Robots Autonomously Self-Assemble into Dedicated Morphologies to Solve Different Tasks

(Extended Abstract)

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ABSTRACT

We present the first real-world multi-robot system that can autonomously self-assemble (and dis-assemble) to form different morphologies capable of solving tasks that appear in an a priori unknown order.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems

General Terms

Algorithms, Design, Experimentation

Keywords

Swarm robotics, morphology control, morphogenesis, self-assembly

1. INTRODUCTION

Self-assembling robots can autonomously form physical connections with each other. Multi-robot systems composed of such robots can overcome the physical limitations of their individual constituent robots and potentially have the flexibility to solve diverse tasks. However, in order to leverage this potential, the self-assembly process must be controlled to allow the robots to form appropriate morphologies.

To the best of our knowledge, this is the first study in which real-world autonomous self-assembling robots use distributed morphology control to solve a sequence of different tasks. Much of the research in morphology control is either purely theoretical, or based on highly abstracted simulations [4, 1, 7, 6]. Other studies have used embodied robots (either physical or simulated) [5, 8], but none of the existing research uses morphology control to solve real-world tasks. Real-world self-reconfigurable [9] and self-assembling [3] systems have been studied, but usually with a focus on the hardware rather than autonomous morphology control.

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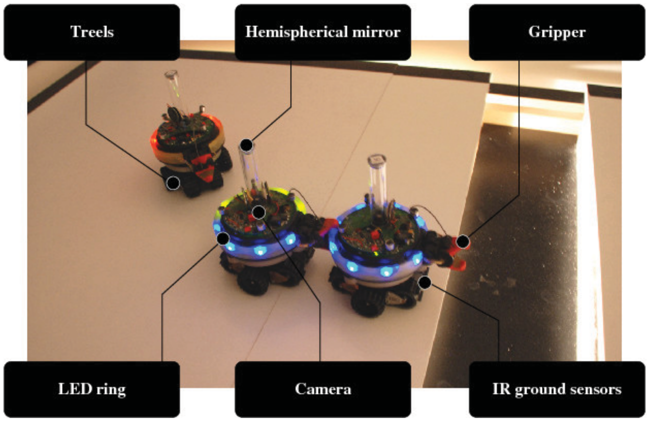

Figure 1: The SWARMBOTS platform.

2. EXPERIMENTAL SETUP

We use the SWARMBOTS robotic platform, that consists of autonomous robots called *s-bots* (see Fig. 1). During experiments, the same control logic is executed by each s-bot independently. S-bots can form physical connections with each other using a dedicated gripper. S-bots can coordinate using LEDs mounted around the s-bot body. An on-board camera can detect other s-bot LEDs up to 50 cm away and a light source up to 4 m away.

In our experiments, s-bots must navigate to a target light source across an arena containing up to two obstacles that can appear in any order: a gap of 22 cm and/or a bridge that consists of two pipes. (To prevent damage to the robots, we used a black surface instead of a gap when we ran repetitions of the experiment. A video of an experiment with a real gap can be found at `http://iridia.ulb.ac.be/supp/IridiaSupp2009-010`). The order of the obstacles is variable and unknown a priori. Each obstacle is impassable by a single s-bot and requires a dedicated morphology that is not appropriate for the other obstacle — the four s-bot line morphology for the gap (see Fig. 2 - bottom) and the two s-bot *support* morphology for the bridge (see Fig. 2 - top). S-bots detect when they have encountered or overcome an obstacle using their ground sensors. Because of the sensory limitations of the s-bot, we placed reflective materials before and after the bridge obstacle to allow them to distinguish it from the gap obstacle and to locate the bridge.

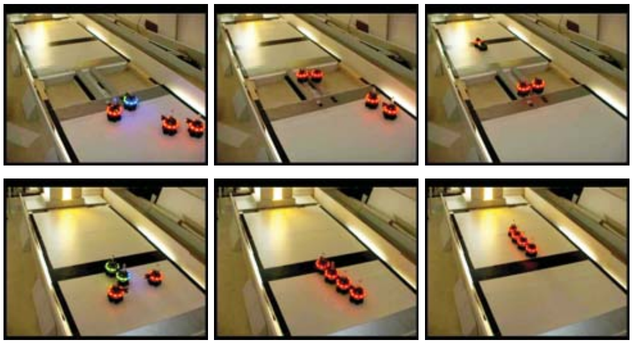

Figure 2: Four robots cross the bridge obstacle by forming two 2 s-bot support morphologies (top) and the gap obstacle by forming a 4 s-bot line morphology (bottom).

3. CONTROL

In this study, we extend the distributed morphology generation language SWARMORPH-script [2], which uses the paradigm of local directed morphology extension — s-bots that are already part of the morphology invite connections from unconnected robots in a particular direction by illuminating a corresponding configuration of the LEDs. Morphology growth starts when a single s-bot encounters an obstacle and invites the first connection of a new morphology. As new robots connect to the morphology, they communicate visually with the s-bot to which they connected using sequences of LED based signals. In this way, newly connected s-bots receive instructions on which obstacle-dependent morphology they are part of and their position in it.

Once a morphology is complete, the s-bots coordinate using visual notifications to overcome the obstacle. In the line morphology, a notification is propagated from robot to robot, starting with the last s-bot to connect to the morphology all the way up to the seed (the s-bot closest to the gap). Upon receiving the notification, the robots start to move. Similarly, once the last s-bot has crossed the gap (as detected by ground sensor readings), it notifies the robot to which it is connected and detaches from the morphology. The next robot in the line forwards the notification and disconnects, and so on. In this way, the line morphology is disassembled after the obstacle has been overcome and all the s-bots continue individually until the next obstacle is encountered. Similar coordination mechanisms enable the cooperation required to navigate over the bridge obstacle and to disassemble afterwards.

4. RESULTS AND CONCLUSIONS

We conducted 5 experiments in which two robots encountered the bridge, 5 experiments in which four robots encountered the gap, and a proof of concept experiment in which four robots encountered first the bridge and then the gap. In all experiments, the s-bots had no a priori knowledge of which obstacles they would encounter or the order in which they would appear. Videos of each type of experiment are available at `http://iridia.ulb.ac.be/supp/IridiaSupp2009-010`.

In all 5 bridge obstacle experiments, the robots correctly determined the nature of the obstacle and formed the correct morphologies. In 3 out of 5 experiments, the robots successfully crossed the bridge. In 2 out of 5 experiments, inaccuracies in the detection of the target light source caused the robots to veer sideways off the bridge, and they had to be manually placed back on the bridge. In every experiment, the robots successfully detected that they had crossed the bridge and disassembled.

In all 5 gap obstacle experiments, the robots successfully detected the gap, formed the appropriate morphology and crossed the gap. In 2 of the 5 experiments, the disassembly process failed due to a robot not detecting a notification.

In this study, we have demonstrated that by forming dedicated morphologies, a group of self-assembling robots can overcome obstacles insurmountable for a single robot. In our experiments, the response to the different types of obstacles – namely the formation of dedicated morphologies – was preprogrammed. We are currently investigating morphology control in heterogeneous swarms, where flying aerial robots can assist ground based wheeled robots to form appropriate morphologies adaptively (see `www.swarmanoid.org`).

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