Self-Assembly and Morphology Control in a Swarm-Bot

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I. INTRODUCTION

For any robotic entity to complete a task efficiently, its morphology must be appropriate to the task. If the task is well-defined in advance, the morphology of a robotic entity can be pre-specified accordingly. If, however, some of the task parameters are not known in advance, or if the same robotic system is required to solve several different tasks, morphological flexibility may be required. It is easy to imagine, for example, that navigating on uneven terrain and hole-crossing are likely to require different morphologies.

The field of modular self-reconfigurable robotic systems is dedicated to the study of systems with morphological flexibility (for a good overview see [17]). The components of such systems can autonomously reorganise into different configurations. Several different hardware architectures (lattice, chain/tree, mobile) and many different implementations and control mechanisms have been proposed [3], [9], [13], [16]. However, in the majority of current implementations, the components are either manually pre-assembled or rely on their environment (be it natural or man-made) to provide the energy required for independent movement. Once assembled, most existing systems are furthemore incapable of autonomously assimilating additional modules.

Self-propelled self-assembling robotic systems, in contrast, are made up of independent autonomous mobile components that are capable of forming physical connections with each other without external direction. Such self-assembling systems are potentially more flexible than pre-connected self-reconfigurable systems. Several architectures have been proposed, which have been implemented with varying degrees of success [2], [4], [6], [7], [8]. However, none of the existing systems display any meaningful control over the morphology of the connected entity formed through the self-assembly process.

Another related research field is formation control. Here, groups of robots steer themselves into one or more pre-specified formations [1], [5], [10], [11]. Mechanisms to maintain these formations while the group is in motion are also studied. Proposed approaches include the use of virtual structures, leader-follower schemes, and decentralised, behaviour-based methods. Most existing approaches rely either on global communication or on each robot having access to a blueprint of the global pattern (or both). Much of the research has been conducted in simulation only.

We propose a distributed control mechanism for a self-propelled self-assembling robotic system that allows robots to form specific, connected morphologies. Global morphologies are 'grown' using local visual perception only. The robots in our system do not have access to a blueprint of the global pattern and the algorithmic rules are solely based on what a single robot can see in its immediate surroundings. None of the robots have any predefined position in the final morphology, except for the seed robot that initiates the self-assembly process. Robots that are part of the connected entity indicate where new robots should attach in order to grow the local structure appropriately.

We demonstrate the efficacy of the mechanism by letting groups of up to 9 real robots self-assemble into four different morphologies: line, star, arrow, and dense.

II. HARDWARE PLATFORM

We use a number of real robots known as *s-bots* [12]. The *s-bot* platform has been used for several studies in swarm intelligence and collective robotics. Overcoming steep hills and transport of heavy objects are notable examples of tasks which a single *s-bot* could not solve individually, but which have been solved successfully by teams of self-assembling *s-bots* [7], [14], [15].

Each *s-bot* is equipped with an Xscale CPU running at 400 MHz, a number of sensors including an omni-directional camera, light and proximity sensors. Each *s-bot* also has a number of actuators. These include 8 sets of RGB coloured LEDs distributed around the circumference of the main *s-bot* body. These LEDs can be controlled individually and can be perceived by other robots at a range of up to approximately 50 cm. The *s-bots* also have a gripper that allows them to form physical connections with one another.

III. Control Principles

In this study, we start from a single predesignated robot, the *seed*, and "grow" morphologies progressively. The robots know in advance which morphology they are forming.[1] However, none of the robots have any knowledge about the global characteristics of the connected structure. Simple rules govern the local growth of the structure. By appropriate manipulation of these rules, different global morphologies emerge. Robots that are already part of the connected structure dictate how and when other robots should assemble to them.

The robots coordinate using their camera and coloured LED ring. Our control mechanism makes use of the colours red, green and blue. Green and blue indicate the left-hand side and right-hand side of a *connection slot*, respectively. A connection slot specifies a location and a direction in which the current structure should be extended. The connecting robot is lit up in red. After a robot has connected, it signals that the connection slot is no longer available by briefly opening an inverse connection slot. We refer to this procedure as a *handshake*. The seed and the newly connected robot are then free to open new connection slots.

During the self-assembly process, all non-connected robots (except for the seed) search for connection slots. When a robot finds a slot, it aligns itself in the direction indicated and attempts to assemble to the robot with the open slot. Once connected, the robot can open one or more connection slots itself, according to the rules of the specific morphology being formed.

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[1]Adaptive self-assembly into specific morphologies is a subject of ongoing research. Here, the robots themselves choose which morphology to form based on task parameters. Different encountered obstacles could, for example, trigger the formation of appropriate obstacle-specific morphologies.