2005 International Symposium on Nonlinear Theory and its Applications (NOLTA2005)
Bruges, Belgium, October 18-21, 2005

Development of Virtual Dynamic Environment for Autonomous Robots

Ken Sugawara†

†Department of Information Sciences, Tohoku Gakuin University
2-1-1 Tenjinzawa, Izumi-ku, Sendai 981-3193 Japan
Email: sugawara@cs.tohoku-gakuin.ac.jp

Abstract—In multi-robot system, communication is indispensable for effective cooperative working. In this system, direct communication by physical methods such as light, sound, radio wave etc. is quite general, but the communication by chemical methods, which play important roles in biological systems, has not been treated because of some technical difficulties. This paper shows 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 using the color sensors. Performance of this system is discussed by the experiments of foraging task and the division of labor, which are generally observed in ant societies, and often treated as the task for multi-robot system in robotics.

1. Introduction

Social insects such as ants and bees establish well-ordered societies[1]. In their society, what each individual does is only simple tasks responding to circumstantial conditions. No central control is there, but the whole system exhibits complex and adaptive functions. How does simple individual show complex and effective behaviors as the group? Not only scientists but also engineers are interested in such interactive biological systems[2]. 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 from various viewpoints[3]. One of the most important aspects in a multi-robot system is the ability of robots to execute tasks cooperatively. Working together, they complete tasks that a single robot cannot.

For effective working, mutual communication between units is indispensable. In previous works in robotics field, the direct communications have been introduced, and in most cases, physical media such as light, sound, radio wave have been used for the communication. These 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 in their world(Fig.1). It is well-known that some insects use the chemical signals, which are generally called pheromone, and they show very interesting behaviors depending on the properties of pheromones.

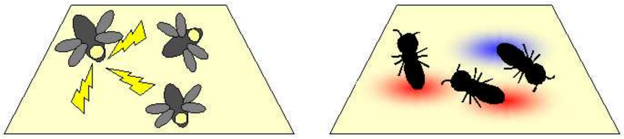

Figure 1: Communication method. Physical communication and chemical communication.

2. What is Pheromone?

Pheromones, a kind of chemical signals released by an organism, enable 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. 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 release. 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[4]. 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 Computer Graphics. 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.2 shows the schematics and photo of this system. It is composed of LC projector to project the CG and 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 determines its actions autonomously based on the condition of the CG on the floor.

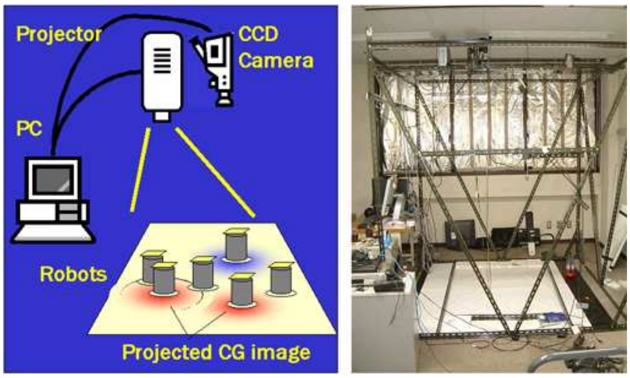

Figure 2: Virtual Dynamic Environment for Autonomous Robots (V-DEAR). Schematics (left) and photo (right).

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 robots.

In this paper, two types of cooperative working are demonstrated below introducing the virtual pheromone expressed by this device.

4. Applications

4.1. Case 1: Foraging Behavior

As one of the application of this system, we will show the foraging task which is inspired by ants. Foraging is one of the most popular tasks in the researches of multi-robot systems, but the communications by physical methods have been treated in most studies[5][6][7][8][9].

•Robot
Each robot has five fundamental behaviors as follows: "searching," "attracted," "recruiting," "homing," and "avoidance" (Fig.3). When a robot in searching state finds food, it stays there for a short time and picks up the food. After that, it moves to home leaving a pheromone. When arriving at home, it lays the food there and starts foraging again. The robot which detects the pheromone follows the trail, if it has no food.

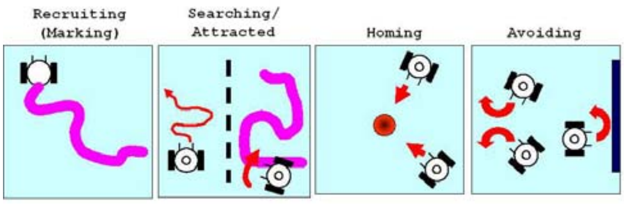

Figure 3: Fundamental robot behaviors. "Recruiting," "searching," "attracted," "homing" and "avoidance."

The robot used in this experiment 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. Two wheels are positioned at the bottom-center of the robot, which enable to move forward or backward in a straight or curved trajectory, and can turn on the spot.

The maximum number of robots used in this experiment was three.

•Pheromone
Dynamics of pheromone is described as

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

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

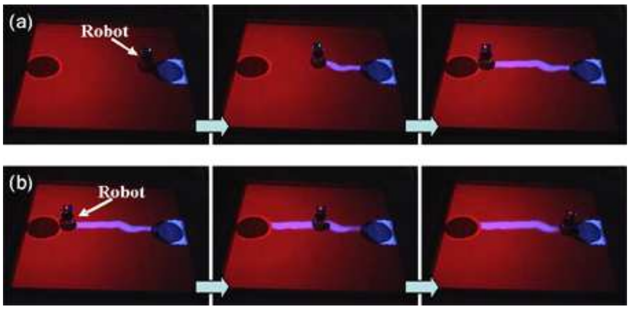

Figure 4: Basic behavior of the foraging robot. (a) On discovering food, the robot lays chemical trail while returning to nest. (b) The robot detecting the pheromone follows the trail.

•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.

•Results
Fig.5 is the snapshot of the foraging by a robot in the homogeneously food-distributed field, where Fig.5(a), (b) are the case of ($D = 0.05, k = 0.1$), ($D = 0, k = 0$), respectively. In case that the evaporation rate of the pheromone is high (Fig.5(a)), the pheromone hardly remains. The evaporation rate and the diffusion coefficient are too low (Fig.5(b)), the pheromone remains clearly.

Fig.6 is the snapshot of the foraging by two robots in the locally distributed field, where fig. 6(a),(b) are the case of ($D = 0.15, k = 0.01$),($D = 0.15, k = 0.002$),respectively. In case that the evaporation rate of the pheromone is high (Fig.6(a)), the pheromone trail hardly remains. However, the evaporation rate is low (Fig.6(b)), a stable trail is formed between the food point and their nest.

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 the reverse can be said for the performance of the robots in localized field.

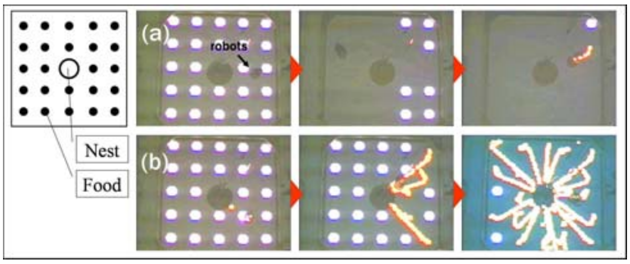

Figure 5: Snapshot of experiment in homogeneously distributed field. (a)$D = 0.05, k = 0.1$, (b)$D = 0, k = 0$.

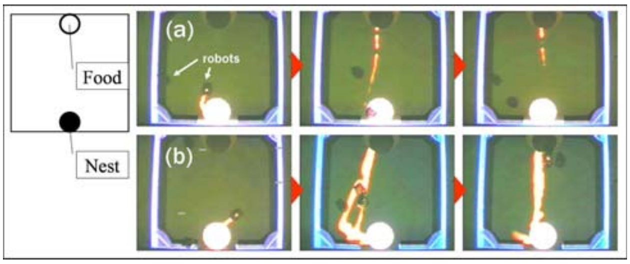

Figure 6: Snapshot of Experiment in locally distributed field. (a) $D = 0.15, k = 0.01$ (b) $D = 0.15, k = 0.002$.

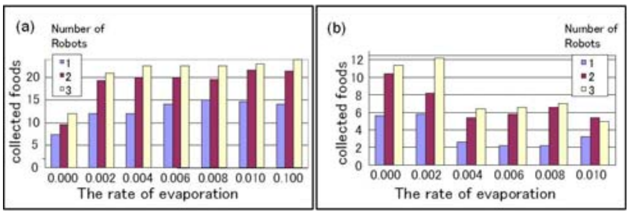

Figure 7: Relation between the evaporation rate and the number of collected foods. Parameter is the number of the robot. (a) Homogeneous field. (b) Localized field.

4.2. Case 2: Division of Labor

Division of labor performed by social insects, such as ants and bees, is one of the most advanced functions that they have evolved. This function is also useful for multi-robot system. Especially, when they need to engage in complex task which can be divided into some simple tasks, their performance can be drastically improved by introducing the division of labor. For executing the division of labor effectively, it is necessary to assign the tasks to the robots in proper ratio, and to maintain the ratio against environmental disturbance. In this section, the experiment of division of labor is discussed mainly focusing on the proportion regulation of population. In order to share the nest information, stock materials are introduced here.

•Experimental Setup

In this experiment, each robot can take two states, ”staying” and ”foraging”, and decides one of the two states based on the total amount of the stock in the nest. The stock material is consumed constantly depending on the number of staying robots in the nest, and it is added when the foraging robot returns to the nest.

Fig.8(a) shows the experimental field. As shown in Fig.8(b), a half of the field is ”the nest” and the robots usually move around in this area (Task 1). The other half is ”the work space” and the robots moving around this area carry back food to their nest (Task 2). V-DEAR system monitors the total amount of food stock and expresses it by the brightness of the nest. Each robot detects it and decides its state autonomously.

•Result

Fig.9 shows the number of robots in each state. Here experimental parameters are given to set the ratio between task 1 and 2 to 2:1. Initial number of robots is six(Fig.9(a)). After their behavior becomes stable, three randomly selected robots are removed from the field(Fig.9(b)). Here dashed lines are the average of each state. You can see the rate is kept on the average in spite that the total number of robot is forced to be changed.

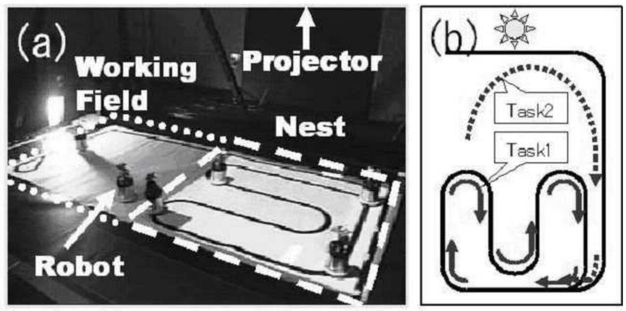

Figure 8: (a)A snapshot of the experiment. (b)Schematic of the experiment.

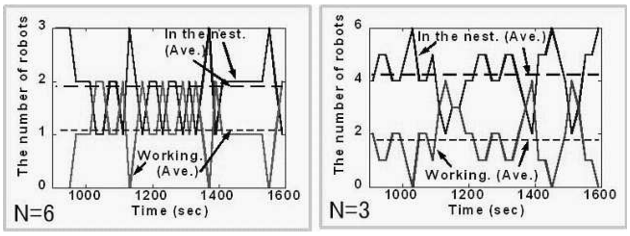

Figure 9: The number of robots in each task. (a) In case of six robots. (b) In case of three robots. Dashed lines are the average of each state.

5. Summary

This paper shows virtual pheromone system in which chemical signals are simulated with the graphics projected on the floor, in which real robots decide their action depending on the color information of the graphics using the color sensors. Performance of this system is discussed by the experiments of foraging task and the division of labor, which are generally observed in ant societies, and often treated as the task for multi-robot system in robotics.

**

The author would like to thank T. Kazama and K. Suseki for contributions to the experiments, and T. Mizuguchi for valuable discussions. This work was partially supported by a Japanese Grand-in-Aid for Encouragement of Young Scientists from the Ministry of Education, Science and Culture (No.15760291).

References

[1] D. M. Gordon and M. Schwengel, *Ants at Work: How an Insect Society Is Organized*, Simon & Schuster, 1999.

[2] E.Bonabeau, M.Dorigo and G.Theraulaz, *Swarm Intelligence - From Natural to Artificial Systems*, Oxford University Press, 1999.

[3] Y.U.Cao, A.S.Fukunaga and A.B.Kahng, ”Cooperative Mobile Robotics:Antecedents and Directions,” *Autonomous Robots*, 4, pp.7–27, 1997.

[4] A.T. Hayes, A. Martinoli, and R.M. Goodman, ”Distributed Odor Source Localization”, *IEEE Sensors*, Vol. 2, No. 3, pp.260–271, 2002.

[5] L. Steels, ”Cooperation between distributed agents through self-organization,” *Proc. of the First European Workshop on Modeling Autonomous Agents in a Multi-Agent World*, pp. 175–195, 1990.

[6] A. Drogoul and J. Ferber, ”From Tom Thumb to the Dockers: Some Experiments with Foraging Robots,” *Proc. Simulation of Adaptive Behavior*, pp.451–459, 1993.

[7] T. Balch and R.C. Arkin, ”Communication in Reactive Multiagent Robotic Systems,” *Autonomous Robots*, 1, pp. 27–52, 1994.

[8] R. Beckers, O.E. Holland and J.L. Deneubourg, ”From Local Actions To Global Tasks: Stigmergy and Collective Robotics,” *Artificial Life IV*, MIT Press, pp. 181–189, 1994.

[9] M.J.B. Krieger, J.B. Billeter, ”The call of duty: Self-organized task allocation in a population of up to twelve mobile robots”, *Robotics and Autonomous Systems*, Vol.30, pp.65–84, 2000.