

REPORT

Swarm Intelligence research at IRIDIA, Université Libre de Bruxelles

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Swarm intelligence deals with natural and artificial systems composed of many individuals that coordinate using decentralized control and self-organization [1, 2, 5]. The main focus of swarm intelligence research is on the collective behaviour that results from local interactions of individuals with each other and with their environment. There are many examples of natural systems that are studied in swarm intelligence research: ant and termite colonies, fish schools, bird flocks, animal herds and even human crowds. There are also a number of human artefacts that are studied: swarms of robots, computer programs that tackle difficult problems in optimization and in data analysis. IRIDIA, the artificial intelligence laboratory at the Université Libre de Bruxelles, is known world-wide for its work in swarm intelligence. In particular, in the last 20 years my research group has been focusing on swarm optimization and on swarm robotics.



Fig.1 A swarm of s-bots.

Swarm optimization

The two best-known swarm intelligence techniques for the solution of optimization problems are ant colony optimization (ACO) and particle swarm optimization (PSO).²

Ant colony optimization

(www.aco-metaheuristic.org)

The main contribution of my research group has been in ant colony optimization, a population-based metaheuristic that can be used to find approximate solutions to NP-hard problems [9, 8, 6, 4]. In ACO, a set of software agents called artificial ants search for good solutions to a

given optimization problem. To apply ACO, the optimization problem is transformed into the problem of finding the best path on a weighted graph. The artificial ants incrementally build solutions by moving on the graph. The solution construction process is stochastic and is biased by artificial pheromones, that is, numerical parameters associated with graph components (either nodes or edges) whose values are modified at runtime by the artificial ants. ACO has been applied to a large number of NP-hard problems, often obtaining state-of-the-art performance—an overview can be found in [11]. ACO has also been applied to network routing problems in a number of different situations: from standard packet-switched networks offering a best-effort service [3], to highly dynamic mobile ad hoc network [12]. More recently, ACO has been extended to tackle continuous and mixed variable optimization problems, with very encouraging results [18, 14].

Particle swarm optimization

My group has also contributed to particle swarm optimization research [13, 10]. In particular, we have proposed a novel high-performing PSO algorithm called Frankenstein's PSO [15], and the use of incremental learning techniques within PSO [16].

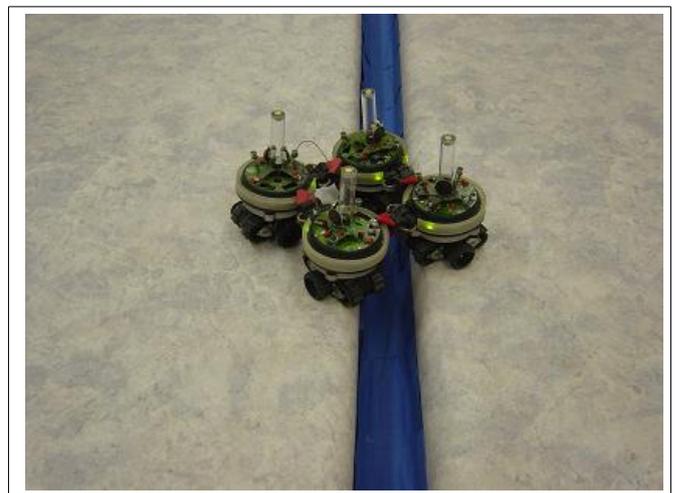


Fig.2 A swarm-bot made of four s-bots attached to each other can pass over a trough that is too large for a single s-bot.

Swarm robotics

Swarm robotics is embodied swarm intelligence. In other words, it is an approach to the control of groups of robots with a focus on systems that are composed of a large number of autonomous robots that cooperate to perform tasks that are beyond the capabilities of a single

²Research in swarm optimisation has been partially funded by the French Community of Belgium via the “Meta-X” ARC project, by the European Commission via the Marie Curie programme, and by the European Research Council via the Advanced Grant “E-SWARM; Engineering Swarm Intelligence Systems”.

robot. Additionally, the robots' sensing and communication capabilities are local and the robots' actions are neither directed by a centralised controller nor based on any global knowledge. In this field, I have coordinated two European projects: Swarm-bots and Swarmanoid.³



Fig.3 The object search and retrieval scenario.

Swarm-bots (www.swarm-bots.org)

The main objective of the Swarm-bots project⁴ was to study a novel approach to the design and implementation of self-organising and self-assembling artefacts. One of the main achievements of the project was the design, construction and control of 35 s-bots (Fig.1), autonomous robots capable of grasping each other using a gripper and to communicate using sound and colour. By grasping each other, s-bots form bigger connected structures that we call swarm-bots. A swarm-bot can perform tasks that a single s-bot cannot. An example is given in (Fig.2).

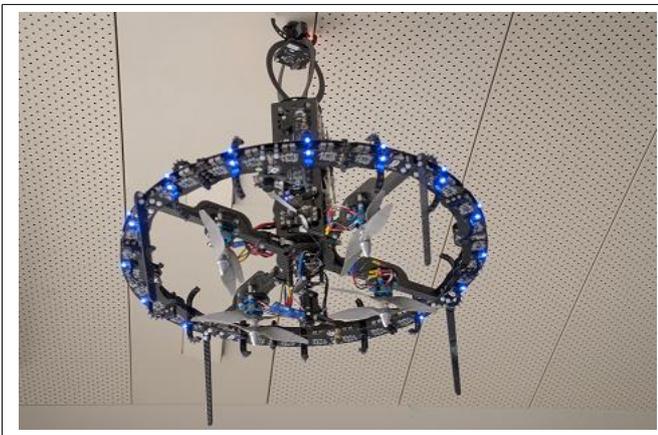


Fig.4 An eye-bot.

These robots have been used to run a number of experiments in which the robots were given tasks that were beyond their individual capabilities, but that could be performed via cooperation. An example scenario we considered was the search and retrieval of an object. The object was too heavy to be transported by a single robot and therefore the s-bots needed to find strategies to physically cooperate. Additionally, the object was placed in

a large environment so that, given their limited sensing capabilities, the s-bots also needed to cooperate both to find the object and to find an appropriate path to the goal location. An illustration of the experimental environment is shown in Figure 3. The interested reader can find detailed descriptions of the results of these experiments in [17].



Fig.5 A foot-bot.

Swarmanoid⁵ (<http://www.swarmanoid.org>)

The main scientific objective of this research project⁶ was the design, implementation and control of a novel distributed robotic system composed of three types of robots called eye-bots, foot-bots and hand-bots. The name of each robot type is reminiscent of their principal respective robot functionality. Eye-bots (Fig.4) are flying robots equipped with a camera and whose main functions are to search the environment and to guide foot-bots towards a goal location. Foot-bots (Fig.5) are robots that can move on the ground and transport objects or other robots. Finally, hand-bots (Fig.6) are robots that can manipulate objects and climb structures, but cannot move on the ground: they are transported by foot-bots (Fig.7). Collectively, these robots form a swarmanoid. Over the course of

³These two project were funded by the Future and Emerging Technologies programme of the European Commission; in addition to IRIDIA, coordinator of the project, participants in the projects were EPFL, Lausanne, Switzerland; IDSIA, Lugano, Switzerland; and ICST, CNR, Rome, Italy.

⁴The project lasted 3.5 years: from October 1, 2001, to March 31, 2005.

⁵The neologism "swarmanoid" is the contraction of the terms "swarm" and "humanoid". The idea behind it is that a swarmanoid is a robotic system composed of a swarm of robots that perform tasks that are usually performed by humanoid robots.

⁶The project lasted 4 years: from October 1, 2006, to September 30, 2010.

the project we built a swarmanoid composed of about 60 autonomous robots of the three above-mentioned types.

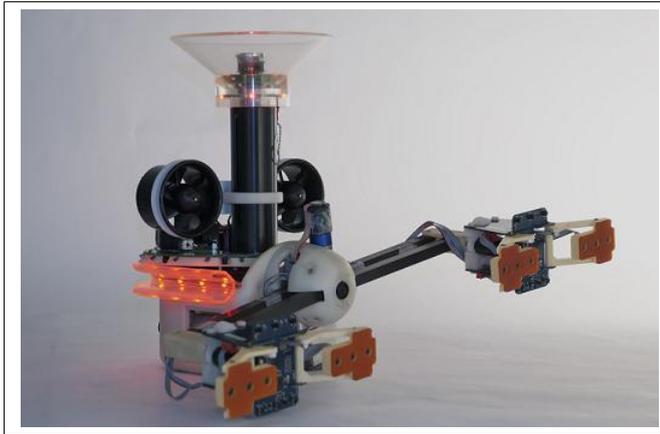


Fig.6 A hand-bot.

In a large scale experiment, we deployed the swarmanoid to search for and retrieve a book that was placed on a shelf at the end of a corridor in a standard office environment. To do so, constituent robots of the swarmanoid had to cooperate both logically and physically. The eye-bots' main mission was to search for the book and, once found, to indicate to the foot-bots the path to reach it. Foot-bots were charged with transporting hand-bots to the shelf. Once there, hand-bots climbed the shelf and grasped the book. They were then carried, together with the book, to the start location. A video of the experiment, fully described in [7], won the AAAI 2011 Best AI Video Award and can be seen at www.aaavideos.org/2011/swarmanoid_the_movie/.

Current and future research

I believe that, in the future, swarm intelligence will be an important tool for engineers interested in solving certain classes of complex problems. However, our current understanding of how to use swarms of artificial agents largely relies on rules of thumb and intuition based on the experience of individual researchers. This is not sufficient for us to design swarm intelligence systems at the level of complexity required by many real-world applications, or to accurately predict the behavior of the systems we design. For these reasons, the main goal of ongoing research in my lab⁷ is the development of a rigorous engineering methodology for the design and implementation of artificial swarm intelligence systems. This same goal is also being pursued by another European project, ASCENS: Autonomic service-component ensembles, where we are trying to adapt software engineering methods so that they can be used in the design and implementation of swarm robotics systems.

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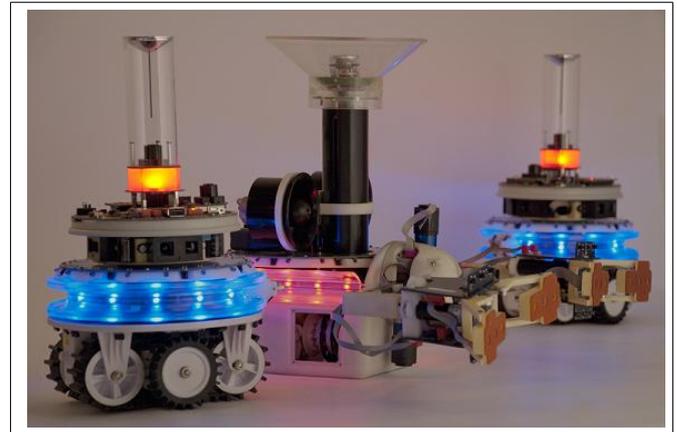


Fig.7 Two foot-bots are approaching a hand-bot that they will then transport.

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