The Fifteenth International Symposium on Artificial Life and Robotics 2010 (AROB 15th '10),
B-Con Plaza, Beppu,Oita, Japan, February 4-6, 2010

Research on Movements in Formation of Multiple Mobile Robots

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Abstract: Multi-robot systems are expected to improve the ability of processing tasks, a work efficiency, and an extendability of a robot system by cooperating each other. However, using multiple robots complicates its control system. As one of the associated problems, robot movements are picked up. Since a robot formation is useful to transfer multiple robots to their destinations effectively, many studies have been performed. This paper describes a method, which is called "IET method," for forming a formation with multiple robots. The method can specify the position of each robot in a group and change the shape of a formation. Note that each robot is assumed to have different ability and identified each other. Alternatively, the method needs a system that obtains the ID and relative position of the robots. We describe how to construct the measurement system using wireless communication and ultrasonic sound, and evaluate it through some simulation experiments.

Keywords: Multi-robot system, Formation, Robot identification, Measurement of relative position.

I. INTRODUCTION

Multi-robot systems are expected to improve the ability of processing tasks, a work efficiency, and an extendability of a robot system by cooperating each other. Note however that using multiple robots complicates its control system. When transferring multiple robots simultaneously, it is difficult to move them to their destination smoothly due to the fact that any robot is an obstacle for other robots, and vice versa. Since a robot formation is useful to transfer multiple robots to their destinations effectively, many studies have been performed up to now.

In [1], the size of virtual robots that has not been considered yet is reflected on simulations, and the line and circle formations are formed while avoiding obstacles. In [2], line, polygon and circle formations are realized in simulations by adjusting its own position, while referring to the positions of the furthest robot and closest robot. The reference [3] aims to use robots as macrosensors, in which the distributed in a space by using the concept of a virtual spring mesh. In these research, since similar or homogeneous robots have the same ability in function, it is not concerned that any robots go anywhere in the formation. It should be noted, however, that in multi-robot systems, robots that have different ability in function should cooperate to accomplish some complicated tasks each other. In such a case, it is necessary to deploy the robots at each desired position where their ability is demonstrated enough. For example, a robot that has the ability to recognize the environment or to remove obstacles should be placed at the most outer part of the swarm.

There are some studies for using heterogeneous robots. Jakob and Maja [4] propose a method for forming a formation with some identified robots. Its key idea is to set that every robot in the group positions itself relative to a designated neighbor robot (i.e., its friend). In their paper, the time required for forming a desired formation or changing a formation to another one was evaluated through several experiments with some real robots. Balch and Arkin [5] propose a method for forming "line," "column," "diamond," and "wedge." However, it is behavior-based control, so the reconfiguration of parameter values needs to decide own behaviors. Therefore, it is not easy to change any current robot formation to other one.

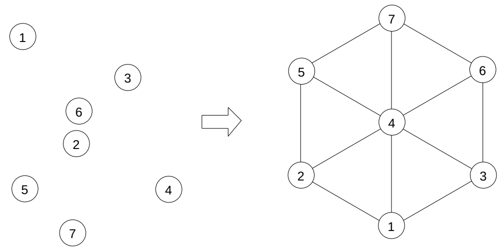

Fig. 1. A formation with a specified position

In this paper, we propose a formation method for a multi-robot system, which can specify the position of each robot in a group and can change easily the shape of a formation. Note however that each robot is assumed to have different ability each other, and the developed method is here called "IET (Imaginary Equilateral Triangle) method."

Alternatively, the method needs a system that obtain the ID and relative position of robots. We describe here how to construct the measurement system using wireless communication and ultrasonic sound, and evaluate it through some simulation experiments.

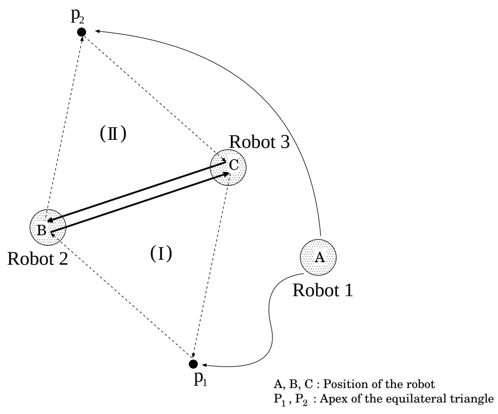

Fig. 2. Apexes for forming an IET

II. FORMING OF A FORMATION WITH IET METHOD

First, assume that the shape of formation is composed of a combination of some equilateral triangles (Fig. 1). According to this assumption, robots can form several formations by changing the combination of the triangles. Especially, it is easy to add or exclude a robot to the existing formation of robots. In order to realize a formation, it is essential to form an equilateral triangle with three robots. Therefore, we propose an IET method to form an equilateral triangle with robots.

1. IET Method

Consider the case where there exist three robots as shown in Fig. 2. If Robot 2 and Robot 3 do not move anymore, then Robot 1 has to move to P_1 or P_2 to form an equilateral triangle. Here, the points P_1 and P_2 are the apexes of equilateral triangles whose base is just to be BC (or CB). As a triangle BCP_1 or BCP_2, an equilateral triangle imagined by using the position of other two robots is called IET.

Since there are two possible IETs for one base, a rule for determining one candidate is set as follows:

- Two reference robots and the associated order are given to every robot.
- An IET fabricates the triangle clockwise according to the reference order of robots.

If Robot 1 is given Robot 2 → Robot 3 as the reference robots, the destination of Robot 1 is just P_1, whereas Robot 3 → Robot 2 are given, the destination is reduced to P_2.

For a case where all the robots move, the fundamental view is the same as the former case. When the initial distribution of three robots is shown as Fig. 3(a), every robot images each IET at each initial position (Fig. 3(b)) and moves toward to the apex of each IET (Fig. 3(c)). Fig. 3(d) shows the state of three robots after consuming a few steps from Fig. 3(c). It can be expected that the group form of three robots approaches an equilateral triangle by spending more time steps. Thus, three robots can form an equilateral triangle formation by respectively moving toward the apex of an IET.

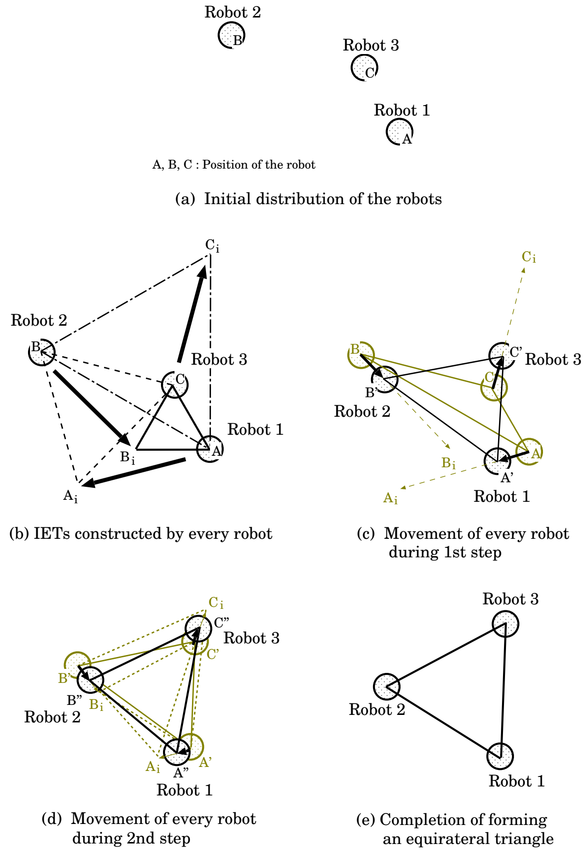

Fig. 3. Formation of an equilateral triangle

When forming a formation by multiple robots, each robot forms an equilateral triangle with given reference robots to form a desired formation by setting reference robots suitably as shown in Fig. 4. Fig. 5 shows a simulation result.

III. OBTAINING ID AND POSITIONS

The IET method needs a system which can obtain the ID and relative positions of robots in a team to realize a formation by using real robots. Thus, we propose a system with wireless communication and ultrasonic sound. As shown in Fig. 6, three ultrasonic sensors are equipped to a measuring robot (Robot 1), whereas a ultrasonic transmitter is equipped to other robots (Robot 2, Robot 3). Note that every robot has a wireless communication ability. The positions of ultrasonic sensors are apexes of an equilateral triangle whose centroid matches the center point of the robot. As an example of detecting the ID and position of a robot, we describe a situation where Robot 2 is the object to be measured.

1) *Request of measurements*
Robot 2 sends own ID to other members by wireless communication (broadcast). This sending is a cue to begin the measurement of relative position of the robot. Until the measurement is completed,

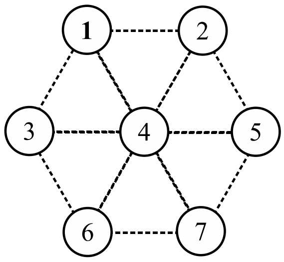

Table of reference robots

Robot's ID	Order of reference robots
1	2 -> 4
2	4 -> 1
3	1 -> 4
4	1 -> 2
5	4 -> 2
6	3 -> 4
7	4 -> 5

Fig. 4. Hexagonal formation

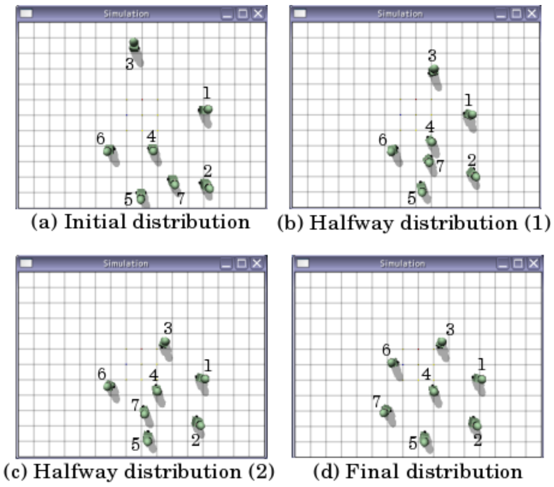

Fig. 5. Simulation of forming the shape of a hexagon

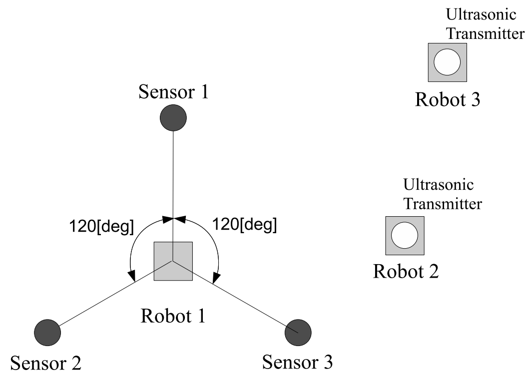

Fig. 6. System of measuring a robot's ID and its relative position

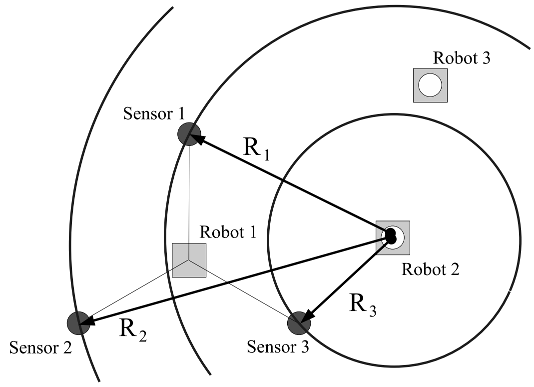

Fig. 7. Receiving an ultrasonic wave and calculating distances between sensors and robot 2

other robots can't send both wireless signal and ultrasonic sound.

2) *Transmitting an ultrasonic sound*
Robot 2 transmits an ultrasonic sound omnidirectionally, simultaneously with the transmission of own ID.
3) *Receiving the wireless signal and ultrasonic sound*
Assuming that the wireless signal can approximately arrive at robot 1 with 0 [s], the distance between the sensor and the Robot 2 can be calculated with a counted time, which is the time until the ultrasonic sound arrives after receiving the wireless signal (Fig. 7).
4) *Estimation of relative position*
The relative position of Robot 2 (x_2, y_2) is estimated by figuring out the coordinate point where three circles whose radius is the distance to Robot 2 cross.

IV. SIMULATION EXPERIMENTS

In this section, we evaluate the accuracy of estimation of a relative position of a robot through two simulation experiments. Fig. 9 shows the experimental environment. Robot 1 is a measuring robot, and the origin of the coordinate is defined as the center of Robot 1, where the x-directional coordinate is just to be a line connected with the origin and Sensor 1. Although Robot 1 estimates the position of Robot 2 (x_2, y_2) based on the distance between sensors and Robot 2, the measured value includes noise up to ± 1 [%]. The accuracy of estimation is evaluated for cases where the distance between sensors, L, or the distance between robots, D, changes independently.

Additionally, the sound speed is 340 [m/s], and standard deviations are calculated with 100 times of measurement result per one plotting.

1. Experiment 1: Distance between sensors

In this experiment, the impact of the distance between sensors, L, on the estimation accuracy is evaluated when L changes from 0.1 [m] to 0.5 [m]. Here, the position of Robot 2 is (x_2, y_2) = (3.0 [m], 3.0 [m]): in other words, L = 4.243 [m] and θ = 45 [deg]. Fig. 10 shows a result of the simulation experiment. The result indicates a great impact of the distance between sensors on the estimation accuracy.

2. Experiment 2: Distance between robots

In this experiment, the impact of the distance between robots, D, on the estimation accuracy is evaluated, when D changes from 1.0 [m] to 10.0 [m], under the fixed values of $L = 0.3$ [m] and $\theta = 45$ [deg]. Fig. 11 is the result of the simulation experiment. The standard deviation increases exponentially with the distance between

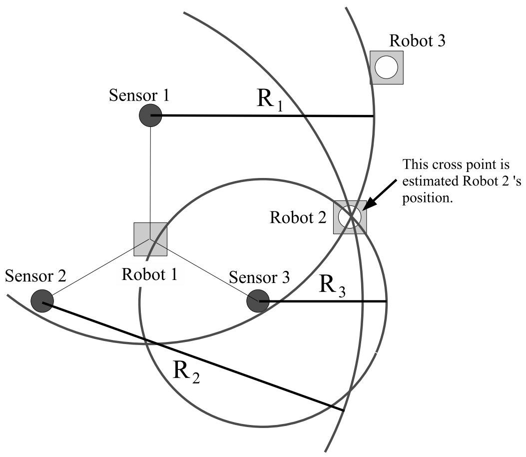

Fig. 8. Estimation of the position of robot 2

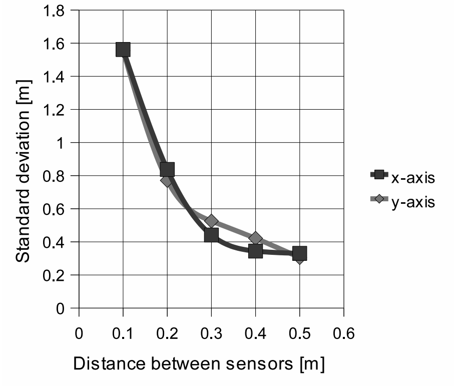

Fig. 10. Relationship between an estimation accuracy and a distance between sensors

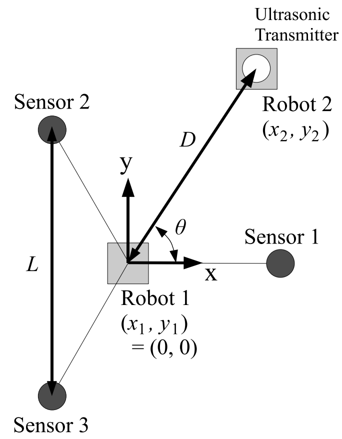

Fig. 9. Symbol of simulation parameters

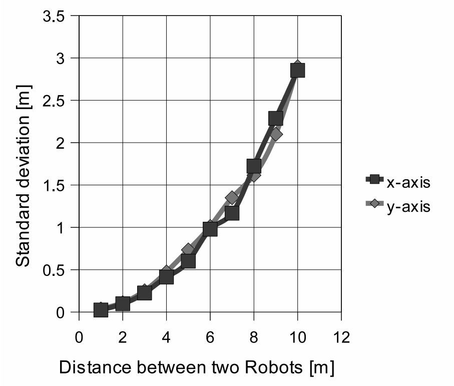

Fig. 11. Relationship between an estimation accuracy and a distance between two robots

robots. Although the accuracy of ultrasonic sensors is ± 1, the accuracy of the proposed estimation method is inferior to is when a certain boundary is crossed, and it is not reliable if the distance exceeds the boundary extremely. The result shows that the system can ensure the accuracy equivalent to ultrasonic sensors ($\pm$ 1 [%]) up to about 5 [m] range, where the distance between sensors L = 0.3 [m].

V. CONSIDERATION

Although a longer distance between sensors allow us to obtain more accurate estimation of relative position, the size of the system is about 0.3 [m] from the view-points of the robot size to be fabricated. Thus, from the result of experiment 2, the system needs the estimation distance up to 5 [mm] to ensure the accuracy equivalent to ultrasonic sensors ($\pm$ 1 [%]). However, instead of using reflected ultrasonic sound, a sound transmitted from the object robot is measured directly. It is expected to obtain the better accuracy of measuring distance than any general measurement system with ultrasonic sound. Since the accuracy of measuring distance gives a big impact to the estimation accuracy of relative position of the robot, an improvement of the accuracy of measuring distance may give us a better estimation result.

VI. CONCLUSIONS

In this paper, we have explained the IET method and proposed the system which can obtain ID and a relative position of a robot simultaneously. The proposal system was tested in simulation experiments which examine the impacts of the distance between sensors or robots on the estimation accuracy. In the future, we need to construct and test the system in a real experiment.

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