Influencing Emergent Self-Assembled Structures in Robotic Collectives Through Traffic Control

Extended Abstract

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ABSTRACT

Multiagent self-assembly allows collectives to reach areas otherwise inaccessible to any particular agent. However, the coordination of this collective is not trivial, so each agent's position in the structure is usually determined apriori. In our approach, we take inspiration from army ants and use a simulated model of the *Eciton Robotica* robot [4] to form emergent structures with bio-inspired local rules. We demonstrate that by coupling this with traffic control, we can induce the formation of a structure and control certain characteristics without pre-computed paths or central coordination.

KEYWORDS

Collective Behavior, Swarm Robotics, Bio-Inspired Robotics, Self-Assembly

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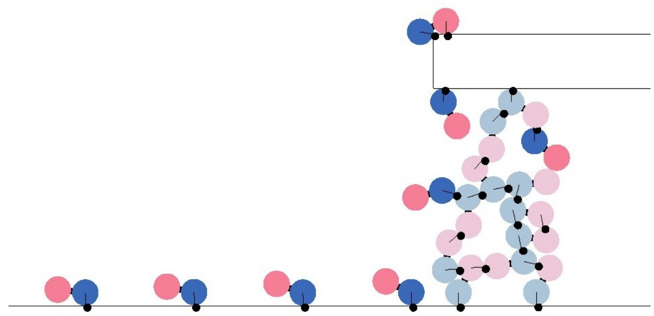

Figure 1: Structure formed by *Flippybots* in the simulated island environment. The lightly shaded robots are in their bridge state, and considered part of the structure.

1 INTRODUCTION

Self-assembling multiagent systems can create structures through simple rules which help them perform complex behaviors. In nature, social insects build structures that not only allow them to perform otherwise impossible tasks – army ant bridges help traverse rough terrain, weaver ant chains carry heavy loads, and fire ant rafts keep the colony afloat – but can also adapt to their environment and the needs of the group [1, 2, 5, 12].

Most work on self-assembly in robotics has focused on creating structures where the size and shape are predetermined. This can range from the vast number of modular robotic systems [13], to independently mobile robots such as M-blocks [8], or even self-assembling boats [7]. However, the vast majority use complex path planning to move modules to specified locations. While useful in many cases, this method of building explicitly requires an outside designer, making it impractical in scenarios where there is insufficient information to preplan a detailed design.

Emergent robotic structures, in contrast, can potentially conform to unknown environments and respond to stimuli with little to no prior knowledge. Far fewer examples exist of this type of self-assembly. Swarm-bots formed pulling chains and foraging paths [3, 6], and Slimebots [9] similarly adapted their shape around obstacles. More recently, Swissler et. al have used a goal-driven recruitment strategy for FireAnt3D [11] with ReactiveBuild [10] to self-assemble 3D structures in simulation.

In this paper, we present a method imitating the structure formation behavior of natural swarms through goal-driven formation similar to ReactiveBuild: robots use a bio-inspired state machine, local sensing, and knowledge of a specified goal location to self-assemble an emergent structure that allows the collective to reach that goal. We use a simple rule inspired by army ants, where robots join the structure if they sense that they are stepped on by another robot. We couple this with a speed control function to induce a local traffic jam and thus structure formation, and we show how varying two speed control parameters affects the location and form of the structure. The robots, named *Flippybots*, move via a flipping gait and are modeled after *Eciton Robotica* from Malley et. al [4], but the

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algorithm could be applied to any robot that can self-climb, sense other robots, and sense its relative position to some goal location.

2 GOAL DRIVEN STRUCTURE FORMATION

The core idea behind goal-driven structure formation is that we can set a particular goal that the robots must reach, and they will automatically assemble a structure that enables them to reach that goal. We run our experiments with the *Flippybots* in a 2D test environment, shown in Figure 1, where robots spawn and move from left to right across a flat terrain, with a floating island in the top right of the environment. We set the top-left edge of the island as the goal; robots must build a structure to reach this island.

Each *Flippybot* uses a simple state machine to determine its behavior. By default, it begins in its "walking state", where it flips forward until another *Flippybot* has gripped it. At that point, the first *Flippybot* goes into its "bridge state", where it stops in place. The first *Flippybot* remains in this state until released. Once released, it will wait for a short time period before returning to its walking state. This simple state machine makes it possible for several *Flippybots* to self-assemble as a collective.

For the robots to reach the goal, we slow down robots' speed as they move closer to the goal and induce a traffic jam around the goal. Robots collide in the traffic jam, causing many of them to stop to allow other robots to climb over them. In this manner, the robots assemble a structure that continues to build until some subsequent robots reach the goal.

To induce a traffic jam, we use a speed control function to set the speed of a robot at any particular x coordinate. The following equations define our speed control function.

$$v(x) = \frac{v_0}{1 + e^{k(x - x_s)}} \tag{1}$$

$$v(x_g + \sigma) = v_f \tag{2}$$

$$x_s = (x_g + \sigma) - \frac{1}{k} ln(\frac{v_0}{v_f} - 1) \tag{3}$$

where x is the robot's x position, $v(x)$ is the flipping speed at x, v_0 is the robot's initial flipping speed, v_f is the robot's final flipping speed, and x_g is the goal's x position. k and σ are parameters that we can tune in order to change characteristics of the assembled structure, where k is a proportional gain constant, and σ is a goal offset.

The exponential ensures robots start at a high speed, and gradually slow down as they approach the goal, reaching their lowest speed beneath the goal. This maps well to a simple alternative, a step function, while the continuity makes it realistic to a hardware system as robots in the real world cannot stop instantaneously, and easy to tune via the gain and offset.

Note that we do have some apriori knowledge of the environment; we know that the robots will have to assemble a structure upwards to reach a floating island. Our equations might change if the robots needed to instead cross a bottomless pit. However, there is no pre-planning outside of determining a goal for the robots to reach, and some idea of what obstacles the robots will face in informing our equations. The *Flippybots* form a structure with only knowledge of their position, and whether they are stepped on. There is no communication between the robots.

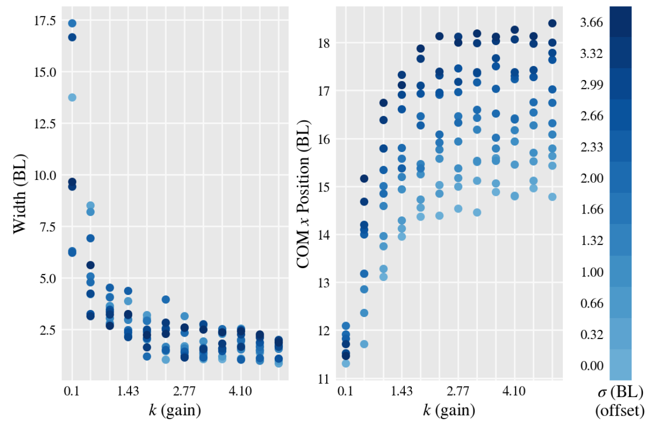

Figure 2: Subplots showing structure characteristics. We see how we can influence x position and width through our k-σ values.

3 RESULTS

We calculate the width and x position of the COM (Center of Mass) of all successfully formed structures. All robots in a bridge state at the time that any robot reaches the goal are considered part of the structure. The width is the distance from the leftmost point in the structure to the rightmost point. COM is the center of mass of all robots in the structure. All distance measurements are in BL (Body-Lengths), where 1 BL is the length of 1 *Flippybot* along its longitudinal axis.

We see how k and σ values influence the size and position of structures in Figure 2, where we sweep various k (gain) and σ (offset) values and show characteristics of the emergent structure. Width declines with respect to k at low k values until around $k \geq 2.77$ where the widths appear to stabilize around $1 - 3$ body-lengths, indicating that structures become thinner and more efficient as k increases. The relationship between width and k seems to be exponential, which may be related to the shape of the speed control function, where increasing k increases the "sharpness" of the speed control function. We further see that σ predictably controls the relative x position of the bridge at high k values. The x position shifts to the left at lower k values due to the earlier slow down of the robots.

4 DISCUSSION

In this paper, we have shown how we can influence emergent structures from self-assembling robot swarms through goal-driven structure formation. We see that through tuning simple parameters, k and σ, we can influence structure characteristics. Future work should investigate how we can influence other characteristics of these structures as well as how robots might dissolve structures once they are no longer necessary.

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