Foraging Swarm Robots System Adopting Honey Bee Swarm for Improving Energy Efficiency

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ABSTRACT

We can efficiently collect crops or minerals by operating multi-robot foraging systems. As foraging spaces become wider, control algorithms require 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 the main barriers in operating multi-robot foraging systems. 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 the behavior model of honey bee swarm inspired by a honey bee colony in nature.

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

Foraging swarm robots, Honey bee swarm, Self organization, Behavioral model, Energy efficiency.

1. INTRODUCTION

Nowadays robots are replacing people in various fields. They are in factories that need precise process or huge physical strength, in being contaminated by radioactivity, in other planets, in the deep sea, in the Polar Regions, and so on. Many small robots are useful for exploring the nest of insect that is too difficult to approach by people [1]-[3]. Recently, many research scientists have studied swarm robotics adopting the swarm intelligence to mimic a swarm by a lot of robots. Swarm intelligence also has been researched by many scientists in recent years. Bonabeau has defined the swarm intelligence as "any attempt to design algorithms or distributed problem-solving devices inspired by the collective behavior of social insect colonies and other animal societies" [1]. Bonabeau et al. gave attention to solitary social insects such as ant, honey bee and termite. We can observe that a swarm of social insects demonstrates intelligent actions in daily life easily. For instance, a honey bee colony around their nest moves systematically. An ant colony also behaves in a smart manner for surviving. Similarly a swarm of birds keep a flock while they are flying. An immune system [2] in the human body consists of a lot of cells and molecules obstructing disease [3]. The action of bird flocking or fish schooling motivates the use of Particle Swarm Optimization (PSO) Algorithm [4].

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2. SWARM ROBOTICS

Swarm robotics is a novel approach to the control method of the multi-robot system adopting swarm intelligence. The multi-robot system consists of a large number of simple structured robots in swarm robotics environment. The robots are equipped with the things for performing their mission to simplify their structures. The simple robot structure makes mass production possible so that the multi-robot system is set up and maintained economically [5]. Each robot of the multi-robot system is similar to social insects such as ant, honey bee and termite. The each robot has pincers and equipment for moving like social insects. It also has not much physical and computing power. However, the multi-robot system in swarm robotics can perform complex missions that the single robot cannot do easily [6]-[8]. The system can forage objects in the search area efficiently and transform its own shape into suitable organizations for performing missions. This property by their interactions and cooperation make the multi-robot system more powerful [8]-[11].

2.1 Self-Organization

Self-organization is the ability to solve problems without accurate information by a given pattern. The robots of the multi-robot system construct themselves to fit to the structure though the property of self-organization.

Many small robots using the interactions in swarm robotics are controlled by their own rule without a central controller. Four basic properties of self-organization have been arranged by Bonabeau et al.: Positive feedback, negative feedback, fluctuations and multiple interactions [1].

2.1.1 Positive feedback

It is simple behavior rules such as recruitment and reinforcement in ants or bees. For instance, honey bees dance to signal the location of the food source they have found so that the colony takes the effect of reinforcing the search probability at the region. These rules are the examples of positive feedback.

2.1.2 *Negative feedback*

Negative feedback is the opposite of the positive feedback. It is necessary to keep the system in a situation when the food source is exhausted. The system can reduce the level of saturation and waste of energy via the negative feedback mechanism.

2.1.3 *Fluctuations*

Each individual of the swarm moves randomly and changes its task. There is much uncertainty in the swarm robot system because of errors caused by unexpected situations and randomness. However, the uncertainty like mutation in an evolutionary algorithm becomes the key possibility to find better solutions.

2.1.4 *Multiple interactions*

The key point of self-organization for having this property is the compositively continuous interactions from their own action with others for duration of time.

2.2 Foraging Robots

Foraging robots are a group of robots that collect objects using a behavioral model. A robot of foraging system can be equipped with an infra-red sensor for searching and avoiding and GPS for finding the storehouse. Additional equipment such as clamper, motor, wheel, and battery are also necessary for carrying out the foraging mission.

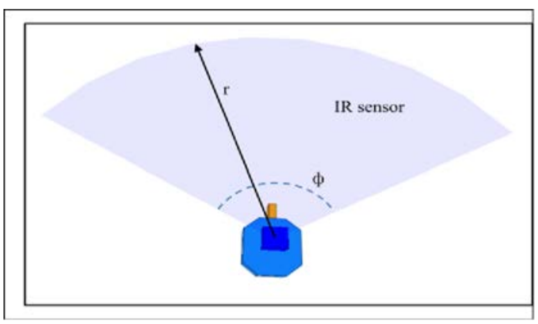

Figure 1. The composition of a robot of foraging robot system.

Each robot wanders around to find food, and brings the food home, or returns home to recharge energy when the stored energy is depleted. We can simplify the basic foraging activity of animals and humans based on a four-state behavioral model. They look for objects such as food and mineral in the search area. If they find objects, they collect them. They come back home with the objects and finally store them at the storehouse. Then, they resume their work and look for food again.

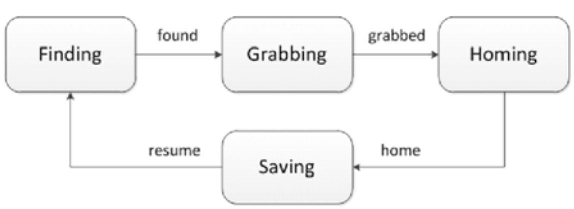

Figure 2. Finite state machine of basic foraging activity.

A robot tries to search for food in the search region in a random manner; the robot moves forward at a constant speed and changes its direction stochastically. If the remaining energy of a robot is depleting as a result of the time spent, it gets back to home and recharges its energy. If the robot finds a food, it approaches and grabs the food, and then goes home to place the food in the storehouse. While approaching the food, it is possible that other robots intercept the food or the food disappears from the sight of the robot in the course of avoiding some obstacles. In such a case, the robot searches for the food around and continues its collecting and storing activities. Alternatively, the robot traverses other areas for discovering foods.

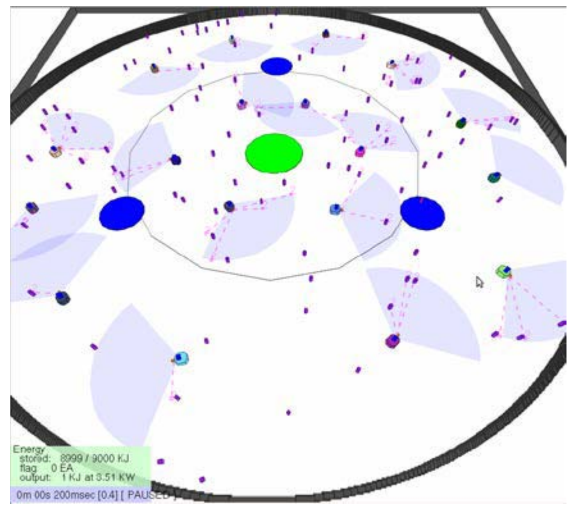

Figure 3. A concept of foraging robot system.

2.3 Honey Bee Swarm

A swarm of honey bees consists of three components: food sources, employed foragers and unemployed foragers [12]. The honey bee swarm is operated by interacting with each component. For instance, Employed foragers carry the honey from the food sources to the hive. While employed foragers work, unemployed foragers explore in the search region. Unemployed foragers find an efficient food source to carry food and then, they order the employed forager direction the employed should go next.

2.3.1 *Food Sources*

It affects the worth of a food source that means the proximity of the food source to the nest, amount and density of energy determine the value of the food source. The profitability of a food source can be estimated by the weighting factors.

2.3.2 *Employed foragers*

The employed foragers carry food to the hive from the food source. They are ordered to go to the food source by unemployed foragers. They carry information that assists to change the profitability of associated source.

2.3.3 *Unemployed foragers*

Unemployed foragers are divided into two models those are scouts and onlookers. The scouts continually search for food sources. If they find some food sources, they announce the information such as the proximity of the food source to the nest, amount, and density of energy and so on to onlookers. The onlookers stay in the hive. They have a role to share information with the employed foragers. They approximate the profitability of the food sources. The food source which has the best profitability is chosen for the target food source [13].

3. HONEY BEE SWARM FORAGING ROBOTS

In this section, we investigate the method to apply a honey bee swarm to the foraging robot system. The honey bee swarm foraging robot system is based on the foraging robot system adopting the behavior model. Each individual of swarm foraging robot system behaves by their own rule. We defined a behavior rule of the honey bee swarm foraging robot in Figure 4. In this figure, we divide the unemployed foragers into two roles as onlookers and scouts. The employed foragers move between home and cache as a food source and carry foods to home. The scouts randomly move around home to find new food sources. If they find food, they save information such as amount, distance, location and so on to their memory. The onlookers wait for the scouts to get the information, and then they approximate the profitability of the food sources. In this proposed system, it is possible to change the role. Each individual of the system changes their role by their own rule such as time threshold and conditions.

4. EXPERIMENTAL RESULTS

We compared our proposed system with an existing simple foraging robot system to verify the effectiveness of our approach. The systems observed the changes in energy consumption per one foraged food upon the time spent. In our study, 'uncooperative' is the existing foraging robot system and 'cooperative' is our proposed system. We experimented by Stage/Player that is an open-source simulator based on C++ and OpenGL programming language in Linux operating system. The experiment results were computed by the average values of running the simulator ten times. Each individual part of the system spends different amount of their energy at their state as described in Table 1. All conditions such as the time of generating food and the location of generated food that is randomly positioned were fixed in the experiment.

We used the energy consumption per food as shown in (1) to measure the efficiency of the system. The value of energy consumption per food was computed by that the number of foraged foods divided by the total consumed energy consumption. This value means the average of energy spent on each individual.

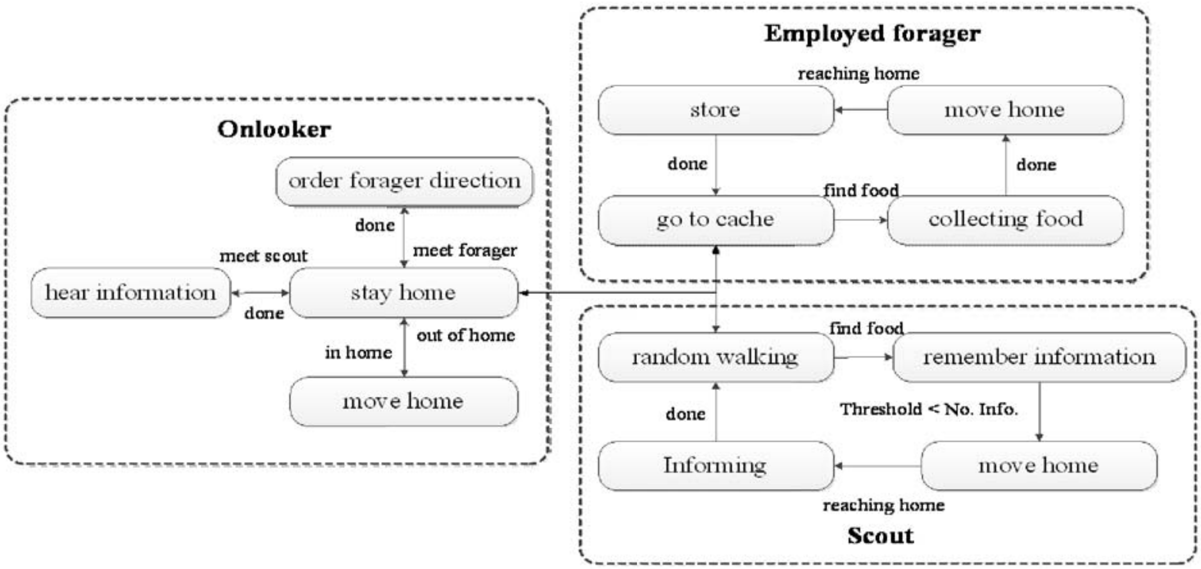

Figure 4. A state transition diagram of the proposed honey bee swarm foraging robots.

Table 1. The robot energy consumption of each state.

State	energy consumed(unit/sec)
go to work	6
random walking	8
approaching food	8
collecting food	12
searching area	8
Moving	8
Store	12
Waiting	1
Avoidance	6 or 9

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

In Figure 5, the cooperative system that is our proposed honey bee swarm foraging system had better energy efficiency than the uncooperative system that is a simple foraging robot. All individuals of the existing system work for the same foraging mission. They cannot adapt to changing situations because they only repeat their own simple rule but our proposed algorithm can adjust themselves by interactions. Before the 1800 second the existing system had better energy efficiency than our proposed system because all individuals in this experiment did not have any food at initial time so that it needed more initial energy. Our proposed algorithm needed some energy for the cooperation but the cooperation provides reducing to spend the energy.

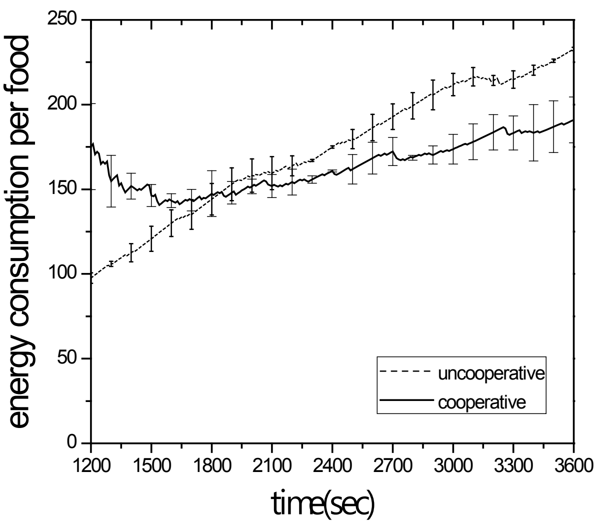

Figure 5. Energy consumption per one foraged food as the spending times.

5. CONCLUSION

The swarm foraging robots system can improved its energy efficiency by adopting honey bee swarm inspired by nature. It was performed by applying a new behavior model.

In the experimental results, our proposed approach was shown to have better performance than the existing system because our proposed system can adapt to the changing external environment by self-organization property.

We supposed that, in the environment of the foraging systems, the food is distributed uniformly and is produced continuously. 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.

We adopted a honey bee swarm into the foraging robot system to improve the energy efficiency and verify the effectiveness of the method with the assumption that the area of search space and the number of individuals of foraging robot system are known. In the future, we are going to extend our honey bee swarm foraging robots system to more practical situations where the number of the foraging robots and the area of search space are unknown.

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