Toward Soft Heterogeneity in Robotic Swarms

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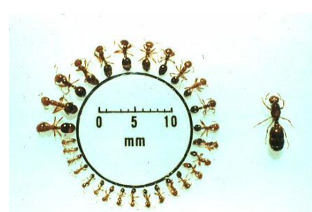
Abstract

Diversity and inequality are essences of our real world. Ant colonies are comprised of hundreds of individuals, with no two of them being exactly identical. A flock of birds contains individuals with slight variations in size, speed and vision. Looking at human societies such diversity can be seen among individuals differing in body shape and in physical and cognitive abilities. The concept of softly heterogeneous robotic swarms uses the notion of heterogeneity in nature, and introduces a swarm of robots which all have the same goals, but have minor differences in their capabilities. This term is in contrast to the hard heterogeneity of swarms in which robots are of strictly different types and have strictly different goals and capabilities.

1 Biological Inspiration

Polymorphism is a known phenomenon in biological systems, meaning that various forms or types of individuals are seen among the members of a single species. This phenomenon can be seen in many different expressions in nature, ranging from polymorphic ants and birds (with differences in, e.g., size, color and strength) to different blood types in humans. Natural polymorphism can be categorized into discrete variations (e.g., blood groups) and continuous ones (e.g., smooth height variations in human population). Figure 1(a) illustrates three types of bees known as Workers, Queen and Drones, which have different sizes and different capabilities but still live together in the same colony.[1] Figure 1(b) illustrates a continuous-like polymorphism in the form of size of workers in a colony of fire ants, in which the largest workers can have up to 10 times the size of the smallest workers.[2]

(a)



(b)

Figure 1: Illustration of different types of polymorphism (a) discrete polymorphism in bee colonies (b) continuous polymorphism in ant colonies

[1] http://www.tutorvista.com/content/biology/biology-iv/biotic-community/species.php
[2] http://acwm.lacounty.gov/scripts/rifa.htm

2 Principle of Soft Heterogeneity in Swarm Robotics

Heterogeneity in complex systems is an issue that has attracted the attention of different research communities in computer science, artificial intelligence and robotics. For example, in [1] various types of heterogeneity that can be ascribed to particle swarm optimizers are studied. This can improve the efficiency of computational techniques. Heterogeneity of complex networks has been also studied, e.g. in [2], where the dynamics of epidemics in complex heterogeneous architectures are investigated. Heterogeneity has recently found its way to swarm robotics as well. In [3] a distributed robotic system which consists of three different robot types (eye-bots, hand-bots and foot-bots) is introduced. We refer to such structures, in which different robots have different capabilities and different goals as hard heterogeneity in swarms.

In contrast, we define the soft heterogeneity in swarm robots as the situation in which a group of similar robots all have the same goals but slightly different levels of capability. As an application of such systems, consider a scenario in which a group of simple robots try to uniformly disperse in an unknown environment. Each robot can simply compute its distance with the neighboring robots and after computing the borders of its own territory, moves toward the center of the territory. Gradually, all robots make a uniform coverage in the area (i.e. known as Voronoi coverage). This approach can be very efficient in convex environments. However, as soon as nonconvexities such as obstacles are added to the environment, this approach fails as robots get stuck behind the obstacles (i.e. reaching the local optimum in a coverage problem). In [4] we proposed a coverage method (called StaCo), based on the concept of Stackelberg game, which uses soft heterogeneity in a swarm to overcome the problem of local optima. In StaCo all robots have the same basic capabilities except that some of the robots have better perception ability and can predict the behaviors of other robots. Consequently, the proposed softly heterogenous swarm avoids the only locally optimal solutions, while it is less costly compared to a uniform swarm of advanced robots. The other advantage is that if a robot fails during the mission, other robots in the swarm, even if they have a different level of capability, can replace the failing robot. This makes such swarms highly robust compared to swarms with hard heterogeneity where replacing another robot type is not an option.

The provided definition of softly heterogenous robotic swarms suggests that these swarms can perform better than the long-established uniform swarms in various scenarios. For instance, they can perform both exploration and exploitation of an environment in a rescue mission, or can act highly flexibly in passing obstacles and nonconvexities in a flocking mission. In general, using this novel concept of soft heterogeneity in robotic swarms can avoid available limitations of traditional swarm robotics.

3 Demonstration

This demonstration aims at showcasing the potential applications of softly heterogenous swarms and concentrating on the key characteristics of these systems. A collection of videos and images of the heterogeneity in nature initiates the demo. Afterward, the performance of StaCo [4], as an example of soft heterogeneity in robotic swarms, is compared with traditional Voronoi-based coverage in environments of different levels of complexity. Finally, various simulations of soft heterogeneity in other swarm robotic applications such as swarm flocking and swarm foraging will be demonstrated. As regards our future work, we aim at demonstrating the benefits of soft heterogeneity with swarms of real robots.

References

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