Algorithms for Control and Interaction of Large Formations of Robots

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Abstract

NSF and NASA sponsored a workshop to discuss harvesting solar power in space. One solution considered was the use of a swarm of robots to form a solar reflector. How can these robots organize to form a large parabolic structure and be effectively controlled? The approach of this project is to treat the formation as a lattice of cells. Each cell is in one of a given state governed by a set of rules. A command that indicates the geometric formation is sent to a seed robot; the formation would then transform as neighbors attain their calculated relationship based on the formation definition.

Introduction

In April 2000, NSF and the NASA held a workshop to explore the concept of harvesting solar power in space. Space Solar Power (SSP) involves placing a large reflector panel in space and focusing a beam of solar energy on a panel on Earth. The result was a series of challenges that would need to be addressed, most significantly, the difficulties and high-cost of transporting the components for constructing a large reflector as well as the construction of the reflector itself.

One solution considered was the use of robots. The workshop report articulated one version of this solution in which the reflector is composed of a formation of robotic units:

> [The reflector is] actually created by having a swarm of coordinated independent semi-intelligent objects [(i.e., robots)] acting in concert. A solar reflector might be created in this way by having thousands of small free-flyers, each with a piece of mirror attached to themselves, fly into and then maintain a parabolic formation. One advantage of this strategy is that if the system is ever damaged, the swarm could reconfigure to eliminate the damaged elements but still maintain whatever level of uniformity might be required. (Bekey, et al 2000).

This poses some interesting research questions. For example, once deployed, how does this large collection of robots communicate and coordinate their activities to form an organized structure resembling a reflector? How do the robots know when and where to move to maintain their position within the formation? And how can one operator or a small group of operators communicate with thousands of robots to effectively change the formation as needed?

For a formation of robots numbering in the thousands, such as the 33,000 that Landis (2004) projected would be needed for SSP, direct control through a remote operation interface is impractical. Robot formations of this size will require some level of autonomous control. The approach of this project is to treat the formation as a type of cellular automaton, where each robotic unit is a cell. The robot's behavior is governed by a set of rules for changing its state with respect to its neighbors. By designating a small percentage of robots as "leaders", human intervention would change their orientation directly. This would start a type of chain reaction in the formation. This is analogous to seeing a crowd in a baseball stadium "doing the wave", where each individual's reaction in the crowd is based solely on the people sitting nearby.

Background

This approach to the autonomous control of creating and maintaining multi-robot formations is similar to work done in coordinating formations of Earth-bound, mobile robots (Fredslund & Mataric 2002, Balch & Arkin 1998). This work has been inspired by biological or organizational systems, such as geese flying in formation. In Fredslund *et al.* (2002), mobile robots are assigned a particular formation to follow, like a line, a V-shape, or a diamond. Each robot is assigned a position in the formation and an identification number that is transmitted, allowing each robot to find its neighbors. Using sensors and intercommunication, each robot is able to identify its neighbor and adjust its orientation appropriately.

A variety of work has also been done to apply reactive control structures to create emergent group behaviors. Flocking algorithms have been used for both physical and simulated robots (Ando et al, 1995). A digital hormone model, inspired by biological cell interaction, has also been proposed for robotic organization (Shen, et al 2004). However, these apply more to swarms, or collections that move with no group organization, as opposed to formations, which maintain a global structure. Robot formations have been applied to applications such as automated traffic cones (Farritor & Goddard 2004), while swarm behavior control has been applied to urban search-and-rescue robotics (Tejada, et al 2003).

The current work on robot formations requires units to have some sense of where they belong and who their neighbors are supposed to be. One of the goals of this project is to generalize the need for this information or at least create it more dynamically as the swarm becomes a formation and as the formation adjusts its pattern.

Formation Control

A desired formation is defined as a geometric description (i.e., mathematical function). A human operator chooses a robot as the *seed*, or starting point, of the formation. If the robots are not initially put in a formation, then a neighborhood must be dynamically built. This is done by implementing an auctioning method where a robot is chosen to be a neighbor based on its distance to the desired location on the geometric description. This information is determined by calculating a relationship vector from c, the formation-relative position (x_i, y_i) of the auctioning robot, and the intersection of a function F, which defines the formation, and a circle centered at c with radius, r, where r is the distance to maintain between neighbors in the formation [Figure 1].

Using sensor readings, robots then attempt to acquire and maintain the calculated relationship with their neighbors, and thus are independent of their actual position values on a global coordinate system. Once a neighborhood is established, relationships and states are communicated locally within that neighborhood. Despite only local communication, the calculated relationships between neighbors result in the overall organization of the desired global structure. Thus, it follows that a movement command sent to a single robot would cause a chain reaction in neighboring robots, which then change states accordingly, resulting in a global transformation. Likewise, to change a formation, a seed robot is simply given the new geometric description, and the process is repeated.

The control algorithm is currently being implemented and tested in a simulated environment.

Future Work

To manage the robot formation, a graphical user interface will be developed that will provide a human operator with a visualization of the formation and information of each individual robot unit. Through the interface, the operator will be able to choose a robot that will become the "seed" to instigate a formation change.

After successfully showing a proof-of-concept in a simulated environment, it will be implemented and tested on a modest number of physical robots, proving that the approach is viable in real space. For more information, visit http://roboti.cs.siue.edu/projects/formations.

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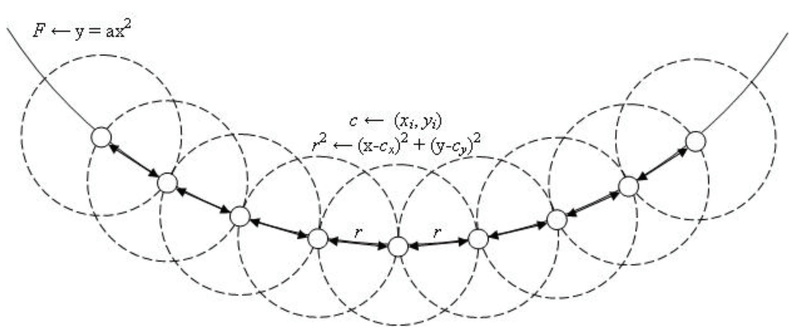

Figure 1: The cellular automata reactive control algorithm.