Foraging Behavior of Ant-Like Robots with Virtual Pheromone

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Abstract

In multi-robot system, communication is indispensable for effective cooperative working. To apply chemical method to the communications of multi-robot system is challenging topic, but it is not easy to treat real chemical materials for the robots because of some technical difficulties. In this paper, we show virtual pheromone system in which chemical signals are simulated with the graphics projected on the floor, and in which the robots decide their action depending on the color information of the graphics. We examined the performance of this system through the foraging task, which is one of the most popular tasks for multi-robot system.

1 Introduction

Recently, research in the area of multi-robot systems has been very active, and many researchers are currently studying the behavior of these types of systems[1, 2]. One of the most important aspects in a multi-robot system is the ability of robots working cooperatively. Working together, they complete tasks that a single robot cannot.

For effective working, mutual communication between units is indispensable. Many researchers have introduced the direct communication, and in most cases, physical media such as light, sound, radio wave are used for the communication. Those media are also employed in biological system: for example, fireflies make use of light as a mating signal, and crickets use the sound as the signal. However, as we know, not only physical signals but also chemical signals are used for the communication. It is well-known that some insects use the chemical signals, which are generally called pheromone. They show very interesting behaviors depending on the properties of pheromones. One of the most popular pheromone-controlled behaviors is foraging of ants. Here, pheromone released by organism enables individuals to communicate with each other.

Pheromones are available not only for direct communication but also for indirect communication. In insect world, pheromones are used for various purposes: alarm, aggregation, sex attractant, recruitment, defense, trail-making, and so on.

2 Properties of Pheromone

Important characteristics of pheromones as a chemical signal are described as follows:

•Marking

Most pheromones do not disappear immediately and remain in the field for some time. It means agents can share an information based on the pheromones even in the absence of signal source agent. Foraging ants, for example, move from the food source to their nest laying "recruit pheromone" while food remains at the source, and they can find out the food efficiently thanks to this property.

•Diffusion

Most pheromones are volatile and spread over a large area. This characteristic is used for long range communication, for generating chemical gradient field, and so on.

•Evaporation

Pheromone disappears by evaporation because of its volatility. This characteristic leads to the erase of needless/useless information. In case of ant societies, less food remains at the food source, less pheromone the ants lay. As a result, they can avoid useless energy consumption for foraging.

•Diversity

There is a lot of materials which are used as pheromones, and moreover, some of them are used in combination. In ant societies, for example, each individual can distinguish its colony's mates and ones of other colonies based on the difference of mixture rate of some pheromones.

3 Virtual Dynamic Environment for Autonomous Robots (V-DEAR)

As described above, communication by chemical material such as pheromone has some interesting characteristics that physical communication system does not have, but few researches treat real chemical materials as a communication media for physical robot system[3]. We can consider following reasons. At this stage, it is not easy to treat chemical material comparing with the physical medium, and it is also not easy to get proper chemical sensors. Moreover, chemical materials, especially gas, are invisible and it is quite difficult to observe how they spread and affect robots' behaviors.

Here we propose "Virtual Dynamic Environment for Autonomous Robots (V-DEAR)" for real robot experiment. In this system, pheromones are replaced with graphics projected on the ground. Robots decide their actions following the color information of the projected CG. As virtual pheromones are represented as CG, we can avoid the problems described above. In addition, we can easily control the rate of diffusion, evaporation, diversity, etc. of the virtual chemical materials.

Fig. 1 shows the schematic and photo of this system. This is composed of LC projector to project the CG and the CCD camera to trace the position of the robots in the field. The robot moving on the field has sensors on the top to detect the color and brightness of the field, and determine its actions autonomously based on the condition of the CG on the floor.

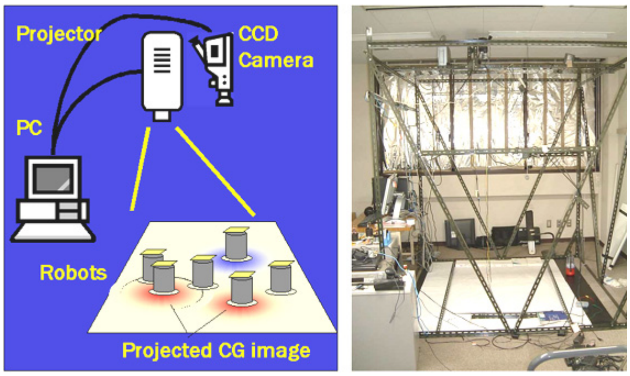

Figure 1: Virtual Dynamic Environment for Autonomous Robots (V-DEAR). Schematic (left) and photo (right).

Combining the position information of the robots acquired from CCD camera and the projected CG by projector, we can realize the dynamic interaction between the environment and the robots.

In this paper, we will show you the performance of this system through the foraging task by the interacting robots. This is one of the most popular tasks in the study of multi-robot system, but almost all of them treat physical communication methods[4, 5, 6, 7, 8].

4 Experiment

4.1 Robot for Experiment

•Robot

Each robot has the five fundamental behaviors as follows: "searching," "attracted," "recruiting," "homing," and "avoidance" (Fig. 2). When a robot in searching state finds food, it stays there for a short time and picks up some of the food. After that, it moves to home leaving a pheromone. When arriving at home, it lays the food there and goes searching food again. The robot which detects the pheromone follows the trail, if it has no food.

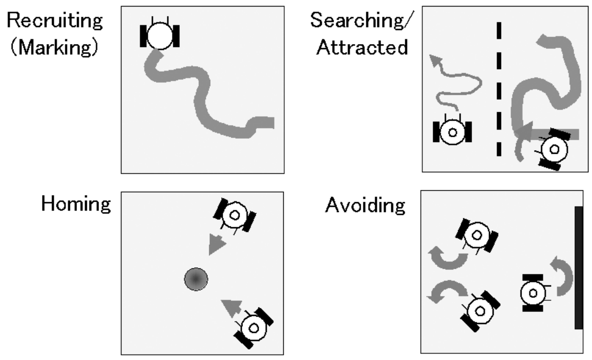

Figure 2: Fundamental robot behaviors. "Recruiting","searching," "attracted","homing," and "avoidance."

The robot used in this experiment is shown in Fig. 3. It has touch sensors extended to 8-directions to detect collision, a pair of infrared sensors to return to home, three color-sensors to detect field condition, bottom sensors to detect "Home", and 1 LED to indicate its state.

•Pheromone

Dynamics of pheromone is described as

$$\dot{\rho} = \delta + D\nabla^2\rho - k\rho, \qquad (1)$$

where ρ is the concentration of pheromone, δ is injection concentration, D is a diffusion coefficient, and

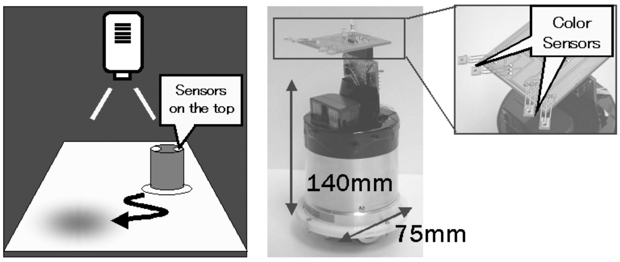

Figure 3: Robots detect the field condition by sensors on the top.

k is the rate of evaporation.

Fig. 4 shows the basic behavior of the foraging robots. On discovering a food, the robot turns on a LED on the top and moves towards the nest. The V-DEAR system detects the LED and projects a CG pheromone trail during the LED is turned on. When the robot arrives at the nest, it turns off the LED and changes into the searching state. If it finds the pheromone trail, it follows the trail.

Here you can see the trail pheromone, or a band of light is projected following the homing route of the robot (a), and a robot traces a band (b) in Fig. 4.

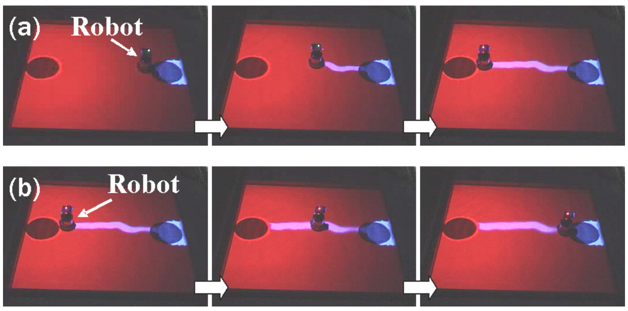

Figure 4: Basic behavior of the foraging robot. (a) On discovering food, the robot lays chemical trail while returning to nest. (b) The robot detecting the pheromone follows the trail.

4.2 Field for Experiment

•Field
The field for this experiment was an 90 × 90 cm black surface with the wall at the boundary. A nest is represented with a yellow circle on the ground and IR-LED array is placed there.
•Food distribution
We can consider various types of food distribution. In this experiment, we chose homogeneous and localized distributions.

In homogeneous distribution, 24 food points are projected on the field. When a robot in searching state detects the color of food point, the robot turns on the LED on the top and changes its state to homing state. When the V-DEAR system detects the LED, it erases the corresponding food point and starts to draw the virtual pheromone following the robot's homing route.

In localized field, the behavior of robots is same as the case of homogeneous distributed field, but the quantity of food is assumed to be infinite, i.e. the food point is not erased.

4.3 Results

Fig. 5 is the snapshot and the trajectories of the foraging by a robot in the homogeneously food-distributed field, where Fig. 5(a) and (b) are the case of ($D = 0.05, k = 0.1$) and ($D = 0, k = 0$), respectively. In case that the evaporation rate of the pheromone is high, the pheromone hardly remains. On the other hand, when the evaporation rate and the diffusion coefficient are too low, the pheromone remains clearly in the field. Here the trajectory shows that the robots are trapped by their own pheromone and tend to do useless searching.

Fig. 6 is the snapshot of the foraging by two robots in the locally distributed field, where fig. 6(a) and (b) are the case of ($D = 0.15, k = 0.01$) and ($D = 0.15, k = 0.002$),respectively. In case that the evaporation rate of the pheromone is high, the pheromone hardly remains. However, the evaporation rate is low, a stable trail is formed between the food point and their nest. In this case, the robots can search and carry the foods by tracing the laid pheromone effectively, which can be observed from the trajectory.

Fig. 7 shows the relation between the evaporation rate and the number of collected foods. Fig. 7(a) is the result of homogeneously food-distributed field, and (b) is the result of locally food-distributed field. The parameter in these graphs is the number of robots (1∼3).

These graphs clearly show that less pheromone is left in the field, more foods are collected in homogeneous field, and that the performance becomes better when a pheromone trail is formed continuously in localized field.

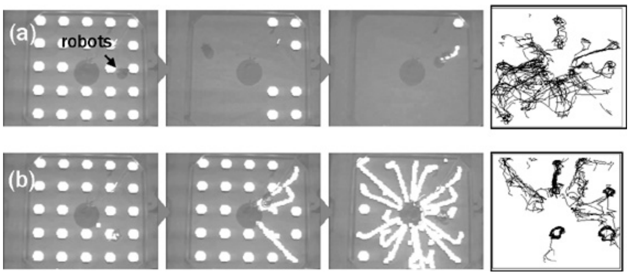

Figure 5: Snapshot of experiment in homogeneously distributed field. (a)$D = 0.05, k = 0.1$, (b)$D = 0, k = 0$.

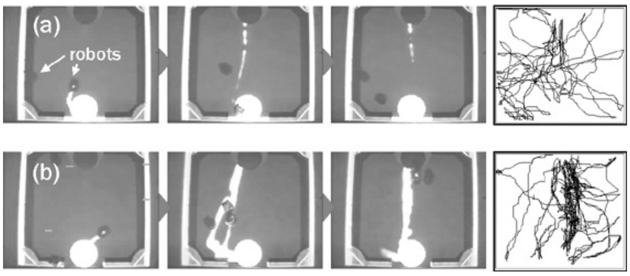

Figure 6: Snapshot of experiment in locally distributed field. (a) $D = 0.15, k = 0.01$ (b) $D = 0.15, k = 0.002$.

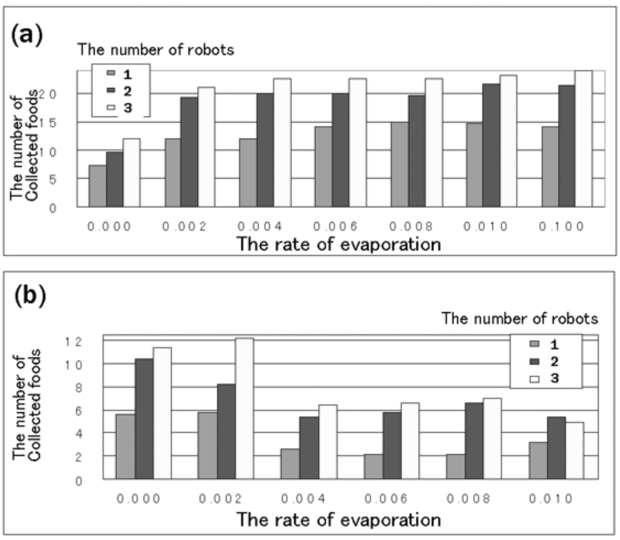

Figure 7: Relation between the evaporation rate and the number of collected foods. Parameter is the number of the robot. (a) Homogeneous field. (b) Localized field.

5 Conclusion

In this paper, we treat indirect communication by chemical signal between the robots, and investigate a foraging behavior by multi-robot system. Here we proposed a Virtual Dynamic Environment for Autonomous Robots (V-DEAR), where we can simulate chemical system such as pheromone, and discussed the foraging by the experiment.

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