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Cooperative Swarm Control for Multiple Mobile Robots Using Only Information from PSD Sensors

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Abstract

Recently, many studies on swarm robotics are being conducted, in which the aim seems to be the realization of complex task ability by cooperating with each other. Future progression and concrete applications are being expected. The objective of this study is to construct an attractive system by using multiple mobile robots. First of all, multiple mobile robots with six PSD (Position Sensitive Detector) sensors are designed. The PSD sensor is a kind of photo sensors. A control system is considered to realize such a swarm behavior as Ligia exotica by using only information of PSD sensors. Experimental results show interesting behaviors of multiple mobile robots such as following, avoidance and schooling. The proposed system was intriguingly demonstrated to high school students in OPEN CAMPUS 2010 held in Tokyo University of Science, Yamaguchi.

1 Introduction

Recently, many studies on swarm robotics are being conducted, in which the aim seems to be the realization of complex task ability by cooperating with each other. It also seems that the research of swarm robotics includes the design of robots, their physical body and their behavior as a controller. Future progression and concrete applications are being expected.

In this study, multiple mobile robots with six PSD (Position Sensitive Detector) sensors are designed [1]. The PSD sensor is a kind of photo sensors. A control system is considered to realize such a swarm behavior as Ligia exotica as shown in Fig. 1 by using only information of PSD sensors. A lot of organisms who behave with making a group live in everywhere on the earth. Ligia exotica is one of such an organism that swarms at the seashore. Experimental results show interesting behaviors of multiple mobile robots. They are the following behavior, avoidance behavior and schooling behavior. The collective behaviors such as the following, avoidance and schooling emerges from the local interactions among the robots and/or between the robots and the environment.

Figure 1: Ligia exotica swarming at seashore.

2 Mobile Robots with PSD Sensors

In experiments, a mobile robot is used as shown in Fig. 2, which is developed based on three wheeled omni-directional mobile robot provided by Tosa Denshi. In order to real-timely measure the distances to objects, the robot is improved with six PSD sensors. The PSD sensor is mainly composed of an LED, electrical resistance and photodiode, and can calculate the distance through the triangulation technique. In order to cope with the problem of narrow directivity of the PSD sensor, the number of the PSD sensor is increased to six. If possible, PSD sensors more than six are desirable to further reduce the dead angle. Also, each robot has a Bluetooth wireless device to communicate with a PC server.

As for control scheme, self-control mode and server-controlled mode are proposed for the mobile robots. The PC server gives either mode to each robot. When the self-control mode is given, the robots behave based on their own decisions. This will be applied to a simulation of Ligia exotica swarming at seaside where they escape around because of the surprise to a sudden surrounding change. In this case, the swarm itself behaves as controlled, however, each individual seems to have only very simple action pattern. That is the reason why several easy action patterns are given to the robots in the self-control mode. However, the software development environment of the mobile robot using a free C language has two restrictions. The one is that the ush ROM of the mobile robot is only 8 kB. The other is that mathematical standard library such as "exp ( )" cannot be compiled. Thus, for example, it is impossible to directly apply the potential eld method for path planning.

The server-controlled mode is considered to cope with the poor development environment. In the server-controlled mode, the robots behave according to commands transmitted from the server. All information measured by PSD sensors of each robot are transmitted to the server once, the server can send action commands to the robots totally considering the behavior of the swarm. Of course, the potential eld method is available on the server side where the Windows Visual Studio runs. This will be also applied to a simulation experiment of complex swarm intelligence where software developments with comparatively large-scale are required.

Figure 3 shows the coordinate system of this type of mobile robot. ω_i $(i = 1, 2, 3)$ is the angular velocity of each wheel. Also, v_i $(i = 1, 2, 3)$ is the velocity of each wheel given by

$$v_i = r\omega_i \quad (i = 1, 2, 3) \tag{1}$$

where, r is the radius of the wheel. If the position and orientation vector of the robot, i.e., the origin in the robot coordinate system Σ_R, is given by $[x\ y\ \phi]^T$, then the velocity is represented by $[\dot{x}\ \dot{y}\ \dot{\phi}]^T$. First of all, following equations are obtained from Fig. 3 [2, 3].

$$\dot{x}_r = \quad \frac{1}{2}v_1 \quad \frac{1}{2}v_2 + v_3 \tag{2}$$

$$\dot{y}_r = \frac{\sqrt{3}}{2}v_1 \quad \frac{\sqrt{3}}{2}v_2 \tag{3}$$

$$\dot{\phi}_r = \frac{1}{L}v_1 + \frac{1}{L}v_2 + \frac{1}{L}v_3 \tag{4}$$

where L is the distance between the center of the robot and the center of each wheel. Eqs.(2), (3) and (4) lead to

$$\begin{pmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{pmatrix} = \frac{1}{r} \begin{pmatrix} \frac{1}{3} & \frac{1}{\sqrt{3}} & \frac{L}{3} \\ \frac{1}{3} & \frac{1}{\sqrt{3}} & \frac{L}{3} \\ \frac{2}{3} & 0 & \frac{L}{3} \end{pmatrix} \begin{pmatrix} \dot{x}_r \\ \dot{y}_r \\ \dot{\phi}_r \end{pmatrix} \tag{5}$$

By using the relation given by Eq. (5), the robot can be controlled kinematically.

Figure 4 shows the static measurement result of a PSD sensor, which is the relation between the actual distance and the digital value obtained from the PSD sensor. It can be seen that the sensible distance is within the range from 10 cm to 90 cm.

3 Self-Control Mode

In self-control mode, each robot behaves by using only information obtained from six PSD sensors shown in Fig. 5. The robots have three types of self-control modes, which are a following mode, an avoidance mode and a schooling mode. All mobile robots can communicate with a PC server. The PC server switches the mode of each robot individually by sending broadcast commands.

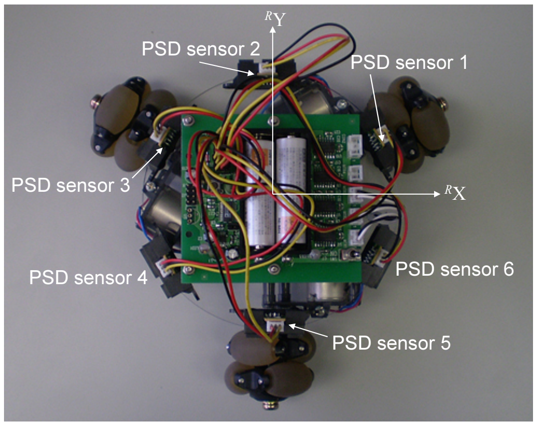

Figure 2: Mobile robot with six PSD sensors.

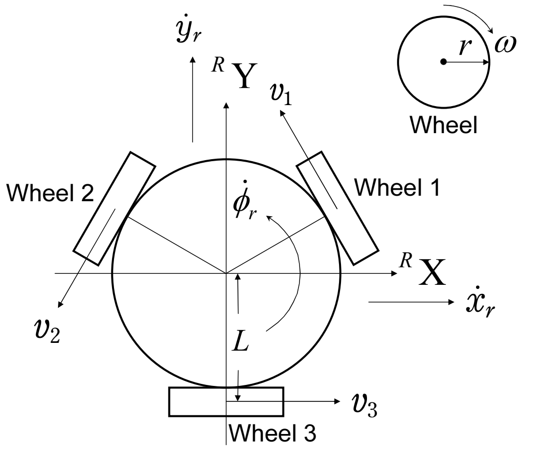

Figure 3: Kinematic model of the mobile robot.

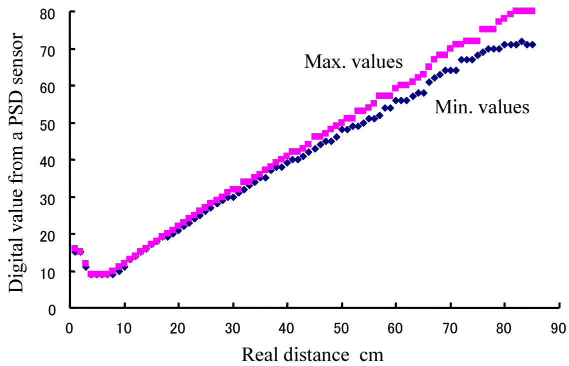

Figure 4: Relation between actual distance and digital value measured from a PSD sensor.

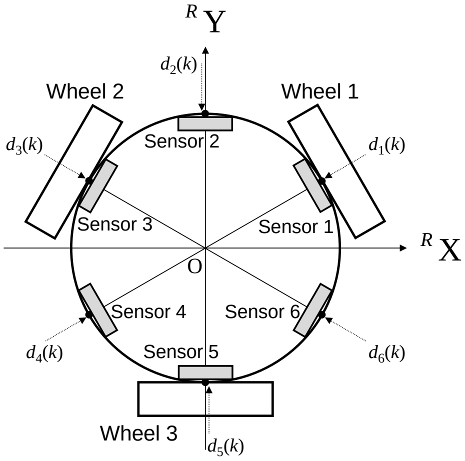

Figure 5: Six PSD sensors equally xed on a mobile robot.

3.1 Following mode

If the following mode is given, mobile robots try to follow a moving object including other mobile robots in the sensitive region. Six PSD sensors can independently detect distances $d_i(k)$ $(i = 1, ..., 6)$ at the discrete time k. $d_i(k)$ is the value measured by i-th PSD sensor. If the distance to the nearest object is larger than a desired value d_d, the robot tries to shorten the distance by generating the velocity given by

$$\dot{\boldsymbol{x}}_r = v\frac{\dot{\boldsymbol{x}}_{ri}}{\|\dot{\boldsymbol{x}}_{ri}\|}\{d_d \quad \min_i d_i(k)\} \ (\forall d_i(k) > d_d) \tag{6}$$

where $\dot{\boldsymbol{x}}_r = [\dot{x}_r \ \dot{y}_r]^T$ is the translational velocity in Eq. (5), v is the scalar signifying the magnitude of the robot's velocity, $\dot{\boldsymbol{x}}_{ri} = [\dot{x}_{ri} \ \dot{y}_{ri}]^T$ is the vector signifying the direction as shown in Table 1. d_d is the desired distance to the nearest object.

Table 1: Velocity components to move to the direction of each PSD sensor.

i	1	2	3	4	5	6
$\dot{x}_{ri}$	$\sqrt{3}$	0	$\sqrt{3}$	$\sqrt{3}$	0	$\sqrt{3}$
$\dot{y}_{ri}$	1	2	1	1	2	1

3.2 Avoidance mode

If the avoidance mode is given, each mobile robot tries to move away from moving objects including other mobile robots in the sensitive region. When six PSD sensors simultaneously detect shorter distances compared to the restriction d_d, the robot preferentially leaves the nearest object. If the distance to the nearest object is smaller than d_d, the robot tries to expand the space to be d_d by generating the velocity given by

$$\dot{\boldsymbol{x}}_r = v\frac{\dot{\boldsymbol{x}}_{ri}}{\|\dot{\boldsymbol{x}}_{ri}\|}\{d_d \quad \min_i d_i(k)\} \ (\exists d_i(k) < d_d) \tag{7}$$

3.3 Schooling mode

If the schooling mode is set to all mobile robots, they try to regularly move along the inner of a circular fence keeping the distance to both the fence and other mobile robots. This mode allows the robots to behave like carps in a Japanese arti cial circular pond. For example, when a robot moves counterclockwise along a circular fence, the following control law is basically applied.

$$\dot{\boldsymbol{x}}_r = v\frac{\dot{\boldsymbol{x}}_{r2}}{\|\dot{\boldsymbol{x}}_{r2}\|} \tag{8}$$

In this case, the orientation is simultaneously controlled by

$$\dot{\phi}_r = K_\phi\{d_6(k) \quad d_1(k)\} \tag{9}$$

where K_ϕ is the gain which can control the orientation of the robot to be parallel to the inner of the circular fence.

3.4 Experiment and discussion

In order to evaluate each behavior, three experiments were conducted.

3.4.1 Following mode

In the following mode, each robot basically stood still and looks around. When an object was detected in the sensing area, the robot tried to follow the object. In order to overcome the problem of blind spot and to skillfully sense a moving object, PSD sensors 1, 2 and 3 shown in Fig. 5 were used. The front of the robot is the direction of sensor 2. The following was conducted to the direction of sensor 2. Note that the sensors 1 and 3 were assistantly used in order not to lose sight of the object. It was observed from the experiments that a robot in following mode could run after other robots.

3.4.2 Avoidance mode

In the avoidance mode, each robot moves around randomly when no object is detected. If a robot detects an object in sensing area, it moves to the reverse direction to the object. Also, when plural objects are detected at a time, the nearest one is regarded as an object and the others are ignored. Desirable and interesting avoidance behaviors were observed from the experiments. Figure 6 shows an experimental scene.

3.4.3 Schooling mode

In the schooling mode, each robot rst moved to the front direction to detect a circular fence. After detecting a circular fence, the robots moved around to the counterclockwise direction. Seven mobile robots in schooling mode could move around the fence like carps. In this case, the robots could keep a distance to

Figure 6: Experimental scene of avoidance mode.

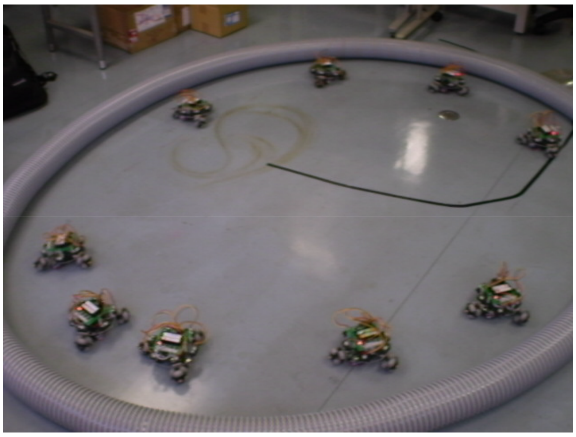

Figure 7: Experimental scene of schooling mode.

the fence by using the two PSD sensors, nos. 1 and 6. Figure 7 shows the experimental scene of the schooling mode, in which nine mobile robots are schooling along the inner of fence.

It has been con rmed from the simple experiments that the actual simulations for following, avoidance and schooling behaviors can be conducted for multiple mobile robots.

4 Conclusions

The objective of this study is to construct an attractive system by using multiple mobile robots. First of all, multiple mobile robots with six PSD (Position Sensitive Detector) sensors have been designed. The PSD sensor is a kind of photo sensors. A control system has been considered to realize such a swarm behavior as Ligia exotica by using only the information of PSD sensors. Experimental results have shown interesting behaviors of multiple mobile robots such as following, avoidance and schooling. The proposed system was intriguingly demonstrated to high school students in OPEN CAMPUS 2010 held in Tokyo University of Science, Yamaguchi and was very instructive to the students.

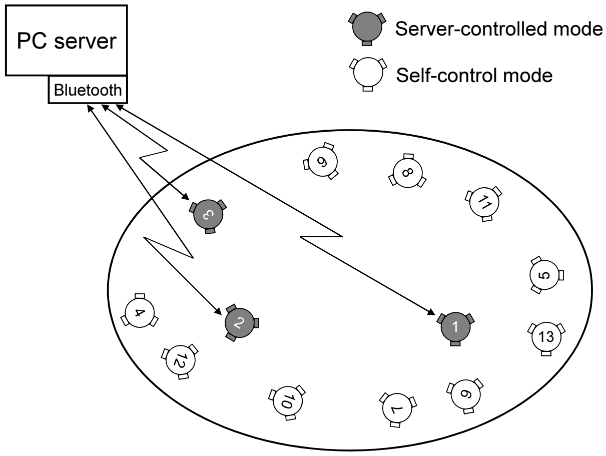

Figure 8: Example of server supervisory mode, in which robots 1, 2 and 3 are set to server-controlled mode, also the others are set to self-control mode by a PC server.

When many multiple mobile robots are used to simulate a swarm or a school, the cost with the increase of the number of robots becomes a serious problem. Therefore, there is an essential demand to construct the system at as low cost as possible. In future work, we plan to consider a server supervisory mode in order that a high level software architecture can be constructed even under the condition of technically and costly poor hardware platform of each mobile robot. In server supervisory mode, all mobile robots can be broadcastly switched self-control mode or server-controlled mode as shown in Fig. 8.

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