The Shortest Path Planning Using A-Star Algorithm in RGV Based Overhead Hoist Transport Dispatching System

Yann-Shuoh Sun, Chiao-Wen Liu, Chung-Chiang Cheng, and Chao-Wen Yang

***Abstract*—Overhead hoist transport (OHT) has been widely applied in industry, especially in semiconductor manufacturing processes. The most important issue in the OHT control system is how to determine the shortest path for each transportation task. This paper presents an optimal path planning based on minimization of travelling distance of arbitrary starting location and destination in a specific layout for a workhouse. The A-star algorithm is utilized to solve the problem in the paper, and an example of two rail guided vehicles of OHT system with a routing layout of plural encircle loops under specific operation conditions are examined.**

***Index Terms*—Overhead Hoist Transport (OHT), Rail Guided vehicle (RGV), A-star algorithm.**

I. INTRODUCTION

OVERHEAD hoist transport (OHT) has been a developing technology for implementing delivery of slot magazines used in semiconductor packaging and testing industry. Compared to other Automated Material Handling System (AMHS) solutions or other grounded automation delivery tools (e.g. automated guided vehicle; AGV), there are several restrictions in implementation of OHT transportation system; The movement of rail guided vehicle (RGV) of OHT carrier is defined as unidirectional flow at specific route in the OHT rail loops; The functions of detour or direction shifting are done by switch in the cross between rails; Finally, the improper task arrangement results in roundabout route or even deadlock. To solve the problem mentioned above, the dispatching strategies and optimal path planning for a batch of tasks are proposed in the paper. The A-star algorithm is presented as optimal path planning in the paper, which is an effective approach based on determining the minimum distance from arbitrary start and end location. The shortest path of each task is determined and the prior task passes the rail and rail switch before the later task if the common paths are used by both the tasks.

The contributions of this paper are briefly listed as follows:

This work was supported by Industrial Technology Research Institute with scientific knowledge and technology developing research project (grant no. L353C81200).

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- The dispatching strategy of combination both workcentre and vehicle initiated dispatching is applied in RGV based OHT system with two vehicles and specific routes of layout in real implementation.
- The A-star algorithm for shortest planning for each RGV task is developed in RGV based OHT system.
- Combined with the shortest path planning and tasks dispatching strategy, both simulation and implementation in site run well in practice.

The rest of the paper is organized as follows: In section II, a briefly introductions of the relative works in recent years are presented and the background of the dispatching and routing problems are discussed and relative strategies are provided. A-star algorithms is introduced, and the procedure of implementation for the algorithm is described in the section III. The background problem of RGV OHT configuration are described in section IV. The conditional simulation and results for demonstration of the OHT layout are expressed in section V. Finally, a conclusion is drawn in Section VI.

II. LITERATURE REVIEW AND DISPATCHING STRATEGIES

A. Literature Review

There are plenty of researches on AMHS application in various industries. The OHT system with RGVs on rail is especially focused in the paper due to its widely used in semiconductor manufacturing in the past. The kind of AMHS is also adopted in the semiconductor packaging and testing processes and the demands are keeping on increasing. Some of dispatching rules used in AMHS system were already proposed in 1980's.

Egbelu et al. [1] suggested workcentre initiated dispatching tasks and vehicle initiated dispatching tasks, and compared the various dispatching strategies on a fabrication plant with a specific layout. A well review about dispatching strategies is presented by Co, C.G. et al. [2], and Sinriech, D. et al. [3]. A tandem configuration layout for simplifying management of AGVs and avoiding deadlock is proposed by Bozer, Y.A. et al. [4]. Tanchoco, et al. [5] provide a widely discussion about AGV dispatching, the strategies of both pre planning and event-driven are studied. Mantel R.J. et al. [6] discuss the layout of routes, numbers of vehicles and processes controls in dispatching problem. It shows that the layout of routes and processes controls play the roles in case study. The performances between traditional and tandem configuration layout, such as AGV utilization, mean flowtime, mean tardiness and percent tardy, are compared by Ross, E.A. et al. [7]. Hwang, H. et al. [8] developed a dispatching algorithm based on bidding concept. Ganesharaja, T. et al. [9] summarize the optimal and heuristic procedures available for flow path design, fleet size determination of AGVs, and operational issues such as job scheduling, AGV dispatching and conflict-free routing. Aarab, A. et al. [10] present a design procedure of the single loop flow path. The procedure is based on the use of tabu method whose initial solution has been determined for geometrical considerations. Qui, L et al. [11] note the similarities with known problems in parallel and distributed systems, which is suggested to apply analogous ideas in routing and scheduling AGVs. Vis, I.F.A. et al. [12] present a minimum flow algorithm to determine the minimum number of AGVs required at a semi-automated container terminal. Qiu, L. et al. [13] review the literatures of AGV routing and scheduling, which the algorithms are divided into algorithms for general path topology, optimization of path network, and algorithms for specific path topologies. Tuan, L.A. et al. [14] note that guide-path design can be divided into three categories: conventional, single loop and tandem systems. Reza Zanjirani, F. et al. [15] propose tabu search and genetic algorithm for designing AGV routes in a tandem configuration. The Q-learning algorithm is applied by Jeon, S.M. et al. [16] for AGV routing in port container terminals. The routes with the shortest travel time for each delivery order are found and estimation of the expected travel time of vehicles are shown by Q-learning. Dijkstra's Algorithm is proposed by Shaikh A. et al. [17] to find the shortest path for numbers of AGVs and calculate the path required by each AGV. The presence on any obstacle between two stations is detected and the path is recalculated. Chang, X. et al. [18] propose a GA based simulation optimization methodology to solve a real-time multi-objective dispatching decision problem for the integrated delivery in a 300mm semi-conductor wafer fabrication Fab.

Based on the literatures reviewed above, some of the former dispatching strategies are referred and A-star algorithm is utilized to solved the OHT routing problem. Both the dispatching rules and procedures of path planning algorithm are described.

B. Dispatching strategies

Egbelu et al. [1] provided several heuristic dispatching rules, which part of dispatching strategies are adopted in the paper. The dispatching strategies are divided into workcentre initiated dispatching task and vehicle initiated dispatching task. A brief expression is presented as following.

The strategies based on workcentre initiated dispatching task can be listed as below:(1) Random Vehicle rule; (2) Nearest Vehicle rule; (3) Farthest Vehicle rule; (4) Longest Idle Vehicle rule; and (5) Least Utilized Vehicle rule. If there are not any task balance considerations, the nearest vehicle from task start location is the choice of the dispatching algorithm for path planning. Under the rule of nearest vehicle, the distances of the vehicle demand station from every available vehicle are computed. The most suitable vehicle is chosen by the shortest distance from demand station. The shortest distance of every vehicle to the demand station is determined by A-star algorithm.

Similar to the workcentre initiated task assignment problem, several heuristic rules are available for the strategies based on vehicle initiated dispatching task. Possible dispatching rules are shown as follows: (1) Random workcentre rule; (2) Shortest Travel Time/Distance rule; (3) Longest Travel Time/Distance rule; (4) Maximum Outgoing Queue Size rule; and (5) Minimum Remaining Outgoing Queue Space rule. Also, Shortest Travel Time/Distance rule is the choice which the assigned vehicle to any workcentre with shortest distance, which is the choice of the dispatching algorithm for path planning based on vehicle. Again, the estimation of shortest distance is the same as the rule of nearest vehicle rule described previously. i.e., A-star algorithm.

In practice, workcentre initiated dispatching task and vehicle initiated dispatching task are both considered in the dispatching strategies. At first, the dispatching system receives the task demands from manufacturing execution system (MES). The task demands are issued by dispatching system, every vehicle in the dispatching system computes the cost of the task on its own based on shortest path planning by vehicle initiated dispatching task. Then all the vehicles issue their individual costs to the dispatching system for choosing the suitable vehicle. The chosen vehicle is planned for the individual task demand based on shortest path by workcentre initiated dispatching task through the computing of dispatching system.

III. A-STAR PATH PLANNING ALGORITHM

A. An introduction to A-star algorithm

Path planning addresses the problem of finding an optimal path from the starting point to the goal, which obstacles and deadlock of traffic are avoided, and the costs are minimized while multiple dispatching task are assigned to vehicles. The A-star algorithm is used in the paper for optimal path searching and brief descriptions about the algorithm and processes flow are shown below.

The A-star algorithm uses heuristic function to estimate the distance between an arbitrary position on the plane and target position. An example is shown in Fig1, which a blue block is the goal. The algorithm takes the starting vertex (parent node) shown in red block as the current vertex. The surrounding vertices (children nodes) in the eight directions of the current vertex are thus evaluated by the heuristic function, as shown in Figure 1. The vertex selected as the next parent node is based on the smallest evaluation value, and the iteration loop continues until the target point is found. Each parent node is the smallest evaluation node, where the path formed by these parent nodes is the optimal path planned by the A-star algorithm.

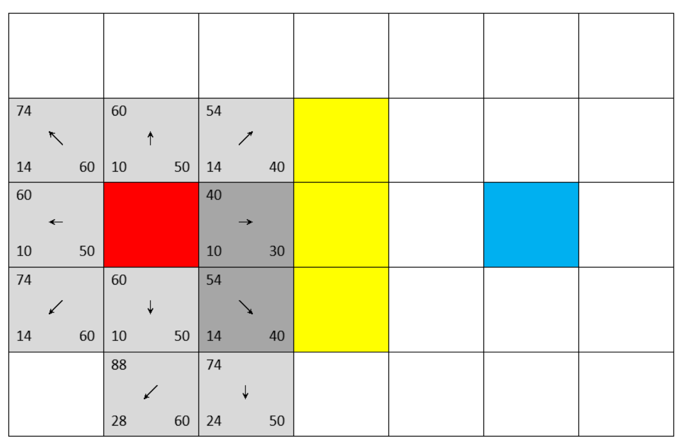

Fig. 1. A sketch map used to describe the starting vertex (red block), obstacle vertex (yellow blocks) and goal (blue block) in path planning, the block size is 10 in side and 14 in diagonal.

A-star algorithm is based on the minimization of cost function F(n) in (1)

$$F(n) = G(n) + H(n) \quad (1)$$

G(n) represents the exact cost of the path from the starting point to any vertex n. H(n) represents the heuristic estimated cost from vertex n to the end point. Where n is the current node. That is, G(n) is the cost of moving from the starting points along the generated path to the current node n, and H(n) is the minimum cost estimate from the current node n to the ending nodes. F(n) is the total cost of the path. According to the coordinates of the current node n and target nodes (x1, y1) and (x2, y2), H(n) is defined as

$$H(n)=[(x1-x2)^2+(y1-y2)^2]^{1/2} \quad (2)$$

$$F(n)=G(n)+[(x1-x2)^2+(y1-y2)^2]^{1/2} \quad (3)$$

A-star combines Dijkstra's Algorithm in G(n) and Greedy Best-First-Search in H(n). A-star balances the two as it moves from the start to the end through the information used to determine the best path both the vertex n near the start and the goal. Each vertex n between the start and end, the calculation of A-star examines the vertex that has the lowest F(n) = G(n) + H(n).

There are several types of distance heuristic. For example:

1) Manhattan distance

$$D = |x1-x2|+|y1-y2| \quad (4)$$

2) Chebyshev distance

$$D = \max (|x1-x2| , |y1-y2|) \quad (5)$$

3) Euclidean distance

$$D = (|x1-x2|^2 + |y1-y2|^2)^{1/2} \quad (6)$$

(x1, y1) and (x2, y2) are the two-dimensional planar coordinates of node 1 and node 2 respectively. In the paper of representations of the map, the Manhattan distance is used as the distance heuristic estimation.

B. Methodology

Through the computer programming, there are two data list during the procedures of A-star algorithm, where one is open list and another one is close list. The methodology of programming is briefly described as below.

The data in the open list need to be sorted, and the data in the close list is the vertex sequences of the path. At first, the starting vertex is placed into the open list and the F(n) is calculated. Then, the vertex of minimum F(n) is placed in the open list, the other vertices are placed in to the closed list. Next, determine if the current node in the close list is an ending vertex. If the vertex of ending is true, the A-star algorithm process ends. If false, continue to expand the current children vertices and calculated their F(n)s. Then place the vertices and their F(n)s into open list. Finally, sort the open list until the loop is done. The results described as steps above are shown in Fig 2.

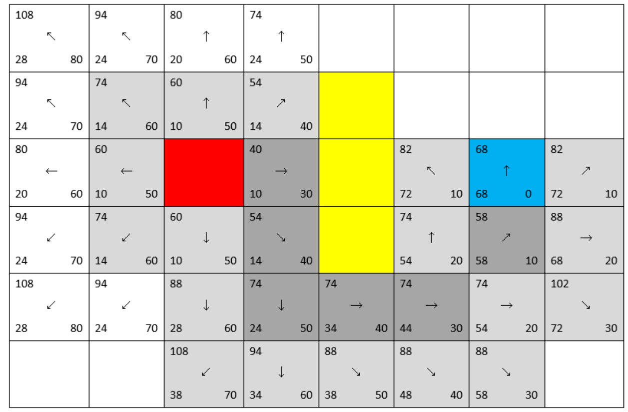

Fig. 2. The results of A-star algorithm path planning are shown in the blocks with deeply grey color. The value of F(n) is shown in up left in every block; the values of G(n) and H(n) are shown in bottom left and bottom right respectively.

The procedures of searching the shortest path based on A-star algorithm can be summarized as following.

1) Starting:
Starting with a vertex, an open list is established and the starting vertex is placed in the open list.

2) Finding the adjacent vertices:
Find all the reachable vertices adjacent to starting vertex. Then, the vertices are placed in the open list too.

3) Saving the starting vertex as parent node:
The starting vertex of all the reachable vertices adjacent to it is saved as parent node in the open list.

4) Saving and deleting:
Deleting the starting vertex in the open list. Then a closed list is established and the deleting vertex is placed. The nodes placed in the closed list are not checked any more.

5) Compute the cost function F(n):
The F(n) = G(n) + H(n) is computed. G(n): actual travelling distance; H(n): Manhattan distance.

6) Choose the optimal node:
The optimal node is chosen according the cost function computed above.

7) Search all the reachable nodes adjacent to starting vertex for better path:
All the reachable node will be traversed. If an adjacent node is already in open list, the new path is checked by verifying new cost function F(n) for lower G(n).

8) Deleting the chosen node:
Delete the optimal chosen node from the open list and the newer node is added.

9) Repeating the processes:
Above procedures are repeated until the ending vertex is added in closed list.

The flow chart is presented as Figure 3.

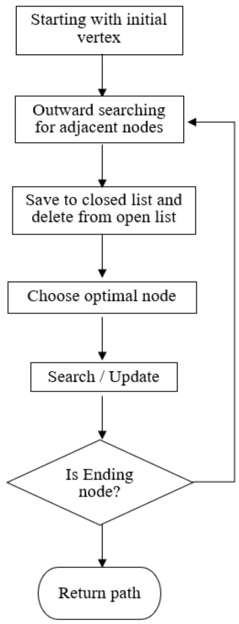

Fig. 3. The Procedures of shortest path searching of A-star algorithm

IV. Problem Description

A. Problem Formulation

The layout map of stations and routes for two RGVs' operation is shown as Figure 4. The configuration of the map is composed of six enclosed loops. Each route in the map is unidirectional and the direction is shown by arrow. The map will be transformed to graph data structures, which is an abstract data type (ADT) defined by the collections of vertices and edges. Each vertex of Figure 4 denoted by prefix v shows the location of station. The line between each vertex shows the edge of the route. The dimensions of the map configuration are about 9600mm length and 8000mm width. The detail sizes of lengths are also shown in Figure 4.

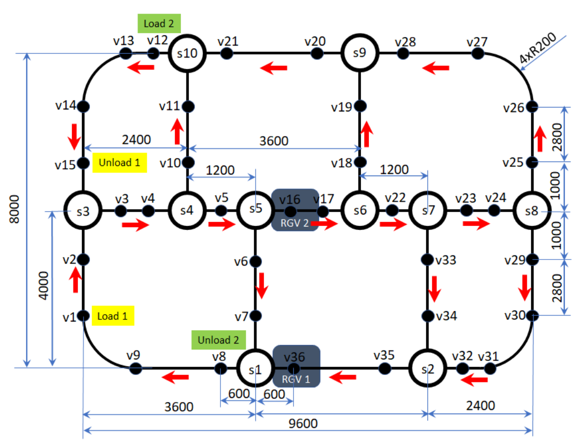

Fig. 4. Operating environment of an RGV based OHT system. (Dimension of distance: mm)

The circles located in the crossover of edges with prefix s denote the switch for railway direction switching. The switch is an ADT object which consists of three vertices and three edges shown in Figure 5. There are three doors for choosing the travelling paths in a switch. While an RGV gets through switch from its inlet, The RGV may be guided to the proper direction by switch.

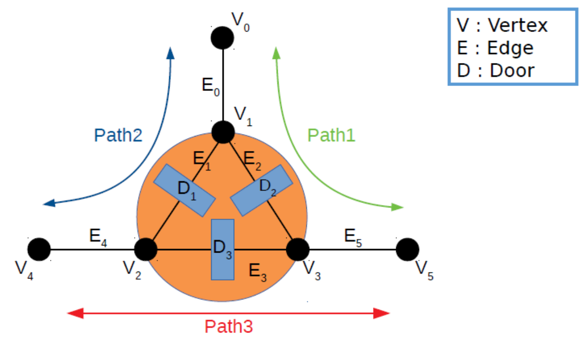

Fig. 5. Configuration of railway switch ADT.

B. Map Construction

Before applying shortest path searching procedure, the information of adjacent vertices of any vertex and any edge between two vertices and its directions in the layout map should be established as a graph data structure, which is the collection of vertices and edges.

After the graph data construction is completed, the sibling tree between starting and ending vertices can be traversed and the shortest path is found through A-star algorithm. The procedures of find shortest path from any starting and ending vertices are described next.

V. Simulation Result

A. Description of Simulation

A real example based on map layout of Figure 4 described previously is introduced to demonstrate the dispatching strategies and path planning algorithm of shortest distance with two RGVs. The simulation tasks of arbitrary peer to peer deliveries are issued by MES twice a time. The tasks more than two will be placed in the queue of first in / first out (FIFO). The RGV which finished the assigned job from manufacturing execution system (MES) will be released and a new task from FIFO queue may be assigned. The priorities of tasks are ordered by the sequence of issues. The RGV with high priority task is privileged the utilization of switch. The switch is released to another RGV after the RGV with high priority task passes through. Each task is composed of workcentre initiated dispatching task and vehicle initiated dispatching task. The simple task management for RGV dispatching is expressed as above. The demonstration of task dispatching of path planning with shortest distance is described as following while two tasks are issued at a time and two RGVs are stopped at arbitrary locations. The following case of simulation is described as below: The material transferring orders, which are loading from v1 and unloading to v15, and loading from v12 and unloading to v8 are issued respectively. Meanwhile, the two RGVs stop at v16 and v36 respectively.

B. Vehicles Initiated Dispatching

The RGV's dispatching system is in charge of transferring the task order from the MES to the path planning of individual RGV for each demand order. While the demand orders of v1 to v15 and v12 to v8 are issued in sequence, both of the RGV compute the shortest distance and path for the two demand orders. In this stage, the vehicles initiated dispatching are going on and both of the RGVs report their shortest paths according to the issued jobs by A star algorithms, which the shortest distances are calculated by each RGV followed the procedures shown in Figure 3. RGV dispatching system assigns the demand orders to the two RGVs to their nearest task start location by bidding function of RGVs. Later the two RGVs follow their paths planning to their task assigned start location on their own. As the results shown in TABLE I and TABLE II, the first task order of v1 to v15 is assigned to RGV at v36 because of minimum distance of F = 4314mm. Meanwhile the second task order of v12 to v8 is assigned to RGV at v16 for the shortest distance of 10000mm. The paths planning for both of RGVs are shown in bold typeface in path column of TABLE I and TABLE II.

C. *Workcentre Initiated Dispatching*

After the two RGVs arrive at their start locations of the demand orders respectively, the paths planning of individual RGVs for their task order are determined by RGV's dispatching system. In this stage, the workcentre initiated dispatching are instead of vehicles, and both of the RGVs follow their shortest paths according to the paths planning by RGV's dispatching system, which are also computed by A-star algorithms in the same procedures shown in Figure 3. The results of demand task path planning for RGVs are shown in the TABLE III and TABLE IV respectively. For the first task order of v1 to v15, the RGV from v36 follows the path of shortest distance 15514mm; for the second task order of v12 to v8, the RGV from v16 follows the path of shortest distance 13914mm. The paths planning for both of RGVs are shown in bold typeface in path column of TABLE III and TABLE IV.

TABLE I
THE VEHICLES INITIATED DISPATCHING OF TASK V1 TO V15

Vehicle initiated task to v1

RGV@	*path*	*F(n)*
v16	v16,v17,s6,v22,s7,v33,v34,s2,v35,v36,s1,v8,v9,v1	**14314**
v16	v16,v17,s6,v22,s7,v23,v24,s8,v29,v30,v31,v32,s2,v35,v36,s1,v8,v9,v1	23028
v16	v16,v17,s6,v18,v19,s9,v20,v21,s10,v12,v13,v14,v15, s3,v3,v4,s4,v5,s5,v6,v7,s1,v8,v9,v1	27028
v36	**v36,s1,v8,v9,v1**	**<u>4314</u>**

TABLE II
THE VEHICLES INITIATED DISPATCHING OF TASK V12 TO V8

Vehicle initiated task to v1

RGV@	*path*	*F(n)*
v16	**v16,v17,s6,v18,v19,s9,v20,v21,s10,v12**	**<u>10000</u>**
v16	v16,v17,s6,v22,s7,v23,v24,s8,v25,v26,v27,v28, s9,v20,v21,s10,v12v	17114
v16	v16,v17,s6,v22,s7,v33,v34,s2,v35,v36,s1,v8,v9,v1,v2,s3,v3,v4,s4,v10,v11,s10,v12	25114
v16	v16,v17,s6,v22,s7,v23,v24,s8,v29,v30,v31,v32,s2,v35,v36,s1,v8,v9,v1,v2,s3,v3,v4,s4,v10,v11,s10,v12	33828
v36	v36,s1,v8,v9,v1,v2,s3,v3,v4,s4,v10,v11,s10,v12	**15114**
v36	v36,s1,v8,v9,v1,v2,s3,v3,v4,s4,v5,s5,v16,v17,s6,v18, v19,s9,v20,v21,s10,v12	26314
v36	v36,s1,v8,v9,v1,v2,s3,v3,v4,s4,v5,s5,v16,v17,s6,v22, s7,v23,v24,s8,v25,v26,v27,v28,s9,v20,v21,s10,v12	37428

TABLE III
THE PATH PLANNING OF WORKCENTRE INITIATED DISPATCHING OF TASK V1 TO V15

Station initiated task: v1 to v15

path	*F(n)*
v1,v2,s3,v3,v4,s4,v10,v11,s10,v12,v13,v14,v15	**15514**
v1,v2,s3,v3,v4,s4,v5,s5,v16,v17,s6,v18,v19,s9,v20,v21, s10,v12,v13,v14,v15	22714
v1,v2,s3,v3,v4,s4,v5,s5,v16,v17,s6,v22,s7,v23,v24,s8,v25,v26,v27,v28,s9,v20,v21,s10,v12,v13,v14,v15	29828

TABLE IV
THE PATH PLANNING OF WORKCENTRE INITIATED DISPATCHING OF TASK V12 TO V8

Station initiated task: v12 to v8

path	*F(n)*
v12,v13,v14,v15,s3,v3,v4,s4,v5,s5,v6,v7,s1,v8	**13914**
v12,v13,v14,v15,s3,v3,v4,s4,v5,s5,v16,v17,s6,v22,s7,v33,v34,s2,v35,v36,s1,v8	25114
v12,v13,v14,v15,s3,v3,v4,s4,v5,s5,v16,v17,s6,v22,s7,v23,v24,s8,v29,v30,v31,v32, s2,v35,v36,s1,v8	32828

VI. CONCLUSION AND DISCUSSION

In this paper, a shortest path planning based on A-star algorithm is proposed and an example of OHT system of six encircle loops with two RGVs is simulated. The dispatching strategies of tasks planning and management are also detailed. The RGV based OHT system is already implemented as a demonstration site in the laboratory of a system integration and automation company in Taiwan. There are some interesting experiences as further works listed as below.

Delay due to communications of wireless networks will decrease the performance of dispatching especially more than six vehicles. Moreover, the available paths will reduce for later jobs if too many vehicles in limited routes. The side effects due to communication delay and finite available routes may be the topics of further study.

The better scheduling will be more efficient than free dispatching. That is, assigning paths for some specific tasks manually are sometimes better than shortest paths planning. It means that the shortest path may not be less time consuming. Other factors should be considered as more important weighting functions than shortest distance. A well-established database of dispatching rules may also improve the performance of OHT RGV dispatching system. It may be another topics worth to be studied in the future.

ACKNOWLEDGMENT

This work has been supported by the scientific knowledge and technology developing research project "Collaborated Control Techniques of Distributed Autonomous Robots" by Industrial Technology Research Institute (ITRI) with grant no. L353C81200.

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