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Swarm Robotics

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INTRODUCTION

Swarm Robotics is a biologically inspired approach to the organisation and control of groups of robots. Its biological inspiration is mainly drawn from social insects, but also from herding and flocking phenomena in mammals and fish. The promise of emulating some of the efficient organisational principles of biological swarms is an alluring one. In biological systems such as colonies of ants, sophisticated cooperative behaviour emerges despite the simplicity of the individual members, and the absence of centralised control and explicit directions. Such societies are able to maintain themselves as a collective, and to accomplish coordinated actions such as those required to construct and maintain nests, to find food, and to raise their young. The central idea behind swarm robotics is to find similar ways of coordinating and controlling collections of robots.

BACKGROUND

The mechanisms that underlie social insect behaviour have inspired an approach that emphasises autonomy, emergence and distributed functioning, and avoids a reliance on centralised control and communication. This approach underlies both swarm robotics, and the closely related notion of artificial "swarm intelligence". The term "swarm intelligence" was first coined in the context of cellular robotic systems, on the basis of the features that the simulated robotic collections shared with social insects: namely "decentralised control, lack of synchronicity, simple and (quasi) identical members" and size (Beni and Wang, 1989). Bonabeau et al (1999) describe as swarm intelligence, "any attempt to design algorithms or distributed problem-solving devices inspired by the collective behaviour of social insect colonies and other animal societies" (pg 7, Bonabeau et al, 1999). The key ingredients of swarm intelligence that they emphasise are self-organisation, and stigmergy, (indirect communication via the environment). Martinoli (2001) similarly describes the swarm intelligence approach as emphasising "parallelism, distributedness, and exploitation of direct (agent-to-agent) or indirect (via the environment) local interactions among relatively simple agents.

Swarm robotics has been described as the application of swarm intelligent principles to collective robotics (Sharkey and Sharkey 2006). The same principles of decentralised local control and communication are applied to physically instantiated robots. In swarm robotics, the emphasis is on using a number of simple robots that are autonomous, not subject to global control, and that have limited communication abilities. The reliance on local communication means that the potential problems of communication bottlenecks, or centralised failure, are avoided. The system benefits from the redundancy of using several robots: if individual robots were to fail, others could take over, and new ones could be added without the need for recalibration of communicative systems. In the same way, the activities of an ant colony need not be affected by the removal of some of its members. The simplicity of the individual robots means that they are able to respond quickly to the environment. There are also several tasks, such as exploring an environment, that can be accomplished more efficiently if a number of robots are used.

Of course, using a collection of robots creates some new problems itself (Bonabeau et al, 1999). There is the possibility of stagnation: without global knowledge, a group of robots can find themselves in a deadlock situation. Too many robots trying to reach the same location, or perform the same task could obstruct each other. Another problem is finding a solution to a task: how can situations be engineered in order that a desired solution can emerge? Nonetheless, the promise of being able to send a number of autonomous robots to perform a task, particularly in sites that are remote and inhospitable to humans, outweighs the disadvantages**.**

SWARM ROBOTICS

Early work in swarm robotics can be illustrated by describing a series of studies in which simple robots are shown to be able to collect a number of objects in one place, and even to sort them. This work was initiated by a paper by Deneubourg et al (1991), and observations of the ability of ants to work together to sort their brood into clusters of eggs, larvae and cocoons, despite the insects' limited communicative abilities. In their simulations, "ant-like robots" (ALRs) moved randomly in a two dimensional environment populated by objects, and showed a greater probability of picking up the isolated items they encountered, and a greater probability of dropping them at locations where more items of that type are present. Their simulations demonstrated that the model eventually resulted in clustering and sorting of objects. Beckers et al (1994) applied these ideas to actual robots. Their robots had IR sensors for obstacle avoidance, a gripper to pick up the objects, and a microswitch that was activated when they pushed three pucks or more. They could (i) travel in a straight line until (ii) an obstacle was detected, whereupon they would turn to avoid it, or (iii) until their micro switch was activated, whereupon they would drop the pucks they were carrying, and turn away. Since the robots` grippers would automatically collect up pucks they encountered, these behaviours were sufficient to result in the eventual collection of all the objects in a single cluster. Holland and Melhuish (1999) extended these results: augmenting the robots` behaviours with a "pull-back" rule that required robots to pull pucks of one colour back for some distance before releasing them. Its effect was that (after several hours), pucks scattered across the arena were collected up by the robots, and sorted into clusters of different colours. More recently, Wilson et al (2004) reported further investigations of different minimalist solutions to 'ant-like annular sorting' using simple robots and simple mechanisms.

Other swarm robotic studies have also explored the behaviours that can be accomplished by robots that respond in a fixed manner to environmental stimuli, and that do not directly communicate with each other. A number of studies were designed to investigate explicitly cooperative tasks, (tasks that have been designed to require cooperation), such as pushing a box that is too heavy to be pushed by a single robot (Kube and Zhang, 1996; Kube and Bonabeau, 2000). Stick pulling (Ijspeert et al, 2001) is a similarly explicitly cooperative task that involved locating sticks in a circular arena and pulling them out of the ground in circumstances where the length of the stick means that a single robot cannot pull it out by itself, but must collaborate with a second robot. Ijspeert et al (2001) used reactive robots with minimal sensing abilities. Their results show that collaboration can still be obtained despite the absence of signalling, planning, or direct communication.

These studies share a number of features. They all involve a number of robots. The robots are autonomous, and not controlled centrally; the control methods used could be scaled up to larger numbers of robots, or scaled down to smaller numbers since each robot performs a set number of fixed behaviours in response to certain stimuli. The individual robots are certainly simple – they have no knowledge of the environment they are in, or even of the other robots in it. They are essentially reactive: they have no knowledge or map of their environment, and they have no ability to communicate directly with other robots, or to receive instructions. Nonetheless, they exhibit apparently co-operative behaviour. Many of the studies make use of the concept of stigmergy, a term introduced by Grassé (1959) in the context of his observations of termite building behaviour. He noted that termite workers were stimulated to further constructive activity in the presence of particular features of a construction. The behaviour of the termite is affected by changes in the environment created either by itself, or by other termites: a form of indirect communication, where environmental changes have a signalling function. All of the examples discussed here explicitly draw analogies and parallels to living biological systems. Together, they illustrate some of the potential of swarm robotics: despite the simplicity of the individual robots, their interactions with the environment result in the performance of tasks in the physical world, and demonstrate that cooperation between such simple entities can emerge in the absence of any planning, centralised coordination, or even any direct communication between the robots.

Nonetheless, as research in swarm robotics has developed, so has a certain lack of clarity and agreement about the terms to be used and about what their defining features are (see also Dorigo and Sahin, 2004). There is agreement that swarm robotics implies the use of control and communication methods that are decentralised and scalable, so that communication bottlenecks are avoided, the robots operate autonomously, and the