CONTROLLING AND COORDINATING MOBILE MICRO-ROBOTS: LESSONS FROM NATURE - IMEC'99 NASHVILLE, USA, 99

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ABSTRACT
Assuming that mobile micro-scaled robots will be built in the future it is reasonable to speculate how such machines can be controlled. At the micro-scale robots will experience considerable limitations. Against this background, and inspired by natural collective systems, the paper explores collective minimalist mechanisms for the key aspects of moving through the environment, regulating the size of robot groups and acting on the environment.

1. INTRODUCTION
With the advent of new micro-machining technologies including micro-sensing, micro-actuation as well as micro-electronics and micro-computation it is reasonable to assume that very small mobile robots will be built in the future. It is reasonable to speculate therefore how such machines can be controlled and how their activities can be co-ordinated. Realistically, there will be considerable imposed limitations for designers and constructors of micro-scale mobile robots. Micro-robots will be seriously constrained in communications, sensing, actuation and computation. Energy use must be strictly limited because energy will not be able to be carried around in quantity and therefore it is highly likely that it will be extracted from the environment. These limitations of such minimalist robots are likely to be compounded by the assumption that at small scales the working environment becomes extremely hostile. It is therefore argued here that the capacity of a single minimalist robot to achieve anything or even to survive for any length of time will be doubtful. It is further argued therefore that multiple robot solutions will be required. The question is therefore '*How can one get a lot of dumb robots to do something smart?*' This paper briefly revues some of the work undertaken at IASeL which has attempted to answer such a question. The approach is inspired, in particular, by natural collective systems such as the social insects.

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). Social insect systems are composed of many identical insects; they exhibit system reliability; they adapt to environmental changes; and they are robust with respect to individual insects failures. Studies of social insects show us that groups of individuals, limited in their ability, can collectively achieve remarkable feats. Such feats as migration, building, foraging for food and materials as well as the maintenance and defence of nests, and brood appear to be achieved without recourse to many of the aspects often considered necessary for intelligent behaviour. These would often include; internal symbolic representations of the world, global information, symbolic reasoning over the world model, planning, and high bandwidth communications. The idea of making robotic systems which are modelled on such systems is therefore very attractive. Engineers often like to make systems with similar characteristics such as the use of simple components, use of many identical modules; reliability of system operation; adaptability to environmental changes; and robustness with respect to component failures. Realistically, we can only expect to be able to build really quite dumb and simple small scale robots, with rudimentary sensing and locomotion in the foreseeable future. At the micro-scale some of the engineering virtues of social insect systems including; simplicity, repeated units (therefore reduced unit costs) may well be necessary. Other aspects of social insect, such as, adaptability, robustness and redundancy could prove to be vital for the completion of designated tasks. It is argued that if the principles which govern the collective behaviour of a natural swarm system could be discovered, then it would offer engineers and roboticists the prospect of building minimalist, robust, task-achieving systems, with built in redundancy.

Such considerations provide the motivation to look at the individual and collective abilities of very simple mobile agents, with the prospect of developing behavioural strategies which might be applicable for future collective micro-robot systems. Sections 2 and 3 discuss mechanisms allowing micro-robots to move through their environment and then act on it.. It has also been speculated that it may be very useful for robots to organize themselves into 'work gangs' of a desired size in order to act on the environment. These themes, along with mechanisms supporting synchronous changes in behaviour are dealt with in sections 4 and 5. The paper attempts to show that it is possible to control and co-ordinate the actions of a collection of simple (and possibly very small) mobile robots to