Distributed Auction-Based Initialization of Mobile Robot Formations

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Abstract

The field of multi-robot coordination, specifically robot formation control, is rapidly expanding, with many applications proposed. In our previous work, we considered the problem of establishing and maintaining a formation of robots given an already connected network. We now propose a distributed auction-based method to autonomously initialize and reorganize the network structure of a formation of robots.

Introduction

The field of multi-robot coordination, specifically robot formation control, is rapidly expanding, with many applications proposed. Among them are search and rescue, battlefield reconnaissance, exploration, survey, and of central consideration to our method, Space-Based Solar Power and sparse aperture telescopes. The problem of maintaining formations of this sort has been addressed by our previous work, a distributed formation control architecture which has been implemented in both simulation and on physical robot platforms, henceforth referred to as CATALST (Cellular Automata for Transformations of Agents in Large-Scale Teams; Mead 2008). This control architecture enables distributed coordination, while only requiring local communications between neighboring agents.

We propose to expand the CATALST architecture by allowing autonomy in the initialization of the formation. This is accomplished by dynamically assigning positions within the formation to robots via a distributed auction process, as the formation is being formed, in situ.

Background

The CATALST architecture has been implemented around the concept of robots as cells in a cellular automaton. An individual robot's behavior is reactive with respect to its neighbors, producing order among the entire group. Each unit need only be aware of its relative position and orientation to each neighbor in its neighborhood to calculate and realize a motion path to reach its desired position. A formation is then established and maintained using a distributed reactive control architecture, requiring no global information and no central leader.

The CATALST architecture uses a *seed* cell within the automaton to instigate changes initiated from an external controller to the rest of the formation.

Once the seed cell has been determined, the phase change from swarm to formation may begin. At this point, the seed must select n robots to fill the cells which directly neighbor it in the automaton. With static neighborhoods, along with having a pre-defined robot to fill the seed cell, each cell in the automaton has a pre-defined robot to fill it. This leads to inefficiencies when the number of robots increases beyond the order of a few tens of robots. A robot which is not yet assigned to a cell in the automaton may be in close proximity to an open cell, while the pre-defined robot to fill that particular cell is relatively far away. In order to solve this problem, we propose dynamically assigning robots to the automaton based upon which available robot will best fill the cell.

Auction Method

Our solution to the problem of finding the best robot to fill an available cell in the automaton is to have a cell at some location, c_i hold an auction for the empty neighboring cell, c_j. Auctioning is a tested method for coordinating multiple mobile robots and has even been applied to formation initialization (Lemay *et al*. 2004). Lemay's approach is to have each individual try to solve the problem of formation initialization, and then to auction among them for the best solution. While this is distributed, it is not dynamic. If it turns out that there were unknown or dynamic obstacles, the calculated solution may no longer be useful. Michael *et al*. 2008 presents a distributed approach to task allocation that is applicable to the initialization of a robot formation. While similar, our work distinguishes itself in that tasks (positions) are not known *a priori*, but, rather, are produced dynamically as a product of interactions between neighboring cells; also, we do not rely on a central coordinator—auctions are created and resolved locally.

A topic-based publish/subscribe model is used to facilitate communication among a group of cells in the automaton and among robots wishing to join the formation (Mead *et al*. 2009). The publish/subscribe paradigm allows a distributed group of agents to send (i.e., publish) and receive (i.e., subscribe) various types of information regarding select topics of interest. This allows state information to be passed among neighbors. A topic is addressed with a unique identifier, which for our purposes is a *formation-relative position* p_j (a Euclidean vector describing the relative location of the cell in the formation; Mead 2008). Subscribers can then discriminate between relevant and irrelevant published information. The content of a topic is the state of the cell c_j associated with p_j.

We assume that the swarm has been deployed to the vicinity of the desired location for the formation, and that a seed has been selected (currently by a human operator).

Implementation

As described in our previous work (Mead *et al*. 2009) and demonstrated in simulation, the auctioning of a single cell begins with the auctioneer, c_i, requesting information on the formation relative position in question, p_j. One of three responses may occur at this point: (1) If the position is already occupied, having been filled in an auction generated by a third cell, c_j, will respond directly, exchanging state information with the auctioneer. The auctioneer initiates regular contact with this cell as a neighboring cell, and no further action is required with this cell. If there are no other open auctions for this position, there will be no response. (2) A response from another publisher on the topic of p_j indicates that an auction is currently being held by another cell in order to fill p_j. (3) No response is received, implying that no other cell has an interest in p_j and that c_i is clear to publish an auction announcement regarding the opening.

In the case of Condition (3), c_i will announce an auction for the open position if c_i is closer to the seed than the position to be auctioned. The auctioneer becomes the publisher on the topic of the position to be auctioned.

A robot receiving the auction announcement will respond with a bid if two conditions are met: (1) either the robot has no neighborhood, or has a neighborhood which is not yet full, that is, the number of neighbors is less than the maximum number possible for the current formation definition and (2) if the robot is currently assigned to a cell, the distance from the current cell to the seed must be greater than that of the position being auctioned. If these conditions are met, the bidder will bid on the position. The bid consists of a weighted sum composed of the distance d from the bidder to the position being auctioned (p_i) weighted by an *energy cost modifier E*, and the number of existing neighbors n in the bidder's neighborhood weighted by a *relation cost modifier X*:

$$B(p_j) = E\,d + X\,n \tag{1}$$

We assume that the robots are equipped with a sensor or sensors capable of determining the distance from the bidder to the auctioneer, and the bearing of the auctioneer as it relates to the bidder. This distance and bearing may then be used to calculate the distance from the bidder to the position being auctioned.

After a period of time, which may be tuned for each deployment, the auctioneer announces the winning bidder, which is the minimum of the received bids. The auctioneer now passes publishing rights on to this bidder, which then becomes a cell in the cellular automaton. This process continues indefinitely, and will eventually result in bringing all robots, which were not associated with a cell, into the formation.

Future Work

We propose to utilize the existing simulator, which has been evaluated with tens of thousands of simulated robots, to perform more substantial tests on causing large numbers of robots to move from a randomized starting location to an organized formation via our method of distributed auctions. We will use empirical tests to find values for E and X, and to determine the increase in efficiency over statically defined neighborhoods.

For more information and related work, please visit http://roboti.cs.siue.edu/projects/formations/auctioning.php

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