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Leader election and gathering for asynchronous fat robots without common chirality ☆

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ABSTRACT

This paper proposes a deterministic *gathering* algorithm for $n \geq 5$ autonomous, homogeneous, asynchronous, oblivious unit disc robots (fat robots). The robots do not have common coordinate system and chirality. A robot can sense or observe its surroundings by collecting information about the positions of all the robots. Based on this information, they compute their destinations for moving and move there. Initially, the robots are stationary and separated. Robots are assumed to be transparent but solid. The algorithm for gathering is designed in such a way that the robots do not collide. In order to avoid collision we do not allow all the robots to move at a time. A unique robot, called *leader* is elected to move to its destination. No other robot moves till the leader reaches its destination. When the leader reaches its destination, another leader is selected from the remaining robots. However, *leader election* may not be possible in an arbitrary configuration. In this paper, we characterize all geometric configurations where leader election is possible and present an algorithm for leader election in such a case. An important property of our leader election algorithm is that it is possible to elect a leader from the remaining set of robots also.

1. Introduction

A swarm of robots [31] is a collection of identical, tiny mobile robots. The robots together perform a complex job, e.g., moving a big body [29], cleaning a big surface [26] etc. In hostile environments, it may be desirable to employ large groups of low cost robots, working together, to perform various tasks. This approach is more resilient to malfunction and more configurable than a single high cost robot. The idea is inspired by the observation of social insects. They are known to coordinate their actions to execute a task that is beyond the capability of a unit.

1.1. Framework

An extensive volume of research [2,5,6,10,16,19,23,27,28,30] has been reported in the context of multiple autonomous mobile robots exhibiting cooperative behavior. A basic model, having minimal capabilities, is popular in the literature [17]. Under this model, the world of the swarm robots consists of multiple mobile robots moving on a 2D plane. The robots

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have local coordinate system defined by sense of direction (SoD), orientation or chirality and scale. They are assumed to be correct or non-faulty. The robots are considered dimensionless or points. They are *autonomous*, *homogeneous* and perform a cycle consisting of four states *Wait–Look–Compute–Move*. The robots may be inactive or idle in the *wait* state. In the *look* state, a robot takes a snapshot of its surroundings, within its range of vision. Then in the *compute* state, it executes an algorithm for computing the destination to move to. The algorithm is the same for all robots. In the *move* state, the robot moves to the computed destination. The robots are *oblivious* i.e., they do not preserve any data computed in the previous cycles. There is no explicit communication between the robots. The robots coordinate among themselves by observing the positions of the other robots on the plane. A robot is always able to see another robot within its visibility radius or range (limited or unlimited). The robots may or may not be synchronized. In fully-synchronous (FSYNC) model, all the robots execute their cycles together. In such a system, all robots get the same view. As a result, they compute on the same data. In semi-synchronous (SSYNC) model, a set of robots execute their cycles together. A more practical model is asynchronous (ASYNC) model, where the actions of the robots are independent. By the time a robot completes its computation, several of the robots may have moved from the positions based on which the computation is made. Here, a robot in motion is visible. A robot may stop before reaching its destination. This model is known as CORDA (Co-OpeRative Distributed Asynchronous) model [18].

1.2. Earlier works

Several coordination problems have been formulated for swarm robots. Most of them are based on geometric pattern formation. This paper addresses a very well known and challenging problem involving robot swarms, namely *gathering*. The objective is to collect multiple autonomous mobile robots into a point or a small region. The choice of the point is not fixed in advance. Initially the robots are stationary and in arbitrary positions. Gathering problem is also referred to as *point formation*, *convergence*, *homing* or *rendezvous* [34]. For a long time many researches have been addressing this problem on this basic model of robotic system with different additional assumptions. Under the FSYNC model, gathering is solvable [3, 10]. If a global coordinate system is assumed, then it is also solvable even if the robots have limited visibility [20]. If multiple robots are at the same point then the point is said to be a point with *multiplicity*. Depending on the model a robot may or may not be able to detect the multiplicity of a point. No deterministic algorithm exists under SSYNC model that solves gathering without any agreement in local coordinate system or multiplicity detection [34]. With chirality and eventually consistent compass,[1] gathering is solvable for SSYNC model even with limited visibility [35]. Gathering problem is not solvable for two robots even with multiplicity detection [34]. Cieliebak et al. [9] have reported gathering algorithm for $n > 2$ asynchronous robots using multiplicity detection. In ASYNC model, for a set of $n \geq 2$ robots, there exists no deterministic oblivious algorithm that solves the gathering problem in a finite number of cycles, hence in finite time, without multiplicity detection [34]. However, randomized approaches can solve the gathering problem [24,25]. The scope of the this paper is limited to deterministic algorithms.

Czyzowicz et al. [12] extended the model by replacing the point robots by unit disc robots called *fat robots*. The fat robots are *solid* and may create physical and/or visual obstructions for other robots. The methods of gathering of two, three and four fat robots have been described by them. Two robots move towards each other and stop when they are in contact with each other. Three and four robots move asynchronously to a point which is invariant with respect to the movements of the robots. One such point in the plane is the point which minimizes the sum of distances between itself and all the robots. This point is called the *Weber or Fermat or Torricelli* [4] point. It does not change during the robots' movement, if the robots move only towards this point. However, the *Weber* point is not computable for more than four robots [4]. Thus, this approach cannot be used to solve the gathering problem for more than four fat robots. Gathering any number of fat robots have been investigated by many recent research works [11,8,1]. However, these solutions are for synchronous robots. Cord-Landwehr et al. [11] have proposed gathering algorithm for synchronous fat robots. Furthermore, they assume that the gathering point is predefined and given to the robots in advance. Two versions of the problem have been studied by them. In one version they proposed a randomized algorithm. In the other version, they assume the robots have identification and communication power. Bolla et al. [8] have proposed a simulation based strategy for gathering any number of synchronous fat robots. Recently Agathangelou et al. [1] have proposed a solution for gathering any number of asynchronous fat robots. However they assume, common chirality for the robots.

Solutions to many problems related to geometric pattern formation require that a unique robot be selected among a set of robots using only their locational information [32]. This is known as *leader election*. A deterministic solution for leader election depends largely on whether the robots have a common SoD and/or common chirality [21]. With common SoD and common chirality, leader election is possible for any number of robots. With common SoD and without common chirality, leader election is possible if the number of robots is odd. In general, with no common SoD leader election is not possible. Dieudonné et al. [13] studied leader election problem for the robots considering no common SoD but having common chirality. They have characterized all possible initial positions of the robots from which it is possible to deterministically elect a leader. They also showed that this characterization holds without common chirality if and only if the number of robots is odd. Recent works [14,15] show that arbitrary pattern formation and leader election are equivalent for $n \geq 4$

[1] Compasses are unstable for some arbitrary long periods, but they stabilize eventually.