In International Conference on Artificial Life V Nara Japan, 1996

Getting the Most from the Least:
Lessons for the Nanoscale from Minimal Mobile Agents

O.E. Holland and C.R. Melhuish

Intelligent Autonomous Systems Engineering Laboratory
Faculty of Engineering
University of the West of England
Bristol BS16 1QY, UK
email o-holland, cr-melhu@uwe.ac.uk

Abstract

Micro and nanoscale robots will require simple sensing, computation, and locomotion schemes. Drawing on investigations of the locomotion of very simple animals, this paper studies the abilities of single and multiple agents with single omnidirectional sensors and minimal computational complexity to move appropriately in relation to point sources and gradients of energy. Surprisingly efficient individual homing behaviour is obtained. Collective motion in response to static and moving targets is produced easily, both without interaction between agents (pseudo-swarming) and with interaction (true and secondary swarming), and shows some benefits for the individual under some circumstances. Some algorithms show emergent polarisation during pseudoswarming. Many of the collective simulations are strikingly reminiscent of the movements of particular insect and bird species.

1. Introduction

Engineers like to make systems with certain characteristics: use of simple components, use of many identical modules; reliability of system operation; adaptability to environmental changes; and robustness with respect to component failures. The engineer's view of natural collective systems, the best known of which are social insects, is that they use simple components (since the individual insects are typically much less complex than their solitary relatives); they use many identical insects; they exhibit system reliability; they adapt to environmental changes; and they are robust with respect to individual insect failures. The idea of making robotic systems which are modelled on such systems is therefore very attractive. However, it is surprisingly difficult to make the simplest robots possible because modern technology is based around controllable and easy to use complexity. Modern microprocessors are cheap, reliable, and extremely powerful. Memory is cheap. A video camera on a chip is a hundred dollars or so. Small reliable servo motors, encoders, and motor control chips are readily available. Why not use them? And if you're using them, why not take advantage of their power - a Kalman filter will improve performance here, an edge detection algorithm will help there, and so on. Besides, an ant is really a much more complex and powerful machine than even the best modern robots, and so surely building the simplest robot possible would be misguided as well as perverse?

These arguments are real and powerful in most conceivable robotic domains. However, at micro and nano scales, things are different. All we can expect to be able to build in those domains over the next few years are really quite dumb and simple robots, with rudimentary sensing and locomotion. At these scales, the benign macro environment becomes a viscous and swirling fog where sensing will be limited and difficult; energy use must be strictly limited, because energy can no longer be carried around in quantity but must be taken from the environment. The capacity of a single robot to achieve anything or even to survive for any length of time will be in doubt - only collective actions will succeed. It is in this domain that some of the engineering virtues of social insect systems - simplicity, repeated units - become imposed necessities, and others - reliability, adaptability, robustness - look more desirable than ever. These concerns have prompted us to look at the individual and collective abilities of the simplest possible mobile agents, with a view to developing behavioural strategies for collective micro and nanorobot systems.

There is a useful biological literature on the movement in various environmental conditions of simple animals such as protozoa, bacteria, and maggots. Schöne (1984) reviews early and modern literature on taxes, kineses, and tropisms, and provides useful abstract models of the simplest biological sensor systems. Particular investigations of interest include Colombetti and Francesco (1983), Foster and Smith (1980), Ricci (1989), Koshland (1980), Bray (1992), and Feinleib (1980).