Wait and Replan Approach for Conflict Resolution in Traffic Control of Multiple Automatic Guided Vehicles

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***Abstract*— The traffic control system plays a very important role in the automatic guided vehicle system. Many industrial and academic teams have developed and built several rule-based scheduling and traffic control, hoping to resolve the problem of traffic congestion. At the same time, it maintains the best route with high efficiency. and reduces system time. In this paper, the traffic control patents issued by Texas Instruments and OMRON Corporation. will be analyzed individually, and the differences between the two sets of traffic controls will be compared. Furthermore, these traffic controls are realized in MATLAB and the "Waiting and Replanning" has been added and tested in several scenarios. Finally, numerical data are provided to evaluate its performance.**

***Keywords*—multiple automatic guided vehicles; traffic controls; waiting and replanning**

I. Introduction

Manufacturing industries around the world are undergoing digital transformation, also known as *Industry 4.0*. In the early days, factories will set up production lines to enhance their production efficiency. However, the supply of materials is still handled by people, which often leads to the interruption of logistics and production. When AGV(Automated Guided Vehicle) are introduced into the manufacturing industry, it becomes the best solution. AGV execute tasks according to the predetermined path, and walk on the track, including acceleration, deceleration, parking and other functions. It can achieve a variety of assignments with mechanical arm or carrying vehicle. However, the most important core of the ground control system of the AGV is traffic control system.

Path planning means to find an optimal feasible path under certain environmental constraints. According to a given starting node and end node, it refers to one or some shortest path, shortest time, lowest cost and other factors. When the number of AGVs in the field increases, resource competition and conflict resolution will become a thorny issue. At this time, the traffic control system needs to help solve these problems.

Traffic control system provides "real-time monitoring management", that is, it is hoped to monitor and prevent accidental collisions through the background, so as to plan the situation of multiple AGVs in the same field. The back-end management system can plan the path of each AGV in real time and deploy the speed of AGV and the time spent at the node or job position, etc., prevent AGV from blocking each other (dead knot). If a blocking situation occurs, according to the current environment and update the AGV configuration to solve the blocking problem. Traffic control system plays a very important role in complex systems and task scheduling. The robustness of traffic control logic will affect whether it can effectively solve problems such as traffic congestion, conflict accidents and vehicle lockups, while maintaining the best path planning.

Researchers have conducted many studies, different applications and proposed many solution strategies. Kim and Tanchoco [1] gave an algorithm combining Dijkstra's algorithm and a time window on a two-way path network. Taghaboni-Dutta and Tanchoco [2] proposed an incremental planning method. But this method sacrifices the optimal path. It can be found from various studies that many algorithms and rules have been proposed for more efficient traffic management.

In the industry, there are many robot companies or logistics factory operators individually or in cooperation with other technical teams to develop the lowest cost and highest efficiency traffic management methods, and most of the lowest cost is the shortest time for discussion. This article will discuss and analyze the traffic management logic of two robotics research and development companies (Texas Instruments and OMRON Corporation), and further simulate the actual situation to verify the two methods and briefly describe the problem with examples.

II. The current methods of traffic control system

In this chapter, we will mention the patents issued by Texas Instruments and OMRON Corporation separately, and discuss the content of the patents. Texas Instruments' approach to traffic management is mainly based on whether

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the node is "free"(could be used). If it is not available, the AGV will wait. OMRON Corporation's approach to traffic management is mainly to find new alternative path, which are suitable for applications where the field is larger and there are more feasible roads.

A. Texas Instruments: Waiting for the busy nodes

In 1988, Texas Instruments applied for one patent [3]. This patent is for arranging AGVs to resolve conflicts in AGV dispatching strategy and traffic control system. This method was to successfully solve the problem.

The content of this patent has multiple parts. First, it is proposed to use nodes to represent the work station (pickup station/delivery station) and the corner for the internal environment of the factory. Then, the nodes in the entire field will independently record their own status. The nodes will be marked as "free" or "busy". When the dispatch system will schedule tasks and dispatch AGV after stationary system receiving the tasks. After the AGV is selected, the traffic system will generate a possible route (the nodes are all idle) and further generate a list of nodes which AGV may follow to complete the task. The node in the list will be marked as busy. When the AGV passes this node, it will be marked as free. If other AGV meets the node on the road which is busy, it will wait for this node until it is free, so it can further avoid conflicts. Figure 2 is the flow chart of the traffic control logic.

B. OMRON Corporation: Alternative roads

Omron Corporation applied for two patents [4] [5] in 2013, Two key points are job management system for a fleet of autonomous mobile robots and autonomous mobile robot for handling job assignments in a physical environment inhabited by static and non-static obstacles.

Under the traffic management system, if there are fixed or unfixed obstacles on the best path generated by the AGV, the second path will be generated immediately, and the conflict will be avoided by repeated inspection and correction. When other AGV are affected in the task execution, the other AGV will also generate another executable path, This mechanism is to generate and change the current position of the AGV and the path on the map for many times to complete the driving of the AGV. At present, if the condition of no AGV meets the executable task or the AGV cannot generate the executable path, it will report back to the job management system and wait until the executable path is generated. Figure 3 is the flow chart of the traffic control logic.

III. Approach Simulation and Comparison

Conflict is a serious problem in the AGV system. Particularly, when there are lots of AGVs in the field. When there are two (more) AGVs receive the tasks, traffic control system need to schedule the tasks and have mechanism to avoid the conflict, called traffic control logistics. In this article, there is a case to implement different logistics and compare the different between these methods.

A. AGV system environment

This article is simulated as a grid map (Figure 4). Each step of the AGV is a node. In the article, using V(a, b) to represent the node which is located at (a, b). This method makes it easier to arrange obstacles and calculate the (Heuristic Estimate) formula on the map. In this map, black means obstacles, and white means available. The walking road is a two-way monorail. The red nodes are shown as nodes that are calculated, and the determined shortest path will find the shortest path to the target from the calculated nodes.

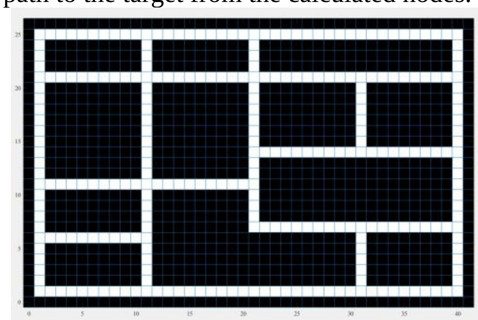

Figure 1 The grid map

B. Principle of A algorithm*

The A* (A-Star) algorithm[6] is one of the methods to solve the shortest path problem. It is an improvement from the well-known Dijkstra algorithm[7]. Although the Dijkstra algorithm can search all paths to ensure that the shortest path is found, it is not as good as A* algorithm. A* algorithm is so fast and concise. The main principle of A*star is that there is a special Heuristic Estimate formula, which quickly eliminates many obviously bad paths, and then quickly calculates a satisfactory path.

The Heuristic Estimate formula is as follows:

$$f(n) = g(n) + h(n) \quad (1)$$

g(n): the distance from the starting point to the current node.
h(n): predict the distance from the current node to the end point (this is the main evaluation formula of the A* algorithm).
f(n): evaluation score of the current node.

Where h(n) is represents the estimated distance from any vertex to the target vertex. Manhattan distance(2) is used in this article.

$$h(n) = |\, n_{tx} - n_x \,|+|\, n_{ty} - n_y \,| \quad (2)$$

The following uses MATLAB to simulate and present A* algorithm.

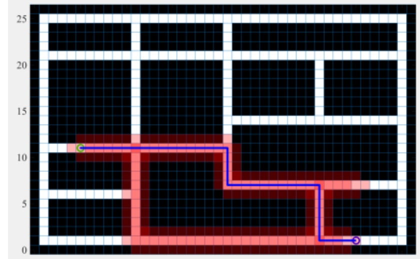

Figure 2 single AGV situation

TABLE I. PATH PLANNING DETIAL OF AGV

AGV#	**Spending Time**(1s/node)	**Total Length**(1/node)
Single	41s	41
	Start node	**End node**
	V(5,11)	V(35,1),

The result indicate there are more than one shortest path in the simulation. However, in the algorithm, we would consider turn right at first. To be more specific, the order is "right", "down", "left" and "up". And, the red nodes mean these nodes were considered and searched.

C. *Traffic Control Logistics For Multi-AGVs*

This article simulates traffic logistics for multi-AGVs. We simulated the two above methods and add the extra one. The extra one is waiting for AGV which is executing the task to complete the task.

TABLE II. TRAFFIC CONTROL LOGISTICS

AGV#	Traffic Control Logistics
single	Plan a shortest path by A*star alogrithm
Multiple	1. Wait for AGV1 to complete the task.
	2. Wait for the necessary node to turn to not be used.
	3. Replace an alternative path, which does not overlap with the path of AGV1.

To be more specific, there are three flow charts to implement the three method logistics.

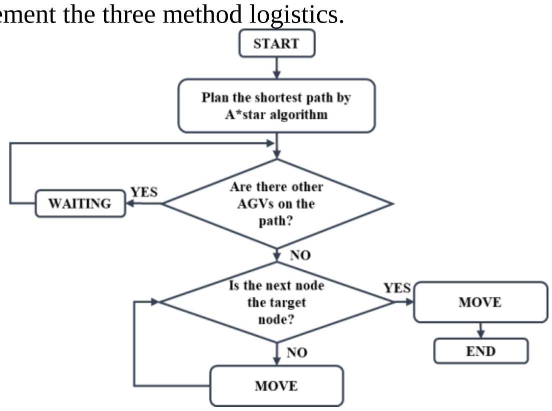

Figure 3 Method 1 : Wait for AGV1 to complete the task.

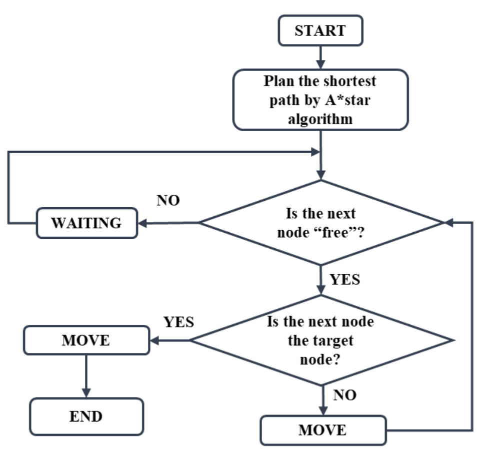

Figure 4 Method 2 : Wait for the necessary node to turn to not be used.

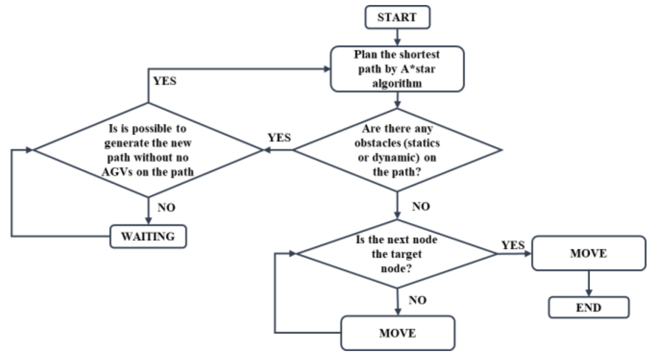

Figure 5 Method 3 : Replace an alternative path, which does not overlap with the path of AGV1.

D. *Simulation*

This article uses MATLAB to make algorithm and traffic control logistics presentations. For multi AGVs, we would simulate the three traffic control logics. Finally, we may simulate a case to comparison different cases for different traffic control logics.

Method1. Wait for AGV1 to complete the task.

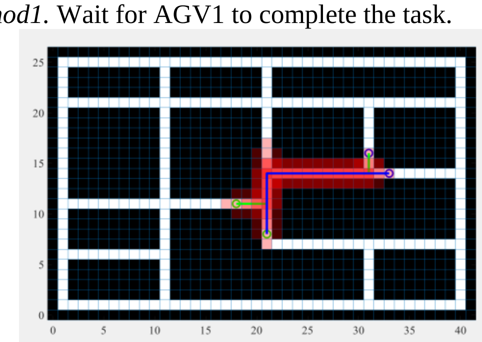

Figure 6 multi AGVs situation in method 1

AGV1 starts from V(18,11) to V(31,16)(Path GREEN), while AGV2 starts from V(21,8) to V(33,14) (Path BLUE).

TABLE III. PATH PLANNING DETIAL OF AGVS

AGV1	***Total Spending Time****(1s/node)*	***Total Length****(1/node)*
	19s	19
AGV2	***Total Spending Time****(1s/node)*	***Total Length****(1/node)*
	19s	19
system	***Total Spending Time****(1s/node)*	***Total Length****(1/node)*
	38s	38

Method2. Wait for the necessary node to turn to not be used.

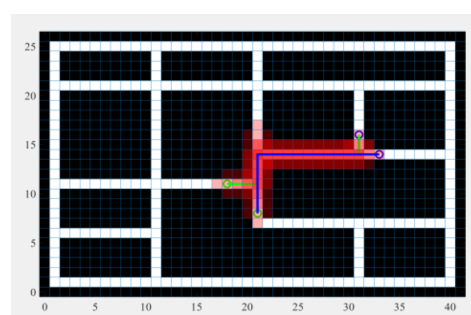

Figure 7 multi AGVs situation in method 2

AGV1 starts from V(18,11) to V(31,16)(Path GREEN), while AGV2 starts from V(21,8) to V(33,14) (Path BLUE).

TABLE IV. PATH PLANNING DETIAL OF AGVS

AGV1	***Total Spending Time****(1s/node)*	***Total Length****(1/node)*
	19s	19
AGV2	***Total Spending Time****(1s/node)*	***Total Length****(1/node)*
	20s	19
system	***Total Spending Time****(1s/node)*	***Total Length****(1/node)*
	20s	38

Method3. Replace an alternative path

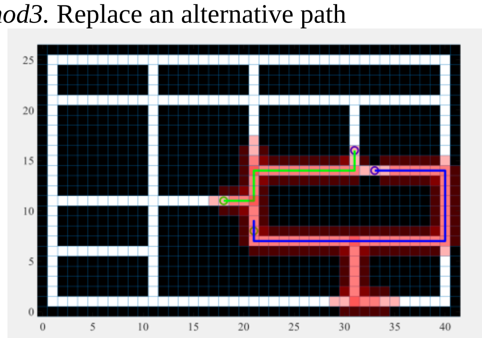

Figure 8 multi AGVs situation in method 3

AGV1 starts from V(18,11) to V(31,16)(Path GREEN), while AGV2 starts from V(21,8) to V(33,14) (Path BLUE).

TABLE V. PATH PLANNING DETIAL OF AGVS

AGV1	***Total Spending Time****(1s/node)*	***Total Length****(1/node)*
	19s	19
AGV2	***Total Spending Time****(1s/node)*	***Total Length****(1/node)*
	36s	36
system	***Total Spending Time****(1s/node)*	***Total Length****(1/node)*
	36s	55

TABLE VI. COMPARISOM OF DIFFERENT TRAFFIC CONTROL METHOD

Method	***System Time****(1s/node)*	***System Length****(1/node)*
Method 1	38s	38
Method 2	20s	38
Method 3	36s	55

According to the above result, the method 2, “wait for the necessary node to turn to not be used” would be the most efficient method. The AGVs in most cases are just wait for one node. At the same time, the AGV can maintain the shortest path. However, this method cannot avoid the opposite collision. There would be one more rule that the AGV may stay at the node and wait for the other AGV pass the whole collision path.

There are no the opposite collision problem in the method 1 and method 3, because basically the AGV may not share the same node at the same time. Yet, according to the result, system spend more time in method 1 and method 3. In the worst cases, AGVs may spend the most time in method 3, if the alternative path is really far from the shortest path, particular, there are seldom possible paths and there are lots of AGVs in the field.

IV. CONCLUSION

This paper introduces the key technology traffic control system of AGV, and simulates and discusses the development traffic control system of two companies. The simulation in this paper is divided into two parts. The first part is a single AGV situation. The shortest path planning can be completed efficiently by the A*star search method. The second part is a multi AGV simulation environment. The two methods(alternative roads and wait for AGV to complete task) are relatively inefficient and not the shortest path, but conflicts are less likely to occur (opposite conflicts). The method of waiting for used nodes is more efficient and holding the shortest path method in most cases. The disadvantage is that it is not easy to spoil the conflict situation. Therefore, extra rules are needed to resolve the conflict. Comparing the two traffic control logics in different cases, there may be advantages and disadvantages (for system time). Therefore, a more complete traffic control logic should not only have one kind of traffic control logic. It needs to use multiple logics and compare them to suit the case.

Through simulation, it is possible to compare the robustness of different traffic logics. At the same time, it is found that the robustness of the traffic control system will affect whether it can effectively solve traffic congestion, conflict accidents, AGV lockups and other problems, while maintaining optimal path planning. In the end, the main contribution of this paper is to verify and experiment on the mature algorithms of the industry, and put forward the entry points that can be improved.

V. REFERENCES

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