Cooperative bridge building by self-reconfigurable modular robots based on ants' stigmergic behaviour

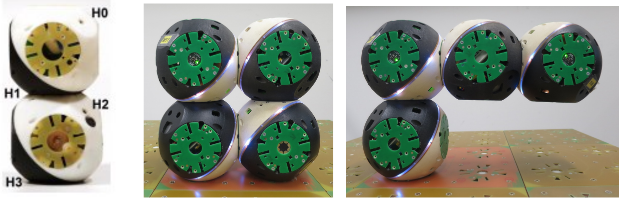
Jasmine Nguyen-Duc[a], Mehmet Mutlu[a,b], Simon Hauser[a], Alexandre Barnerdino[b], Auke Ijspeert[a]
[a]Biorobotics Laboratory, EPFL, Lausanne, Switzerland, *jasmine.nguyenduc@epfl.ch*
[b]Computer and Robot Vision Laboratory, IST, Lisbon, Portugal

1 INTRODUCTION

Insect societies have particular ways of self-organising. To improve their efficiency in task managing, ants are capable of forming a bridge-like self assemblage. “Army ant bridges are remarkably strong and adaptive; the insects begin to build them as soon as they sense a gap in their path and disassemble them once traffic has cleared” [1].

This research presents a method for robots to accomplish the construction of a bridge similarly to ants. For this, the concept of stigmergy must be studied. The use of stigmergy in the robotics field has lead to the creation of an artificial swarm intelligence. The particularity of stigmergy is mainly the use of indirect communication and the absence of a central leader. So the robots take initiatives without needing an external command or any direct communication with their “teammates”. The decision making of each agent is based on a set of rules and on the time varying environment.

Roombots are self-reconfigurable modular robots (SRMRs) designed in Biorobotics Laboratory of EPFL. Each module has two adjacent cube-like shapes and has three rotary degrees of freedom (DOF) as seen in Fig. 1a. Roombots are capable of self reconfiguration and locomotion by gripping onto specific surfaces. Active Connection Mechanism (ACM) and proximity sensors are positioned at the extremities of each module.



(a) (b) (c)

Figure 1: (a) Single RB module [2] and (b) an agent composed of two modules in standing position and (c) during a step forward.

The most common way of controlling SRMRs is centralized where all SRMRs are connected to a central computation unit, which decides how each module should behave. However, there exists distributed control ways too [3], [4]. Centralized methods usually suffer from high dimentionality of SRMRs and distributed methods may fail to find a solution for a desired task. Creating an algorithm inspired by a biological method used by ants would enable Roombots to achieve a certain primitive task, namely, crossing a wide gap that requires collaboration of multiple modules.

2 METHODOLOGY

2.1 An algorithm from ants

In previous studies, ants have been noticed to follow a set of simple rules while forming bridges: (1) if a gap is ahead, stop moving or slow down; (2) if an ant is immobile in front, climb on top of it and continue walking; (3) as long as an ant is on top of another, freeze. These are morphology-free commands that can be converted to an algorithm.

In our Roombots adaptation, each agent randomly explores the environment. The exploration is modelled as: ant continues walking in the same direction with 80% chance, changes direction with 15% chance and stops (without detecting gap) with 5% chance. The formation of a bridge can take a very long time since the agents just walk around randomly in the environment. However, agents can be attracted towards a gap, for example, driven by smell or light. We considered that there exists a slight attractor towards the gap. Thus, ants are more likely to walk towards the gap and start forming bridges during the exploration.

When a gap is detected while exploring, an agent leans forward and freezes for a fixed amount of time. If no other robot climbs over it in during the frozen period, the leaning robot stands up again and resumes exploration. If on the contrary, another robot does climb onto it, it stays frozen independent of time. Thus, the foraging robot has enough time to walk across the leaning robot's body. Once the other side of the gap is reached by a climbing robot, the bridge is formed and allows others to forage across it. As long as there are foraging agents on top of the “bridge-builders”, they cannot stand up. Once there are no more foraging ants on the bridge, the first agent that formed the bridge stands up first and crosses the bridge while disassembling it.

2.2 Roombot's mechanics

Each Roombots module has only 3 DOF that is quite low compared to capabilities of a real ant. In order to have more capable robotic units, metamodules of two modules (attached in series) have been considered as the smallest robotic agent (ant) as shown in Fig. 1b and Fig. 1c. Together, the two modules form a biped that is capable of walking in all four directions in the grid environment. Locomotion sequence is defined as follows: (1) Front module grips the ground and (2) back module releases connection. Then, (3) back module is first lifted up and (4) brought to the front side by a rotation of the gripping (former-front) module.

To detect a gap or an obstacle, the agent uses an IR sensor located at the tip of each "leg". Before dropping the leg onto the ground, the IR sensor is orientated downwards, checks for obstacles and gaps. In the absence of obstacles or gaps, it drops the leg to the ground and resumes exploration.

The presented method is essentially a distributed control framework. However, detection of collisions is a challenging task to be implemented in hardware. Even though, Roombots hardware allows rough torque measurements to detect unexpected collisions, we prefer not to execute actions that would result in collisions. Collisions could be avoided with distal sensors which are not yet integrated. Therefore, we tackle the collision problem in a centralised manner. As a compromise, only one agent moves at a time.

2.3 Logic-level simulation

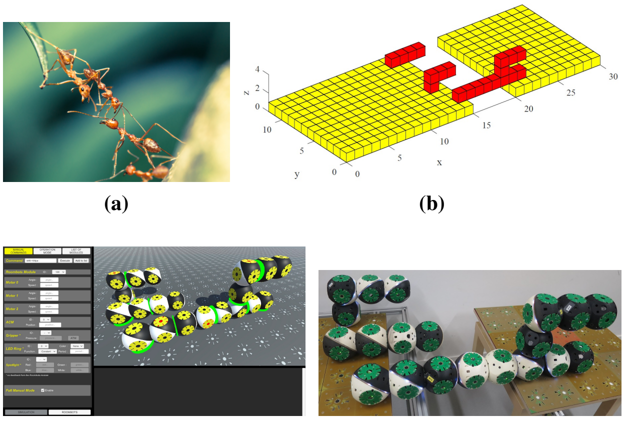
MATLAB is used to simulate the proposed method. Robots and the environment is abstracted into 3D voxel grid. Environment voxels are fixed and agent voxels are updated at each step according to the decision agent takes. Although, distributed agents can all move at the same time, in this work, only one agent moves one step at a time to simplify collision problems. Each step in the MATLAB simulation is a predefined set of actions (motion primitives) in real robots.

2.4 Experimental set-up

The simulation environment has a flat floor with a (four-unit wide) uniform gap that a single agent (ant) cannot cross. All agents are initially placed to one side of the gap and the experiments are concluded when all agents cross the gap or a single one is left behind. Different number of agents was tested varying from two to seven. Although, we envision a fully autonomous framework including the real hardware as shown in Fig. 2, for this work the the main focus has been the logic level simulation as illustrated in Fig. 2b.

3 RESULTS

The most obvious difference between this simulation and the biological system is related to the conformation of the bridge. The bridges formed in the simulation are much simpler in shape (only linear) and shorter. There are three major reasons for that. (1) Ants are very strong and can carry up to 50 times of their body weight. For Roombots, that number is slightly more than one. (2) Ants can hold on to each other in many different ways, whereas Roombots need to be well aligned and have much less connection possibilities. (3) Only a limited set of motion capabilities of Roombots have been considered for simplicity. Each action of an agent is a predefined set of motion primitives. In other words, the command "Move one step forward" translates into a set of consecutive actions such as "DOF 2 of Module 1 goes to 120 degrees", "ACM 2 of Module 1 disconnect"... It is possible to enrich considered motion primitives to enable formation of more realistic bridges.



(a) (b)

(c) (d)

Figure 2: Whole envisioned pipeline of the work consists of (a) Inspiration from real ants (credit iStock/lirtlon) (b) modeling the behaviour for distributed SRMR control using predefined motion primitives, (c) obtaining real action sequence and (d) execution on the real robotic system.

4 CONCLUSIONS

We have discussed cooperative behaviour for Roombots that cross a gap of a certain distance by self-assembling into a bridge. It is inspired by stigmergic foraging in ant colonies. In the simulation, the agents modify the environment by leaning over a gap when it is detected, thus decreasing its length. Other agents were shown successful in climbing over the ones leaning to extend the bridge until the other side is reached. The bridge becomes a shortcut which allows ants to reduce the distance to reach their target. This work will be extended with richer set of motion primitives to enable formation of larger and stronger bridges.

References

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