

Spatial-organizing Behaviors in Swarm Robotics

Introduction

Swarm robotics utilize many kinds of collective behaviors to carry out complex real-world tasks as a swarm while maintaining individual behaviors. One category of collective behaviors in a swarm is spatially-organizing behaviors, which focus on how to organize and distribute robots in space [1]. This paper is a review of spatial organizations commonly used in swarm robotics.

Commercial Applications of Spatial Organizations in Swarm Robotics

Current applications of swarm robotics utilize spatial-organizing behaviors, e.g. aggregation and self-assembly. Although most prototypes and products that utilize aggregation behavior etc. are designed for research purposes, there are several startups and labs producing robots which can execute spatially-organizing behavior in a swarm. A recently founded startup Hydroswarm produces a swarm of self-developed “small, autonomous underwater drones” for underwater exploration, which can adjust their positions relative to each other with collective behavior. Currently the startup is focused on producing and testing a customer version before proceeding with industrial production, and no cost for the drones is enclosed yet [2].

Senseable City Lab at MIT created a swarm of robots called Seaswarm to clean up oil spills in the sea/ocean. Individual units in the swarm communicate through GPS and WiFi to position themselves according to the aggregation behavior of the swarm as can be seen in the promotional video [3, 4]. Estimated cost of each unit is \$20K if produced in large numbers, and commercial product will be released in a near future [5].

Another commercial product that utilizes aggregation behavior in a swarm is Jasmine Micro-Robots. These 30x30x20 mm micro-robots are equipped with two microcontrollers (Atmel Mega88 and Mega 168) and can successfully re-embodiment “biological aggregation behavior of honeybees” [6]. Each Jasmine micro-robot costs around 100 Euros and related software is open source [7].

Technology behind Spatial Organizations in a Swarm

Most commonly used spatially-organizing behavior in swarm robotics is aggregation behavior. Aggregation allows robots in a swarm to get close enough to successfully interact with each

other. Two main approaches used for aggregation behavior are *Probabilistic Finite State Machines (PFSMs)* and *Artificial Evolution* [1]. Probabilistic Finite State Machines approach is the most common approach and implements separate states for different behaviors of the robots. Transition among these states are ensured with a stochastic component. Starting state of the robot is *approach* which causes the robot to explore an environment. When the proximity conditions are met, i.e. when the robot discovers another robot in the area, a state transition occurs and the robot enters a *wait* state. Based on the number of the robots in the environment, or the formation of the swarm, the robot stochastically determines whether to join or leave the aggregate [1, 8].

Another spatially-organizing behavior used in swarms is *self-assembly*. Self-assembly and morphogenetic behaviors allow robots to connect to one another without human intervention or external direction [1]. After connecting to another robot, the robot extends its morphology accordingly to include the newly attached robot [9]. Another aspect of self-assembly behavior is to decide which robot should assemble with the other; proposed solutions include using artificial evolution and recurrent neural networks to make time-dependent decisions about who will attach whom [10].

Military experts believe that the bionic aero vehicles inspired from swarm intelligence technology with spatially-organizing behavior capabilities will become applicable in a few years [11].

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