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Research of AGV Scheduling and Path Planning of Automatic Transport System

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Abstract

This paper focuses on AGV scheduling and path planning of automatic transport system. Using the topological modeling method to build an electronic map; based on A (A-Star) algorithm and complex scheduling strategies to solve single AGV path planning, this paper presents a one-way graph path based planning algorithm which solves the problem of multi-AGV path planning, avoids system conflicts and enhances system stability. And the algorithm is verified by the AGV automatic transport management system, which is based on VC++6.0 and SQL Server.*

Keywords: *AGV, task scheduling, path planning*

1. Introduction

With the development of enterprise information integration, the AGV automatic transport system is widely used as the important means of logistics information and automation technology. It enables enterprises to reduce labor costs and improve efficiency greatly [1]. As the main algorithm in the system, AGV automatic transport management system plays a key role in the AGV system. It provides a theoretical basis for the design and implementation of management systems to study multi-AGV scheduling and path planning algorithm [2].

2. Electronic Map Modeling

The main methods of electronic map modeling include grid modeling method, geometric modeling method and topological modeling method [3]. Under the situation that location information is related to each other in the environment, topology modeling method is particularly applicable due to its compact structure.

The model established by topology modeling method is as follows. In a directed connection network, V represents the set of nodes while E represents the set of edges in the graph. Each side can be expressed as ordered elements on both nodes. Each edge has a weight, which is usually a positive number (distance, costs, walking time or walking cost information). Focus on the guidance of one-way path, the electronic map is drawn by using topological modeling method in the AGV PC management system, as shown in Figure 1.

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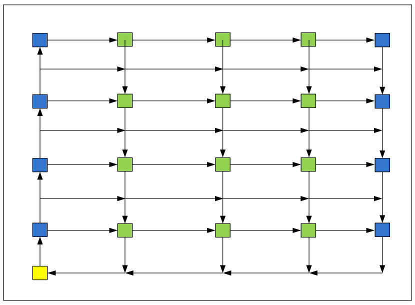

Figure 1. The Electronic Map

Electronic map includes the following data features.

(1) Spatial characteristics

Electronic map reflects the actual layout of the elements of the spatial position information in the AGV automatic transport system.

(2) Quantitative characteristics

The number and status information of work stations, storage facilities, charging equipment can be seen in the electronic map.

(3) Related characteristics

The connecting information of different devices and sites can be fully described and displayed in real time in the map.

3. Single AGV Path Planning Algorithm

In accordance with certain performance indicators, path planning looks for an optimal or optimum path from the initial position to the target position in the environment. In the AGV transport system, path planning is top-down planning [4], including two aspects:

(1) Access to environmental information, containing path information, job site information, charging station information, call site information, job information and other information;
(2) Solve the optimal path on the basis of environmental information based on known performance indicators.

In a single AGV system, there is no interference and line failure caused by clogging from other vehicles because of the simple environment. The starting and end points of the vehicle are determined by the transportation instruction and the route planning system just needs to select the shortest path [5]. Dijkstra algorithm, A * algorithm, artificial potential field method and its improved algorithms, genetic algorithm and neural network algorithm can be used to solve the shortest path problems.

This paper uses the A* algorithm to search a single AGV shortest path solution. A * algorithm is a heuristic algorithm. In the A * algorithm, it is not necessarily to search all of the feasible solutions. It will increase search efficiency but it cannot guarantee the optimal solution. In fact, the difference between A * algorithm and the traditional search algorithm is the qualifications, which means we can set the threshold and choose whether to give up some of the nodes [6]. A *(A-Star) algorithm is as shown in Equation (1).

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

Where *f(n)* is the estimation distance from starting point S to the destination F by node n; *g(n)* is the actual distance between starting point S and node n; *h(n)* is evaluation function from node n to the destination F.

In the process of the A* algorithm, the reasonable function *h(n)* needs to be chose to ensure to find the shortest path (optimal solution). If the selected value of *h(n)* is less than the actual distance from node n to the destination F, it will need to search more nodes and larger range and increase the amount of computation. But in this way you can get the global optimal solution.

If the selected value of *h(n)* is more than the actual distance from node n to the destination F, it will accelerate the speed of solving because some part of nodes will be given up based on *f(n)*. The disadvantage is that the optimal solution may be contained in discarded nodes so you can only ensure that the final solution is a better one.

So the value of the valuation function should be close to the actual value to solve the shortest path. In a directed connection diagram, the value of *h(n)* is based on the Euclidean distance (Linear distance) between two nodes, as in shown in Equation (2).

$$f(n) = g(n) + \sqrt{(x_d - x_n)^2 + (y_d - y_n)^2} \tag{2}$$

For any node n, the valve of *g(n)* is definite and the value of *f(n)* depends on the valuation function *h(n)*. It will make sure to search along the target direction since the value of *h(n)* is equivalent to linear distance between node n and the target node F.

Considering the characteristic of AGV system and the utilization rate of the path, it will increase its weight if the utilization rate of the path is low in the application process of the algorithm. On the one hand, it increases overall utilization, on the other hand it reduces conflict between the AGVs.

4. AGV Scheduling Index

At present, there are two main types of scheduling indexes: single scheduling index and complex scheduling index. Single scheduling index is scheduling tasks according to a unique index or standard, which is typically moving distance (distance-based), queue length (workload-based), wait time (time-based) or other parameters. Taking the multiple indexes or standards into account, complex scheduling index will set the weights of different indexes depending on their priorities. Such as, the tasks' transport distance and vehicle priority or the degree of priority sites and the buffer time of the materials.

In this paper, the index is based on complex scheduling index and also taking the utilization of the vehicle and the distance of vehicle traveling into account [7], as in shown in Equation (3).

$$\mathrm{Z} = \min\left\{\mathrm{k_p} \bullet \left(\mathrm{d_{iu}} \bullet \omega_1 + \mathrm{d_{il}} \bullet \omega_2\right) + \mathrm{k_q} \bullet \mathrm{u_i}\right\} \tag{3}$$

Where d_{iu} is the empty running distance of the i-th AGV; d_{il} is the load running distance of the i-th AGV; ω_1 denotes empty running coefficient; ω_2 is the load running coefficient; k_p indicates he distance coefficient; k_q is the utilization efficiency coefficient; u_i is the utilization of AGV.

5. AGV Path Planning Based On Directed Graph

Multi-AGV automatic transport systems are mostly guided by one-way path [8]. In this paper, AGV path planning is based on directed graph according to guidance.

5.1. Preconditions

Algorithmic will solve the shortest path in the directed graph *G=(V, E)*, which means that for a given starting V and ending F, the shortest path is asked to find from V to F (represented by set of nodes on the path).

Unlike bidirectional guidance path, one-way path must form a loop to ensure the normal movement of AGV. According to Figure 1, electronic map has to make changes to meet the characteristics of a one-way guidance path, as is shown in Figure 2.

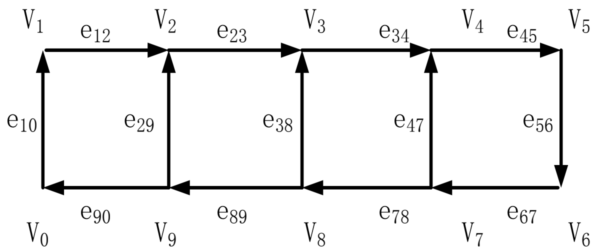

Figure 2. Improved Path Connection Diagram

Based on the above premise, the preconditions of AGV path planning algorithm according to a directed graph are as follows.

(1) Any side is only one-way traffic and the moving direction of each side has been given at the beginning of the system. Each side also allows multiple vehicles to pass.
(2) AGV advances at the same speed and the specific speed is determined by the actual situation. The speed is temporarily assumed at 48m/min or 0.8m/s.
(3) Each AGV can only execute one task at the same time. Namely after receiving instruction from vehicle scheduling system, vehicle must complete the instruction before it can accept the next transport task and it cannot return or uninstall halfway.
(4) Any path (path between two adjacent nodes) can accommodate the vehicle and the two paths cannot occupied by one AGV at the same time.
(5) The minimum safe distance between vehicles is determined by the length and speed of AGV to prevent accidental collisions between AGVs.

It can be seen that the pre-conditions of algorithm and multi-AGV path planning algorithm based on time window are similar and the main difference lies in whether the edge is one-way traffic.

After the transport task initialization, task scheduling system would give the vehicle a secondary dispatch based on special circumstances. The major reasons for the secondary task scheduling are as follows:

(1) AGV fault;
(2) Guidance path failure;
(3) AVG conflicts.

The first and second situation need manual processing to correct system parameters according to the AGV system and the changes of guide path. The third case is now the main consideration. In the movement of AGV, there are mainly three different types of path conflicts, as shown in Figure 3.

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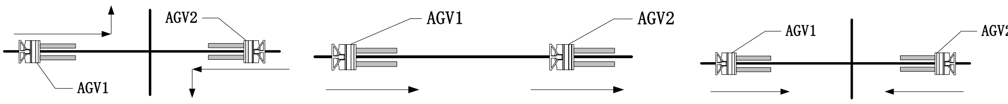

Node conflict Chase conflict Facing conflict

Figure 3. Path Conflicts

(1) Node conflict

Two vehicles would have conflict at a node when they arrive a node at the same time and move along different directions.

(2) Chase conflict

Two vehicles would have chase conflict at a time when they move at the same direction and the back vehicle moves faster.

(3) Facing conflict

Two vehicles would have facing conflict when they move in opposite direction since each path can only pass a single vehicle at the same time.

For the first and second type of conflicts, the scheduling system will make the higher priority AGV pass first in accordance with waiting-strategy. The third type of conflict needs to be solved by the time-window or one-way map.

5.2. Conflicts Detecting and Solving

Node conflict, chase conflict and facing conflict are three common conflicts in the multi-AGV path planning. The vehicles can avoid facing conflict for they can just move along one-way as a result of one-way guidance path.

Dynamic detection of geometric distance between the vehicles can be taken for the node conflict, as shown in Equation (4).

$$D=\sqrt{\left(\left(x_1-x_2\right)*\left(x_1-x_2\right)+\left(y_1-y_2\right)*\left(y_1-y_2\right)\right)} \quad (4)$$

When the distance between vehicles is less than a given threshold value, algorithm would detect whether the next nodes of vehicles is the same. There is a node conflict if they are the same nodes. Otherwise, they cannot make up a conflict node. We can use the same method to detect the chase conflict.

The waiting-strategy can be used to all the conflicts with this algorithm. We just need to make the distance between two nodes larger than the distance of safe movement since there is no limit of time-window and multiple vehicles can pass a path at the same time.

5.3. Algorithmic Process

Based on directed graph, AGV path planning algorithm is using the limitations of hardware (guidance path) to enhance the stability of the system and reduce the requirements for the algorithm, so the algorithm process is relatively simple.

On the basis of task scheduling requirements, there are three AGVs individually located at $V_{1,}$ 、 V_2、 V_5 and they are going to each destination node V_6、 V_7、 V_0. According to multi-AGV time -window algorithm (S= { V_1、 V_2、 V_5}, T={ V_6、 V_7、 V_0}), the tasks are assigned as follows: task 1completed by AGV1, task 2 by AGV3, task 3 by AGV2. Single AGV path planning algorithm can be directly applied to solve the three tasks because there is no path which AGV cannot pass in the electronic map. The results are shown in Table 1.

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Table 1. Results for One-Way Map Algorithm

Task Number	Starting point	Terminal point	Moving path
m_1^1	v_1	v_6	$e_{12}-e_{23}-e_{34}-e_{45}-e_{56}$
m_2^3	v_2	v_7	$e_{23}-e_{34}-e_{47}$
m_3^2	v_5	v_0	$e_{56}-e_{67}-e_{78}-e_{89}-e_{90}$

5.4. Algorithm Analysis

The advantages of AGV path planning algorithm based on directed graph are as follows: small amount of computation to help to develop and implement procedures; avoiding or resolving the conflicts between AGVs to enhance the stability and reliability of the system; simple algorithm and short operating-time to ensure the real-time performance of the system. And this algorithm is especially suitable for the automatic transport systems which are complex or have many AGVs for the number of AGV has little effect on the algorithm. However, due to one-way guidance, the solution for the optimal path may not be the shortest path. That is, to some extent at the expense of some of the transport efficiency.

6. System Developing

In this section, the functions mentioned above about AGV automated transport management system will be developing and there is a brief description of its processes.

6.1. Electronic Map Expressing

The electronic map can be expressed in two ways. One is similar to the description of the From-to Diagramming. The other is expressed by the linked-list structure.

The linked-list structure is used in this paper. Similar to Tree structure, each node in the linked-list structure contact with other nodes through a parent and child nodes. This structure takes up less space for storage for there is no redundant data. And the description of the relationship between the nodes is relatively clear, which shows the movement direction of the segment path. The specific structures in this paper are as follows.

```
struct NODE
{
   float x;
         float y;
         float g;
         float h;
         float f;
         NODE *pParent;
         NODE *pNext;
};
```

6.2. Data Verifying

The AGV simulation program is written by multi-process communication technology, whose feasibility is verified by the simulation of AGV automatic transport system. The information of AGV is shown in Table 2.

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Table 2. The Initialization of Transport Task

AGVID	Conditions	Power	Coordinates X	Coordinates Y	Task Number	Utilization
1	Normal	77	250	300	0	55
2	Normal	100	150	200	0	56
3	Normal	50	200	266	0	77
4	Normal	66	400	286	0	89
5	Normal	68	477	200	0	87
8	Normal	76	98	400	0	59
9	Normal	89	432	100	0	95
10	Normal	68	200	159	0	90

Assign start node 23 and destination node 21 to the new task, as is shown in Figure 4.

According to Table 2, AGV8 is the best choice since its utilization is just above AGV1 and AGV2 but length of the path far less than the others. After scheduling completed, the task list is shown in Figure 5. The result shows the scheduling function can complete the control according to the scheduling index.

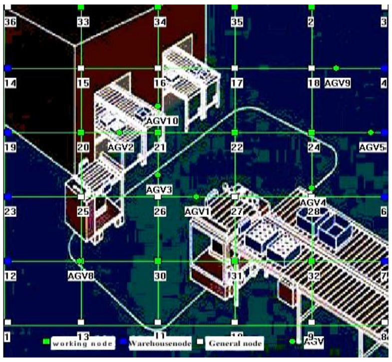

Figure 4. The Position of AGVs and Task

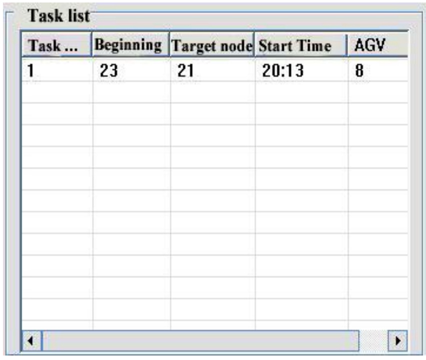

Figure 5. Single-Task Scheduling Result

The following simulation is for the multi-tasking situation and achieves AGVs communication, whose port is defined as 5000. The specific tasks are imported from Excel, as is shown in Table 3. And the importing of node information begins with the starting point of the section.

Table 3. The Initialization of Transport Tasks

Task Number	Start Node	Destination Node	Start Time	Date
1	12	33	8:51	2014-05-01
2	14	34	8:51	2014-05-01
3	19	35	8:51	2014-05-01
4	23	2	8:51	2014-05-01
5	4	21	8:51	2014-05-01
6	5	22	8:52	2014-05-02

System will dispatch the AGV according to the information tasks. There are two types of AGVs scheduling: going to the start node and going to the destination node from the start node. System just needs to dispatch the path to the start node for the start node to destination node is already determined. Scheduling results are shown in Table 4, which

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will be sending to the corresponding AGV, as shown in Figure 6 and Figure 7. The corresponding path of AGV2 is shown in Figure 8.

Table 4. Scheduling Results

AGVID	Coordinate X	Y	Task Number	Path
1	250	300	5	27-31-10-11-13-1-12-23-19-14-15-16-17-18-4
2	150	200	4	21-26-30-11-13-1-12-23
3	200	266	2	26-30-11-13-1-12-23-19-14
4	400	286	0	0
5	477	200	0	0
8	98	400	1	29-13-1-12
9	432	100	6	4-5
10	200	159	3	21-26-30-11-13-1-12-23-19

As can be seen, the algorithm can give the current optimal solution for each assigned task in the scheduling process. To verify the algorithm in the case of the performance of different paths, now make the following changes in the path. The result can be realized by algorithm or manual route planning, as shown in Figure 9. We can add a task 7 after AGV3 planning and the red line is the path displayed in the map.

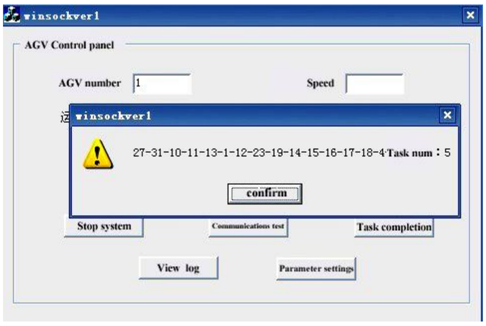

Figure 6 AGV1 Scheduling Information

Figure 7 AGV2 Scheduling Information

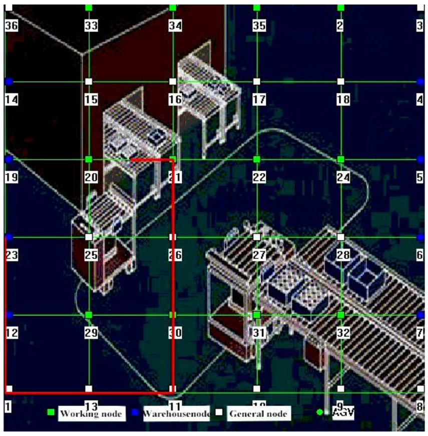

Figure 8 Scheduling Path AGV2

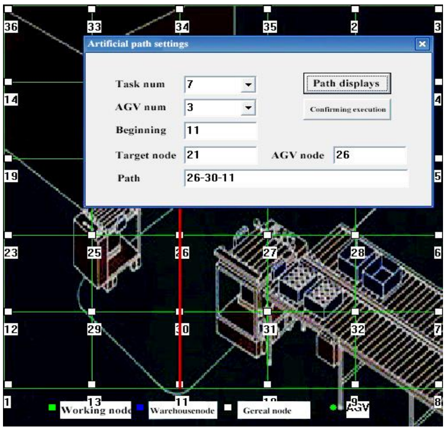

Figure 9 Manual Route Of Planning

7. Conclusions

With the increasing development of enterprise information technology, information and automation of logistics has become an inevitable trend and AGV

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automatic transport system is the typical representative of this trend. Based on actual demand, this paper uses topological modeling method to build an electronic map and the A * algorithm for solving the shortest path; researches and summarizes the AGV scheduling theory, determines the type of scheduling system and gives AGV scheduling index and conflicts resolutions; uses path planning algorithm based on one-way graph as the solutions of multi-AGV path planning to avoid system conflicts and enhance stability; develops the AGV automatic transport management system, realizes and verifies each functional module in VC ++ 6.0 and SQL Server platform.

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