Implementing a Cooperative Framework Among Bio-inspired Robots Based on Phonotaxis

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Abstract. This paper proposes the development of a cooperative framework among mobile robots, inspired in the phonotaxic behavior (tracking the source of a specific sound) observed in cricket mating. By means of this behavior, in combination with two other individual behaviors (for communication and obstacles avoidance) a set of five cooperation primitives is reached. A simulation platform has been used to test the design. Furthermore, two real robots, one acting as the female and the other one as the male, have been developed and tested: male emits a calling song (at a specific frequency) and female tracks or moves away from the sound source.

1 Introduction

Cooperation allows robots to deal with large-scale problems obtaining two principal advantages over Single-Agent Systems: improved performance and fault tolerance [14]. Multi-Agent Systems are based on the thought that a group of robots, of little functionality, can obtain better performance than a single highly qualified robot in complex domains, such as planetary science tasks [6] or cleaning tasks [9]. However, coordinating that kind of systems is a complex problem.

Nowadays, Multi-Agent Systems have a good test framework called RoboCup Challenge [3] [10], the robotic soccer competition. Numerous solutions proposed there [17] [18] use a hierarchical architecture for robots design, with a low level made up of reactive behaviors and a high level or higher levels for more complex tasks.

Mataric [13] proposes the use of basis behaviors or cooperation primitives, building blocks from which cooperative behaviors emerge. Although it is stated that the choice of the basis behaviors depends on the domain and the goals, the next set was chosen: Safe-Wandering, Dispersion, Aggregation, Homing and Following. Other behaviors, such as group navigation (flocking) or searching (foraging), can be obtained by combinations of the basis set. Mataric proposes two types of combinations: complementary, for concurrent output behaviors, and contradictory, for mutually exclusive behaviors.

To develop the basis behavior set mentioned, robots have to be able to distinguish the members of its group from the environment obstacles and to know their position.

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Phonotaxis (tracking the source of a specific sound) provides robots with these capabilities, as well as individuals and groups identification. At this point, the research work carried out by Barbara Webb et *al.* [19] [11] [12], where cricket phonotaxis is studied using robotics as a tool, has been the main reference of this work. Behaviors studied by biology are an inspiration source for cooperative robotics [1][2][5].

By using phonotaxis in several ways and by combining it with other individual behaviors (communication and navigation) it will be shown that it is possible to generate the five cooperation primitives, obtaining an alternative to other methods, such as those used by Mataric [13]. The aim of this paper is to prove the usefulness of phonotaxis in the area of cooperative robotics, as a complementary mechanism to other proposals offered in the literature.

This paper is organized as follows. Section 2 details the materials and methods used. Section 3 introduces individual behaviors. Section 4 describes the cooperation primitives implementation. Section 5 presents the experimental result from both simulation and real testing. Section 6 gives some conclusions, remarks and future research lines.

2 Materials and Methods

The proposed cooperative framework has been tested at two levels. As a first step, the cooperation primitives set was implemented for a homogeneous system of *n* (dynamically set) robots in a simulation framework, Virtual Robot Simulator (VRS) [15]. Afterwards, a pair of real robots, one acting as the cricket female and the other one as the male in the cooperative behaviors, were developed.

In both cases, robots show a behavior-based architecture [2] [4]. Each independent behavior is in charge of a specific task, and gets inputs from sensors and its outputs rule actuators. New behaviors can be added incrementally to the system with this architecture. Robots can achieve three individual behaviors: phonotaxis, navigation avoiding obstacles and communication. The latter two have been chosen for two reasons: a) they are important or even fundamental for autonomous operation and b) they are useful to test phonotaxis in the cooperative robotics area. The cooperative primitives are implemented at a higher level.

In simulation, each robot is modelled with a thread. Threads only communicate with the environment (main thread of VRS) by the simulated sensors and actuators, as robots do in the real world. For more detail, see [16].

Real robots made possible to test whether sound is a valid way of identifying and locating mates in the real world. These robots have a small, exoskeleton type structure mainly made of hard plastic. They use a differential drive platform with two wheels at the back and a caster one at the front. This paper presents the results of the experiences developed with a pair of real robots. A homogeneous group of more than two robots is being developed and the real multi-robot framework will be studied in the future.

3 Individual Behaviors

The combination of the individual behaviors depends on the objectives. Thus, a specific behavior management algorithm, which defines the (rigid) combination of individual behaviors, is needed for each primitive. Although, in principle, the way of implementing these individual behaviors should not affect the resultant framework, a brief comment on this implementation is made below. Of course, the specific implementation is determined by the features and capabilities of the robots used.

Phonotaxis provides robots with the capability to locate and identify individuals and groups. Two sub-behaviors have been implemented, inspired in crickets mate.

The male behavior consists in generating the calling song, in order to attract or repel ”conspecific” females. This song is made of: syllables, bursts of sound with a species-specific carrier frequency; chirps, each one with a number of syllables; and silent spaces between chirps [12]. Thus, the calling song can be parameterized by [7]: carrier frequency, syllable rate, number of syllables per chirp, duty cycle and chirp rate.

In the cooperative framework proposed, the song of a robot codifies its identity at syllable level. The identification of a robot contains two codes: group and individual code. The individual code starts from 0 and grows until the number of robots of the group. A sung syllable represents a logic 1 and a non-sung syllable is a logic 0. First syllable in a chirp has to be sung, the rest can be used to store the identification code.

The female behavior consists in tracking (or moving away from) the male. First of all, females need the recognition capability of their species (group) specific calling song. Carrier frequencies different to the specifics of its group are rejected by hardware filtering. The other song parameters can be detected by software.

An explicit communication model has been implemented. Thus, not only robots know of mates existence, but a communication protocol is also established [5]. The communication sensor uses infrared technology. The protocol has been implemented over Philips RC5 code, so that a remote control can be used to send commands or communicate with the robots.

To achieve navigation avoiding obstacles, two types of sensors have been added to the robots: bumpers and infrared sensors. The readings of these sensors are the inputs of a Fuzzy Rules Based Navigation System [8] with feedback variables. The feedback variables take their value from previous decisions of the system, so that robots are able to maintain continuous movement and avoid hesitation.

4 Cooperative Primitives

The five basis cooperative behaviors proposed by Mataric [13] have been developed to make up the cooperative framework. Phonotaxis function has to be outlined because of its locating and identifying capabilities. Moreover, as it will be shown later, phonotaxis gets even more useful for primitives development because of its distance limitation, combined with infrared communication distance limitation. The maximum distance for sound reception has to be longer than the maximum distance for the infrared communication. Next, the basis cooperative behaviors are explained.

Safe wandering is defined as *the ability of a group of agents to move about while avoiding collisions with obstacles and each other*. To achieve this task, the main challenge for a robot is avoiding moving mates. In infrared communication, the emitter has to be oriented towards the receiver. This feature makes this type of communication very useful for safe wandering. If a robot receives a communication, it understands that the emitter robot is moving towards it. To avoid collision, the receiver robot emits a calling song which codifies the emitter's identification (sent in the communication), so that this one knows that it has to change its movement direction. Robots should communicate their identification in the same direction of movement of the wheels. Therefore, a pair of communication emitters, one looking forward and one looking backward, are needed to emit when moving forward and backward, respectively.

Dispersion is *the ability of a group of agents to spread out in order to establish and maintain some minimum inter-agent distance*. This minimum distance, in our framework, is the maximum distance for calling song detection. Each robot in turn sings and listens. It sings so the rest can move away from it, and listens to move away from the rest. Every robot adopts a movement trajectory in the opposite direction to the sound source, made up of orientation (by using phonotaxis behavior) and translation periods (by using navigation). The turns in orientation periods have a constant component and a random component, so the turning angle changes. This prevents from infinite loops.

Aggregation is defined as *the ability of a group of agents to gather in order to establish and maintain some maximum inter-agent distance*. In this case, the maximum distance is the maximum distance for communication detection. When a robot wants the rest to approach, it starts singing. The other robots which detect the calling song try to get to the first one adopting a movement trajectory towards the sound source, made up of orientation (by using phonotaxis behavior) and translation periods (by using navigation). Before each navigation period, robots send a ”Hello Request” command to establish communication with the calling robot. If any of them is close enough to this robot, it receives the communication request, stops singing and establishes communication. Once the communication protocol is finished, the calling robot will start singing again unless all its mates have arrived.

Following is defined as *the ability of an agent to move behind another retracing its path and maintaining a line or queue*. Probably, This is the most complex primitive to perform. To establish a queue, one assumption has to be done: each robot knows the identity of the immediate preceding and following robots or whether it is the first or the last one in the queue. The robots form a queue according to their identification. Thus, the previous assumption is satisfied if each robot knows its own identification and the number of robots in the group. Again, this information is needed to codify calling songs, so the assumption is definitely true.

Every robot, except the first one, waits until hearing its predecessor's calling song to start the algorithm, and it does not react to the calling song of other robots. When it hears the proper song, it turns towards the sound source by using phonotaxis behavior. In this only primitive, the turns are done by moving only a wheel, so that the robot gravity center moves. These little translations make possible for the robot to recover the trail when it has lost. During this process, the robot in turn rotates and sends its identification through the communication sensor. If the predecessor receives the identification, it understands that the next one is properly oriented. Thus, it stops singing and navigates for a time interval. This algorithm is repeated for every pair of consecutive robots from the front to the end of the queue. When the last but one robot stops singing, the last one waits for a delay (time supposed for predecessor navigation) and then navigates.

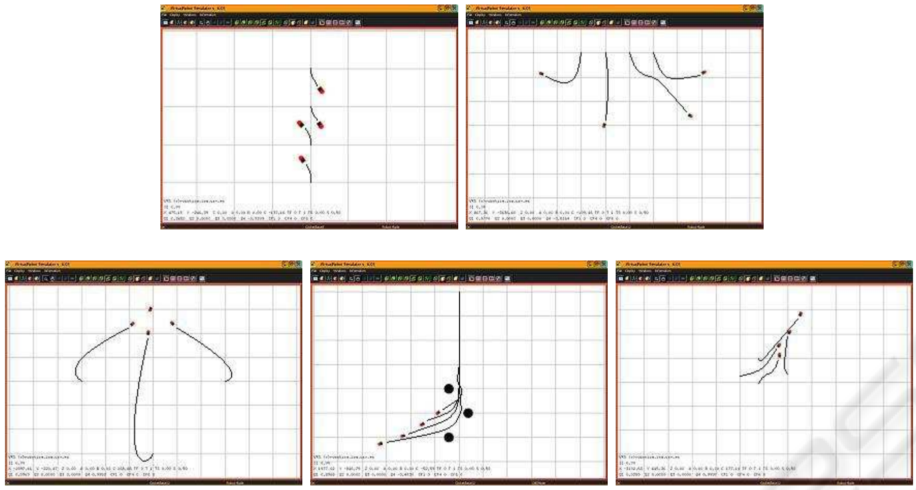

Fig. 1. Simulation tests: (a) Safe wandering, (b) Dispersion, (c) Aggregation, (d) Following, (e) Homing.

Finally, we can define homing as *the ability to find a particular region or location*. This behavior is very similar to the aggregation. Actually, the only difference is the calling element, a static base, which is used instead of the calling robot. The fact that a static base is needed to locate a place can be seen as a disadvantage. If there is no base located in the place the robots have to reach, one of the group of robots has to perform another homing strategy, like greedy local pursuit, used in [13]. In this case, one cooperative homing strategy can be the combination of an aggregation around that robot and a following towards the desired location.

5 Experimental Results

5.1 VRS Simulation

In this section, the results obtained in the simulation of a group of four robots are shown. The experiments were performed from a challenging initial formation. In the safe wandering test (Figure 1(a)), the four robots were set out in a straight line, the first two looking towards the other two and vice versa. In the dispersion test (Figure 1(b)), the robots show an initial formation where every one is facing the same direction and they are close to each other. In the aggregation test, the calling robot stayes at the top of the image (Figure 1(c)) and the other robots are facing the opposite direction to the center of the image. In the following test (Figure 1(d)) the robots initially are arranged in a queue, in order to pass through the columns. The formation of a queue starting from an arbitrary formation is tested in the homing test (Figure 1(e)). Homing can be seen as a particular aggregation. Actually, it is exactly the same if we use a robot of the group to mark the desired location. Therefore, the test performed for aggregation can be valid for homing, too. In section 4, it was proposed an aggregation phase followed by a following

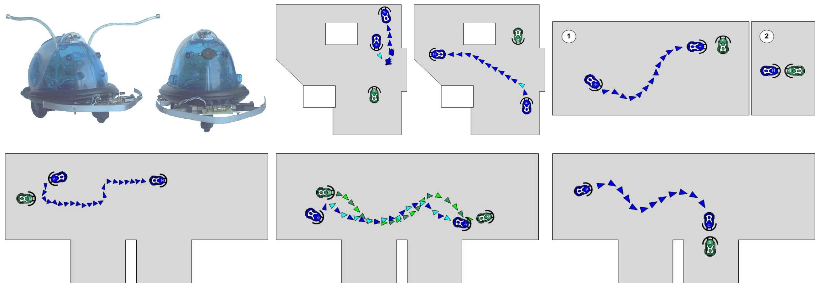

Fig. 2. Real robots (a) and tests: (b) Safe wandering, (c) Dispersion, (d) Aggregation, (e) Following, (f) Homing.

phase to achieve homing without a marking base. The automatic formation of a queue of robots is fundamental for this definition of homing and this is why it has been tested.

The outcomes show that the framework based on a phonotaxic behavior works properly. Robots are able to avoid themselves, to join or separate and to form and maintain a queue while avoiding obstacles.

5.2 Real Environment

The ideal system consists of a group of *n* robots which dynamically adopt the male or female role, depending on the cooperative behavior they are performing, their role in that behavior and/or the part of the management algorithm they are executing. The ideal system performance has been tested in the simulation, but no noise was implemented. Now, sound as a feasible communication medium in real environments has to be proved. Two robots have been developed (Figure 2(a)), one with the male capabilities and one with the female capabilities. The experiences in the real world were performed in a big (10 meters x 4 meters), closed room, with white furniture. The presence of furniture is important to evaluate the effect of the bounces of the sound. The environment of the test is not specially noisy, as those of some applications for industrial automation. Dealing with noisy environments is part of the future work to be done. All the experiences shown were filmed and then represented as drawing pictures to illustrate motions[3].

In the tests done, only the female robot navigates because it is the only robot able to react to sound. The safe wandering tests (Figure 2(b)) show how the female reacts to sound (light triangles) and then navigates avoiding objects. In the first experience, the female robot even has to turn all the way round. Dispersion, aggregation and homing tests are very similar. The female robot moves away from (Figure 2(c)) or towards to (Figures 2(d) y 2(f)) the male adopting the typical zig-zag movement of the crickets [7]. Figure 2(d) show the two phases of the aggregation: first the female gets closer to the male and then, once it is close enough, the communication protocol is established. Note that homing is very similar to the aggregation but with no second phase. For the other definition of homing (aggregation + following), the queue formation of the two robots

[3] Real videos can be downloaded from: http://ttt.gan.upv.es/ jcamacho/crickets/videos.

(not shown) is achieved just by steering the male robot after the aggregation. Finally, in Figure 2(e), the female and male position and orientation for every time interval during the following test are shown. Odd intervals are drawn in dark color while even intervals are shown in light color.

As it can be seen, the primitives are performed correctly by the female robot, but there are some erratic decisions in the phonotaxis. Several consecutive errors in the phonotaxis sensor can cause non expected behaviors, as the turn towards the top in Figure 2(c). The error percentage has been empirically calculated as 13.2% (without echo), a high error value. This is, nonetheless, a good result which suggests that the framework would get even better performance with a more detailed design of the sensor.

6 Conclusion

This paper is another contribution to demonstrate that bio-inspired behaviors are an alternative methodology. There is a current of opinion which claims that complex planning methods can be replaced by biologically observed behaviors, which emerge from the combination of simple behaviors. Probably, the best way to obtain intelligence is by imitating it. Based on the results obtained, it can be concluded that:

1. Phonotaxis is a useful behavior for mobile robotics in environments where sound is a feasible communication medium.
2. A cooperative framework, made of phonotaxis and other individual behaviors, has been developed and tested in simulation and real world, in this latter case with two robots. This framework is mainly based on the combination of two communication methods: one directional (infrared) and one omnidirectional (sound).

From the second conclusion, it can be stated that the system keeps functional whatever two communication methods are used, as long as one is directional and the other one is omnidirectional and the distance limitation of these methods is proper. The methods choice will depend on the environment characteristics. In this paper, sound was chosen as the omnidirectional communication method. Sound can be an alternative to visual techniques when the number of obstacles reduces the performance. Future work is mainly aimed at:

a) A real, homogeneous, *n* robots system development.
b) Improving the sound sensor and testing the framework in noisy environments.
c) Comparing this framework with visual cooperative systems in environments with many and/or big obstacles.
d) More complex cooperative tasks development using cooperative primitives.

Generalization of the real framework for *n* robot seems to be a very challenging task. Two main problems have to be addressed: codification of the identification in the sound (at syllable level) and interferences among songs. In simulation, the cooperative system lose efficiency as more robots are included in the same environment. To avoid interferences, a Frequency Division Multiplexing (FDM) is proposed. Moreover, as these ”cricket” robots, by definition, only react to calling songs with specific parameters, different groups of robots can act over the same environment by using different parameters songs.

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