Bee-inspired foraging in an embodied swarm (Demonstration)

Sjriek Alers*, Daan Bloembergen, Daniel Hennes, Steven de Jong, Michael Kaisers, Nyree Lemmens, Karl Tuyls, and Gerhard Weiss

Maastricht University, PO Box 616, 6200 MD, Maastricht, The Netherlands
http://maastrichtuniversity.nl/swarmlab

ABSTRACT

We show the emergence of Swarm Intelligence in physical robots. We transfer an optimization algorithm which is based on bee-foraging behavior to a robotic swarm. In simulation this algorithm has already been shown to be more effective, scalable and adaptive than algorithms inspired by ant foraging. In addition to this advantage, bee-inspired foraging does not require (de-)centralized simulation of environmental parameters (e.g. pheromones).

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems

General Terms

Algorithms, Experimentation

Keywords

Swarm Intelligence, Foraging, Swarm Robotics

Online material

http://swarmlab.unimaas.nl/papers/aamas2011demo/

1. INTRODUCTION

Many species have evolved over a long period of time to display behavior that is highly suitable for addressing complex tasks. In recent years, we see an increasing interest in taking inspiration from such behavior in order to create artificial systems that can also address complex tasks. Especially behavior within colonies of social insects, such as ants and bees, is receiving a great deal of attention, because this behavior is remarkably effective and robust given the highly limited capabilities of individual insects. The phenomenon that intelligent behavior emerges from a collective of interacting agents that each are relatively simplistic, is generally referred to with the term *Swarm Intelligence* (SI).

In this work, we aim to transfer social-insect behavior to embodied systems, i.e., to robots. For this purpose we investigate foraging behavior. Foraging is the task of locating and acquiring resources. Typically, the task has to be performed in an unknown and possibly dynamic environment [7]. We aim at developing a collective of robots that displays effective foraging behavior without any form of central control or simulation. The foraging task can be seen as an abstract representation of many other relevant tasks, such as patrolling and routing. Therefore, a successful embodied implementation of distributed foraging can result in promising applications in e.g. security patrolling, monitoring of environments, exploration of hazardous environments, search and rescue in crisis management situations, et cetera.

Most research in SI is centered around and inspired by ant behavior [1]. Although ants have limited cognitive capabilities, they are able to effectively perform difficult tasks, e.g. distributed foraging. Ants deposit pheromone trails during their exploration of the environment. This acts as the swarm's memory. Ants are attracted to existing pheromone trails, which implies that these trails are enforced by other ants traveling over them. A mechanism that counteracts on this self-enforcing behavior is the natural evaporation of pheromone over time. Ants thus use pheromone to *recruit* other members of the colony for visiting certain food sources, and to *navigate* from their nest to the food and back again.

Although pheromone is easy to implement in simulated SI systems, deploying it in embodied systems is not trivial. For instance, we would ideally have physical means of representing pheromone trails in the environment, which is only feasible in controlled environments such as factories (e.g. a grid of RFID tags being placed in the floor). In the absence of such physical means, the pheromone trails need to be simulated, either by a centralized component, or by the robots themselves. This places a high computational burden on the distributed system and limits scalability and applicability.

In our work, we focus on SI mechanisms that are not based on pheromone, namely the recruitment and navigation mechanisms employed by honeybees. Instead of using pheromones, honeybees make use of a mechanism called Path Integration for navigation, and the mechanism of direct communication for recruitment. Previous research in bee-inspired SI has led to the creation of a number of highly effective bee-inspired optimization algorithms [3, 4, 5] in simulation. The employed mechanisms are inherently fully decentralized, which makes bee-inspired algorithms also extremely suitable for implementation in embodied systems.

In this paper, we present an implementation of the basic bee-inspired algorithm *Bee System* (BS) [3] on an embodied swarm. We investigate how capable the algorithm is in coordinating a large collective of robots in a situated foraging task. Our goal is to test for robustness, efficiency and scalability. In our demonstration, we present the first implementation of BS into a collective of autonomous robots, i.e., the ePuck robots (http://e-puck.org).

2. BIOMIMICRY FORAGING

We intend to demonstrate biomimicry foraging. More precisely, we

*Contact author: sjriek.alers@maastrichtuniversity.nl

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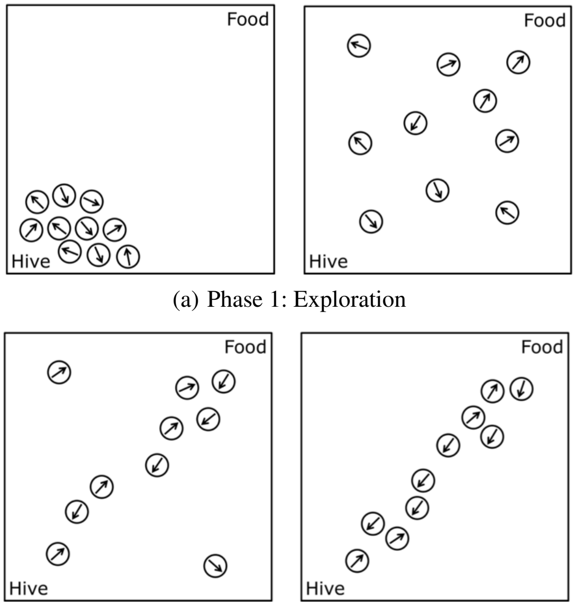

(a) Phase 1: Exploration

(b) Phase 2: Exploitation

Figure 1: Biomimicry Foraging

have an open arena space which contains a starting location (the hive), a food source, and a swarm of robots. For clarity, the hive and the food source, which are represented by robots, are also indicated by visual markers. The task of foraging can be divided into two phases, each consisting of two episodes, see Figure 1. Initially, the robots are in the exploration phase. Episode one of this phase represents the case where all robots are still located around the hive. In the second episode, the robots start to explore the environment in search for a food source. Once a robot finds a food source, phase two starts. Episode one of this phase deals with the robot returning to the hive loaded with food. On arrival at the hive, the robots communicate the position of the food source to other robots and by doing so recruit other swarm members. Finally, knowledge on the location of the food source is exploited; the robots will commute between hive and food source.

All components in the environment are represented by robots. Therefore, the robots exhibit three distinct behaviors: (1) hive behavior, (2) food-source behavior, and (3) foraging behavior. The first two behaviors are performed by one robot each. The rest of the swarm performs foraging behavior. The hive and food-source robots are placed at an initially static location in the arena. The foraging robots are mobile and initially placed near the hive location.

A foraging run can be described as follows. Leaving the hive, the foraging robots start exploring the environment using a movement pattern defined by a Lévy distribution [9]. Exploration by insects, birds, and mammals has been found to be closely modeled by such a Lévy distribution. Essentially, the distribution is characterised by many short distances and few long distances being travelled. In between traveling forward according to the distribution, robots perform (pseudo-)random turns. As a result of this movement pattern, the area covered by the collective is large, and collisions between two individual robots are rather unlikely.

During exploration and exploitation, the foraging robots are able to compute their present location from their past trajectory continuously and, as a consequence, can return to their starting point by choosing the direct route rather than retracing their outbound trajectory [2, 6]. This navigation mechanism is called Path Integration (PI) and its result is a PI vector indicating the location of the departure location (i.e. the hive or the food source). Foraging robots are able to store two PI vectors, one indicating the hive and one indicating the food source. The former is created during exploration for food sources. The latter is created during return to the hive. Whenever a robot encounters a food location, it takes some of the virtual food by means of local communication with the food source robot. Then, it directly returns to the hive using the PI vector indicating the hive. On arrival at the hive, the foraging robot has created a PI vector indicating the direction and distance toward the food source.

The robots recruit other robots by means of direct communication. Upon arrival at or near the hive, they communicate their PI vector to the hive and deliver the virtual food. Other robots are now able to exploit search experience by copying the PI vector and using it to travel to the food source. If a foraging robot gets lost during its PI-guided trip, it will search for its goal using a Lévy flight. For example, such a disruptive event may occur if the starting location is not exactly at the hive location, the hive location is moved, or the experimenter moves a food source. The latter is also demonstrated.

3. CONCLUSION AND FUTURE WORK

The demo serves as a proof of concept. We show how the bee-inspired SI mechanism is used in a real-life autonomous robot collective which mimics the basic foraging behavior of bees.

As this first experiment serves as a proof of concept for the direct deployment of bee-inspired algorithms into a robot swarm, upcoming experiments will focus on scalability, robustness, and efficiency on foraging tasks in more complex and dynamic environments. We will also extend the embodied algorithm to mechanisms developed in simulation already, such as landmark navigation [4].

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