Sharing a Charging Station in Collective Robotics

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Abstract.

This research focuses on the design of teams of mobile robots that are able to operate in real life situations and non-controlled environments. In order to perform any service, robots have firstly to display two properties: autonomy and self-sufficiency. An autonomous and self-sufficient robot that takes part in a team does not necessarily contribute to the well-functioning of its partners. Thus, we need to develop specific mechanisms in order to ensure autonomy and self-sufficiency for those robots that form a team. This paper explores two mechanisms to enable a team of robots to behave in an autonomous and self-sufficient manner for as long as possible while taking into account the needs of partners.

keywords: robotics, multi-agent systems, autonomous robots, conflicts resolution, charging station.

1 Introduction

This research focuses on the design of teams of mobile robots that are able to operate in real life situations and non-controlled environments [2]. The corridors of our laboratory, for instance, are one of the scenarios with which our robots should be able to cope, in order to perform services such as distributing mail, guiding visitors, security, and so on. In order to perform these services, robots have firstly to display two properties: autonomy and self-sufficiency.

Autonomy is concerned with the decision-making process and means self-government [6]. An autonomous robot is not assumed to be independent of external programming, but of external control when it is running. Thus, it must be able to perform the actions for which it has been designed using its own capabilities, *i.e.* its sensors and its actuators. In contrast, **self-sufficiency** denotes the ability of a system to maintain itself in a viable state for long periods of time [6]. A self-sufficient robot has to ensure at least its energy supply by itself. For that, it has at its disposal certain recharging facilities, *e.g.* rechargeable batteries and a self-recharge device, and relies on several mechanisms so as to be able to examine its power supply constantly and to locate and use a charging station.

Designing a robot that displays a certain degree of autonomy and self-sufficiency is not a trivial matter, and even though such a robot has been built, the preservation of these properties in a team of robots acting together, is not guaranteed. Thus, we need to develop specific mechanisms in order to ensure autonomy and self-sufficiency in robots that form a team. The well-functioning of the team may collapse by the presence of robots that behave individually. This is particularly true in the cases where robots have to share common resources. It could happen, for instance, that the access to a charging station is completely blocked by robots that are persistently trying to recharge their batteries.

This paper explores a simple mechanism to enable a team of robots to behave in an autonomous and self-sufficient manner for as long as possible while taking into account the needs of partners. The paper is organized as follows: section two discusses the problem of sharing an essential resource such as a charging station, and addresses related work. Section three describes briefly the hardware and control of our robots, and the recharge system. Section four presents some experiments and results, and section five discusses conclusions and future perspectives.

2 The Problem of Sharing

2.1 How to Share?

The design of a team of robots that require a common resource raises a number of questions: is this resource limited? how should robots manage this resource? how much information should robots exchange? do they need to communicate? if so, how and how much information? These questions raise important issues of the study of multi-agent systems, which can certainly benefit the design of multi-robot systems.

In our case there is just one resource shared by robots, the charging station. Charging stations are limited resources if there are more robots than charging stations in the environment, or if, even though several charging stations are available in the environment, more than one robot is trying to use the same charging station simultaneously.

Several strategies may be used by robots in order to manage a charging station:

1. **Competing for the resource**. In this strategy, robots compete for the access to charging stations, and the first robot to reach a station is the first to be served.

2. **Establishing hierarchies to access the resource**. The order of access to charging stations has previously been defined by the designer. Robots must be able to recognize the hierarchy of others, in order to decide whether or not to use a charging station.

3. **Conflict resolution**. In this way robots solve the conflict created by the sharing of charging stations through negotiation or a similar mechanism. Robots may give reasons such as their power supply, or the tasks that they are doing, to argue their case for a charging station.

Let us examine the three strategies, in reverse order, according to what is necessary in order to be implemented. The third strategy seems to be the most efficient, in the sense of providing good functionality, because robots consider their real needs when deciding what to do. This is unfortunately the most expensive of the three strategies. Robots must be able to communicate directly, to argue and to contest, but the existing negotiation techniques [4] are beyond the possibilities of real robots.

The second strategy may be implemented in a team where hierarchies have been established for some reason, in which case, the sharing of resources benefits from this *social* system. This does not seem to be as efficient as the third strategy, but is certainly less expensive. Neither direct communication nor a negotiation mechanism is required in this case, but robots must be able to perceive the hierarchy of partners and to identify their own positions among them.

The first strategy is the simplest and the cheapest. Robots do not need to communicate directly, but to compete for the resource and to identify the winner. The problem in this case is that the winner is not necessarily the most starved of the resource. A careful combination of the time that actions last and the weight of robots' needs is therefore required to implement an efficient competition strategy. This is the strategy that our robot team uses and the details of its implementation are given in the next section.

2.2 Related Work

The design of autonomous and self-sufficient teams of robots has not been much addressed in the literature. Successful implementations of real robots able to keep their security and to act in a group are rare.

McFarland and Steels are the first who report experiments about self-sufficiency in robots. McFarland describes an eco-system in which robots cooperate in order to maintain their energy supply. He argues that cooperative behaviors are possible without direct communication, and describes a charging station equipped with lights through which robots indicate *honestly* their recharging needs, thus avoiding or permiting the use of the charging station by other robots [7]. The design of this experiment, as well as several results, are also discussed by Steels [9]. This example illustrates well the idea that competition implemented using simple mechanisms can be a robust strategy to share supply resources among robots.

Michaud *et al.* [8] report experiments of self-sufficient robots using a psychological approach. Their robots use artificial emotions in order to control their motives and their needs and then to activate behaviors such as recharging. The specific problem of the sharing of charging stations is also discussed, but no results are presented in this work.

The questions of recharge and self-sufficiency for one robot are a bit more common. Birk [1] points out the problem of batteries and shows that cell chemistry may constrain robot behavior. Last, a kind of sport record has been established by Yuta and Hada [10]. They made a robot that ran continuously for a week recharging its battery every ten minutes.

The notion of interferences between robots, described in this paper, is also used by Goldberg and Mataric [5]. They propose the use of interferences between robots in order to design and evaluate multi-robot controllers.

Figure 1: A MICRobES robot with its charging station.

3 The Proposal

3.1 Hardware

The research described in this paper is part of the MICRobES[1] project of our laboratory [2]. The experiments are conducted using six Pioneer 2-DX mobile robots of ActivMedia©, provided with a micro-controller, odometers, bumpers, sonars, radio modems and video-cameras.

We also have of a charging station made by our laboratory and France Telecom R&D to enable robots to recharge their batteries by themselves. The robots have been modified in order to use this charging station. Both an electronic card to control the temperature and the voltage, and charging plates at the rear of the robots, have been adapted. The original batteries have been replaced by lead batteries that provide 12VDC power to the robot's electronics and actuators. The charging station has been designed to accept an approximate connection between it and the robots. Robots take from 20 to 30 seconds to reach and connect to the charging station that they have just located. The time needed to recharge depends on the current supply of a robot and the age of its battery; on average 15 minutes are sufficient to provide 2 hours of autonomy (figure 1).

3.2 Control

Whatever the strategy used to share resources, physical robots must cope with dynamic, unpredictable environments. Most processing time of a robot is consumed by its sensory-motor management. Thus, resources invested in the behavioral aspects of robots and therefore in the strategy used to share resources should be rationed if we want to develop robots that are able to act in real-time. Because of these technical constraints, we use a situated approach to control the behavior of our robots.

Robots have a repertoire of basic behaviors that are activated by the external stimuli

[1]MICRobES is an acronym in French for Implementation of Robot Collectivities in a Social Environment.

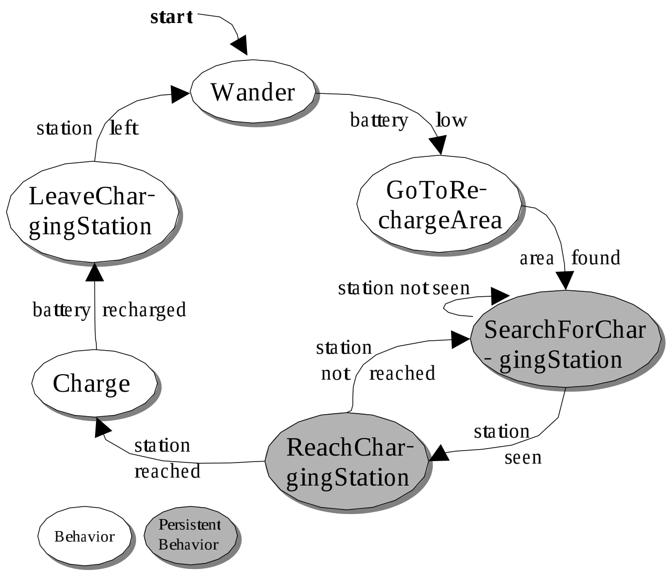

Figure 2: Automaton that summarizes the behavior of an individual robot.

they perceive. Basic behaviors such as avoiding obstacles, wandering, navigation and localization have been implemented and tested on our robots (see [3] for details).

In order to be self-sufficient, a robot has to examine its power supply constantly. When it perceives that it is below the threshold to activate the behavior *GoToRechargeArea*, it goes towards the area where it knows that there is a charging station. If the robot recognizes that it is within this area, it starts to search for the exact position of the charging station by revolving around itself and goes in that direction when it perceives the visual landmark that identifies it. Then, the robot adjusts its position to connect to the charging station, stays there while its battery is been recharged, and finally leaves the station to restart its loop. Figure 2 illustrates the behavior described, for a robot whose main task is to wander.

3.3 Recharging a Team

The problem when designing robots that give a high priority to their own security, is that they are unable to act in a team. Robots controlled by a mechanism such as the one described above, persist in their attempts to recharge their batteries, surround the recharging area and block access. When several robots need to use the charging station, this strategy does not solve their needs and just contributes to their problems.

We have modified the control of robot behaviors, in order to avoid traffic jams in the critical recharge area. Robots no longer use persistent behaviors. Instead, they are ready to leave the recharge area and wander for a while if, after a quick glance, they do not perceive the charging station. If robots are not able to see the charging station, it is because there is a robot already connected, or because there are more robots surrounding the area. In both cases, it would be more beneficial to leave this area, so the robots abandon behaviors involved in recharging and try them again later. This mechanism is illustrated in the figure 3 for a robot that executes *Wander* as its main behavior, and that is part of a team.

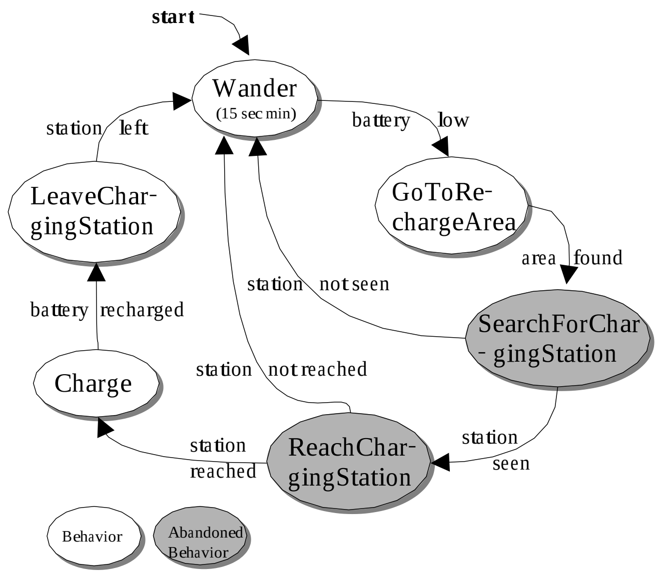

Figure 3: Automaton that summarizes the behavior of a team robot.

In order to use the second mechanism, robots would have to be more careful with their power supply. The threshold to prevent robots from recharging their batteries would have to be modified in order to enable them to remain functioning longer while they try to use the charging station.

4 Experiments and Results

4.1 Experimental Settings

We have implemented the competition strategy in a team of three robots that share a charging station.

The environment, about 20 square meters in area, is L-shaped, *i.e.* since the station is not always in sight, navigation is necessary. Three robots start at the same time. Each run lasts one hour at most or until a robot *dies*. The maximum energy autonomy has been set to 15 minutes in order to have more cycles. In our experiments, the charger gives approximately 5 minutes of energy autonomy for 1 minute of recharge. As three robots work together, the station will be free more or less half of the time.

4.2 Maintaining Alternation

The robots start with different levels of energy autonomy: 5, 10 and 15 minutes. The threshold that triggers the recharge behavior is 7.5 minutes. Figure 4 shows the energy autonomy of each robot during one hour.

We can see that the robots started their charging stages (increasing functions) at very different levels, from 7 to 2 *i.e.* there were often long delays between the moment they triggered the *GoToRechargeArea* behavior and the moment they connected themselves to the station. Delays have one major cause: interference caused by persistent behaviors. This is because a robot may wander into the recharge area and may stand for a while

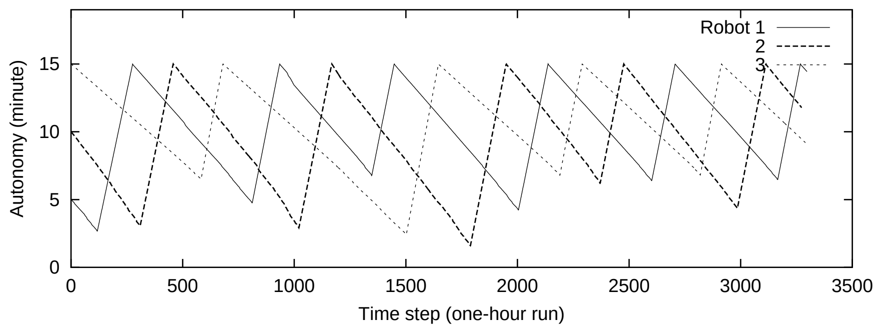

Figure 4: The energy autonomy of three robots that share a charging station.

between the station and another robot that is trying to reach the station or connect itself. Consequently this robot will fail, either because station landmark is hidden or because it cannot get access to the station.

4.3 Creating Alternation

It has been shown above that the robots alternated efficiently at the station, thanks to the different initial energy levels. But what would happen if robots started with the same autonomy? In other words, how can the alternation be created?

Let us now consider the case of robots that all start with 10 minutes of energy autonomy. No experiment is necessary to show that a 4-minute recharge threshold will lead to a disaster as more than two minutes are necessary to recharge one robot.

The new strategy has to exhibit two contradictory properties: greed and priority for a starving robot. On the one hand, when they start robots must try to go and recharge as soon as possible in order to use all their remaining autonomy for a vital purpose. On the other hand, a starving robot must access the station more easily than the others. But remember that no robot knows anything about the other robots' state.

Opportunism is the behavior that makes a robot recharge itself when it sees the station, whatever its remaining autonomy. In theory, associating opportunism with the threshold of the behavior *GoToRechargeArea* regroups the two properties. First, greed, because robots may use the station before this threshold is reached, *i.e.* before they really need energy. Secondly, starving robots have a better chance of reaching the station because their behavior is deterministic: even if they cannot see the station they stay around and check for it regularly.

Figure 5 shows the power supply of an opportunistic strategy experiment. Opportunistic behavior may be triggered only when remaining autonomy is less than 10 minutes: we do not want too greedy robots. Alternation was successfully created and maintained. On this run, no robot failed to connect to the station: nineteen connection attempts led to nineteen recharges. None had to wait, since a robot charging its battery hides the station landmark, thus inhibiting opportunistic behavior. On the other hand, robots went and recharged very early, reducing the duration of working period (7.2 minutes on average).

Opportunism is necessary only at the first stage, to create the alternation, after which the first strategy proved to be efficient. In order to take advantage of both strate-

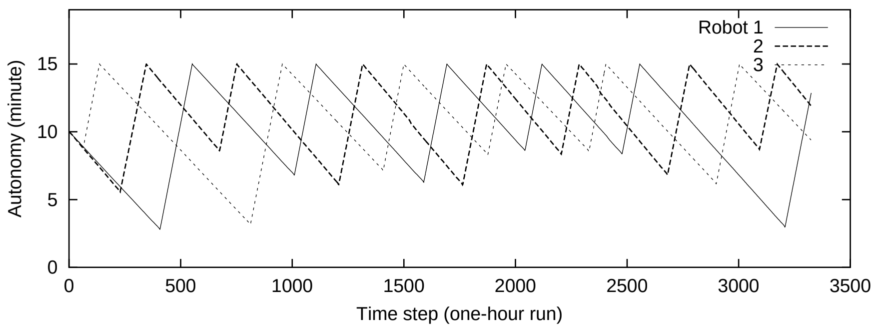

Figure 5: The energy autonomy of the 3 robots with an opportunistic strategy.

gies, a temporary opportunism was implemented. Robots are opportunistic for two cycles, and then adopt the first strategy. Two successful experiments have shown the creation of alternation and long working periods (more than 10 minutes).

5 Conclusions and perspectives

This paper presented two strategies to enable a team of mobile robots to share a charging station. These strategies are based on competition and opportunism without direct communication. This research is oriented to develop simple mechanisms for the design and implementation of autonomous and self-sufficient robots. The mechanisms described may seem simple and even trivial, but are currently used by a team of mobile robots in order to share their charging station. No other successful application using teams of self-sufficient physical robots that are able to operate in non-controlles environments has been reported to our knowledge.

The experiments described are in progress and future work will focus on the implementation and test of alternative strategies used by robots to share their charging station and cope with interferences. The use of direct communication between robots has not been ruled out, if this kind of communication allows a better use of the charging station.

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