the task is logical, that is, the completion time of task i transporting the workpiece to the machine tool by AGV is later than the sum of the start time and execution time of the task, and cannot be earlier than the planned processing time of the workpiece. In Eqs. 7 and 8, the start time of task i of transporting the finished workpiece to the shelf shall not be earlier than the sum of the processing time and completion time of the task transporting the workpiece to the machine tool, nor shall it be earlier than the planned completion time of the workpiece. Eq. 9 indicates that AGV executes tasks in sequence, and drives to task j by raster after completing task i, so the start time of task j cannot be earlier than the time when AGV arrives at the start point of task j. Eqs. 10 and 11 represent variable types, which are 0-1 variables and integer variables respectively.

(2) AGV transportation task assignment based on processing priority

Aiming at the fastest completion of the workpiece according to the production plan, an AGV task allocation algorithm based on the degree of workpiece processing urgency is proposed. Fig. 2 is the algorithm flow. Based on the workpiece processing plan time and completion time set by the intelligent workshop manufacturing execution system, all delivery tasks are sorted according to the urgency of processing to form the whole task sequence. According to the AGV's idle-as-allotment rule, the workpiece delivery task is assigned to the AGV that has completed the preorder task and is waiting for task assignment, and the task sequence of the AGV is updated. Repeat the above process until all workpiece delivery tasks are assigned to the corresponding AGV, and the task assignment is stopped. Finally, the workpiece delivery task sequence of each AGV is formed.

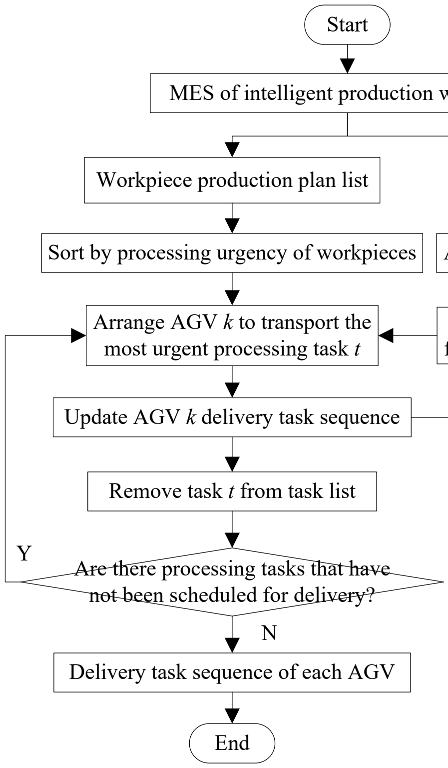

Fig. 2 AGV transportation task assignment based on processing priority

2.1.2 Generation of AGV initial feasible path

In order to facilitate path planning and path expression, the intelligent workshop is rasterized, and each functional area is expressed by grids and coded according to the grid position, as shown in Figure 3. Each grid represents a location node, which can be a device or a driving channel for an AGV or a shelf. The grid in front of the equipment and shelves is the AGV operating station, where the AGV completes the feeding and retaking actions. When the AGV is idle, it stops at the docking position. When the task instruction is received, the AGV will transport the workpiece from the current position to the specified grid position according to the task sequence number, and then carry out the operation of material taking or feeding. The AGV will transport the workpiece in the feasible area of the workshop (grid nodes 1-12 in Fig. 3), and complete the loading, unloading, and transportation of the specified workpiece according to the task sequence. In order to ensure the workshop production process stability, AGV drives in the workspace according to the instructions and follows the principle of driving in the workshop grid channel after the first lateral longitudinal to determine the initial path of AGV to perform each task. According to this path, AGV can reduce the collision probability when driving in the workshop grid channel, and efficiently complete the task of workpiece delivery. Transport such as the current task is to carry a workpiece on shelf 2 to equipment 1 for processing, the initial delivery path of AGV is the grid node 7→8→9→4→3. The AGV picks up the workpiece with the specified number on shelf 2 at the starting node 7, then drives to the end node 3 of the grid according to this path, and puts the workpiece in the designated position in front of the machine of equipment 1. According to the assigned task sequence, each AGV forms the initial transport path of all transport tasks, which is expressed by the grid node number in the sequence.

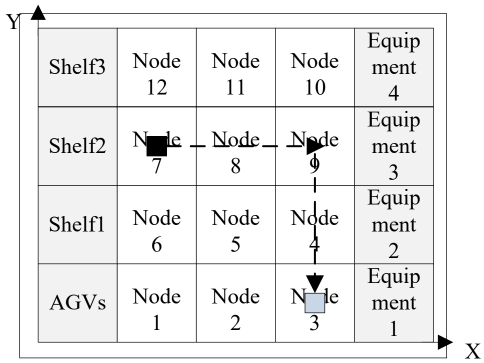

Fig. 3 Floor plan of raster intelligent production workshop

2.2 AGV collision detection and anti-collision algorithm

The purpose of collision detection is to update the initial AGV transport path in real-time so that there are no two AGVs in the same grid position in the workshop AGV driving area. The current grid position and driving time of AGV in the workshop are represented in the form of <position, time>, the variables position and time are non-negative integers. The algorithm of AGV collision detection and anti-collision is shown in Fig. 4.

The heuristic algorithm ant colony algorithm is a probabilistic algorithm used to find the optimal path. It was proposed by Marco Dorigo in his doctoral dissertation in 1992, and its inspiration comes from the behavior of ants in finding a path in the process of searching for food. This algorithm has the characteristics of distributed computing, positive information feedback and heuristic search, and is essentially a heuristic global optimization algorithm in evolutionary algorithms.

The basic idea of applying the ant colony algorithm to solving optimization problems is to use the ant's walking path to represent the feasible solution of the problem to be optimized, and all paths of the entire ant colony constitute the solution space of the problem to be optimized. Ants with short paths release more pheromones. As time goes on, the concentration of pheromones accumulated on the short paths increases gradually, and the number of ants choosing this path also increases. Finally, the whole ant will focus on the best path under the action of positive feedback, and the corresponding is the optimal solution of the problem to be optimized.

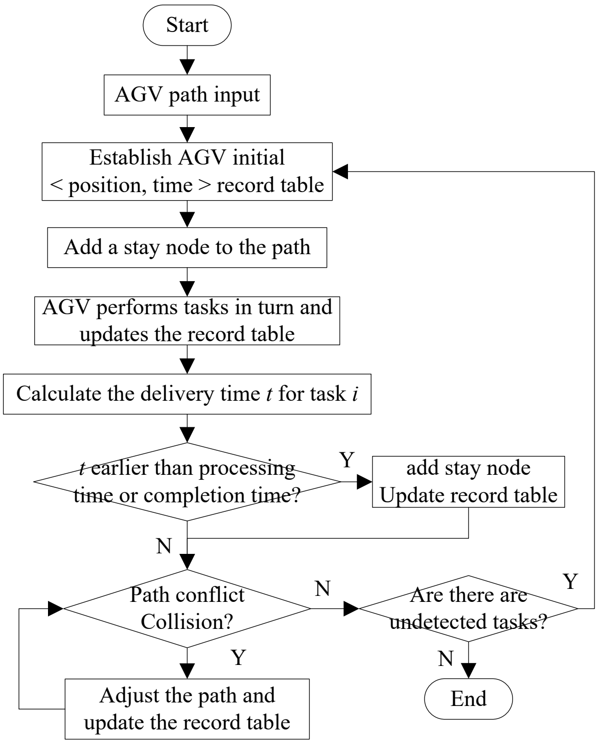

Fig. 4 AGV collision detection and anti-collision algorithm

3. Example verification

The above grid intelligent workshop is still used as the workplace of two AGVs. The model is solved by a heuristic algorithm ant colony algorithm and MATLAB coding. In order to compare the effects of the two task allocation methods in section 2.1, the calculation results are solved and compared respectively, as shown in Table 1. The notation n is the total number of workpiece transportation tasks in the workshop, $p1$ and $p2$ represent the two stages of AGV initial path planning and anti-collision, $t1$ and $t1$ represent the task completion time of each stage, and $d1$ and $d1$ are the corresponding time difference rate. In the AGV initial path generation stage, the total completion time of the AGV initial path calculated by the two task allocation methods is slightly different, and the maximum difference rate is 1.06%. After AGV anti-collision adjustment, the total time calculated by the two scheduling methods is the same.

The operation of multiple AGVs in the intelligent workshop is limited by constraints such as conflict and collision. The completion time of the workpiece transportation task should consider the completion time of the delivery task after constraint detection and path adjustment. In this example, the two scheduling methods have the same results after AGV task scheduling allocation and path step-by-step optimization, which can effectively solve the problem of task scheduling and path planning of multiple AGVs in the workshop, and has good practicability.

To sum up, since multiple AGVs must consider the impact of collision when driving in the same workshop, the actual completion time of the system depends on the delivery time after collision adjustment, that is, the final result of the second stage. For the small-scale example in this paper, the final results of the two methods are consistent, so the two-stage algorithm (time priority) proposed in this paper can effectively solve small-scale problems.

Table 1 Comparison of calculation results

n	Minimum time mathematical model			Processing urgency			Difference rate %	
	$p1$	$p2$	$t1$	$p1$	$p2$	$p2$	$d1$	$d2$
9	43	52	16.68	43	52	6.84	0	0
12	94	96	123.57	95	96	9.44	1.06	0
15	127	127	34.2	127	127	9.51	0	0
18	153	155	216.34	154	155	10.51	0.65	0

4. Conclusion

Aiming at the problems of AGV transportation task scheduling and path planning in the intelligent workshop, according to the corresponding mathematical model established to minimize the maximum delivery task completion time and the workpiece processing urgency, the workpiece delivery task sequence of each AGV is determined and the initial delivery path of AGV is generated. Considering conflict prevention and collision avoidance when multiple AGVs are running, conflict detection and anti-collision strategies are proposed. Finally, an example is given to verify the feasibility and effectiveness of multi AGV task allocation and path planning based on transportation task sequence to avoid conflict and collision.

The experiments prove that the multiple collision avoidance strategies proposed in this paper can efficiently complete the delivery tasks according to the production plan while obtaining the collision free path of AGV. In conclusion, this paper schedules the tasks of AGV according to the manufacturing process flow, and plans the path, and avoids collisions of AGV. Finally, the real-time scheduling scheme of the automated material transportation system is obtained, which can provide a reference for intelligent production workshops. In addition, the algorithm proposed in this paper can be extended to other practical application scenarios such as automated terminals and intelligent warehouses using AGV, and has strong practical value. In future research, the non-uniform motion of AGV will be considered.

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