Building mixed societies of animals and robots

Building Mixed Societies of Animals and Robots

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Abstract

This article presents the European project LEURRE aiming to study, model and control mixed societies of animals and robots. The robotic part discusses general ideas on the design and implementation of robots to be used together with groups of animals. After a presentation of the project, the implications on the special requirements imposed on the robot is discussed. The design process of the robot is described leading to the implementation of the autonomous mini-robot called InsBot. It is very compact, has many sensors and is able to interact with gregarious cockroaches. Programming the robot to be accepted by its natural counterpart gives insight into the basic behaviours necessary in a mixed society. This results are useful for collective robotics as well.

Introduction

The European project LEURRE deals with cooperation between robots and animals in a social context. Its main objective is to demonstrate the possible control of such mixed societies. The control of interactions between artificial systems and living organisms is a key question in many scientific fields like medicine, agriculture or ethology. All biological levels are concerned: from the cellular level with for example interfaces between artificial systems and cells like neurons, the organism level with intelligent prosthesis, or the human level with cooperation between humans and robots.

The principle of experiments using decoys or lures is to isolate, from the others features of the interacting animal, the stimulus inducing a specific behaviour. Many ethological results show that it is possible to interact with animals not only by mimicking reality but also by making specially designed and often simple artefacts [1]. However, once the selected behaviour has been performed by the animal, the interaction stops because the lure cannot “reply”. A key step in interacting with animals is to be able to “reply”, control or manage several related interactions. Robots acting as decoys and able to “respond” to animals by modulating their behaviour accordingly, offer an interesting perspective for biology and robotics.

The main objective of the project is to trigger the emergence of new collective responses or new global patterns by adding to a group of social animals, robots communicating with them, and to show that they can collaborate.

Hence, the main tasks of the project are the following:

- Study behavioural models for mixed societies.
- Provide a validation of the behavioural model by confronting it with a real implementation of a mixed society composed of insects and insect-like robots.
- Control the global behaviour of the society. We will show that it is actually feasible to change the global behaviour of a mixed society by introducing a limited number of robots.
- Provide a general methodology towards the design and control of mixed societies.
- Relevance of our results to quality of life and management of living resources. We aim to demonstrate that the methodology developed for insects is also applicable to groups of vertebrates such as gregarious mammals or birds.

Some of the results will prove to be useful for collective robotics because the behaviours programmed in the robot have to cope with their natural counterpart in order to be accepted as a congener. This gives a better insight into the basic behaviours necessary in a mixed society.

The behavioural patterns based on self-organization in animal societies result from simple, but numerous, interactions and produce "collective intelligence" taking place between individuals distributed in the environment and having access only to local information. Each agent has a simple sensorial apparatus and communication equipment that enable it to respond to two types of local stimulus: the stimuli from the non-social environment and those from the other members of the group that are for example attractive and activating (positive feed-back regulations) or repulsive and inhibiting (negative feedback). In such systems, the signal itself constitutes the information rather than being solely the physical support for an exchange of information [2][3][4]. The individual behaviour accommodates to the signal itself and not to its possible content of information.

Interaction between robots and animals in mixed societies is a challenging new research field. For many years researchers have developed robots inspired by animals [5][6] or robots that use biologic actuators [7], but only a few robots that interact with animals [8][9] and none that try to be accepted as a member of the society.

The European Project LEURRE

The European LEURRE project started in September 2002. Complementary competencies are needed in this project and the teams are:

- CENOLI, Université libre de Bruxelles (ULB), Belgium: core competences in biology and complex systems both from an experimental and theoretical point of view, particularly in self-organization and the dynamics of natural and artificial multi-agents systems.

- International Solvay Institutes for Physics and Chemistry, (ISI), Bruxelles, Belgium: core competences in modelling complex systems and dissipative structures.
- CNRS-EVE, Université de Rennes 1, France: core competence in biology including behaviour and the chemical communications of the cockroaches.
- CNRS-CRCA, Université Paul Sabatier, France: core competences in biology mainly social insects and mammals, collective intelligence and self-organization in biological societies.
- Autonomous Systems Lab (ASL), Swiss Federal Institute of Technology Lausanne (EPFL), Switzerland. The team is mainly involved in designing and building the robots and all the tools that are needed to work efficiently with them. Another important task is to program the behaviours according to the models developed by the biologists and to fit them on the robot's CPU, taking into account the hardware limitations. In short EPFL is involved in building something that can be used as a toolbox for ethologists.

Beside the global results of the project, each team will enhance his specific field of knowledge. From the biological point of view, it helps to understand animal behaviours due to the possibility of testing their behaviours through interaction with artificial systems. For researchers interested in complex system, it is an opportunity to test the link between formal models and their implementation and to test experimentally the effect of the individual parameters on the global pattern. For engineers, it is a challenge for building very small robots that can be compatible with animals. Secondly it is interesting to study perception and sensors for bio-interaction. Finally, as the project includes a collective intelligence, aspect the results will be useful for collective robotics.

Mixed Society of Cockroaches and InsBots

For this research, dealing with animal societies, it is convenient to use animals allowing detailed analysis and modelling. For these reasons gregarious insects are a good choice. The artificial agent in the mixed society is an autonomous mobile robot. The recent results achieved in this field allow us to design a miniature robot with sufficient performance to interact with insects. We call it InsBot for insect like robot. Thus, to achieve the goals we selected American cockroaches and miniature robots to compose the mixed society (Figure 1).

The study of this cockroach-InsBot model is new and has been selected for the following reasons. The social behaviour of cockroaches involves, for example, aggregation, collective decision and parental care. Individuals are able in some situations to memorize visual cues and perform path integration [10]. Aggregation, one of the keystones of social phenomena, is a prerequisite for the development of other forms of cooperation and is involved in many activities. In a homogeneous set-up (see Figure 2), cockroaches are able to cluster to form characteristics patterns [11][12]. However, in natural situations, cockroaches aggregate in places that present particularly interesting

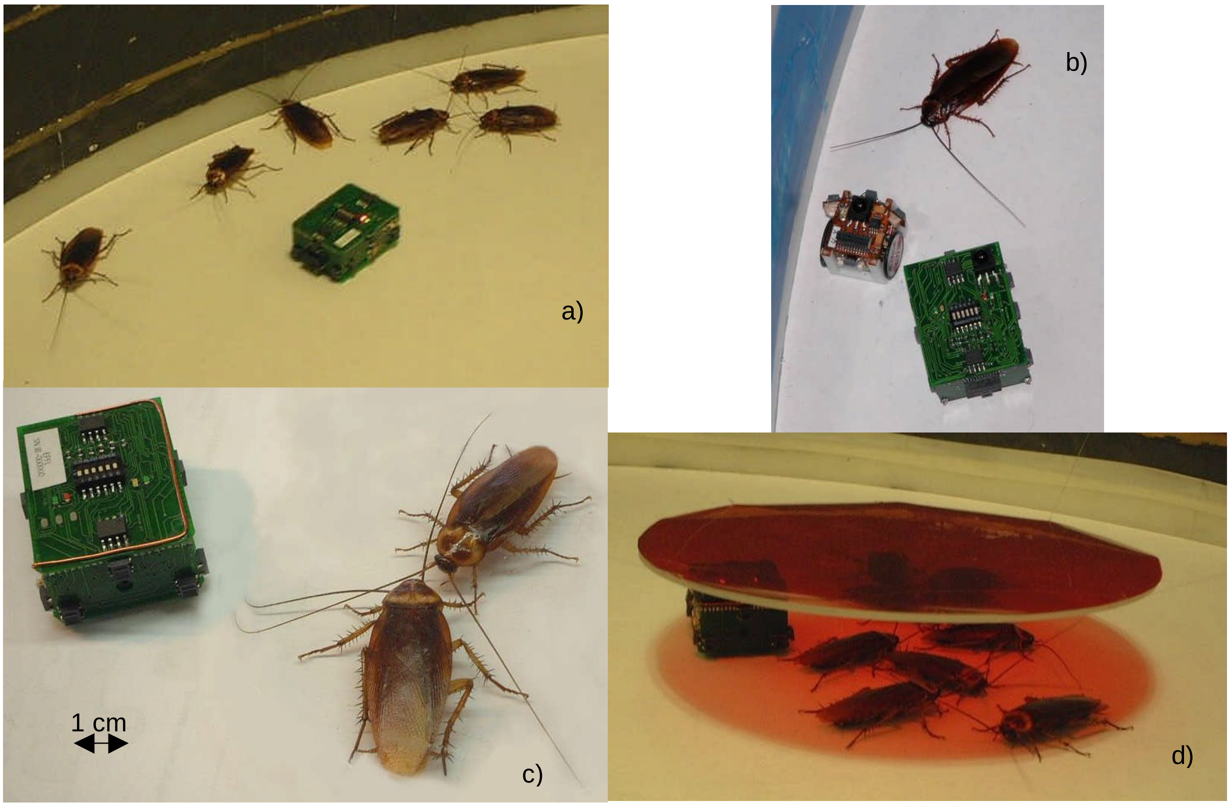

Figure 1. Robots and cockroaches together. a) In the arena. b) InsBot, Alice and cockroach. c) InsBot and cockroaches have similar size. d) Mixed society under a shelter.

conditions. In tests carried out with large and identical shelters, the insects show a strong tendency to aggregate on a unique resting site [13][14]. This collective choice selects only one shelter and the individuals do not spread between the different available possibilities. These self-organized aggregation and collective choice result from, firstly, an exploratory “random walk” and hence a random discovery of a cluster or a shelter and, secondly, some amplifications based on tactile and chemical communications. These amplifications are modulated by the probability to stop correlated to the number of individuals already stopped in a local area of perception. The resting time increases according to the number of congeners present in the local neighbourhood. Chemical cues are used for congener recognition and aggregation. In natural situations, the shelters are not identical, and they are characterized by different parameters, which are more or less easily detected and integrated by an individual. Any parameter of a shelter that increases the individual resting time favours the formation of the cluster in this specific shelter. Because of the competition between shelters, most of the insects will aggregate at the site that has the highest resting time. These patterns of aggregation can be very diverse depending on parameters values, ranging from the gathering of all animals in a unique site to their splitting between several ones. We have demonstrated that the different collective patterns arise from the same generic rules, based on the individual response to local signals including the presence of conspecifics (positive feedback). The perception of the conspecific is based on tactile and on chemical signals that are present on the surface of the insects [11][12][13][14].

The chosen species *Periplaneta americana,* is a classical species used in biology (neurobiology, ethology, etc.). Their two long antennas (around 30 mm) are used as tactile and chemical sensors, their physical characteristics (e.g. size and speed when calm) are similar to those of the InsBots. Moreover, the experimental spatial (about 1m) and temporal scale (a few hours) of cockroach collective patterns make them suitable for our studies. The main problem in animal-robots interactions is that the signal emitted by animals has to be detected by the robot and the robot has to be able to emit signals detected by the animals. So it is important to choose situations in which communications are not only simple, but also that the signals used to communicate are easily detected by the robot's sensors. The short-range interactions between cockroaches are mainly tactile and chemical, implying that they are possible to implement in robots. All these characteristics make the coupling of the micro robots with the cockroaches *Periplaneta americana* a useful and low-cost experimental environment.

Basically, each robot obeys simple rules that determine how it reacts as a function of the signals it receives from the environment, the other robots or the animals. Its decision, position and movement thus affect the decision, position and movement of other members of the group, be they animals or robots. The robot can modify the general behaviour of the mixed society and this change can be measured in such cases where the probability to have an aggregate in each shelter would be otherwise equal. One experimental idea is to influence the aggregate position by adapting the individual behaviour of the InsBots. For example, in a natural situation of collective choice between shelters, the group of cockroaches preferentially select a shelter with lower light intensity. The InsBots can be tuned to settle in a brighter shelter and will be able to modify the choice of the group, leading the insects to choose this brighter shelter instead of a darker one, which they otherwise would have preferred.

The Experimental Setup

The experimental arena is composed of a white plastic arena (1 meter diameter and 15 cm high), an overhead camera and illumination (Figure 2). The same arena is used for experiments with or without shelters. Lighting has reduced infrared emission to avoid problems with the IR proximity sensors of the robot. For safety and experimental reasons, we have to prevent the insects from

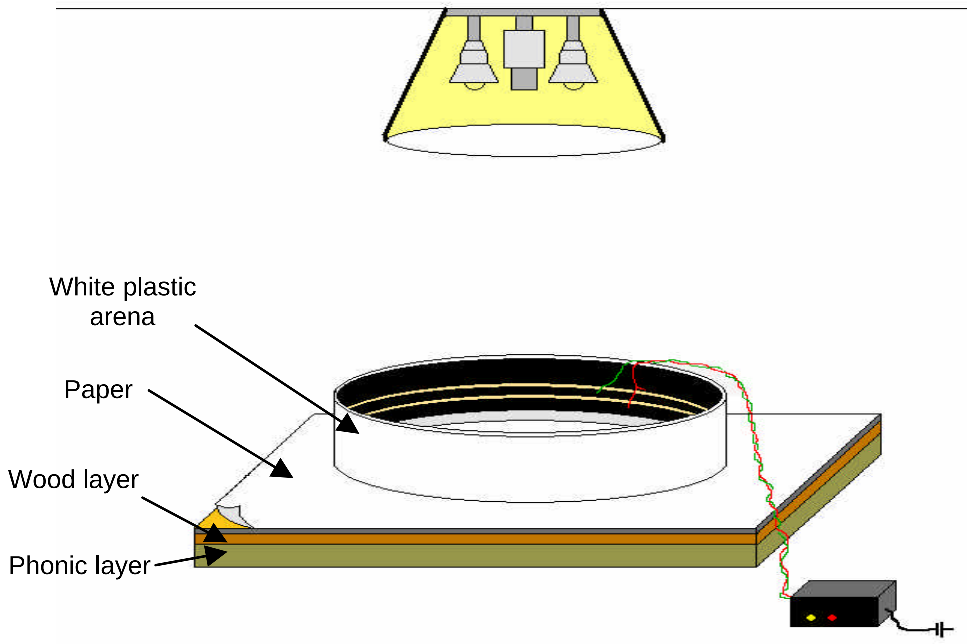

Figure 2. The experimental setup

escaping the arena, so an electrical fence has been added. This low power, low voltage, barrier is not harmful for the cockroaches and the shock is rapidly “forgotten” and does not alter their behaviour. To reduce mechanical vibrations a phonic layer has been added between the ground and the wooden layer. On the wooden layer, a paper sheet is added and changed after each experiment. This change avoids that any chemical tagging left during the experiment will influence the following one. It also allows us to remove dusts or small dirty marks that could affect the mechanical parts of the robots, as dust is a main problem for their very small open watch motors.

The insects are introduced in the arena and about 30 minutes are needed to let them calm. During this time the robots are in stand-by mode. After this first phase, the experiment can start and at this point there are many interactions and movements of the cockroaches and the robots. The first experiments performed without robots have shown that it takes about 2 hours before the appearance of an aggregation or a shelter selection.

The Robot InsBot

The developed robot fulfils the following **requirements**:

- To behave like the insects of the mixed society.
- To be accepted by the insects as a congener.
- To be able to influence the global behaviour of the society.

Considering the description of the cockroaches and how the experiments will be performed, the most difficult points are the small size of the robot, the high level of integration (many sensors) and the darkness of the cockroach cuticle (IR sensors sensitivity). The number and duration of the experiments demand reliable robots and tools. However the behaviours to be programmed seem to be feasible with a simple microcontroller architecture. Finally, the most important information for all behaviours is proximity, which is well managed in mini-robotics.

Design of the InsBot

During the first part of the project we have used Alice robots [15] to conduct some acceptance tests. The tests revealed that the robot and, in particular, its IR emissions, vibration, and size, did

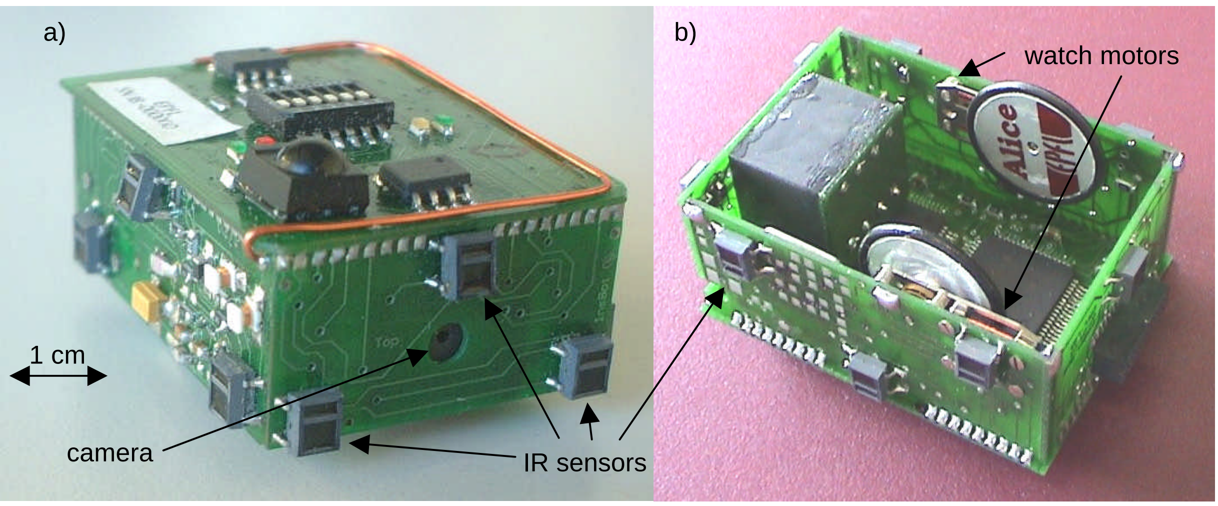

Figure 3. a) The robot InsBot. b) The robot upside down without battery and bottom cover.

not cause the cockroaches to flee. These preliminary tests showed also that it is quite hard to detect the cockroaches because of their brown colour, which absorbs most of the IRs, so we had to increase the power of the emitters. We also found that we needed some wireless communication modules for monitoring, some additional sensors, more computational power and much more memory than Alice. This is why we finally decided to develop a new robot (Figure 3) specific for our mixed society application.

Many sensors might be interesting to interact with animals. Here is a short summary of what we had imagined. In Table 1 potential sensors are evaluated from 1 to 6, based on the following aspects: computational power, energy consumption, and complexity. Because of the limitations on the size of the robot, its autonomy and computational power, we finally decided to implement sensors 1, 2, 4 and 7 in the InsBot.

N	*Type*	*CPU power*	*Energy*	*Complexity*
1	IR proximity	2	3	1
2	Light sensor	1	1	1
3	2D colour camera	6	5	4
4	Linear camera	3	4	3
5	Tactile antennas	2	1	4
6	Vibration sensor	1	1	3
7	Temperature	1	2	1
8	Chemical	4	3	6
9	Humidity	2	2	2
10	Gas sensor	2	2	2

Table 1: SENSORS TYPES FOR “BIO-ROBOTS”

Chemical Sensors. Both emission and reception of chemical signals have to be taken into account. The emission of the “cockroach chemical signal” is rather simple. Indeed the molecules are present on the surface of the cockroaches. This is why we decided to use only a passive chemical communication with just some medium impregnated with the synthesized cuticle pheromones of the cockroach. The difficulty is to identify and synthesize this blend of chemicals.

The reception of chemical signals using a “chemical nose” is much more complicated. This is still a major research field, and there are currently no industrial sensors that can be found for the type of chemicals used in insect communication. One strategy is to mimic the reaction to the signal using the other sensors and to implement only chemical emission. The chosen final solution is to cover the robot with a paper containing cockroach odour and to feel the insects by proximity measures.

IR Sensors. The IR sensors are used for both proximity and brightness measurement. This is the most important sensor because every behaviour is mainly based on proximity information. Not only is the kind of sensors important but also the position of sensors itself. They have been specially positioned in order to distinguish between an obstacle and a cockroach. This is why we decided to place one sensor on top of each face and two on bottom. The top sensor is higher than a cockroach. Thus, in the case of an obstacle, top and bottom sensors are activated; whereas, in case of a cockroach, only bottom sensors are activated. One top and one bottom sensor could have been enough but because of the sensor opening angle, the length and the width of the robot it would have been difficult to perceive obstacles. Moreover, the robot also needs to distinguish another InsBot from a wall. In this case, it uses local communication with the IR sensors. The nearby robot also

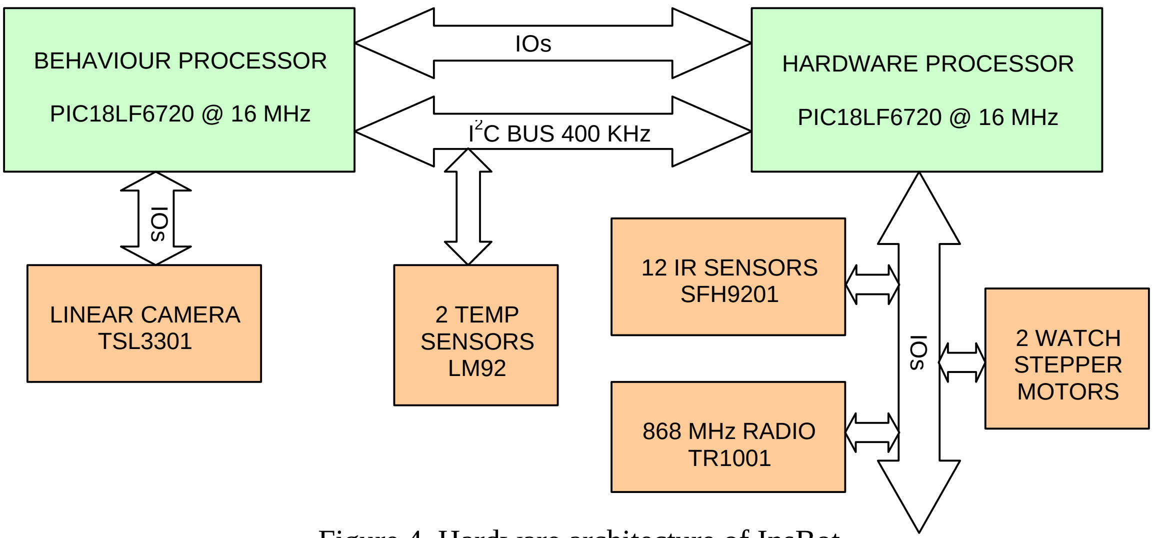

Figure 4. Hardware architecture of InsBot

emits IR signals whereas the border of the arena does not. The measure of the brightness using the same 12 IR sensors is used by InsBot to detect the shelters. It can detect if it is partially or completely under a shelter and thus try to enter or leave this dank area.

Linear Camera: The linear camera is useful to detect objects or groups of cockroaches at a longer distance than the IR sensors. Dark spots are assumed to be a group of individuals.

Temperature: Temperature information is used to adapt the behaviour depending on the temperature if needed, but mainly to follow a temperature gradient like cockroaches. This is why we have implemented two of them placed at the extremities of the InsBot.

Control and Electronics: The control consists of a behaviour level and a hardware level implemented on two processors (Figure 4). The first one, called “Hardware Processor”, is connected to most of the hardware resources (wireless communication, IR sensors and motors). Its basic tasks are to control all these features and pre-process the sensor information for perception. This processor ismainly programmed by the engineers. The second one, called “Behaviour Processor”, will access to all resources through a fast I^2C bus (400 KHz) but can also be interrupted by the “Hardware Processor” with IOs. The camera is the only hardware device that is connected to the “Behaviour Processor” because of the limited number of IOs on the other processor and because this makes the information directly accessible to high level algorithms.

Energy is delivered by a small Li-polymer 190mAh battery for up to 4 hours in the worst case when all features are continuously working. We chose Li-polymer technology because this currently has the highest volumetric capacity among rechargeable batteries, is available on the market, has an affordable price, and a very fast charging time (1 hour for a fast full charge).

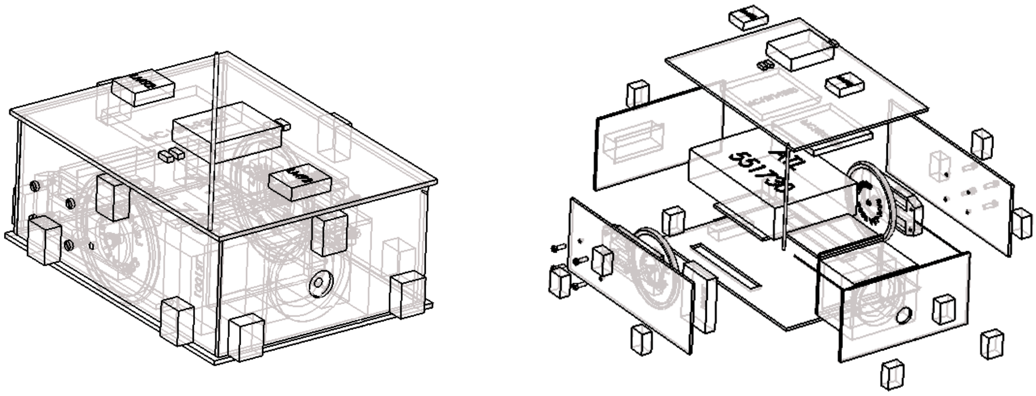

Figure 5. 3D model of InsBot

Mechanics: The robot must be very small and integrate many electronic parts. Therefore, we decided to use the printed circuit boards (PCB) as the mechanical structure (Figure 5). Connections between each PCB are soldered for both electrical and mechanical connection. Regarding locomotion, as for the Alice robot, we chose a differential drive configuration.

3D drawing: Because of the very small size and the high integration level, we have first developed a 3D model of InsBot (Figure 5) to dimension the size and position of each PCB. The 3D model is also very important to visualize the position of each sensor and the feasibility of the assembly.

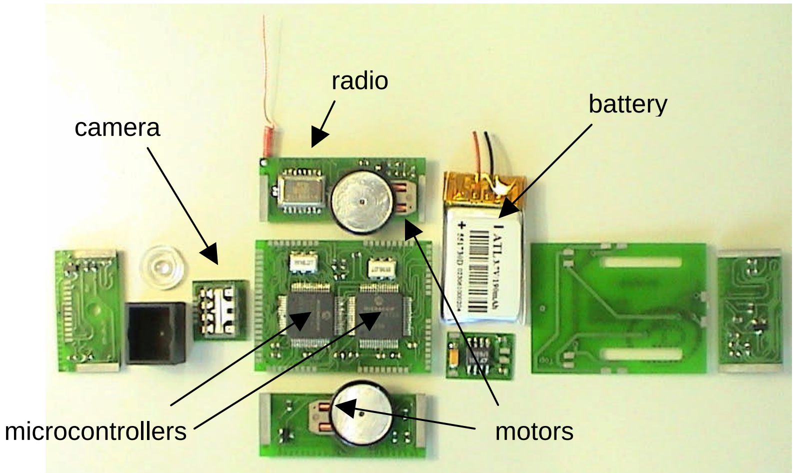

Figure 6. The robot before the final assembly. The 9 PCB seen from inside the robot.

Implementation

After design and modelling, we have finally built an InsBot to validate all assembly aspects. The robot is composed of 9 PCBs (0.6 mm thick) as shown on Figure 6.

Weight	15 g
Maximum speed	5 cm/s
Autonomy	4 hours minimum
Linear camera	102 pixels, 8 bits grey level
Processor	2 x PIC18LF6720 (64Ko Flash) @ 16 MHz
Temp. sensors	0.33C accuracy, 2 units
Proximity sensors	up to 8 cm (white paper), 12 units
Wireless link	125000 baud, 20 meters
Size	41 mm (L) x 30 mm (W) x 19 mm (H)
Cost	about 200 Euros (without assembly)

Table 2: SPECIFICATIONS

The first 6 units have been manually assembled. Because of the very small size of all components and the very precise mechanical parts, it takes around 6 hours to fully assemble one InsBot. Additional units are in production to perform all the mixed society experiments. Table 2 summarizes the general characteristics of the InsBot and the main components.

Software

The source code of InsBots is written in C and is compiled with the CCS PCW compiler (http://www.ccsinfo.com). The compiled hex file is then uploaded to the robot by means of a serial bootloader, so that the user does not need a hardware programmer. Table 3 presents the software architecture and processor tasks of the InsBot.

Software processor	Hardware processor
No OS, library of functions	Multitask and Real-Time OS
Random generators - Uniform - Normal - Exponential Hardware access Hi-level behaviours	Motors control Sensors processing: - Proximity - Brightness Time in milliseconds (4 Bytes) Automatic behaviours: - Obstacle (avoidance-attraction) - Wall following (left-right) - Light (avoidance-attraction) - Temperature (avoidance-attraction) Local communication (IR) Global communication (HF)

Table 3: SOFTWARE ARCHITECTURE AND PROCESSOR TASKS

Tools

Through a *programming board*, each of the 2 InsBot processors can communicate and be programmed with a PC by a serial port. In most recent laptop PCs there are no serial ports, and thus we decided to implement a USB hub and two USB-serial converters in order to use just one USB port on the PC. The programming board also includes two ICD (In-Circuit Debugging) connections for a full re-flash of the processors. The last feature that has been included is a fast charger allowing a full battery charge in 1 hour.

A multi robot *charger block* has been developed because we plan to work with colonies of 20 InsBots. This device includes the same charger as the programming board, but it permits 4 InsBots to be recharged at the same time. It also monitors the battery charging level and other problems. The state is signalized with two LEDs.

To enable wireless communication to the robot, we use a *radio base station* on the PC side. With this board we can communicate both with one specific InsBot, defined by its address, or with all InsBots. The robots can also communicate together. As said before are not using this wireless link to globally control the behaviour of all the InsBot, but only for monitoring the experiments. We have used an USB-serial converter to be compatible with any computer (Windows, MacOs and Linux), and to power this module directly from the PC. All existing applications communicating using a classical serial port (e.g. Hyperterminal, MatLab or any C program) are also compatible because the USB-serial converter emulates a virtual serial port on the computer. The graphical user interface is developed under SysQuake (www.calerga.com).

Chemical Marking

The most important factor is to make the robot recognised as a congener. The InsBot not only has to be accepted in the near environment of cockroaches but has to be identified as a conspecific because it is bearing the specific chemical pheromone. The cuticular surface of insects represents a rich reservoir of chemical molecules, some of which have a high informational value and others are superfluous. Informational molecules are mainly cuticular hydrocarbons that function as intra- and inter-specific signals for insects and in particular social insects. The identification of these compounds involves several steps: the development of adequate behavioural bioassays for the proposed role of a given blend of chemical compounds; the role of the different groups of compounds in the aggregation behaviour; the localization of the secretion source and the identification of the efficient molecules. This chemical blend has been identified by extracting cuticular chemicals followed by gas chromatography and mass spectrometry analysis. At this stage, this pheromone blend is not chemically synthesised but extracted from the insects. Our tests have already shown that indeed the insects prefer to collaborate with a chemically tagged robot and try to avoid non-tagged robots. This system allows us to study the role of chemical communication in robot-animal interaction. Moreover, it can be further developed to study the use of chemical communication in collective robotics.

Ongoing and Future Work

We are now tuning the behaviours implemented in the InsBot in order to mimic the insects. The biologists extracted the trajectories of the cockroaches using a tracking system and quantified the different parameters of the individual behavioural model. The first goal is to have a robot that moves like an individual cockroach and, for example, that presents a resting time that is modulated by the number of insects present in its perception area.

After this first phase, the robot will be introduced in the colony and we will try to analyze which are the most important parameters (size, noise, behaviour, chemicals, etc.) that enable the InsBots to collaborate and influence the insects.

The last part will be to upgrade the individual behaviour of the InsBots to control the global behaviour of the mixed society. The typical experiment in this sense may be to attract the cockroaches to a place or shelter they would not choose spontaneously without the presence of the robot. At this point it will be possible to study and test the parameters and the strategies that permit the control of the whole group.

Conclusion

After around 6 months of analysis with an existing mini-robot (Alice), we have been able to define specifications for a new robot to be used in a mixed society together with cockroaches. Because of the limitation on the physical dimensions and the large number of necessary sensors, some tradeoffs had to be taken. The number of features included in the robot called InsBot makes it an example of a highly integrated system. Moreover, this is one of the first robots devoted to interaction with small insects. It is a step in understanding the mechanisms that underlie complex societies of social animals and will hopefully give a possibility to even control such mixed societies.

Most problems appearing in animal societies have a strong self-organized component: synchronization of activities, aggregation, sorting, etc. Social imitation plays a key role in these species and most of their collective patterns result from positive feed-back [1][16]. The analysis of collective behaviour in these terms implies a detailed observation of both individual and collective behaviour, combined with mathematical modelling to link the two. This is why the study of different examples of collective behaviour is an important task of this project.

Despite this simplicity, the emerging collective pattern may be of remarkable interest [17][18]. In such a context, a control of these interactions by means of a relatively simple robot inducing movements would be able to control the spatial distribution of these wild animals.

Most self-organized systems are very sensitive to small changes at the individual level or of a small fraction of the population. It is possible that a few number of robots interacting within the group might be the source of small differences inducing the whole group to escape from some sub-optimal solution [1]. This gives the opportunity to introduce new collective behaviours and/or to "push" the group towards new patterns and, in this way, to improve breeding conditions, animal welfare, pests management and so on. Outstanding question remain to be addressed: what are the rules which must govern the behaviour of such robots and how should these rules be tuned to generate different patterns and efficient solutions? How may robots modify the organization of the group which leads to new patterns?

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Keywords

Mixed society, artificial life, life control, gregarious animals, miniature mobile robots, insect-like robots, basic behaviours, complexity and control, emergence, self-organization.

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