IDEA GROUP PUBLISHING

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ITB10426

Chapter XV

Biologically Inspired Collective Robotics

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ABSTRACT

In this chapter, we review our recent research in the area of collective robotics, and the problem of controlling multiple robots in the completion of common tasks. Our approach is characterized with a strong inclination for biological inspiration in which examples in nature — social insects in particular — are used as a way of designing strategies for controlling robots. This approach has been successfully applied to the study of three representative tasks, namely, collective box-pushing, collective construction, and collective sorting. Collective box-pushing deals with the purposeful motion of an object too large to be moved by a single robot and we rely on the group prey transport phenomenon found in ants to derive the necessary behaviors for accomplishing this task. Collective construction is concerned with the building of a geometric structure with the combined efforts of many individuals in parallel, without centralized control and we study a species of ant known to possess this capability, to model and control the process of creating a circular nest with multiple robots. Finally, *in collective sorting the broad behavior in ants serves as the motivation behind designing robotic behaviors that depend on only local sensing in clustering objects of different types into separate piles. The success of our proposed approach is supported by both simulation and physical experiments using robots.*

INTRODUCTION

Can the study of collective behavior in social insect colonies assist in the design of multiple robot systems? Within the last 15 years some roboticists have been looking toward social insects for inspiration on how to design multiple robot systems. Motivated by a lack of progress in the traditional AI plan-based approaches to robot design, "behavior" has become the new way (*nouveau* AI) to compose control architectures for autonomous robots (Brooks, 1986).

With its tighter coupling between sensing and action, behavior may allow robots to deal with the uncertainty presented by real unstructured environments in which the robots perform their tasks. After all, social insects were capable of successfully navigating and acting in the face of uncertain and unpredictable environments. It was reasoned that if a single robot required complex systems and techniques in order to perform in a reliable manner, then perhaps intelligent systems could be designed with many "simpler" robots using a minimalist approach to sensing and actuation; where group behavior is an emergent property and control is decentralized. Could system reliability be achieved by trading complexity for redundancy coupled with ”randomness” used to explore possible solution paths, which are often traits found in social insect colonies?

Maybe, biology *can* teach us a thing or two about engineering swarms of simple interacting robots, and the theoretical foundations developed to model and explain these behaviors found in insect colonies can be used to underpin a more rigorous approach to collective robot design.

Nature has already demonstrated the feasibility of this approach by way of the social insects. Collections of ants, termites and other social insects were considered by entomologists to be, at the macroscopic level, robust and reliable despite the many antagonistic forces present at the microscopic level between individuals. The underlying premise is that this approach of studying how social insects collectively perform specific tasks, then modeling their behavior and using that model to develop a robotic implementation, would further our understanding of the design of these artificial systems. If so, would these systems be reliable? And how do we program them for a specific task and what specific tasks should we use as the basis for our designs? More importantly, how exactly should we measure the performance of these new task-achieving systems?

This chapter describes our efforts in the last 10 years at answering some of these questions and speculates on possible approaches for the rest. Our research has followed a task-centric approach, and we have used three representative tasks, collective box-pushing, collective construction, and collective sorting, as examples through which to uncover the principles that underlie the operations of multi-robot systems. In the following, we will first provide background information about how the research field of collective robotics has evolved and shaped itself and we will then discuss the details of our research in the three representative collective robotic tasks. Finally, we will highlight