Online Dispersion Algorithms of Robot Swarms

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Abstract

We develop and analyze algorithms for dispersing a swarm of primitive robots in an unknown environment R. The primary objective is to minimize the *makespan*, that is, the time to *fill* R with robots. We study algorithms in both discrete grids and continuous environments.

1 Introduction

A natural problem that arises in the study of "swarm robotics" is how to effect a fast dispersal and filling of an environment by a group of robots moving according to a set of local rules. We consider two versions of the problem, in which the environment R may be discrete or continuous.

A discrete environment is composed of unit squares (*pixels*) that are induced by the integer grid within a polygonal domain. There is at most one robot per pixel and robots move horizontally or vertically at unit speed. Robots enter R by means of $k \geq 1$ *door pixels* on the boundary of R, each of which acts as an infinite source of robots.

A continuous environment is modeled as a polygonal domain (polygon with holes). The robot swarm begins as a dense configuration of points with the domain and then spreads out as each robot executes a local strategy based on crude sensor data it acquires about its immediate surroundings. During dispersion, the swarm should stay "connected" in the sense that the communication graph, which joins pairs of robots that are close enough to exchange messages, should remain connected.

In both the discrete and the continuous models, robots are primitive finite automata, only having local communication, local sensors, and a constant-sized memory. These local autonomous agents are not centrally controlled, yet are expected to perform the global task of dispersing.

Summary of results: For discrete environments, we provide both theoretical and experimental results. The challenge in obtaining our results is in proving that purely local strategies distributed over a swarm of individual robots can result in a predictable and provable behavior for the collective.

- We give algorithms for the single-door case (i.e., $k = 1$), analyzing the algorithms both theoretically and experimentally in terms of some natural performance metrics, including makespan and total traveled distance of all robots. Our algorithms are based on leader-follower strategies that are carefully adapted from the principles of depth-first and breadth-first search to make them applicable to the local nature of the robot model. We prove that our algorithms have optimal makespan $2A - 1$, where A is the area (the number of pixels) of R. We also compare

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the strategies experimentally on the basis of total distance traveled by the robots.

- We give an algorithm for the multi-door case ($k \geq 1$), based on a wall-following version of the leader-follower strategy. We prove that our strategy is $O(\log(k+1))$-competitive, and that this bound is tight for our strategy as well as other natural strategies (e.g., breadth-first search).

For continuous environments, we do an experimental investigation of heuristic strategies:

- We compare experimentally four dispersion algorithms: Attraction-Repulsion, Head-for-Free-Space, Simple-Sensor, and Leader-Follower, in selected environments with various performance measures.

- We propose three heuristics that are intended to avoid excessive wasteful motion of robots during dispersion.

- We propose an ant-like behavior of robots to minimize further the possibility of the swarm becoming disconnected during dispersion.

This talk is based on two companion papers exploring dispersion algorithms of swarms of robots in discrete [7] and continuous [8] environments.

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