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Agent Based Routing Control for Multi Mobile Robots in Transportation

Ken Sotobayashi *
Dept. of Electrical and Electronic Engineering
Okayama University
3-1-1, Tsushima-Naka Okayama, 700-8530

Masami Konishi
Dept. of Electrical and Electronic Engineering
Okayama University
3-1-1, Tsushima-Naka Okayama, 700-8530

Tatsushi Nishi
Dept. of Electrical and Electronic Engineering
Okayama University
3-1-1, Tsushima-Naka Okayama, 700-8530

Jun Imai
Dept. of Electrical and Electronic Engineering
Okayama University
3-1-1, Tsushima-Naka Okayama, 700-8530

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Auto Guided Vehicles (AGVs) are widely used in a semi-conductor fabricating factory and contribute to the stable production of a high quality semi-conductor products. In the near future, further expansion of the transportation system is expected accompanied with the rapid growth of semi-conductor industries. In such situation, the necessity of performing quick planning of transportation route and transportation control will be elevated. In this paper, practicable planning of the transportation route and transportation control are studied based on the decentralized agent method. Especially, the geometrical sizes of AGVs are considered in the determination of transportation routes and control strategy avoiding the occurrence of mutual collisions or deadlock of AGVs.

1 INTRODUCTION

In many semi-conductor fabricating lines, Auto Guided Vehicles (AGVs) are widely used for transportation to protect products from the defect caused by dusts. For the transportation control, it is necessary to find the appropriate routes of AGVs in which electrical energy for transportation is minimized. There are a lot of studies about vehicle routing problems. In actual transportation, there exist incessant disturbances caused by fabrication process troubles which may make it difficult to find a plausible transportation route for AGVs. Stochastic and evolutionary computation techniques like SA, GA have been successfully applied to this problem by solving combinatorial optimization problems [1] [2] [3] [4]. Recently, a new search algorithm based on the agent model analogous to Ant System has been proposed [5][6]. Semi-conductors fabricating line has been expanded because of the rapid growth of semi-conductors industries. As the result, new needs for high speed routing and flexible transportation control has been born. Further, in semiconductors fabrication bay, the geometrical size of mobile robot must be considered during transportation to prevent the collision with another robot in the narrow area.

In this paper, new method of agent-based transportation routing method using pheromone communication is proposed. The proposed method is applied to the model problems for a semi-conductor fabricating bay. The effectiveness of the method is checked by the numerical example and the experiment using mini sized mobile robots. The proposed method is applied to dynamic motion planning considering the geometrical size of the robot. Based on the experimental results, the practicability of the proposed method is discussed.

*soto@elec.cntr.okayama-u.ac.jp

2 Multi Robots Routing Method

In the following, mathematical model for mobile robots routing problem is described. The decentralized agent algorithm to solve the problem is also presented. At this stage, the geometrical size of robots are neglected in the route search process.

2.1 Transportation Routing Problem

Here we formulate the mathematical model for multi-vehicle transportation routing problem similar to that of the semiconductors fabricating bay. An example of the transportation bay is shown in Fig.1. As shown in the figure, the bay consists of plural nodes and arcs between adjacent nodes. The arc represents a candidate of route for two-ways traffic. Each robot can change its running direction only at a node. In this stage, further assumptions are made as follows.

1. The transportation time between two nodes is the same for all AGVs.
2. When a request for transportation service is given to one AGVs, the start node and the goal node are specified for it.
3. There exists only one route on one arc. Therefore, two AGVs cannot travel between any two nodes at a time, and two AGVs cannot travel between any two nodes in the opposite direction.

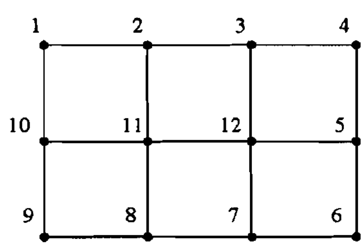

Fig.1: Transportation model for study

The objective of the transportation routing problem is to determine the routes for all AGVs that minimize the total transportation time under the restrictions stated above. The multi vehicles routing problem is formulated by the following Equations.

$$E = \sum_k n_f^k \rightarrow \min \qquad (1)$$

$$\sum_{m \notin M_i} x_{im}^k(n) = 0 \quad (\forall i, \forall k, \forall n) \qquad (2)$$

$$\sum_j x_{ij}^k(n) = 1 \quad (\forall i, \forall k, \forall n) \qquad (3)$$

$$\sum_k \sum_{j \in M_i} x_{ji}^k(n) \leq 1 \quad (\forall i, \forall n) \qquad (4)$$

$$\sum_{j \in M_i} x_{ji}^k(n-1) = \sum_{m \in M_i} x_{im}^k(n) \quad (\forall i, \forall k, \forall n) \qquad (5)$$

$$x_{ji}^k(n) \cdot x_{ij}^l(n) = 0 \quad (\forall i, \forall j, \forall k, \forall l, \forall n, k \neq l) \qquad (6)$$

$$\sum_{i \in M_j} \sum_{j \in T} x_{ij}^k(n_f^k) = 1 \quad (\forall k) \qquad (7)$$

Where, E is the objective function, $x_{ij}^k(n)$ represents 0-1 integer value which equals to 1 if AGV k travels from node i to node j in time period n, and otherwise 0. n_k represents the total transportation time of $\#k$ AGV, M_i represents the number of nodes connected to the node i and T shows goal node. Equation 3 indicates that the AGVs cannot travel only on the arc made by the connected nodes. Equation 2 means that there is only one arc from every other node to the target node for one AGV k. Equation 4 indicates only one AGV can travel from a node into the connected node at a time. Equation 5 represents that it is allowed for an AGV to travel among the connected nodes from time period $(n-1)$ to time period n. Equation 6 indicates that two AGVs cannot travel between two nodes at a time in the opposite direction. Finally, equation 7 shows that each AGV arrives to its goal node at time period n_f^k.

2.2 Decentralized Agent Algorithm

The solution which minimizes objective function given by equation (1) is searched using decentralized agent algorithm under the restrictive conditions in equations (2) to (7). This algorithm is derived referring the idea of the Ant system and that of the Simulated Annealing method. The details of the algorithm are explained in this section. Each AGV agent derives a plausible route in the following steps:

1. *Preparation of initial date:* Each AGV agent contacts the data board of the service request and obtains the starting node and the goal node of the request.

2. *Generation of an initial route:* Each AGV agent independently generates its route without considering the movement of other agents. At the same time the value of the pheromone information ph^k_{mn} is updated. Here, ph^k_{mn} represent the parameters indicating the existence of AGV k at node m in the time period n.
3. *Generation of a new route:*
 (1) Each AGV agent randomly generates a candidate of the node m traveling in time period $(n+1)$ from the node in time period n.
 (2) Each AGV obtains the pheromone information and calculate Δph using the Equation (7).

$$\Delta ph = ph^k_{mn+1} - \sum_{k'(k'\neq k)} ph^{k'}_{mn+1} \qquad (8)$$

 (3) If Δph satisfies the following equation, the candidate of the node is accepted, and otherwise rejected and return to (a).

$$\begin{aligned} d &\leq P \qquad (9) \\ P &= \begin{cases} 1 & ; \Delta ph \geq 0 \\ \exp(\Delta ph/T_p) & ; \Delta ph < 0 \end{cases} \end{aligned}$$

 P is a random number with probability of uniform distribution on the interval [0,1].
 (4) If the candidate node reaches the goal node, a new route is created and return to (a).
4. *Judgment whether the new route is adopted or not:* The difference of the transportation time, Δn_k is calculated. And the new route is adopted if the new solution satisfies the following Equation (9).

$$\begin{aligned} d &\leq Q \qquad (10) \\ Q &= \begin{cases} 1 & ; \Delta n_k \geq 0 \\ \exp(\Delta n_k/T_q) & ; \Delta n_k < 0 \end{cases} \end{aligned}$$

5. *Update of Pheromone Information:* The pheromone information is updated using the Equation (10).

$$ph^k_{mn} = E_v \cdot ph^k_{mn} + S \cdot W \qquad (11)$$

Here, E_v is the pheromone evaporation factor. W is the amount of amount of pheromone information. S is the adding ratio of pheromone information. This value is set to 1 when the AGV k is on the node m at the time n, otherwise set to zero.

6. *Judging the convergence:* If the new route generated at 3 is considered as the final solution, the algorithm is terminated, otherwise, return to 2.

Various constants such as W, T_p are determined empirically and listed in Table 1. These values are also applicable to more large scale problems [7].

2.3 Numerical Experiment

In this section, the performance of the proposed algorithm is investigated by using the following numerical experimental problem.

2.3.1 Two AGVs - Twelve Nodes Problem

The proposed algorithm is applied to a routing for two AGVs - twelve nodes problem. The results of the proposed algorithm are shown in Fig.2.

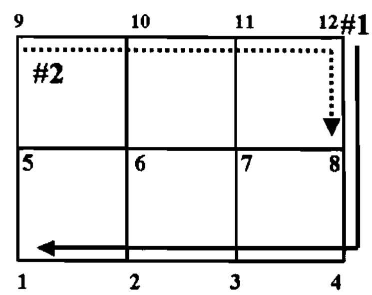

Fig.2: Results of 12 Nodes, 2 AGVs

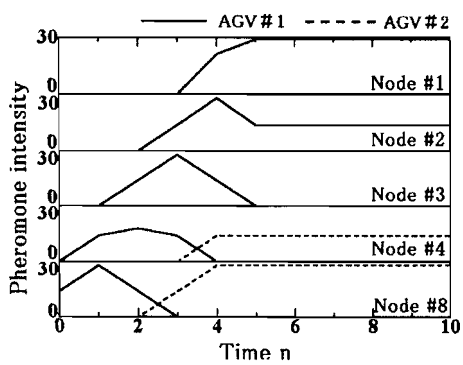

Fig.3: Transition of the pheromone information - 1

In Fig.2, the number at each node represents the node number and named from 1 to 12. #1 and #2 represents the AGV number. The arrows show the transportation routes of AGVs derived by the proposed algorithm. The results show that a feasible route with the shortest time is obtained using the proposed algorithm and there occurs no collision of AGVs. Fig.3 shows the transition of the pheromone information on each node for two AGVs. As shown in Fig.3, each AGV is traveling into the nodes where pheromone information is higher than that of other AGV. Using the pheromone information, each AGV can search its own route independently considering other AGVs.

2.3.2 Comparison with The Proposed Algorithm and GA

In order to evaluate the effectiveness of the proposed algorithm, we compared the solutions generated by the proposed algorithm with those by the GA which is applied to the same problem [1]. In the application of GA all AGVs are treated simultaneously. That is, the individuals are array of chromosome representing moving direction of AGVs at each node. The parameters used for the GA are shown in Table 1.

Table 1: Parameters used for the numerical exanples

For Proposed Algorithm:
W: 10, S: 0.6, E_v: 0.7, T_q: 7.0
T_p: range from 0.1 to 0.4
For Genetic Algorithm:
Number of population: 250, Crossover rate: 0.7
Mutation rate: 0.3

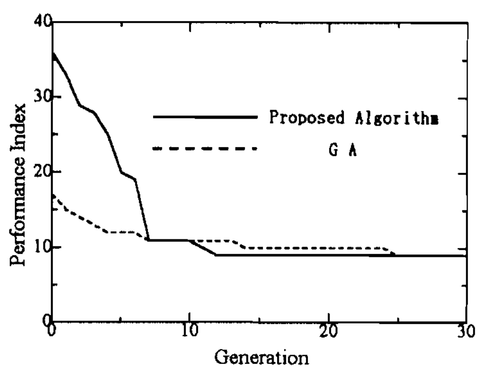

Fig.4: Comparison with the proposed algorithm and GA

The proposed algorithm and the GA are applied to the two AGVs - twelve nodes problem. The comparison of performance obtained by the both algorithms is shown in Fig.4, which shows that the proposed algorithm can generate feasible solution in practicable computation time and is shorter than that by GA. Also, the computation time of the proposed algorithm and GA are shown in Table 2. The number of generations for GA is determined so that the performance of solutions generated by the GA becomes almost the same as that generated by the proposed algorithm. Pentium III (1GHz), AT processor is used for the computation. From the results of Table 2, the computation time of proposed algorithm based on decentralized optimization is much shorter than that of GA.

Table 2: Comparison of the computation time with GA

	Computation time[s]
Proposed Algorithm	0.05
Genetic Algorithm	0.4

This algorithm is successfully applied to actual semiconductor fabrication line composed of 7 AGVs and 143 nodes were also successfully made [7].

3 Routing Model Reflecting Geometrical Robots Size

In the preceding sections, we treated AGV as sufficiently small body that means geometrical size of robot is neglected during route searching. In this section, geometrical size of AGV is reflected on routing for transportation.

3.1 Extension of the Problem

In the above, we proposed the routing algorithm by the decentralized agent as the transportation route planning method, and have shown the effectiveness of the algorithm by numerical experiment. In that case, the size of AGV is set as sufficiently small, and performed the route planning assuming the distances between nodes on the transportation ways are equal. However, in an actual transportation system, AGV has a geometric size, and, of course, it is considered that distances between nodes on the transportation route need not be the same. In the semiconductors fabricating bay the distances between nodes are to be minimized from the needs of cleanness in the bay. In that case the problem to be solved is how to navigate each AGV swiftly responding to the transportation request. Therefore, we must consider the geometrical size of AGV in the determination of their transportation route.

3.2 Collision Avoidance Routing Algorithm

3.2.1 Creating of Virtual Nodes

Here, we consider the way of collision avoiding routing for AGVs. First, the transportation lines for route planning is shown in Fig.5. In this case, distances between the nodes of vertical direction and horizontal one are set to 12 units and 16 units simultaneously. For the routing problem where the distances between nodes are not equal, the method explained before cannot be directly applied. To solve this problem, virtual nodes on the transportation arcs are prepared. That is, arcs between nodes are divided into many virtual nodes the distance of them is shorter than that between original nodes. The way of dividing arc is shown in Fig.5.The distance between two adjacent virtual nodes is set at around 0.1 times of robots size empirically. The conveyance time n of AGV increases by one increment every time when AGV passes through a virtual node. It is assumed that AGV can not stop at any virtual node.

Next, the size of a mobile robot is set up. The size of AGV was also determined by using a virtual node for a measure. The size of AGV is determined as shown in Fig.6. A rotation center is the center of locus, when running. When a mobile robot changes the course, it rotates around the rotation center.

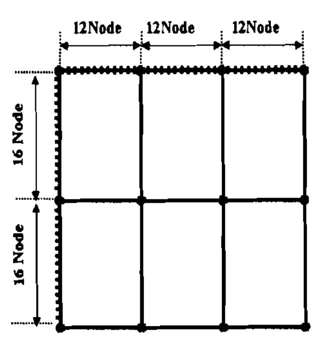

Fig.5: Transportation bay with virtual node

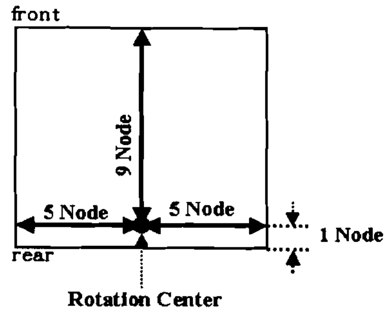

Fig.6: Size of AGV

3.2.2 The Adding of Pheromone Information and Its Detection

Basically, the algorithm of a route planning is the same as that explained in the previous section. However, the method of adding and detecting of pheromone information are changed as follows.

1. **Accumulation of pheromone information:** The update the pheromone information is carried out according to the following formulas.

$$ph_{mn}^{k} = E_v \cdot ph_{mn}^{k} + W \exp(-t/T_r) \qquad (12)$$

   At time instant n, AGV k is running through a certain node. Node m is apart from the node by t times of distance between two adjacent virtual nodes. As shown in equation (12), the pheromone information is added for nodes around the one where the AGV is running through. The maximum value of t is given as T_{max} and T_r is a constant.
2. **The detecting method of pheromone information:** When the AGV arrives at real node, the candidate node next to go is to be decided. The agent estimates the amount of its pheromone information at the candidate node, and compares with that of other AGVs. Then, AGV determines whether to move to the candidate node. During comparing pheromone in formations, the detecting method of its amount at a candidate node is changed. First, the AGV checks the amount of it own information for some nodes around the candidate node. Then, AGV detects the amount of the pheromone information of other AGV similarly, compares them, and decides whether to move or not.

3.3 Numerical Experiment

To check the performance of the new algorithm, numerical experiment is carried out.

3.3.1 Two Robots - Twelve Nodes

The simulation of a route plan is performed. The problem is as shown in Fig.7. As shown in this figure, two AGVs are started from the position where front end of them are faced each other.

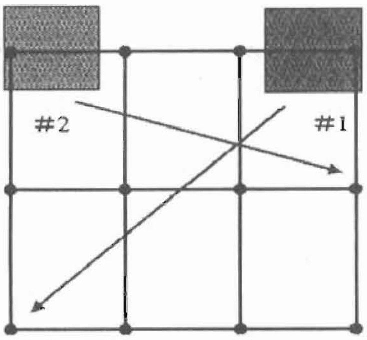

Fig.7: Statement of the problem

Table 3: Parameters used for the numerical exanples

W: 10, E_v: 0.7, T_r: 25, $Tmax$: 16	
T_p: 0.1, T_q: 25, n_{curve}: 6	

Parameters used for numerical example are shown in Table 3. Where n_{curve} is time required when AGV rotates 90 degrees to the right or the left direction.

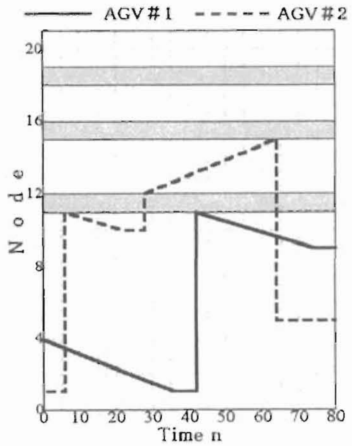

Fig.8: Result of route planning

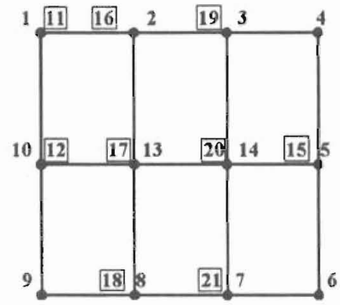

Fig.9: Setup of number of nodes

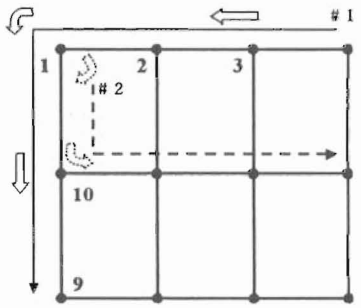

Fig.10: Routing results for AGVs

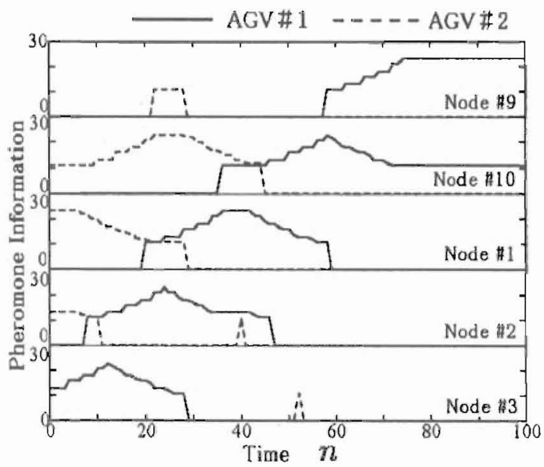

Fig.11: Transition of the pheromone information - 2

Simulated results are shown in the time chart of Fig.8. The node number written along the vertical axis of the time chart is same as shown in Fig.9. The number surrounded by the square is a tentative node number for clarifying that two AGVs did not pass by each other between nodes in the time chart. From the result of Fig.8, it is clear that front ends of two AGVs are faced each other at the first time, and AGV #2 is force to change its running direction. Therefore, there exist the state at the start node where it stops and cease to move for a few time intervals. Then, both of AGV start to go to their goal nodes.

It is clarified from the result that AGVs can move without causing interference even when the size of AGV is considered. The resulting routes in Fig.10 are considered to be the appropriate solution for this problem.

Fig.11 shows the transition of the amount of pheromone information at several nodes during routing. These results are obtained after thirty numbers of searches. These five nodes are the nodes through which AGV #1 runs. As for the amount of pheromones of AGV#2 at these nodes, it can be seen at node #1 then it moves to node #10. This means that the pheromone concentration of AGV#2 at some nodes are changing with time. Finally, judging from the accumulated amount of pheromone information for each AGV at each node, the routes of both AGVs are determined.

3.3.2 Four Robots - Twenty Nine Nodes

In order to confirm the applicability of the algorithm to the transportation bay with a real scale, a numerical experiment in which four mobile robots run in the transportation bay consisting of 29 nodes is tried. This is similar scale as one of the DRAM fabrication bay. The experimental condition is shown in Fig.12, and the result is shown in Fig.13. If #1 and #2 AGV run through the shortest route to their destination, which may occur collision. So, in that case, there exist a case where either #1 or #2 have to get out of the way for another mobile robot. Fig.13 shows that mobile robot #1 has got out of the way for #2. Moreover, #1 may collide with #3 when taking a new route, it was stopped a little at the place A, avoiding collision with #3. Consequently, near optimal routes were planned for whole AGVs showing the validity of the algorithm.

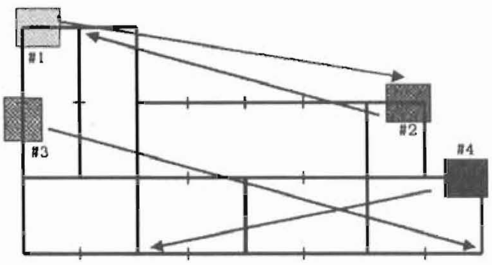

Fig.12: Numerical experiment assuming DRAM fabrication bay

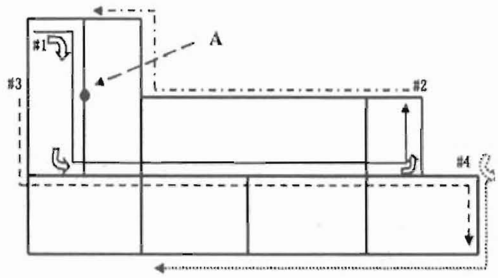

Fig.13: Numerical result

4 Running Test (Two Robots - Twelve Nodes)

In the preceding sections, we explained the route planning method for considering geometrical size of AGV. Here the route planning in case of two sets of AGV run the transportation lines with twelve nodes are tried using mobile robots. That is, laboratory experiments using two mobile robots in the same situation states above. In the following, to check whether the route planned result is good or not, experimental result is described.

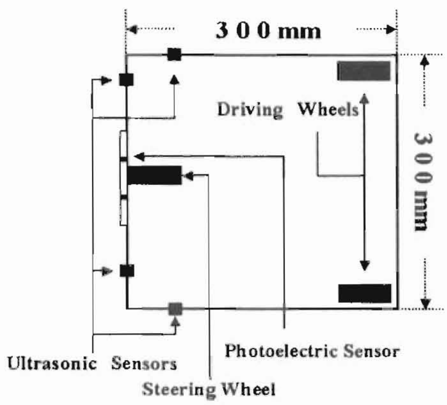

Fig.14: Construction of mobile robot

The function of the mobile robot that uses for an experiment is briefly explained. The mobile robot has a three-wheels. The outside figure in the bottom of the robot is shown in Fig.14.

4.1 Transportation Bay for Experiments

Here, the transportation bay for experiments is explained. The situation of a bay which conducts a laboratory experiment is shown in Fig.15.

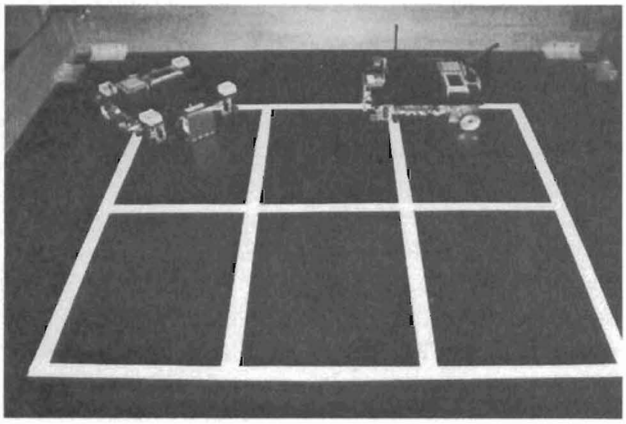

Fig.15: Overview of the experimental bay

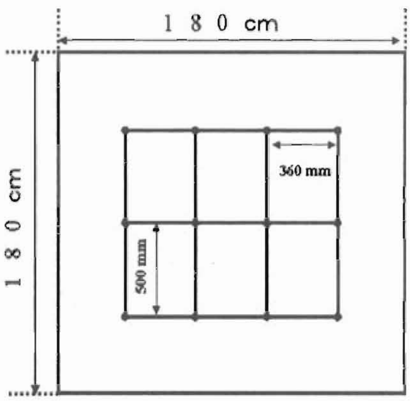

Fig.16: Dimension of experimental bay

The detailed size of the transportation bay for experiments is shown in Fig.16. The horizontal distance between nodes is 36cm, and is 108cm in total. On the other hand, the vertical distance between nodes is 50cm and is 100cm in total. Moreover, the wooden frame is prepared outside of a transportation bay, a size is 180cm × 180cm and its height is 20cm. This is used for the recognition of position by ultrasonic sensor of the robots. Two mini sized robots run in the bay

4.2 Experimental Result

Running route is planned in the same manner using the method described before and experiment was carried out to check if the mobile robots can move without collision. The experimental result is shown in Figures 17 to 19. The figures show a mobile robot's locus by detecting the run position from a mobile robot's ultrasonic sensor. Figures 17 to 19 express three loci by dividing total run time. From these figures, it is known that mobile robots are running safely without collision even if changing the moving direction.

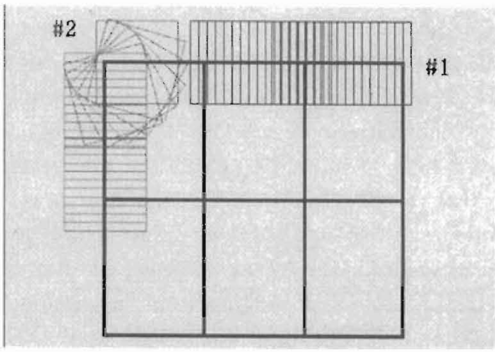

Fig.17: Result of experiment (initial stage)

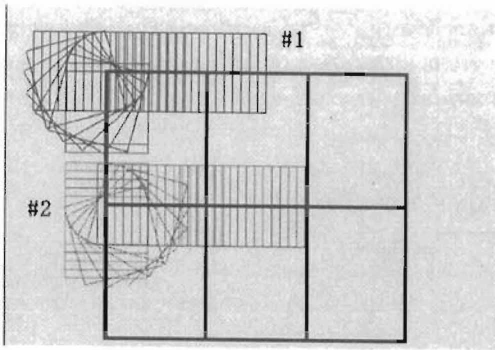

Fig.18: Result of experiment (middle stage)

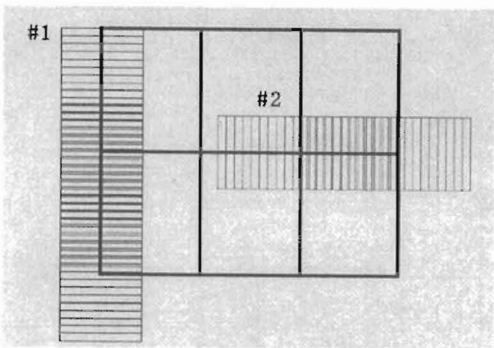

Fig.19: Result of experiment (final stage)

5 Effect of Robot size

To check the effect of robot size on the appropriate route for transportation, computer simulation is conducted. In the simulation, robot size is changed as shown in Fig.20. Sizes of two robots are expanded from 1 to 1.6 times of that treated in the previous sections. The transportation bay is the same as shown in Fig.16. The same procedure is made for this case. The start and goal nodes are also same with that of previous section. The obtained transportation route and the transition of pheromone information for two robots are shown in Figures 21 and 22 simultaneously.

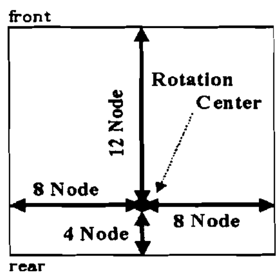

Fig.20: Changed size of AGV

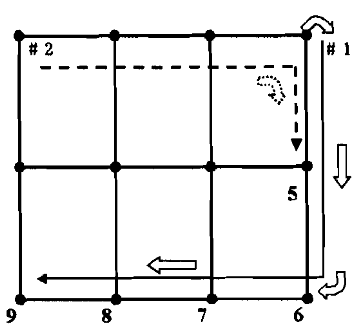

Fig.21: Result of simulation

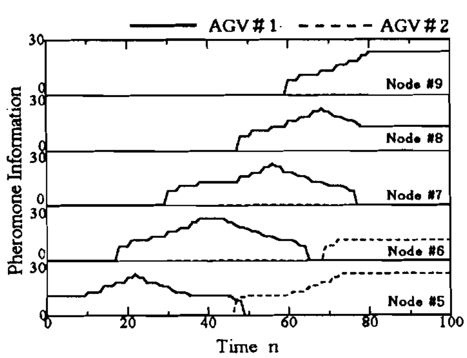

Fig.22: Transition of the pheromone information - 3

From these results, it is apparent that reasonable routing is attained avoiding collision of robots during transportation. Comparing these results with that of smaller robots size in Fig.10, it is demonstrated that transportation route is changed according to the sizes of the robots to avoid the collision of them during transportation.

6 Conclusion

New method for multi mobile robots routing control in transportation has been presented based on the decentralized agent. In the proposed algorithm, each AGV is represented as a decentralized agent and it generates a candidate of its own route so as not to interfere with other AGVs. First, we have applied the proposed algorithm to the route-planning problem for multi AGVs whose sizes are neglected. Using the proposed algorithms, feasible routes without interference among AGVs are obtained in a computation time shorter than that of the GA without lowering the performance level. Furthermore, we extended proposed algorithm, in order to consider the size of AGV. As the result of conducting a numerical experiment with this algorithm, the route without collisions between AGVs has been derived. And the laboratory experiment using the mobile robots has been conducted. The mobile robots has been controlled such as we were expected from the numerical simulation.

Acknowledgment

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