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Invited Paper

Adaptive Control of a Group of Robots for Formation Navigation

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Abstract. Cooperative work of multiple robots has various advantages. The cooperative work of multiple robots can shorten the operation time and be simplified compared with the case of using a single robot. However, control of a group robot is not easy because of changes of characteristics.
The main purpose of this research project is to develop the group robots control system. In particular, development of a system that allows each robot to move as a group even if the characteristic changes is occurred. Two adaptation methods were confirmed their effectiveness.

1. Introduction

Recently, there are a lot of robots around us. Some of them can work alone and others work as a group. When we use a single robot, easy to control it because we don’t have to concern relations with other robots. However, there is a limit on the work by a single robot. Furthermore, its structure tends to be complicated. On the other hand, when we control a group of robots, we have to concern relations with others. Thus, it’s not easy to control a group of multiple robots. However, a group of robots has many advantages. It can shorten the operation time and be simplified compared with the case of using a single robot. For these reasons, research on group robot control has great significance.

The main purpose of this research is to develop a group robots control system that can adapt to changes of surroundings or differences of characteristics. In this research, one group consists of three mobile robots. These are two-wheel independent driven robots. The mechanism of each robot is simple, and each robot trace their own target. Thus, by controlling these targets, we can control the three robots. In this paper, we proposed two methods to adapt to the change when the characteristic of one robot has changed and checked validity of those methods by computer simulation.

2. System Summary

2.1. Robot

Fug.1 shows the Two-wheel independent drive robot which are used in this research. A two-wheel independent drive robot can turn in a small radius and be controlled easily. On the other hand, it is inferior in straight-drive ability. The speed and direction of the robot are controlled by regulating velocity of its left and right driving wheels. Now, the direction of robot’s target is shown by Eq. (1).

$$G\theta = \tan^{-1}\frac{Gy - y}{Gx - x} \tag{1}$$

Now, (x, y) is coordinates for a present position of the robot, and (Gx, Gy) is coordinates for a position of the target. When the distance between two wheels is 2R, the speed of the robot V and the angular speed ω are expressed in Eq. (2) and (3) respectively.

$$v = \frac{1}{2}(vr + vl) \tag{2}$$

$$\omega = \frac{1}{2R}(vr - vl) \tag{3}$$

These equations show that a two-wheel independent drive robot can trace its target by being controlled its left and right driving wheels. At this time, the velocities of the center of the robot in the X- and Y-directions are expressed in Eq. (4) and (5) respectively.

$$\dot{x} = v\cos\theta \qquad (4)$$

$$\dot{y} = v\sin\theta \qquad (5)$$

$$\dot{\theta} = \omega \qquad (6)$$

2.2. Motor

Fug.2 shows a block diagram of DC servomotor.

From this block diagram, a transfer function is determined as Eq. (7).

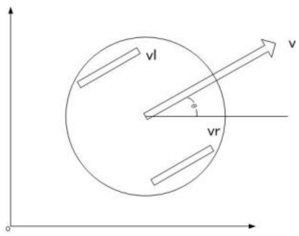
$$\frac{\Theta(s)}{\mathrm{E}_i(s)} = \frac{\mathrm{K}_\tau}{s\{(\mathrm{L}s+R)(\mathrm{J}s+\mathrm{C})+\mathrm{K}_\tau\mathrm{K}_b\}} \qquad (7)$$

2.3. Whole system of a group of robots

Fig.3 shows whole control system. In this research, three robots aim to keep an equilateral triangle.

Firstly, supervisor gives each robot a spot where it should be in order to keep the formation as a virtual target. Then the robots calculate the proper speeds and directions from deviations between their target and their present position. And by suppling proper voltages to motors, the right and left wheels move at speeds of VR and VL respectively. Then the robots move as Eq. (2) and (3) show.

3. Control of Robots



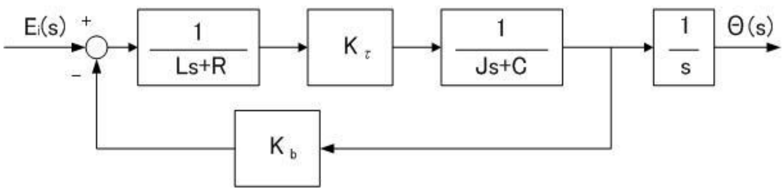


Fig. 1 Two-wheel independent drive robot   fig.2 Block diagram of servo motor

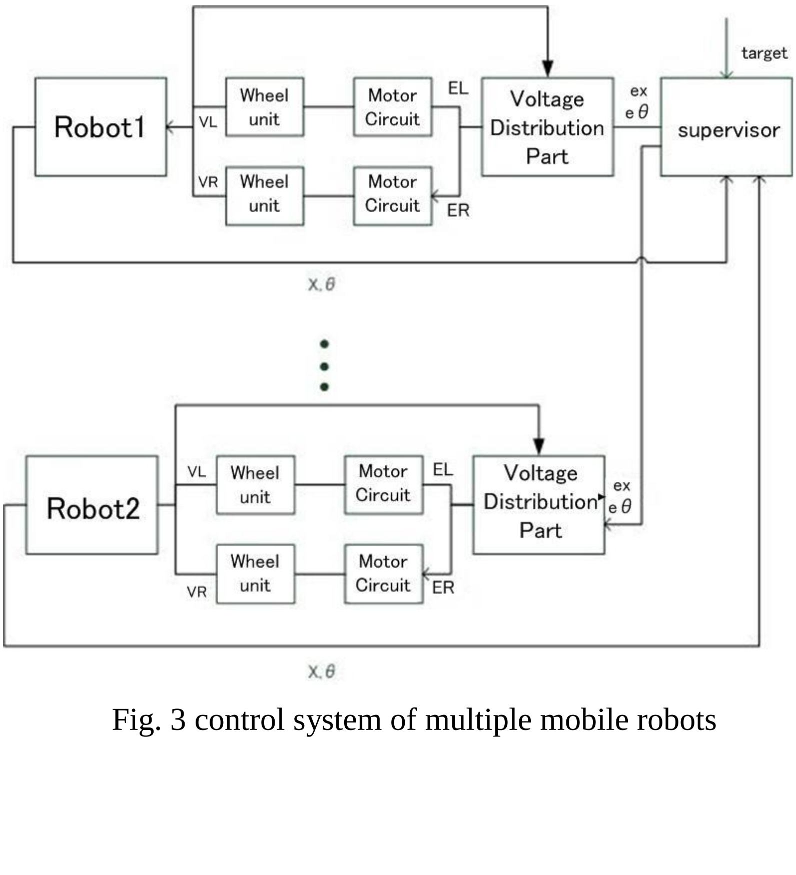


Fig. 3 control system of multiple mobile robots

3.1. Fuzzy Control

As is described in the following paragraph, robots are controlled by fuzzy control method.

The membership functions for fuzzy control are decided experimentally. Through a series of experimentations, we select optimum parameters for membership functions. Rules for fuzzy control were decided in the manner of human operation.

3.2. Decision on Speed Commands

In this research, the speed command change quantities are decided by the fuzzy control with distances between each robot and its target and the current speed of the robot as antecedents. Membership functions and a rule for the speed commands are shown in Fig.4 and table1. Where NR, MD, FR mean near, middle, far, SL, MD, FS mean slow, middle, fast and NB, NS, ZO, PS, PB mean negative big, negative small, zero, positive small, positive big respectively.

3.3. Decision on Angular Speed Command

In this research, the angular speed command change quantities are decided by the fuzzy control with deviation angles between robot advancing directions and robots' target directions and the deviation angle speeds as antecedents. Membership functions and a rule for the angular speed commands are shown in Fig.5 and table2. Where L, M, R mean left, middle, right and NB, NS, ZO, PS, PB mean negative big, negative small, zero, positive small, positive big respectively.

The consequent is same as the speed command.

3.4. Voltage Distribution Part

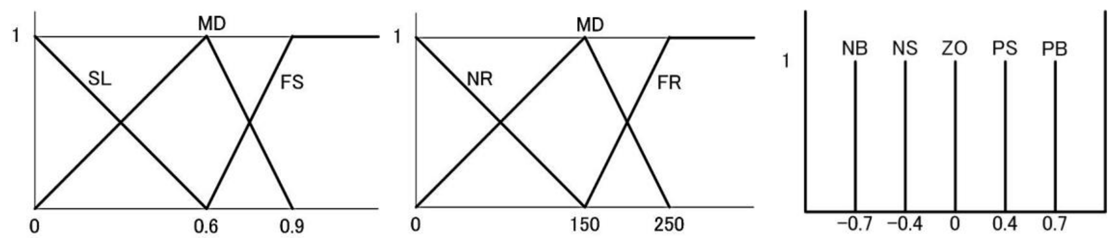
From Eq. (2) and (3), speed commands for left and right wheels v_{lc} and v_{rc} are as following equations, when the distance between two wheels is 2R.

$$v_{rc} = v_c + R\omega_c \quad (8)$$

$$v_{lc} = v_c - R\omega_c \quad (9)$$

The drive voltages are decided by the fuzzy control with deviations between wheel speed commands and wheel speeds and the deviation speeds as antecedents.

Membership functions and a rule for the drive voltages are shown Fig.6 and table3. Where N, Z, P mean negative, zero, positive respectively.



(a)antecedent on speed (b) antecedent on distance (c) consequent

Fig. 4

Table. 1 rule for speed command

		speed		
		SL	MD	FS
distance	NR	ZO	NS	NB
	MD	PS	ZO	NS
	FR	PB	PS	ZO

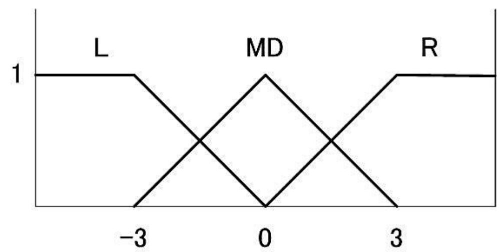


Fig. 5 antecedent for angular speed command

4. Adaptive Control of a Group of Robots

4.1. Control of a Group Robot

In this research, the spots that each robot should be in order to keep a formation like Fig.7 are calculated as targets. First, speed and advance direction of a leader robot are decided by fuzzy inference. Then targets for the other two robots are calculated by following equations.

- second robot

$$\left(\boldsymbol{x}-\sqrt{\mathbf{3}}\boldsymbol{d}\cos\left(\boldsymbol{\theta}-\frac{\pi}{6}\right),\boldsymbol{y}-\sqrt{\mathbf{3}}\boldsymbol{d}\sin\left(\boldsymbol{\theta}-\frac{\pi}{6}\right)\right) \tag{10}$$

- third robot

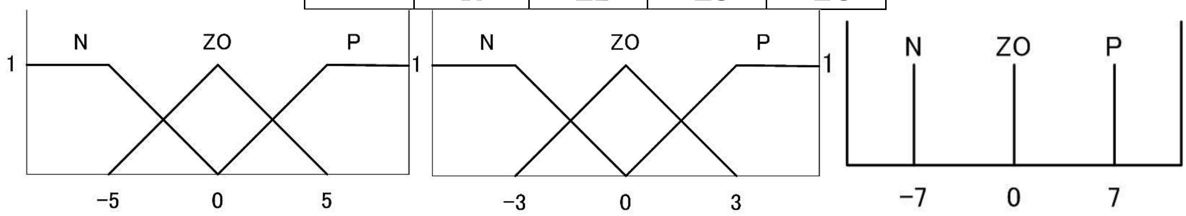
$$\left(\boldsymbol{x}-\sqrt{\mathbf{3}}\boldsymbol{d}\cos\left(\boldsymbol{\theta}+\frac{\pi}{6}\right),\boldsymbol{y}-\sqrt{\mathbf{3}}\boldsymbol{d}\sin\left(\boldsymbol{\theta}+\frac{\pi}{6}\right)\right) \tag{11}$$

4.2. Adaptive Control

Characteristic of right wheel of robot3 changes as shown in table4.The change quantity is very big because of the experimentation. In order to adapt to this change, following two methods were verified.

Table. 2 rule for angular speed command

		deviation angle speed		
Deviation angle		L	M	R
	L	ZO	RS	RB
	M	LS	ZO	RS
	R	LB	LS	ZO



(a) antecedent on deviations (b) antecedent on deviation speeds (c) consequent

Fig. 6

Table. 3 rule for drive voltage

		deviation speed		
Deviation		N	Z	P
	N	ZO	PS	PB
	Z	NS	ZO	PS
	P	NB	NS	ZO

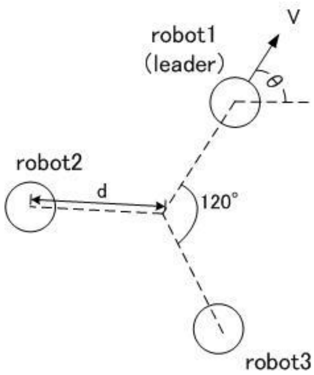


Fig. 7 formation of three robots

Table. 4 characteristic changes

	Viscous friction coefficient (Nmrad/s)	resistance(Ω)
before	0.5	1.1
after	1.5	2

i. Correcting Robots' Targets

In Fig.8, "Target" is the virtual target which the supervisor calculated. But actually, each robot traces "another target". When the robot's running direction deviates from target direction, another target move to direction which can improve the deviation.

ii. Adding Big Drive Voltage

Fig.9 shows the block diagram for this method. When one robot's deviation angle changes rapidly, a big drive voltage to improve the deviation is added without fuzzy inferences. The change amount of drive voltage is based on rules. For instance, when the robot deviate from the correct trajectory to right, right drive voltage increase.

5. Experiment

Fig.10 shows that a robot controlled by fuzzy control is getting to a target. It is simulated via Microsoft Visual Basic 2010. The circle shows the robot every second.

The robot heads to the target and the robot slow down as it approaches the target.

Fig.11 shows how three robots are moving as a group.

The robots are heading to the goal while keeping a formation.

6. Characteristic Change

Fig.12(a) shows a trajectory of the group when the characteristic changes. And Fig.12(b) shows distance between robot3 and its target in x- and y-directions.

Robot3 meanders without going straight until it catches its target. When the characteristic changes, the robot can correct its trajectory by fuzzy inference. However, the distance vibrates for a while.

7. Consequence

Fig.13(a) and 14(a) show the trajectory of group robot in the case of using adaptive control by method ⅰ and method ⅱ respectively. And Fig.13(b) and 14(b) show the distance between robot3 and its target, which means the control deviation, in the same manner as above. The vertical axis of the graphs show the deviations. And the horizontal axis show the time.

From Fig.13, it can be seen that adaptation method ⅰ can damp the vibration of trajectory of robot3 after the characteristics change and can make small the deviation.

From Fig.14, it can be seen that adaptation method ⅱ can restrict the overshoot of deviation and can reduce the damping time.

Comparing performances of these two methods, method ⅱ is more effective to adapt to the

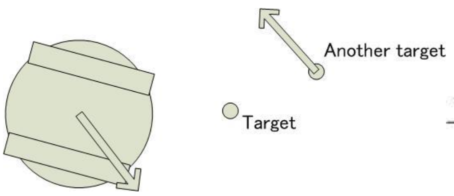


Fig. 8 method 1

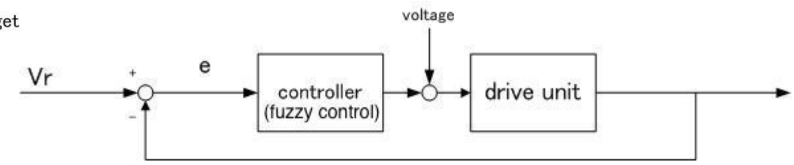


Fig. 9 block diagram for method2

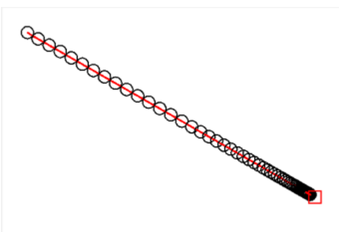


Fig. 10 robot trajectory

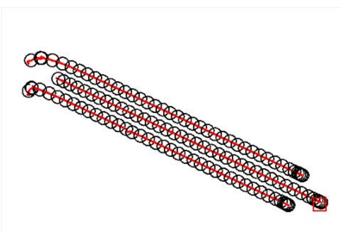


Fig. 11 group trajectory

changes of dynamic characteristics.

8. Conclusion

We proposed adaptive control system of multi mobile robots for formation navigation, where three mobile robots could be controlled as a group and they could adapt to a characteristic change by fuzzy inference. Through some actual trials by computer simulation, these proposed methods are proven to be practical.

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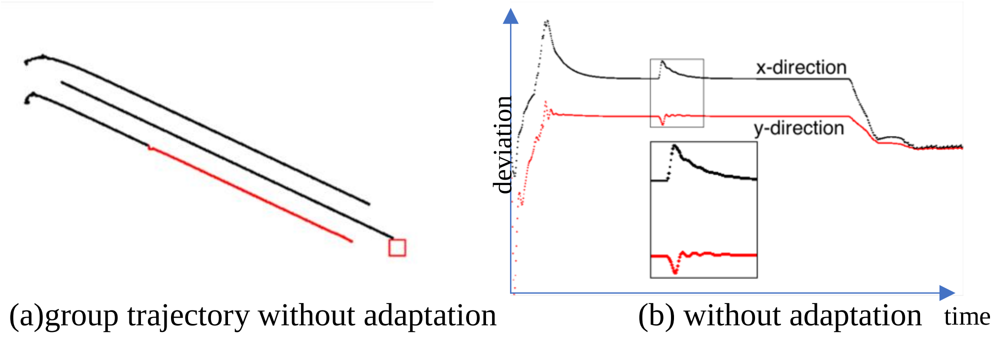
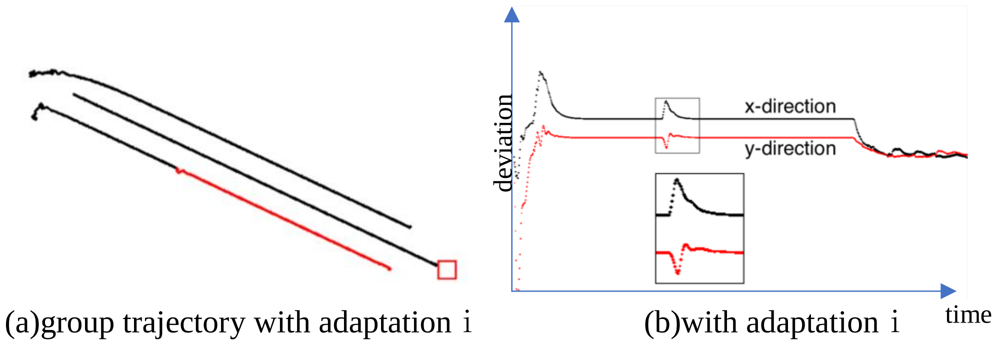


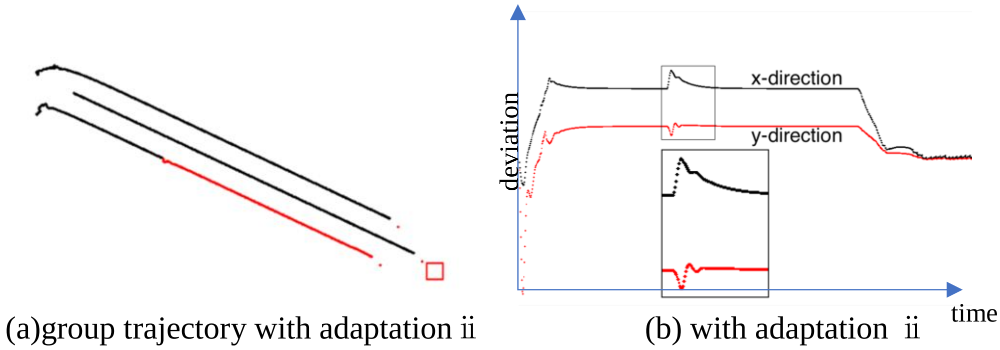
(a)group trajectory without adaptation (b) without adaptation

Fig. 12



(a)group trajectory with adaptation i (b)with adaptation i

Fig. 13



(a)group trajectory with adaptation ii (b) with adaptation ii

Fig. 14