Improving Energy Efficiency Based on Behavioral Model in a Swarm of Cooperative Foraging Robots

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ABSTRACT

We can efficiently collect crops or minerals by operating multi-robot foraging. As foraging spaces become wider, control algorithms demand scalability and reliability. Swarm robotics is a state-of-the-art algorithm on wide foraging spaces due to its advantages, such as self-organization, robustness, and flexibility. However, high initial and operating cost are main barriers in operating multi-robot foraging system. In this paper, we propose a novel method to improve the energy efficiency of the system to reduce operating costs. The idea is to employ a new behavior model regarding role division in concert with the search space division.

Categories and Subject Descriptors

I.2.11 [**Artificial Intelligence**]: Distributed Artificial Intelligence – *coherence and coordination, intelligence agents, multiagent systems.*

General Terms

Algorithms, Design, Performance, Reliability.

Keywords

Swarm Intelligence, Swarm Robotics.

1. INTRODUCTION

Recently, swarm robotics, applying the swarm intelligence to mimic a swarm, is studied by many researchers. People have used central control systems to control a swarm of robots. A central robot control system has the advantages that they are fast and precise because it can control all parts of system when necessary. However, the central control system needs to be robust and flexible as the swarm of robots becomes bigger and more complex. Therefore, the control system usually uses distribution control methods or combines central and distribution control methods together [1]-[5].

In this paper, we introduce methods which are efficient control of a swarm of robots through distribution control method by defining new behavior models and dividing search area in cooperative foraging environment. We compare the required energy per a foraged object of our proposed method with a simple foraging robots system through simulation tests.

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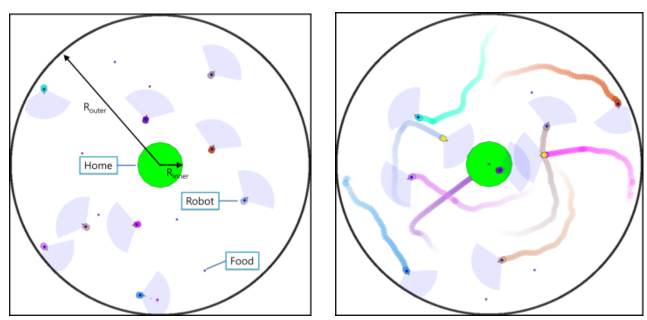
2. IMPROVING ENERGY EFFICIENCY OF THE FORAGING ROBOTS SYSTEM

In the foraging robots system, as seen in Figure 1, each robot wanders around to find foods and bring a found food home or return home to recharge energy when the stored energy is depleted. In this case, the robots stay around the store many times relatively because the probability of searching around home is higher than searching in far away regions. Thus, the probability of collision with other robots becomes higher and higher. It then causes a bottleneck situation and wastes the energy because the density of individuals increases around the store. In this paper, we propose an algorithm using role division and division of searching space to solve this problem, thereby improving energy efficiency.

We can solve both the problems of concentrated robots around home causing the bottleneck situation and far away objects being rarely found by implementing caches. The caches are located at each divided search space by a constant area. Collecting robots in a divided space save the found objects to the cache of that divided space temporarily. Objects stored in the caches are then moved to home by conveying robots, which only perform the object carrying activity between home and a cache. Robots of different roles do not directly exchange the object, but the swarm of robots works through a division of labor. The division of labor makes the work cooperative, and thus reduces concentration of robots and bottleneck situation.



(a) The composition of foraging robot system (b) Trace of foraging robot work (R_{outter}=10)

Figure 1: Instance of the foraging robot system

In this paper, we apply a new behavior model to the existing foraging system to separate collecting and conveying work. The proposed system uses a different threshold time for the conveying and collecting work for changing role adaptively. Robots perform the conveying work during their conveying threshold time and the collecting work for their collecting threshold time. Due to such behaviors of each robot, the proposed system can achieve the effect that robots having two different roles cooperate with each other.

3. EXPERIMENT

Through simulation results, we compared the proposed system with an existing foraging system for verifying the effectiveness of our approach. Experiments were performed to observe changing energy consumption per one foraged object over different criteria, such as times and search spaces. In the experiment result graphs, the existing foraging system is labeled as ‘uncooperative’ and the proposed system is referred to as ‘cooperative’.

Table 1: The robot energy consumption of each state

State	energy consumed(unit/sec)
collecting food	12
moving	8
waiting	1
avoidance	9

The simulation environment is given as in the following. Operating system (OS) is Linux (Ubuntu 8.04.4 LTS). C++ and OpenGL are used as the program language. In the graphs, the results are average values of repeating the simulation ten times for assuring the reliability of the experiment. Energy consumption of a robot, described in Table 1, is used in our simulation to achieve similar parameter settings as in other paper [3] at each situation. One object robot of the proposed system is generated at a random position per ten second.

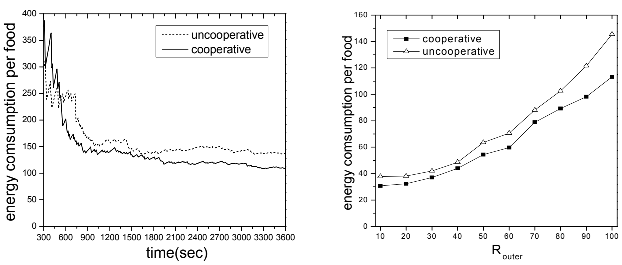


Figure 2: Energy consumption per one foraged food as the spending times (left) and Energy consumption per one foraged food as the changing radius of search space (right).

$$energy\ consumption\ per\ food = \frac{total\ energy\ consumption}{number\ of\ foraged\ foods} \quad (1)$$

The energy consumption per one foraged food is calculated by formula (1) that the total consumed energy is divided by the number of foraged foods for measuring the energy efficiency of the foraging work. Figure 2 show graphs that compares the energy consumption per one foraged food between our proposed approach and the existing algorithm. The energy consumption per one foraged food becomes an equilibrium state after enough times, such as in Figure 2 (left) after 1800 seconds. In Figure 2 (left) before 800 seconds, the consuming energy fluctuates because all robots had no objects and the number of foraged foods in the denominator is zero as the initial condition. The foraging robots system is performed for a long continuous time. Therefore, the results of the energy consumption per one foraged food after enough times fit the aim of our experiment. So, the energy consumptions per food in Figure 2 (right) are measured after 3600 seconds.

Figure 2 (right) shows the change of the energy consumptions per food in two different systems observed under the same conditions in terms of the number of robots (18EA), the frequency of generating foods, and the energy consumption for different behaviors, as the radius of search space R_{outter} is widened. As increasing the R_{outter}, we could obtain better performance of the proposed algorithm than the existing algorithm. In the existing algorithm, the increasing R_{outter} extends the area of search space, and the probability of finding foods at regions far from the home is much lower because many robots only move around home. But, the proposed algorithm can explore larger search area uniformly and can perform better because the distribution of generated foods is uniformly in the experiment.

4. CONCLUSION

We conclude that the foraging swarm robots system of distributed control can be improved, in terms of energy efficiency, by applying our new behavior model and dividing search space.

In the experiments, our proposed approach was shown to have better overall performance than the existing algorithm. Because the proposed algorithm reduces the duplicated search around home and the bottleneck situation in the existing algorithm by employing a new behavior model and the divided search space.

We supposed that, in the environment of the foraging system, the food is distributed uniformly and is generated every constant time. We then tried to improve the performance, i.e., energy efficiency of the system, and verified the effectiveness of the proposed algorithm by experiment in this environment. The proposed foraging algorithm performed better in larger search space even though the robots are equipped with cheap search sensors as in real swarm foraging system.

We proposed a method to improve the energy efficiency of the swarm foraging robot system with the assumption that the area of search space and the number of individuals that forage the objects are known. In the future, we need to extend our swarm foraging robots system to more practical situations such that the number of the foraging robots and the area of search space are unknown.

5. REFERENCES

[1] E. Bonabeau, G. Theraulaz, M. Dorigo. *Swarm Intelligence: from Natural to Artificial Systems*. Oxford University Press, 1999.

[2] C.W. Reynolds. Flocks, Herds, and Schools: A Distributed Behavioral Model. *Computer Graphics*, 21(4): 25-34, 1987.

[3] W. Liu, A. Winfield, J. Sa, J. Chen, L. Dou. Strategies for energy optimisation in a swarm of foraging robots, In: Sahin, E., Spears, W.M., Winfiel, A.F.T. (eds.) *Swarm Robotics, Second International Workshop, LNCS* 4433. Springer, Heidelberg, 2006.

[4] Alan F.T. Winfield. Foraging Robots, In: Meyers, R.A., (ed.) *Encyclopedia of Complexity and Systems Science*. Springer, New York, pages 3682-3700, 2009.

[5] N. Trawny, S.I. Roumeliotis, G.B. Giannakis. Cooperative multi-robot localization under communication constraints. *2009 International Conference on Robotics and Automation (ICRA09)*. Kobe, Japan, pp. 4394 – 4400, 2009.