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Flexibility Evaluation of Action Control Rule for Autonomous Multiple Mobile Robots Based on Decision-Making Function for Panel Cruising Problem

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Abstract

This paper describes the action control rules of each robot in a multiple mobile robot system for the panel cruising problem. To achieve a task by a multiple mobile robot system, it is important to decide the action control rules to avoid collision among the robots. We propose action control rules based on an evaluation function to decide the moving direction. To confirm the flexibility of the proposed action control rules, we focus on the evenness of panel points, which are passing counts to panels, and the energy consumption as the task efficiency. Moreover, we discuss the task efficiency for several workspaces and numbers of robots by comparison of the proposed rule with a simpler rule based on only the panel points.

1. Introduction

Recently, the activity of robots has had an increasing impact on human society and in most robot systems, a complicated task is executed using one robot. However, there may be physical and time limits depending on the task contents. Therefore, the use of a multiple mobile robot system to perform tasks has attracted attention [1]. Here, sweeping and security are the simplest tasks to employ such a system, for allowing them to be achieved in a short time even in a large workspace. In either task, to ensure efficiency, each robot needs to move on workspace evenly, and it is better to reduce energy consumption. Therefore, improvement of the task efficiency and the avoidance of collision with other robots and static obstacles are essential factors.

With this background, we focus on a panel cruising problem, in which it is desirable that each robot sweeps evenly with low energy consumption in the workspace, and we propose an action control rule based on an evaluation function. This rule has four evaluation values to efficiently decide the movement direction for each robot. The usefulness of the proposed action control rule is evaluated by comparing the task efficiency for several workspaces with a rule based on only the panel points.

2. Problem Statement

In this paper, we consider that a multiple mobile robot system sweeps a workspace evenly with low energy consumption. This problem can be reduced to the panel cruising problem. In the panel cruising problem, the workspace is virtually divided into square panels as shown in Fig.1, and robots cruise around each panel [2]. Each panel has a panel point which is the passing count to panels. The robot cannot enter a panel representing a wall or obstacle. The moving direction of the robot is limited to four direction: forward, right, left, and back. In addition, the detection area of a robot consists of the 12 local panels shown in Fig.2 in consideration of the sensor performance. The robot can detect panel points, the positions of obstacles and other robots in its detection area. All robots in the workspace move to the next panel synchronously in one step. The task of each robot is to make the points of all panels to 10 as few actions in as possible while avoiding collision.

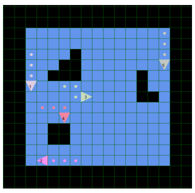


Figure 1: Workspace

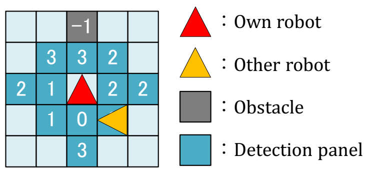


Figure 2: Detection area

3. Action Control Rule

To avoid collision with other robots and to decide the moving direction efficiently, we propose an action control rule based on the evaluation function e_{D} shown in Eq. (1),

$$e_{\mathrm{D}} = \frac{1 - d_{\mathrm{D}}}{\sum_{i=1}^{4} w_i f_{i\mathrm{D}}} \tag{1}$$

where d_{D} is the collision risk, $f_{i\mathrm{D}}$ (i = 1–4) are the evaluation values of the panel point, energy consumption, standard deviation and the degree of freedom of moving as shown in

Table 1, and w_i are the weight coefficients of the evaluation values. Index D means a moving direction such as forward (D=F), right (D=R), left (D=L) or back (D=B). The evaluation function e_D is calculated for the four directions. Each mobile robot moves in the direction whose value of the evaluation function e_D is the largest.

Table 1: Evaluation index

Index	Evaluation value
Point	f_{1D}
Energy consumption	f_{2D}
Standard deviation	f_{3D}
Movement liberty	f_{4D}

3.1 Collision risk

If two or more robots move to the same panel, they will collide. Therefore, we define the collision risk d_D for the positions of the other robot on the surrounding panel as shown in Fig.3 to avoid collision.

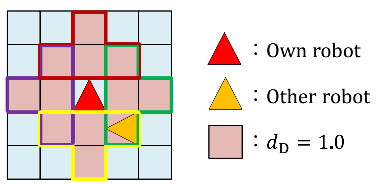
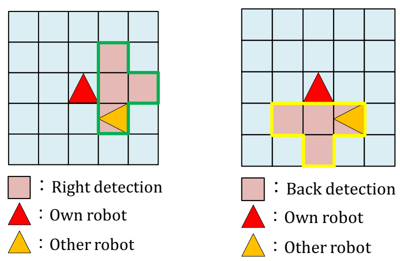


Figure 3: Collision risk

For instance, for the situation shown in Figs.4(a) and 4(b), robots may collide with each other if the own robot moves to the right or back panel. Therefore, the collision risks d_R and d_B are set to 1.0. On the other hand, the evaluation functions e_R and e_B are 0.0 from Eq. (1).



(a) Right (b) Back

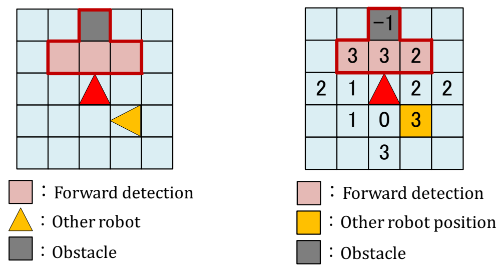
Figure 4: Example of a situation with a collision risk

3.2 Points

Using the detection area shown in Fig.2, a robot can consider panel points for its next two actions. Therefore, the robot can plan its path for two actions based on a panel point, and the evaluation value of point f_{1D} is the minimum value of the panel points due to the two actions calculated by

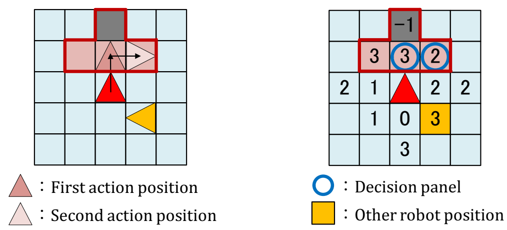
$$f_{1D} = p_{1D} + p_{2D} \tag{2}$$

where p_{1D} and p_{2D} are panel points of the first and second actions, respectively. When the forward direction (D=F) in the situation shown in Figs.5(a) and 5(b) is evaluated, p_{1F} is set to 3 because the first action is the forward direction. Also, p_{2F} is set to 2, which is the minimum value for the second action as shown in Figs.6(a) and 6(b). As a result, the evaluation value f_{1F} is 3 + 2 = 5. If there are a number of panel points for the decision of p_{2D}, the robot gives the priority for the direction as forward > right > left.



(a) Robot location (b) Detection of point

Figure 5: Example of the situation focusing on points



(a) Robot location (b) Detection of point

Figure 6: Moving pattern for two actions

3.3 Energy consumption

The evaluation value f_{2D} is calculated by considering the energy consumption of the path decided by the evaluation of points. Here, the energy consumption of forward movement is set to 1.0 as a reference value. In addition, the energy consumption for each 90° turn is 0.785 in consideration of the turning radius of a two-wheel-drive robot. The energy consumption for each action is listed in Table 2.

Table 2: Energy consumption for each action

Action	Number of action	Energy consumption
Forward	1	1.000
Right	2	1.785
Left	2	1.785
Back	3	2.570
Stop	1	0.000

Here, the number of action is increased by 1 in case of the movement to next panel or 90 ° turn or the stop and it is used as an evaluation index for the time requirement of a task. f_{2D} is calculated by

$$f_{2D} = e_{1D} + e_{2D} \tag{3}$$

where e_{1D} and e_{2D} are the energy consumption for the first and second actions respectively. For the situation shown in Fig.5, the first action is forward and the second action is right, as decided by the evaluation of points. As a result, the evaluation value f_{2F} is $1.000 + 1.785 = 2.785$.

3.4 Standard deviation

The evaluation value f_{3D} considers the standard deviation of points after two actions decided by the evaluation of points. f_{3D} is the standard deviation of points in the detection area of the robot and is calculated by

$$f_{3D} = \sqrt{\sum_{j=1}^{N} \frac{(s_j - \overline{s})^2}{N}} \tag{4}$$

where f_{3D} is only calculated for the panels that are not static obstacles. For the case in Fig.5, the panel points in the detection area become those in Fig.7 and f_{3F} is calculated as 1.168.

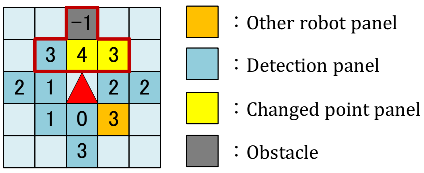
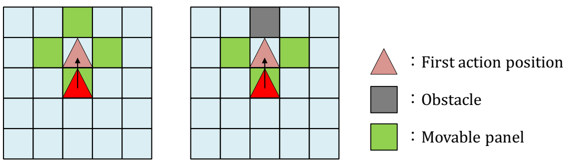


Figure 7: Point placement for detection area after two actions

3.5 Degree of freedom of moving

The evaluation value f_{4D} is calculated by considering the number of selectable moving directions (the degree of freedom of moving) for the next action. As shown in Fig.8(a), if there are no static obstacles in the adjacent panels for the next, the robot can move in all directions, i.e., the degree of freedom of moving f_{4F} is 4. If there is a static obstacle in the forward direction, as shown in Fig.8(b), the evaluation value f_{4F} is 3. For the case in Fig.5, the situation is the same as that in Fig.8(b).



(a) $f_{4F} = 4$ (b) $f_{4F} = 3$

Figure 8: Degree of freedom of moving for robot

3.6 Summary

For the case in Fig.5, the value of the evaluation function d_D and evaluation values $f_{1D} - f_{4D}$ are shown in Table 3. Here, the forward action should be selected from the viewpoint of f_{2D} and f_{4D}. On the other hand, from the viewpoint of f_{1D} and f_{3D}, the back action should be selected. However, the forward or left action should be selected to avoid collision. Therefore, it is important to decide the weight coefficients of evaluation values.

Table 3: Evaluation values for all directions

Direction	d_D	f_{1D}	f_{2D}	f_{3D}	f_{4D}
Forward	0.0	5	2.785	1.168	3
Right	1.0	4	2.785	1.029	4
Left	0.0	2	3.560	0.833	4
Back	1.0	1	4.345	0.715	4

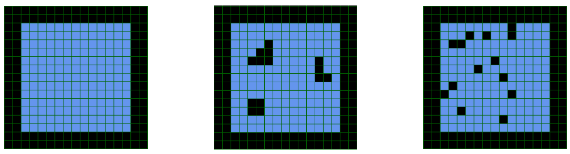
4. Decision Method of Weight Coefficients

In order to decide the weight coefficients w_i suitable for the proposed evaluation function, computer simulations are conducted with four settings of the weight coefficients as shown in Table 4. Here, each weight is intentionally set to concentrate on one evaluation value to evaluate the behavior in the simulation.

In the simulation, the number of robots is set to five with 1000 patterns of initial positions of robots. The simulation results for each evaluation index are shown in Table 5, where each value shows the average number of steps after which the task is achieved; a result with fewer steps is more efficient. Therefore, we decide the weight coefficients as a reciprocal ratio of the number of steps, and the weight coefficients for each workspace are shown in Table 6.

Table 4: Settings of weight coefficients

Index	w_1	w_2	w_3	w_4
Point	0.7	0.1	0.1	0.1
Energy consumption	0.1	0.7	0.1	0.1
Standard deviation	0.1	0.1	0.7	0.1
Degree of freedom of moving	0.1	0.1	0.1	0.7



(a) workspace1 (b) workspace2 (c) workspace3

Figure 9: Patterns of workspaces

Table 5: Average number of steps for each evaluation index

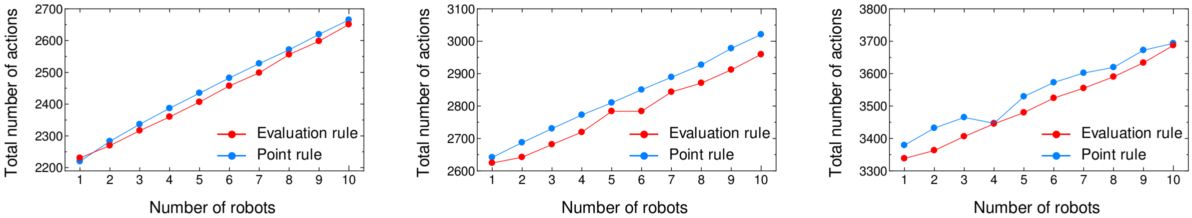
Index	workspace1	workspace2	workspace3
Point	521.6	520.5	561.3
Energy consumption	510.3	635.0	829.4
Standard deviation	522.6	466.9	517.2
Degree of freedom of moving	655.1	952.5	784.9

Table 6: Weight coefficients for each workspace

workspace	w_1	w_2	w_3	w_4
1	0.269	0.269	0.269	0.193
2	0.294	0.242	0.328	0.161
3	0.288	0.192	0.308	0.212

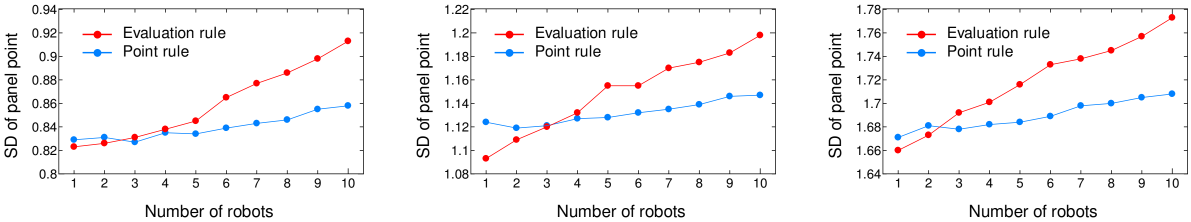
5. Simulation Results

In our evaluation of the proposed action control rule, a simple rule that decides an action based on the point comparison of panels in four directions is used [3]. To evaluate the energy consumption and evenness of the panel points, we focus



(a) Result in workspace1 (b) Result in workspace2 (c) Result in workspace3

Figure 10: Total number of actions at time of the task achievement



(a) Result in workspace1 (b) Result in workspace2 (c) Result in workspace3

Figure 11: SD of panel point at time of the task achievement

on the total number of actions of the robots and the standard deviation of the panel points. Figures 10 and 11 show the simulation results. Here, the result is evaluated from the average value of the simulations for 1000 patterns of initial positions to reduce the dependence on the initial position of each robot.

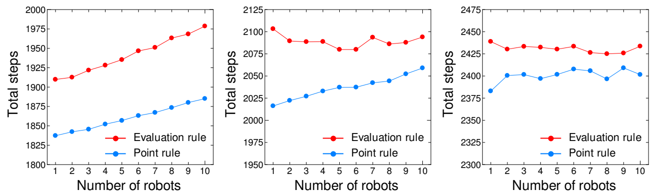
In Figs.10(a) – 10(c), the total number of actions using the proposed rule is lower for almost all results. From these results, we can see that each robot can decide the action while considering energy consumption. However, in Figs.11(a) – 11(c), the standard deviation of panel points is higher in case of three or more robots and the variance of panel points increases as the number of robots increases for the proposed rule.

To discuss the factor determining the variation of panel points, Figs.12(a) – 12(c) show the total number of steps for each workspace. In every case, the total number of steps is higher for the proposed rule. In case of using the proposed rule, the robot considers the energy consumption and selects the forward action relatively frequently. Because the robot cannot move to minimum panel points occasionally, it cannot suppress the standard deviation of panel points. Therefore, for the proposed rule, when the total number of steps is higher, the panel point is tends to vary and robots cannot move evenly compared with the case of the point comparison rule.

6. Conclusions

In this paper, we proposed an action control rule based on an evaluation function with four evaluation values. From the simulation results, it was confirmed that the energy consumption for robots is reduced. However, robots cannot cruise the panels evenly owing to the increased number of steps.

Future works are to design an algorithm to suppress the increase in the number of steps, and to implement the proposed rule on real robots to confirm the task efficiency using a real multiple mobile robot system.



(a) workspace1 (b) workspace2 (c) workspace3

Figure 12: Simulation results for the total number of steps

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