Unreliable Compasses for Robust Gathering of Asynchronous Mobile Robots

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Résumé :
Faire en sorte qu'un ensemble de robots mobiles se comporte comme un système cohérent est une question fondamentale dans les systèmes robotiques distribués. Ce problème est souvent illustré par le problème du rassemblement, où les robots eux-même s'organisent pour se réunir finalement à un emplacement arbitraire. Bien que ce problème aie l'avantage d'être très simple à exprimer, il retient néanmoins la difficulté inhérente aux problèmes d'accord repartis, à savoir, le problème de rupture de symétrie. Dans leur modèle asynchrone avec des robots oublieux et possédant une visibilité limitée, Flocchini et al.[6] ont montré que le problème de rassemblement peut être résolu de façon déterministe, pour autant que les robots partagent la connaissance d'une de direction de référence, telle que fournie par une boussole. Cependant, les boussoles sont des appareils qui sont souvent sujets à des fluctuations. Dans notre recherche, nous avons donc introduit la notion de boussoles instables. Nous avons donné un algorithme qui fonctionne avec des boussoles instables, pour autant que celles-ci passent de temps en temps par des périodes de stabilité. La difficulté réside dans le fait qu'il est impossible pour les robots de déterminer si les boussoles sont dans un état stable ou pas.

Abstract:
Reaching agreement among a set of mobile robots so that they behave as a coherent system is one of the most fundamental issues in distributed robotic systems. This problem is often illustrated by the gathering problem, where the robots must self-organize to eventually meet at some arbitrary location. That problem has the advantage that, while being very simple to express, it retains the inherent difficulty of distributed agreement problems, namely the problem of breaking symmetry. In their fully asynchronous model with oblivious robots and limited visibility, Flocchini et al [6] show that gathering is solvable deterministically, as long as the robots share the knowledge of some direction, for instance provided by a compass. It turns out that, compasses are devices that are often subject of fluctuations. In our research, we have introduced the concept of unstable compasses, and we proposed a gathering algorithm that solves the problem in a system where compasses are unstable for some arbitrary long periods, provided that they stabilize eventually. The difficulty comes from the fact that it is impossible for the robots to determine if their compasses are in stable or unstable state.

Introduction:
The problem of reaching agreement among robots has attracted some attention within the last few years. However, none of the algorithmic results we are aware of consider cases when sensors are unreliable. Particularly, most of the work on asynchronous models for cooperative mobile robots relies on the assumption that compasses provide perfect information. However, these components are frequently prone to failures. For instance, we can imagine a magnetic field created near the robots, which would make their compasses point in erroneous directions. As a result, if the algorithms are not designed to tolerate such transient failures, the robots will not accomplish their given task. In our recent researches, we have been studying the solvability of the gathering problem in the face of instability of the compasses and we have developed an adequate algorithm for solving the gathering

problem. This algorithm assures that robots are active asynchronously (e.g, do not share some notion of time), the robots are oblivious (i.e., they don't remember past actions and observations), they have limited visibility, and their compasses may provide the robots with contradictory information for arbitrary long periods. Our algorithm is guaranteed to recover from any arbitrary configuration when the compasses of the robots eventually stabilize. It has the following desirable properties: (1) Robustness: the algorithm offers protection against transient failures. (2) Self-stabilization, the algorithm is by design self-stabilizing due to the oblivious (stateless) feature of the robots. i.e., starting in an arbitrary configuration, the algorithm always converges toward a desired behavior [3].

1. Unstable Compasses:

A compass is a devise that outputs a direction of reference (for instance, the North) which is the same for all the robots. With an unstable compass, there exists a time after which all the robots agree on the same compass direction. The agreement holds after some time *GST* (Global Stabilization Time) unknown to the robots. It is only guaranteed that the agreement will hold, but the time for which the agreement holds is unknown. More precisely, an unstable compass has the following three properties: (1) the direction of a robot's compass can change with time. (2) at a given time, the compasses of any two robots may disagree. (3) In any execution, there exists some time *GST* after which the compasses of all the robots agree for a sufficiently long period. Yet, the robots do not know when the time GST will occur.

2. Gathering with Unstable Compasses:

As we mentioned earlier, Flocchini et al.[6] has shown that compasses are crucial components for solving the gathering problem in asynchronous systems. However, in practice compasses are frequently prone to failures and can output inaccurate information. Subsequently, our algorithm should be designed to cope with imprecision and instabilities in the compasses. In some of our recent work [7], we studied the solvability of the gathering problem in the face of compass instabilities. We first show that the gathering algorithm proposed by Flocchini et al. [6] does not tolerate instabilities in the compasses. In particular, with unstable compasses, their algorithm results on a disconnection of the vision graph between robots. Second, we proposed a self-stabilizing distributed algorithm for the gathering problem in a system in which the robots have limited visibility, and relying on compasses that are eventually consistent. The proposed solution guarantees that the robots gather at a point in finite time, given that their compasses provide correct output after some unknown period of instability, during which our algorithm can tolerate any number of transient failures of the compasses.

The idea of our algorithm is to solve the problem by achieving the following two subgoals at every time instants. (1) Robots that are mutually visible at some time *t* must remain mutually visible at some time *t+1*. (2) The robots that are located on the leftmost side at time *t* "get closer" to their mutually visible robots (i.e, robots located on their visibility radius) at time *t+1*.

To prove the correctness of our algorithm, we proceed in two steps. In a first step, we show that the connectivity of the vision graph is preserved during the entire execution of the algorithm. That is, regardless of the orientation of their compasses, the robots which are initially visible remain always visible until they collide on the same point. In a second step, we show that after the time GST, if the agreement on the compasses of the robots holds for a long enough time, then all robots will gather at one point in finite number of steps.

We conclude that, in an asynchronous system, anonymous, oblivious mobile robots, with limited visibility, and assuming unstable compasses, the gathering problem is solvable deterministically.

3. Related work:

Despite its apparent simplicity, the problem of gathering robots at a single point has been studied extensively in the literature, in different models and under several assumptions. In fact, several factors render this problem difficult to solve [6,8,9,10]. In particular, in all these studies, the problem has been solved only by making some additional assumptions on the capabilities of the robots. In particular, in the asynchronous model, Flocchini et al. [6] proposed a deterministic algorithm for the gathering problem in the limited visibility setting. However, the proposed algorithm requires that the

robots share a compass that provides perfect information. In contrast, we consider that the compasses of the robots are unstable and outputs erroneous information for some period unknown to the robots. The work of Flocchini et al [6] is the closest to our work, and our algorithm is developed on their model. However, their algorithm fails to solve the gathering problem if we assume instable compasses. Subsequently, we provide a self-stabilizing algorithm that tolerates any number of transient failures in the compasses. The gathering problem has been also studied in the presence of faulty robots by Agmon and Peleg [5] in synchronous and asynchronous settings.
Other studies of the gathering problem include the work of Suzuki and Yamashita [1]. In their model, refereed as a semi-synchronous model, they proposed an algorithm to solve the gathering problem deterministically in the case where robots have unlimited visibility. In the same model, Ando et al. [4] propose an algorithm to address the gathering problem in systems wherein robots have limited visibility. Their algorithm converges toward a solution to the problem, but it does not solve it deterministically. In the CORDA model, referred as an asynchronous model [2], Cielibak et al. [12] proposed a deterministic algorithm that gathers the robots at a point in systems in which robots have unlimited visibility. Among other things, one feature the robots must have in order to solve this problem is the ability to detect a multiplicity of robots at one point. Other studies of the gathering problem have been devoted to design convergence solutions to the problem [11].

Conclusion:

In this paper, we took a new look at the gathering of a group of oblivious asynchronous mobile robots with limited visibility. While, previous work [6] showed that this problem can be solved if the robots are equipped with compasses, we have shown that gathering can nevertheless be solved with unstable compasses, as long as these compasses eventually stabilize to provide consistent information to the robots (the robots are not aware of when this actually happens).
The main benefit of our algorithm is that we solve the problem with a weaker assumption by assuming unstable compasses rather than perfect ones. This weaker assumption leads to stronger results. In particular, we can claim that an *eventual compass* has the same computational power as a *perfect compass* for solving the robot gathering problem if the agreement on the compasses of robots eventually holds for a sufficiently long enough period. This result is important in practice. In addition, our algorithm tolerates any number of transient failures in the compasses.
Finally, the oblivious feature of the robots gives the algorithm the nice property of self-stabilization. In our future work, we want to address the issue of imprecision on the compasses of the robots at some range (that is their compasses are bounded by some imprecision errors), and also the imprecision of other sensors, such as vision. Currently, we are investigating this issue.

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