A Study of Geometric Pattern Formation by Multiple Mobile Robots

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Abstract:

We developed and implemented multi-robot coordination algorithms in this paper to solve problems such as geometric pattern creation, online terrain coverage, and load balanced job breakdown and allocation. We have shown that a well-coordinated robot team produces superior results by effectively using the system's available resources, namely the robots. The creation of geometric patterns using numerous mobile robots is the first issue addressed in this thesis. The uniform circle creation issue, in particular, has gotten a lot of attention. STATE is a decentralized method for uniform circle construction utilizing several mobile robots that we developed and implemented. On our multi-robot test-bed, one of the benchmark algorithms provided by Défago and Konagaya is re-implemented. The STATE algorithm outperforms the Défago and Konagaya algorithms in terms of performance. The STATE method outperforms the others because of its order-preserving scheduling strategy for multi-robot synchronization. The Défago and Konagaya method, on the other hand, employs a probabilistic scheduling strategy for multi-robot synchronization, which results in a higher number of activation steps and a longer time for the algorithm to reach convergence.

Keywords: *Multi-Robot, Geometric Pattern, Coordination, Algorithms, Implemented.*

1. INTRODUCTION

Multi robot systems (MRS) may be defined as groups of robots that work together to complete some difficult job. The scientific community is interested in this approach for many reasons, such as the numerous benefits of MRS. MRS use because they may improve the efficacy and efficiency of a solution for a particular job, such as a team of robots doing a task. Multiple industrial manipulators, military vehicles, and unmanned networked transport vehicles are just a few of the many ways in which MRS may be used. The team of mobile robots described in this thesis is called as MRS and is needed to work together to tackle difficult issues such as geometric pattern creation, rapid job covering, etc.

It is not just the individual's performance that has to be assessed but also the performance of the team. To evaluate system performance, we look at how long it takes to accomplish a job, how complicated the algorithm is, how sturdy the system is, and how fault tolerant it is. For this competition, we'll be judging the performance of the robot team based on four different factors: (1) the job description, (2) group architecture, (3) team makeup, and (4) communication structure (ability of a given robot to recognise and model the intentions, beliefs, actions, and capabilities of other robots). A major goal of MRS is to design and build complex robots that do specific tasks better than single complex robots. There must be agreement amongst the robots to come up with a better solution. It is necessary for each robot in MRS to talk to every other robot in order to accomplish this goal. In explicit communication, messages are transmitted directly, while implicit communication happens by means of detecting and localising other robots.

Designing and deploying multi-robot systems in the real world is challenging because of the abundance of necessary elements. But in spite of that, researchers have found ways to deal with the most distinctive features of MRS, such as group organisation, communication structure, control, group composition, learning, conflict resolution methods, and all in an integrated manner. Multi-robot systems have a significant interrelationship and high connection in features, making it challenging to create a categorization that focuses on a single property.

When numerous robots are sent for complicated tasks such as battlefield surveillance, environmental monitoring, and so on, it is preferable to maintain them in a formation since it increases data collection quality, job completion time, and so on. Maintaining a formation necessitates that the robots follow a certain coordinating approach Individual robots should utilize only local information to execute their coordination approach in multi-robot systems in their organization, which is intended to be decentralized. However, there are times when they must move with great accuracy in a specified precise geometric form, such as when transporting loads in parallel and simultaneously, which requires global awareness of the work environment as well as explicit interrupt communication.

2. LITERATURE REVIEW

Karl Tuyls 2015 In this paper we propose BeePCo, a multi-robot coverage approach based on honey bee colony behaviour. Specifically, we propose a honey bee inspired pheromone signalling method that allows a team of robots to maximise the total area covered in an environment in a distributed manner. The effectiveness of the proposed algorithm is experimentally evaluated on three different sizes of multi robot systems (MRSs) and compared against an ant-inspired coverage algorithm (StiCo) to show the different characteristics of these two approaches.

Subhrajit Bhattacharya 2013 Multi-robot coverage and exploration are fundamental problems in robotics. A widely used, efficient and distributable algorithm for achieving coverage of a convex environment with Euclidean metrics is that proposed by Cortes which is based on the discrete-time Lloyd’s algorithm. This algorithm is not directly applicable to general Riemannian manifolds with boundaries that are non-convex and are intrinsically non-Euclidean. In this paper we generalize the control law based on minimization of the coverage functional to such non-Euclidean spaces punctured by obstacles. We also propose a practical discrete implementation based on standard graph search-based algorithms. We demonstrate the applicability of the proposed algorithm by solving efficient coverage problems on a sphere and a torus with obstacles, and exploration problems in non-convex indoor environments.

Barnali Dasa 2016 Multi-robot search-and-rescue missions often face major challenges in adverse environments due to the limitations of traditional implicit and explicit communication. This paper proposes a novel multi-robot communication system (MRoCS), which uses a passive action recognition technique that overcomes the shortcomings of traditional models. The proposed MRoCS relies on individual motion, by mimicking the waggle dance of honey bees and thus forming and recognising different patterns accordingly. The system was successfully designed and implemented in simulation and with real robots. Experimental results show that, the pattern recognition process successfully reported high sensitivity with good precision in all cases for three different patterns thus corroborating our hypothesis.

Joan Mos 2012 To illustrate children's thinking about patterns and two-part function rules in the framework of an early algebra research project, we have carried out research in New York City and Toronto primary schools to study students' reasoning about patterns and two-part function rules. While several nations require the study of patterns in efforts to incorporate algebra from grade K, there is an abundance of data that shows that it may be difficult for even older children to follow the pattern-to-algebra path. Through the integration of geometric and mathematical representations of developing patterns, we aimed to enhance students' knowledge of the connection between linear function and co-variation. A ten- to fourteen-week intervention was put up in six different metropolitan locations that offered classes from various backgrounds. The study's findings indicate that the intervention aided pupils in their functional thinking and geometric and arithmetic pattern identification and expression. Students who had never learned multiplication were now able to come up with good ways to dissect multiplication issues to help them solve equations. The final study's findings show that students' ability to apply their knowledge of two-part function rules to new situations was enhanced using the experimental curriculum.

3. MOTIVATION AND CONTRIBUTION TO RESEARCH

Theoretical methods for geometric pattern generation have been shown to be sound and complete given a set of too simplistic assumptions. Robots, for example, are regarded as point objects that can detect and move with infinite accuracy, among other things. When developing models or solutions for robotic systems, such assumptions are prevalent. It is recognized that in practice, these assumptions will not be rigorously followed. Nonetheless, approximate answers to these assumptions may be found. As a result, such theoretical methods cannot be compared to other empirical approaches until they are translated into practice. The uniform circle formation problem (UCF) using a team of autonomous mobile robots has gotten a lot of interest in this regard. Because the circle is one of the most basic forms among all geometric shapes, it has become a standard for such research. The following are the highlights of our contributions in this chapter:

(a) Conducted a thorough examination of the different characteristics and assumptions used in theoretical research on geometric pattern creation with multi-robot systems, highlighting significant implementation difficulties.

(a) After discovering approximate solutions to different assumptions, presented a model for practical implementation of algorithms for geometric pattern formation.

(c) In our first efforts to solve the UCF issue with numerous mobile robots, we created a software framework to enable the deployment of two alternative geometric pattern creation algorithms in simulation. The first algorithm is greedy and centralized, whereas the second method is weakly centralized and relies on token passing.

(d) For addressing the UCF issue, a fully decentralized method called STATE is suggested. This method does not rely on atomicity, unrestricted visibility, or a global clock, among other assumptions. The STATE method outperforms the approach proposed in, which will be referred to as the DK algorithm from here on. For multi-robot synchronization, the STATE method is entirely distributed and uses conflict resolution graphs. In the absence of a global clock, the suggested method achieves multi-robot synchronization via message forwarding.

(e) In a controlled laboratory environment, an independent software solution for multi-robot localization was designed and implemented.

4. INITIAL ATTEMPTS

The main objective of this chapter is to suggest a completely decentralized yet efficient algorithm for circle formation and practically validate the efficacy of the same. In this section, we present our initial attempts towards the stated objective.

Software Framework

In this section, we have proposed a software framework for supporting the implementation of the two different algorithms for solving the UCF problem. The high level design of the framework is presented below:

High-Level Design (HLD)

In Figures 1 and 2, the software framework is shown using UML class diagrams. Two well-known software design patterns, the observer and decorator patterns are used in the proposed framework. The robots are put in the environment at random. At first, it's impossible to tell if a robot is a leader or a follower. A robot may take on the role of leader or follower. There are two types of decorators: robot leader and robot follower. A leader election algorithm, such as the one proposed, is used to select the robot that will be the leader. The chosen leader robot is decked out with the duties of a leader. All other robots have been assigned the role of follower. For this, two concrete decorator classes, Robot Leader and Robot Follower, are utilized, as illustrated in Figure 1's class diagram. The robot leader records all of the robot followers and calculates and communicates suitable locations on the circular radius for each of them. The observer design pattern offers a method for leaders and followers to share information. Robot Leader is a Subject in Figure 2, whereas Robot Follower is an Observer.

Robot Followers utilize the Robot Subject interface to become Observers and to deactivate their status as Observers. When the Subject's (i.e. Robot Leader's) states change, this interface only contains one method that is invoked. Robot Leader is a concrete subject that implements the Robot Subject interface and includes methods for registering, removing, and notifying observers. Because it implements the Robot Observer interface, Robot Follower is a concrete observer. To get updates, each Robot Follower registers with Robot Leader. With this HLD in place, we've proposed two methods for addressing the UCF issue in the next section. In simulation, the two algorithms are use.

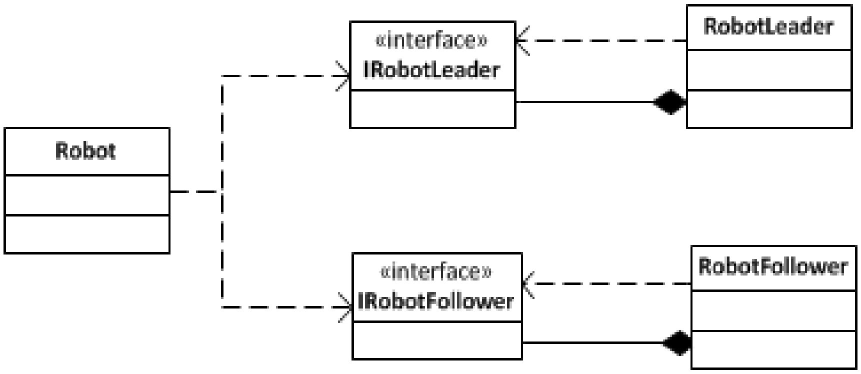

Figure 1 Decorate Robot as Leader or Follower

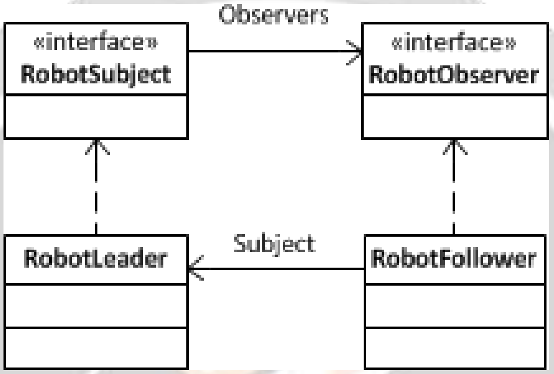

Figure 2 Robot Leaders as Subject and Robot Follower as Observer

A Centralized Algorithm for UCF

A centralized algorithm for solving the problem of UCF is proposed in this thesis. The proposed algorithm starts with the assumption that the leader robot or Robot Leader is already elected and decorated with the role of a leader and all other robots i.e. the follower robots or Robot Follower are decorated with the role of the follower. The algorithm executed by the leader robot for solving the UCF problem is presented below:

Calculate Smallest Enclosing Circle (SEC): Assume a set P of n points representing the position of all Robot Followers, P = {p1, p2, p3,…, pn} in the Euclidian plane □ 2 . The smallest enclosing circle of P, SEC(P), is the circle with minimal radius enclosing all points in P and is shown in Figure 3. It is also well known that SEC(P) = SEC(H), where H is a proper subset of P, consisting of extreme points on the convex hull of P.

Calculate Uniform Positions on the Circumference of SEC: The Robot Leader is positioned at the center of SEC, shown as star in Figure 3.4. It calculates the uniform positions for the Robot Followers on the circumference of SEC.

In Figure 4 the star and triangle robots are active, such that, the one that is on the center (star) is Robot Leader and the other one (triangle) is one of those Robot Followers which was already on the circumference and is randomly picked up as a reference point. It is named First Follower and is positioned (will not move). Now the Robot Leader finds the coordinates of n-1 points for n-1 remaining robots beginning from First Follower, such that, all points are separated from each other by an angular distance of θ degrees:

$\theta = 2\pi/n-1$, where n is the number of Robot Followers

Now we know x and y coordinates of Robot Leader, First Follower, and an angle θ. We want to determine the x and y coordinates of cross points shown in Figure 4 on the circumference of SEC.

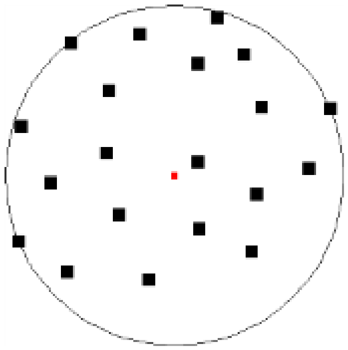

Figure 3 Smallest Enclosing Circle of a Set of Points Representing the Position of Robot Followers

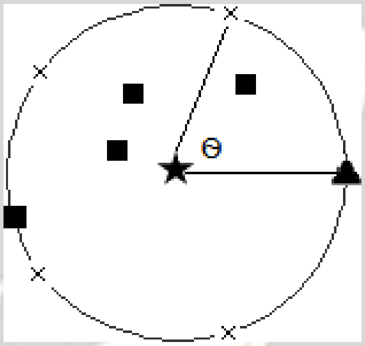

Figure 4 SEC with two Robots on circumference and three Robots inside it

We calculate two points x and y as follows:

x = First Follower. x – Robot Leader. x

y = First Follower. y – Robot Leader. y

To determine x and y coordinates of cross points we run a loop from i = 1 to n-1 and perform the following calculations:

ai.x = Robot Leader.x + x*cos(i*θ) – y*sin(i*θ) ai.y = Robot Leader.y + y*cos(i*θ) – x*sin(i*θ)

This way we determine all uniform positions where Robot Followers are finally positioned. The running time of this algorithm is O(n-1).

Finding right position for Robot Followers: Robot Leader maintains a list of uniform positions. Leaving the First Follower and its position, Robot Leader runs an optimal allocation algorithm for finding the position of each Robot Follower on the basis of distance cost. All Robot Followers are notified their assigned positions on the circumference of the SEC. Robot Followers move to their respective positions. As a result, circle formation by arbitrarily scattered multiple mobile robots in 2D plane is achieved.

A Weakly Centralized Token Passing Approach for UCF

(a) This section describes a weakly centralized method for placing numerous mobile robots in a circular configuration via token passing. This method is a variation on the centralized algorithm that was earlier presented. It's also a leader-follower method, in which the leader robot calculates the equally spread out locations on the circular circumference for all the follower robots. The circle formation issue is split into two sub-problems: (a) leader selection and (b) selecting locations for follower robots from the set of uniform positions calculated by the leader robot. Both of these issues are addressed via token passing to relieve the leader robot of the effort of assigning positions to all of the followers. It is now a weakly centralized algorithm due to the addition of token passing. This method assumes that the leader robot has already been chosen and that all of the locations for the following robots on the SEC's perimeter have been calculated.

(b) The following robots are informed of these locations. Only those follower robots outside the circle with the radius SEC radius eagerly choose their own location based on their distance from it and broadcast this information. It's conceivable that several robots will choose the same location to travel to. All of these robots create a virtual token ring between them based on their IDs, and then use token passing to bid for that position. The bid is just the robot's distance from the location under consideration. The robot with the lowest bid is assigned to the job. The procedure is repeated until there are enough applicants for a particular job. Otherwise, if some robots are not allocated to a job and certain slots are left vacant. All empty slots are assigned to all unallocated robots by the leader robot. The leader robot is relieved of the task of assigning positions to all of the robots thanks to this algorithm.

(C) In this section, we've looked at two centralized algorithms. Furthermore, the second method yields a less-than-ideal assignment. They also have nothing to do with the theoretical research and methods provided in the UCF literature. As a result, the description of these two algorithms will be restricted to this section. In the next part, we've looked at different characteristics and assumptions used in theoretical research on geometric pattern creation with multi-robot systems, as well as some practical difficulties. The DK method, which is one of the most typical state-of-the-art techniques for addressing the UCF issue, is next discussed.

5. ASSUMPTIONS AND SIGNIFICANT PROPERTIES ANALYSIS

The assumption in theoretical study on geometric pattern creation with numerous mobile robots is that the robots are basic and have limited capabilities. As a result, the robots' perceptive abilities are abstracted. It's difficult, if not impossible, to convert most of the assumptions into reality without jeopardizing the model's integrity. Understanding how these assumptions may be approximated is critical. The following is an analysis of some of the assumptions that were considered:

Robotic world model: The robot's world model is an unlimited two-dimensional plane with no noise. In practice, noise in the surroundings has a significant impact on robot operations and should be handled.

Dimensions of the robots: The robots are seen as a point on a plane (dimension less). Robots have a limited dimension in the actual world, which should be taken into account while developing algorithm(s) for multi-robot systems.

Mobility: Robots are thought to be able to move about the globe freely and with limitless accuracy. Real robots, on the other hand, must constantly locate themselves, avoid obstacles, and plan their routes to their destinations.

Visibility: It is believed that the robots are equipped with sensors that report the exact position of all other robots in real time. For basic mobile robots, such a sophisticated sensing system is a very strong assumption. It removes the requirement for localization entirely. Because the robots in multi-robot systems are usually equipped with restricted sensors, motion capture systems are commonly utilised in the interior environment. Localization is accomplished via a system of multiple high-speed cameras that can monitor the reflective markings on the robots at a rate of more than 300 frames per second. Using this technology, one may hope to attain accuracy of less than 1 mm. The robots that are utilised in an outside setting are neither low-cost nor basic in design. Robot odometers with laser scanners and vision-based techniques are commonly used for simultaneous localization and mapping (SLAM).

Anonymity: The robots are believed to be identical and cannot be distinguished from one another. The robots must maintain a specific distance and orientation with their peers in order to create geometric patterns. It can only be done if the peers are accurately located. This is supported by a number of experimental research studies. In actuality, mobile robots constantly locate themselves in relation to the environment's characteristics. Other robots (stationary or moving) and non-robot things in the environment should be detectable by the robots. As a result, anonymity contradicts the requirement for peer robots to be identified. In addition, the premise of limitless visibility supports the notion of anonymity.

Communication: Robots communicate and make decisions based on their implicit observations of other robots. Because robots don't know one other, the presumption of anonymity promotes implicit communication. As a result, implicit communication relies heavily on the notion of infinite visibility, which is difficult to provide with weak robots. In the face of sensor imperfections, noise in the environment, and no explicit communication, a genuine multi-robot system will wind up spending a lot of energy cancelling disturbances. It's possible that it won't be able to accomplish its goal of forming a consistent circle. We have abandoned the notions of anonymity and implicit communication in the work described in this thesis. An algorithm with an explicit inter-robot communication model has been created.

Autonomy: The robots are considered to be self-contained. Autonomous robots are resistant to any outside interference in their activities. Individual robots' cohesive behavior, or how effectively they cooperate and adapt to the motions of other robots, is critical to the mission's accomplishment. A robot tasked with forming geometric patterns must have an accurate understanding of its peers' starting placement. Furthermore, the robots are randomly placed in their surroundings. They must adjust to their new surroundings and begin their task as soon as they are activated. If the system continues to develop and converges to its ultimate state of uniform circular formation, it is considered to be self-stabilizing. Coordinating the activities of mobile robots in a multi-robot system is difficult, particularly when there is no explicit communication or coordination.

System of coordinates: There is no assumption of a global reference frame. Each robot has its own set of local coordinates. All percepts are received in robot-centric coordinates, in other words. As a result, the robots determine their future course of action solely based on local calculations. Again, the robots need accurate information about themselves and their peers (location and direction).

I Agreements: The multi-robot system assumes partial agreement on the local coordinate system of robots, i.e., the direction and orientation of one of the axes, says the X axis, is known. The authors demonstrated that a multi-robot system may create any given pattern with shared knowledge of the direction and orientation of the two axes. There is also no deterministic method that allows an even number of robots to create an asymmetric pattern if the robots only have a partial agreement. They're only able to make symmetrical designs. The circle is a symmetrical design that may be created with any number of robots. To roughly translate this assumption in actual multi-robot systems, extremely accurate heading sensors are required.

Synchronization: Time is shown as an endless series of discrete time occurrences t1, t2, t3,...,tn. It is believed that a global clock tick reaches the robots, causing only a subset of robots to become active at any one moment. Furthermore, it is believed that the LOOK-COMPUTE-MOVE-WAIT activation cycle is instantaneous and that the time required to complete one cycle is minimal. This is a big assumption since, in practice, the time it takes to complete each one activation is random and limited, and it can't be predicted ahead of time. As a result, it's highly probable that some robots will be triggered between any two-time occurrences ti and tj. This goes against SYm's fundamental atomicity assumption and puts the system in an inconsistent state.

6. CONCLUSION

Multiple robots have been seen cooperating to do complicated tasks that would otherwise be impossible or difficult for a single strong robot to complete. The idea behind utilizing multi-robot systems to solve complicated issues is to allocate smaller sub-problems to individual robots while enabling them to communicate with one another for knowledge exchange. Simple robots may be readily constructed and programmed to work together to accomplish a shared goal. When opposed to creating a single expensive robot with many capabilities, multi-robot systems are extremely cost efficient. Because these multi-robot systems are often decentralized and redundant, they are fault tolerant, increasing the system's dependability and resilience. The versatility of multi-robot systems is due to their ease of use. This simplicity, however, adds to the complexity of setting up and implementing such systems. We investigated multi-robot coordination algorithms in three domains: geometric pattern creation, online terrain coverage, and balanced area partitioning/ decomposition in this thesis. The thesis' major contributions to each of these domains are mentioned below.

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