Collective Retrieval by Autonomous Robots

Patrick Emmanuel Meyer
Computer Science Department, Universite Libre de Bruxelles
Boulevard du Triomphe - Campus de la Plaine - CP 212 - 1050 Brussels - Belgium
pmeyer@ulb.ac.be

Abstract. The paper presents an experiment of a collective pulling of one object by three Lego®robots. The robots use two parameters to orient their pulling force: 1. the direction to the nest 2. the local perception of the movement of the prey. Three behavior-based programs have been experimented to study the impact of each parameter. Although a solution can be found by using random trials in the direction of the nest, we observe that a better coordination ensues from a minimal number of agents around the prey. We show that an adequate number emerges from the use of a stigmergic communication through the prey.

1 Introduction

It would be useful to have several robots that could adapt their pulling forces and adjust the number of participants to retrieve to their base different objects with different sizes and different loads. The ants are familiar with collective retrieval but few experiments of collective robotics have studied this strictly collaborative task.

Ants can increase their abilities by cooperation. This can be achieved through the combination of individual efforts within the framework of a collective behavior. Through multiple interaction in distributed systems, a new kind of intelligence ensues, i.e. a "swarm intelligence", [2]. Two noteworthy features of multi-agent systems should be underlined: 1.Robustness: the amount of entities render the system sensitiveless to individual dysfunctioning. 2.Flexibility (or adaptability): the amount of entities varies with the type of tasks.

Communication turns out unfeasible with large numbers of agents. Nature seems to favor two solutions: 1. Hierarchy, because the presence of a leader reduces the interactions (now between the leader and all the other members of the group). 2. Stigmergy, where interaction between the units is not necessary, and as a result, the number of units interacting appear unlimited. The concept of stigmergy has been introduced by Grasse [6] as an indirect communication among social insects through environmental modifications. The environment imposes the work to the worker. In a lot of decentralized systems, with autonomous and even differentiated units, stigmergy appears to be a relevant feature of self-organization [3]. Each multi-agents system in nature seems to have its own degree of stigmergy and its own degree of hierarchy, depending on the number and the intelligence of agents. The aim of using stigmergy in artificial systems is to obtain a highly flexible and scalable system, independent of the number of units. Moreover, we avoid the problems linked to the communication between agents, as well as those due to centralization.

As we can see, the biological model given by the ants is quite illuminating and will guide us in the following experiments.

Collective Transport by Ants When an ant faces a prey, it usually tries to bring it back, whatever the prey size and mass. When the ant initiates the removal of the prey, its pulling behavior appears to be reinforced. If the ant does not succeed, it tries to pull it in another direction, to the extent, sometimes, of changing the gripping point and eventually abandoning the retrieval. We can suppose that the ant leaves pheromons which aim to attract nestmates. After a while, there will be a lot of ants, coming for the prey. In spite of a sufficient number of ants to transport it, they fail to move the prey. The reason is that they lack coordination within the group. At a given moment, which cannot be precisely foreseen, the prey is at last moved towards the nest. Coordination has probably emerged as a result of some stigmergic communication, stimulated by the movement of the prey, but it also seems due to random trials in the pulling[4]. Eventually, the ants will reach the nest along pheromon trails.

Autonomous Collective Robotics The biological paradigm has been successfully imported into robotics in the last decade. Among the major representative fields and experiments, we find: clustering objects [1], collecting objects [5], sorting objects [7], aggregation of bots and the exploration of areas. Those experiments show us how simple robots (simple from the point of view of the hardware and especially, the software) can achieve complex tasks. They do it, by cooperating unconsciously. Few experiments of bio-inspired robotics deal with strictly collaborative tasks. Two principal experiments are the box-pushing experiment [9] and the stick pulling experiment [8]. In the box-pushing experiment, two to six robots push a box from one place of their arena to another place, by passing through one of its corners. It needs at least two robots to push the box. The results of the experiment have shown that the higher the number of robots the less the coordination, and as a result it leads to a longer time to achieve the task[9].

2 Basic Principles

The box pushing experiment [9] was until now, the experiment of collective transport nearest to the biological model. Pulling a box seems to be more adapted to collaboration than pushing it, for two reasons: 1. When some agent is pulling an object, its force can be oriented toward a direction, independently of its gripping point, whereas it is very hard to orient a push. As a result, two robots, situated at two opposite sides of a box, can pull it toward a common direction, but it would be difficult for them to push it in the same direction. 2. Due to a mobile gripper, the robot can feel the movement of the prey through the sensors involved. The information that seem to be relevant in a retrieval by ants are : 1. the movement of the prey, 2. the nest's location or the pheromon trails. We have then used three methods to reach robot coordination. The first focuses on robots that only perceive the movement of the prey; the second deals with robots programmed to rely only on the location of the nest; and the third method mixes both. Those experiments are meant to bring about a collaborative pulling on approximately 80 centimeter. The efficiency of each method is measured by the time taken by the robots. Here are the basic principles of our experiments: 1.Robots are homogeneous. 2.Robots have few sensors and motors (two rotation sensors, one light sensor and three motors (see Figure 1)). 3.There is no leader nor a central controller. 4.There is no explicit communication between robots. 5.Robots have no explicit representations of the environment. 6.Robots do not detect the presence of other robots (i.e. the individual behavior is the same as the collective one)

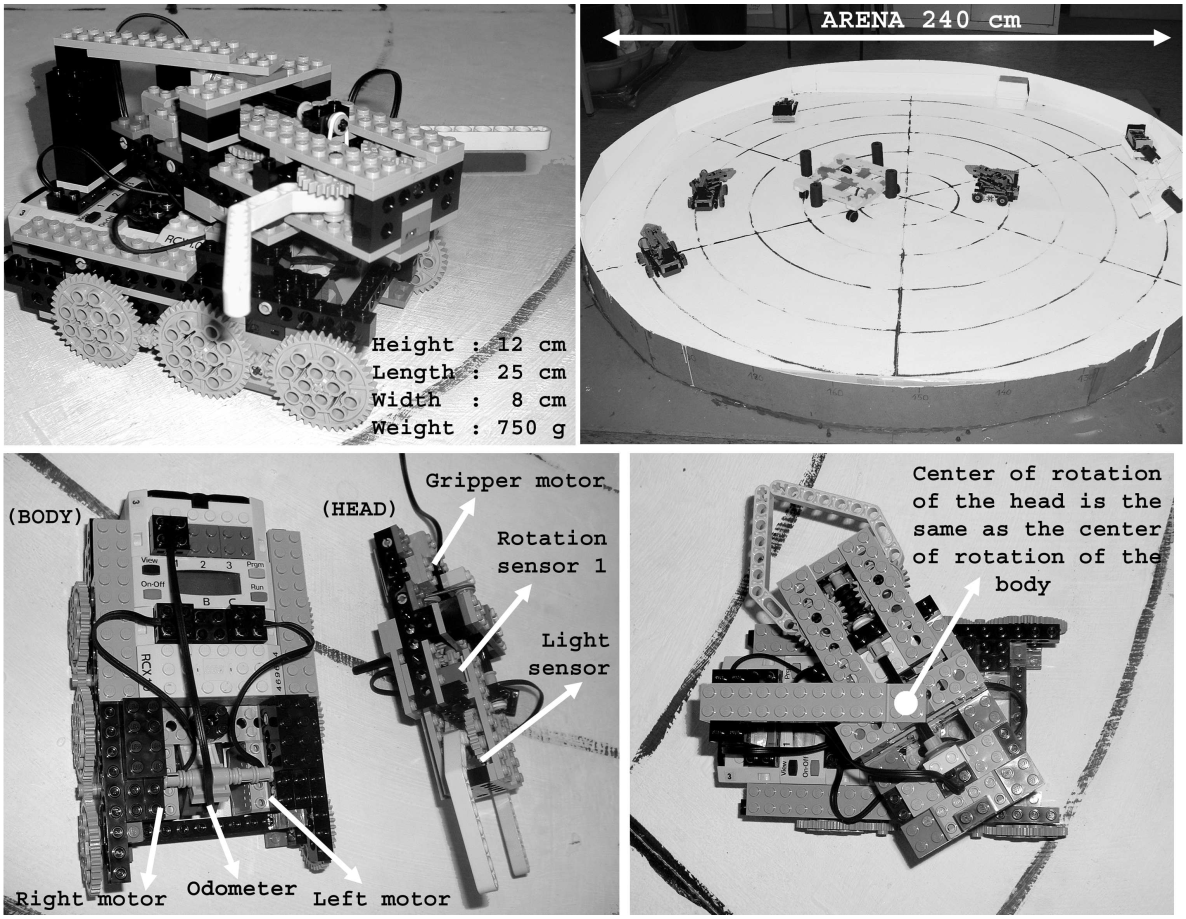

Figure 1: Robots and environment

3 Robots, Programs and Experiments

The robots are made with Lego®Mindstorms™. Three motors (Lego) and three sensors (Lego) are connected with the RCX (Lego microcontroller). The robot is made of two parts: a body and a rotational head (see Figure 1). On the body, there are two motors which ensure the differential drive and one rotation sensor which is used as a unidirectional odometer (see Figure 1). Thanks to that odometer, the robot perceives the longitudinal translations to which it is submitted when it is pulling. On the rotational head, there is a motor that activates the gripper on the front, a light sensor that allows the robot to distinguish between transportable objects and obstacles. Finally, there is a rotation sensor, that measures the angle between the head and the body (see Figure 1), so that the robot can perceive transversal moves of the object, when it has gripped it (see Figure 1). The center of rotation of the body is aligned with the center of rotation of the head, so that the robot can rotate without exerting any force on the object. The transportable object is a wood surface (20cm*20cm) upon which one can add weight. On each side, there is a black tube which can be gripped by one robot, so one up to four robots can simultaneously grip the object. The arena is white and has a diameter of 240 cm (see Figure 1). Now, let us describe the initial situation of the experiment : an object (the prey) is placed in the middle of the arena, while the robots are put in front of the black tubes, ready to grip them.

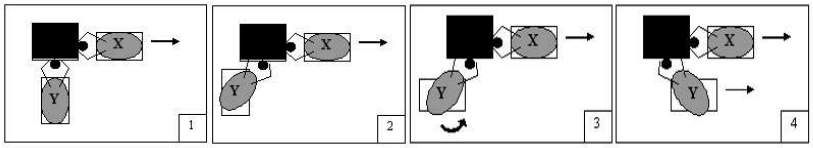

Figure 2: 1) (X) is pulling and robot(Y) is listening; 2) The head from the listening robot (Y) rotates right due to the force exerted by the pulling robot(X); 3) The listening robot (Y) rotates right; 4) Both robots are pulling in the same direction

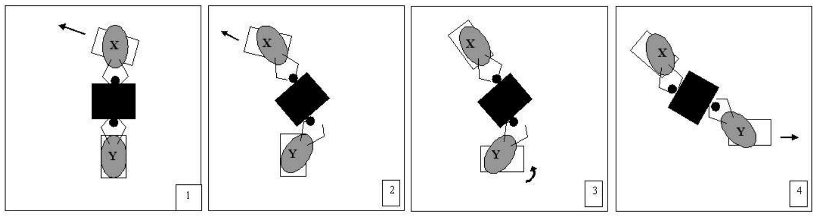

Figure 3: 1) robot (X) is pulling and the other (Y) is listening; 2) The object rotates, causing a rotation of the head of (Y) in a wrong direction; 3) (X) stops its unsuccessful retrieval while the second (Y) rotates to its right; 4) (Y) is pulling causing a rotation of the object and of the head of (X) in a wrong direction, as in 2) for (Y)

Communication through the prey The idea underlying the approach adopted here is to design a robot program, in which the robot can modify the orientation of its pulling force, in function of its local perception (the gripping point movement)(see Figure 2).

When the robot is pulling its prey, its body tends to be aligned with its head, whatever the movement undergone by that prey. This is due to the couple developed by the two motors. The solidarity of the head and the body of the robot prevents its rotation sensor from sensing any signal caused by the rotation of the object. In order for the robot to perceive some movement of the object, it would have to stop the pulling. When pulling is unsuccessful, the robot initiates a waiting process, that we could call a "listening behavior": the robot is awaiting some movement coming from the object. That movement will determine the orientation taken by the robot (its orientation will be the same as the one perceived within the object). The robot enters in that listening behavior (several seconds) if it does not succeed in drawing its prey in its own direction. The local rotations of the prey tubes (the gripping point for the robot) depend on two factors: the application point of the resulting force and the center of gravity of the system. Those two points themselves depend on the situation and orientation of the robots in contact with the prey. Robots placed between those points have a different perception of the direction taken by the prey, compared with the perception that the robots have on the opposite side. As a consequence, the prey is bound to rotate on and on (see Figure 3). We here observe a kind of negative reinforcement. The robots are caught within a deadlock, from which they cannot escape. The information gathered on the movement of the prey appears to be unreliable to allow the robot to start the pulling process, because the local perception of the robots concerning the movement of the prey is not sufficient to perceive the global movement.

Knowing the direction to the nest Ants do use the pheromon trails to orient their pulling. It is local information for the ants, but it can be transformed into global information for robots. Indeed, if each robot is aware that it has to turn either left or right, a limitation ensues as to the possible random trials. This restriction is nonetheless sufficient to allow two or three robots to start their pulling process. Although that method does work, the solution is not optimal, because our robots are not pulling in a parallel way. In fact, the heavier the prey, the more they have to pull it along a parallel way in order to maximize the component of the resulting force along the pulling direction.

Another problem arises: if two robots suffice to bring about the retrieval, adding a robot will slow down the operation. The robot with the largest angle of orientation with respect to the nest will hamper the two others. If that robot tries to redress its orientation, it will stop pulling and begin to rotate. Those two operations are slower than the prey displacement caused by the other robots. In trying to find a better orientation, that robot is doing worse and it will be soon pulled by the two others, while pulling in the opposite direction.

Hybrid Method In theory, however, there should not be more robots than necessary to pull the prey, because the displacement of the prey prevents the robots from gripping it. Indeed, the time needed to close the gripper is longer than the time needed by the two other robots to displace the prey out of reach from the first robot. In some cases, we can nonetheless have three robots around a prey instead of two, which would be sufficient. First, the time needed to reach coordination is too long and a third robot comes along. Second, three robots could be necessary, in order to overcome the static friction force, while only two are enough to overcome the dynamic friction force. So, they begin pulling at three and quickly, the third robot becomes a burden for the two others.

By combining information on the nest location with the information on the movement of the prey, we can obtain interesting results. Indeed, robots initiate the movement due to their random trials in pursuing one orientation (e.g. right or left). If one robot senses (through its odometer) that the object is moving in a direction far away from its pulling direction, it does not try to redress its orientation because it worsens the situation. In such a case, the robot releases its prey. That hybrid algorithm allows the robots to eventually reach an adequate number of agents.

4 Results and Discussion

Our experiment has been made with simple mechanical robots. If the robots could have been conceived and programmed in such a way that they could rotate and pull at the same time, a better coordination could probably have been reached even with an excess of robots. Our experiment confirms that, in the pulling task, there seems to be an ideal number of agents to achieve the task. Then, the goal is not solely to create coordination in a group, but also to discover the mechanisms leading to the optimal number of agents. Using only stigmergic communication through the prey is not sufficient to produce a collective retrieval, because of the noisy information produced by local rotations of the gripping points. By only using the information concerning the way to get to the nest (the only possible solutions in this experiment are left or right), the robots launch the retrieval, but they do not do it in an optimal way. Two problems arise: 1. robots do not reach parallelism, 2. too many robots decreases the performances (see Figure 4). Then, it is important to avoid the lack of coordination, by limiting the number of robots. The hybrid method allows the system to find an adequate number of robots. The orientation and the number of robots depends itself on the weight of the prey. The time taken by the robots in the hybrid method is a bit shorter than in the

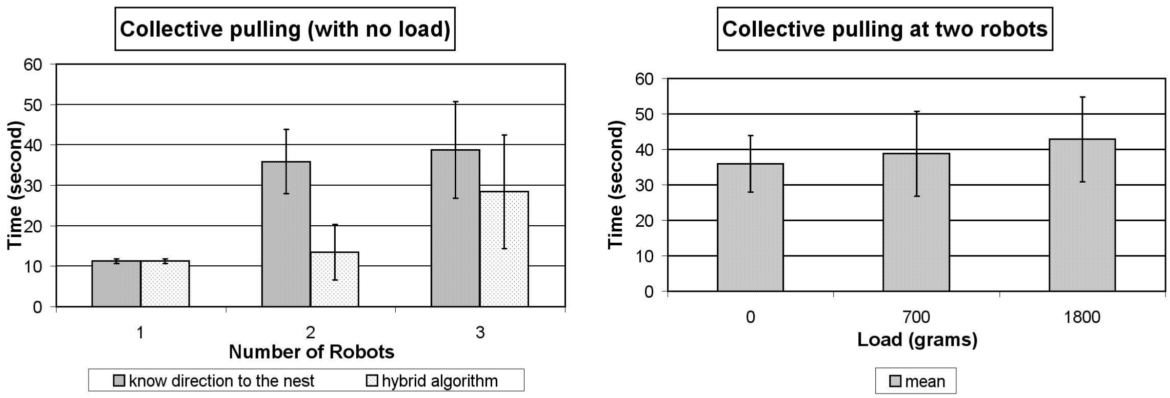

Figure 4: 1) mean retrieval time in fucntion of the number of robots on 10 trials with 2 different algorithms; 2) mean retrieval time at two robots in fucntion of the load (on 10 trials)

'knowing nest location' method on 80 cm. In fact, the larger the pulling distance,the faster the retrieval with the 'hybrid' method, because once the transition period is over (period where the agents find a right orientation and the adequate number), the pulling happens much faster.

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References

[1] R. Beckers, O.E. Holland, and J.L. Deneubourg. From local actions to global tasks: Stigmergy and collective robotics. In R. Brooks and P. Maes, editors, *Artificial Life IV*, pages 181–189. MIT Press, 1994.

[2] Eric Bonabeau, Marco Dorigo, and Guy Theraulaz. *Swarm intelligence : from natural to artificial systems*. Oxford University Press, New York, 1999.

[3] C. Camazine, J.L. Deneubourg, N.R. Franks, J. Sneyd, G. Theraulaz, and E. Bonabeau. *Self-Organization in Biological Systems*. Princetown university press, 2001.

[4] T. Van Damme. *Modelisation et étude expérimentale de la construction et du transport chez les fourmis*. PhD thesis, Université Libre de Bruxelles, 1999.

[5] Dani Goldberg and M. J. Mataric. Robust behavior-based control for distributed multi-robot collection tasks, 2000.

[6] P.P. Grassé. *Termitologia*. Masson, Paris, 1984.

[7] 0.E. Holland and C. Melhuish. Stigmergy, self-organization, and sorting in collective robotics. *Artificial Life*, Volume 5:173–202, 1999.

[8] A. Ijspeert, A. Martinoli, A. Billard, and L. Gambardella. Collaboration through the exploitation of local interactions in autonomous collective robotics: The stick pulling experiments. *Autonomous Robots*, 11(2):149–171, 2001.

[9] Ronald C. Kube and Eric Bonabeau. Cooperative transport by ants and robots. *Robotics and Autonomous Systems*, Volume 30(Issue 1/2):85–101, 2000. ISSN: 0921-8890.

[10] P. Meyer. Expériences sur le comportement collectif et social des robots. Master's thesis, Université Libre de Bruxelles, 2003. Advisor: Professor Marco Dorigo.