Robot-Animal Interaction: Perception and Behavior of Insbot

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Abstract: This paper describes hardware and behavior implementation of a miniature robot in size of a match box that simulates the behavior of cockroaches in order to establish a social interaction with them. The robot is equipped with two micro-processors dedicated to hardware processing and behavior generation. The robot can discriminate cockroaches, other robots, environment boundaries and shelters. It has also three means of communication to monitor, log, supervise the biological experiment, and detect the other robots in short range. The behavioral model of the robot is a mixture of fusion in low-level and arbitration in high-level. In arbitration level a stochastic state machine selects the proper subtask. Then in fusion level, that subtask is decomposed to a hierarchy of sub-tasks. Each sub-task generates a potential field. The resultant force is then mapped to an action.
Keywords: micro robots, mixed-society, robot-animal interaction, behavior modeling

1. Introduction

Over the last decades, researchers in bio-inspired robotics have mimicked animals to design hardware and software structure of the robots. RobotV (Kingsley et al. 2003), RHex (Sarnaly et al. 2001), Biobot (Delcomyn and Nelson 2000), HEL-roach (Kagawa and Kazerooni 2001) and the hexapod micro-robot (Guozheng 2002) are examples of legged-robots which have been mechanically inspired by cockroaches. Some projects are inspired from the behavior of cockroach and implemented their behavior on micro robots (Jost et al. 2004; Garnier et al. 2005).

Some researches have developed hybrid robots by mixing artificial and biological systems. PheGMot-III (Nagasawa et al. 1999) uses real cockroach antennas as a chemical sensor to follow pheromone tracks. Holzer and Shimoyama (Holzer and Shimoyama 1997) designed a system which controls the cockroach's actuators by electric stimulation.

Instead of building exactly the same mechanism as animals our goal in short-term is to have robots which integrate into animal societies, live inside the society and interact with them. Focus of our work is in collective-level. So there is no need to have the same appearance as animals but the functionality of the robot must permit it to integrate into their society and produce *statistically* the same collective behaviors.

By "*integration*" we mean not only the animal's behavior is affected by the robots and the other animals but also the robot's behavior is affected through interaction with the animals and the other robots in the mixed-society. In fact every decision is made collectively by the whole society so that a top-level observer would not see any difference between the animal society and the mixed one. In our model the animal is thus considered as a black box and the important characteristics for our robot is to fit in the mathematical model of collective interactions among individuals involved in the group.

The long-term goal of the project, after the robots are accepted by the society of animals, is to manipulate the collective response of the society by modulating the behavioral parameters of the robots. We hope then to propose guidelines towards a general methodology for performing such a control on mixed-societies.

Among the projects that are related to our work, we can mention the Robot Sheepdog (Vaughan et al. 1997) that controls a flock of ducks by moving them safely to a pre-determined position. Also, the W-M6 rat-like robot (Ishii et al. 2004) tries to create a symbiosis between creature and robot by teaching a rat to push a lever to access a food source. These projects are different from what we are investigating in that their robots are not trying to integrate into the society. Instead they are trying to affect or supervise the society in a centralized manner.

Böhlen developed a robot (Böhlen 1999) that interacts with three chickens in a cage. He manipulates some techniques to mechanically reduce chickens' anxiety towards the robot. The goal of the robot is to integrate with chickens but does not try to affect their behavior.

Our work is a part of the LEURRE European project which aims to study mixed-societies of animals and robots. This multi-disciplinary project gathers the competence of the biologists, ethologists, chemists and engineers from different European universities:
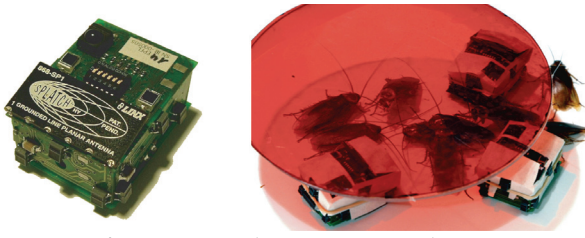
Fig. 1. Left: InsBot without cover. Right: InsBots with covers aggregated with cockroaches under a shelter (©ULB)

Université Libre de Bruxelles, Université Paul Sabatier, Université de Rennes and Ecole Polytechnique Fédérale de Lausanne. Our team is mainly involved in design, building and programming the robots and the tools needed to manage them. Behavior of robots is programmed according to the models developed by biological researches. Preliminary tests run on a mixed-society of cockroaches and robots. More experiments will be done with other animals to verify the methodology.

In this paper we focus on the behavior generation issue and describe how we implemented the aggregation behavior of cockroaches on our insect-like robot, InsBots. More details on hardware aspects are found in (Colot et al. 2004; Tâche et al. 2005).

The paper is organized as follows: The required functionality of the InsBot is summarized in the next section. Then a short review on the perception of the robot is presented. In section 4, the behavioral architecture of the robot is explained in detail. Finally the test results followed by conclusion and future works are explained.

2. Functionality of InsBot

InsBot requirements do not specify that the robot should look like a real cockroach. Instead it should:

- Behave like a real cockroach among its group.
- Get accepted by them as a congener.
- Be able to influence their collective behavior.
- Be equipped with monitoring and debug facilities

InsBot (Fig.1) is a 41x30x19 mm^3 robot. Its rigid body is composed of PCBs that allow mechanical and electronic connections at once. It has a 190 mAh Li-Po battery that allows autonomy of at least 3 hours (required for biological experiments) and 2 miniature differential-drive step-motors for locomotion. It weighs 17gr and can move up to 5cm/s. It has several sensors and communication tools:

- 12 x Infrared (IR) proximity sensors, 3 in each side. They are placed at different heights to allow discrimination of different objects. They are also used for local communication between the robots.
- 2 x Photodiodes on top, for detection of the shelters.
- 1 x linear camera (102 pixels) in front to enhance cockroach detection.
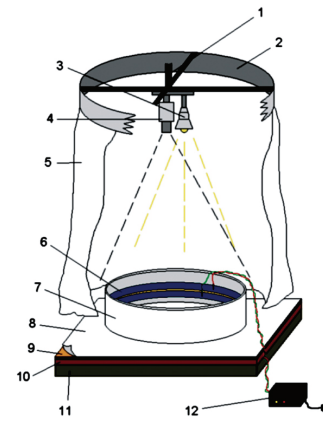- 1 x IR receiver to remotely control the robot.

Fig. 2. Experimental setup composed of neon light (3), camera (4), electrical fence (6, 12), white plastic arena (7), paper layer (8), phonic layer (9) and wooden layer (10). Shelters are absent (©ULB).

- 1 x radio transceiver (@868MHz) to communicate with an external computer. It is used mainly for debug or monitoring.
- 2 PIC18F6720 micro-processors (@16MHz) with 128K program memory, 3840 byte SRAM data memory and 1024 byte ROM.

One of the processors, called the "*Hardware Processor*", is connected to (almost all of) the hardware resources. It prepares the sensory data by noise-filtering, scaling and calibrating their values. This information is then transmitted through a 400 KHz I²C bus to the "*Behavior Processor*", which hosts the behavioral algorithms.

To enhance the acceptance of the robot into the cockroach's colony, it is covered by a paper impregnated with cockroaches' pheromone (Fig. 1, right).

3. Perception

In this section we focus on the detection algorithms that have been tuned for optimal perception of the environment.

3.1. Experimental Setup

The perception methods described in this section have been tuned for the particular setup shown in Fig.2. It is a circular white plastic arena (1m diameter, 20cm high) with an electrical fence to prevent the escape of the cockroaches. The floor is composed of anti-vibrations materials covered with a white paper. The paper is changed after each experiment. The illumination is given by 4 neon light bulbs with low IR emission to reduce the interference with IR sensors.

There are two circular suspended shelters under which the cockroaches aggregate. The shelters (called "dark" and "bright" shelter hereafter) are composed of dark plastic layers hanged at 5cm from the ground. To create different levels of shadow different number of layers are grouped.
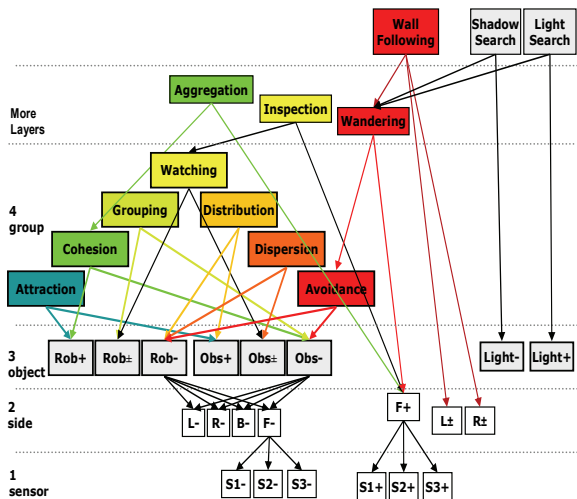
Fig. 3. An example of the behavioral architecture. Rob, Obs, L, R, B, F , +, -, and ± stand for robot, obstacle, left, right, back, and front, attraction, repulsion, and following (combination of attraction and repulsion), respectively. It is assumed that the typical robot has 3 sensors at each side, where S1, S2, S3 are located at front. Weights and some other details are not shown.

levels. The final output is the result of the cooperation among the activated behaviors.

The arbiter runs on the behavior processor. It is a finite state machine that implements aggregation in mixed-society. The remaining behaviors run on the hardware processor. We call them *reactive behaviors* in the sense that they map a stimulus directly to a response. They have faster access to sensors and actuators. The running cycle of the reactive behaviors is 10 times faster than the centralized arbiter (50 vs. 500 ms).

4.1. Reactive Behaviors

Reactive behaviors are generated by means of the potential field method (Arkin 1998; Reynold 1994). Each behavior generates a potential field. Each potential field maps the sensory space into the motor space through attraction or repulsion force (rx, ry). The final velocity of the robot corresponds to the resultant force (Rx, Ry), which is the weighted sum of those force vectors. The weights are specified empirically. The resultant force is then transformed to the speed of the wheels.

Behavior Layers

The lowest layer deals with a specific sensor. This layer provides the primitive behaviors. Each primitive behavior assign different levels of attraction or repulsion to the value of a sensor *S*, i.e. (rx, ry) = F(S). F can be constant, binary, or proportional attraction/repulsion, or combination of them.

The second layer deals with sides i.e. left, right, etc. Here a group of primitive behaviors of the first layer are combined to generate a force toward/from a direction. For instance *move-forward* behavior is achieved by assigning a constant attraction force to the front-side sensors.
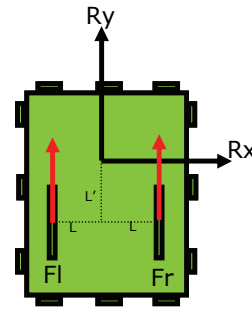

Fig. 4. Converting resultant force to speed vector

The third layer deals with objects, i.e. wall, cockroach, robot, or unknown object. For instance *obstacle-avoidance* is *left-avoidance* behavior if an obstacle is detected at left plus *right-avoidance* if an obstacle is detected at right, etc (Fig.3, layers 2 and 3).

The fourth layer deals with a group of objects. This layer composes collective behaviors like *dispersion*, *cohesion*, *watching*, etc. For instance *watching* behavior is the result of following all objects.

It is possible to add more layers and create more complex behaviors. For instance *light-search* behavior is built from *wandering* and *light-attraction*, where *wandering* is composed of *avoidance* and *move-forward*.

As a summary, a typical architecture of behaviors for a robot equipped with only IR proximity sensors is shown in Fig. 3. To fit in one figure the types of distinguishable objects with IR sensors were limited to robots, obstacles, and ambient light. Also some of the behaviors in the 3 first layers are not shown.

Behavior layers are designed carefully to maintain scalability and reusability of components both in higher levels and even on another robot. We have implemented the same architecture on Alice micro robots (Caprari 2003). It is scalable via adding more layers or modules.

Transformation of Force to Speed

Finally, the resultant force (Rx, Ry) is transformed to the speed of the wheels. Inspired by the law of physics, we can write the following relations for Fig.4:

$$\begin{cases} \sum F = 0 \Rightarrow R_y = F_L + F_R \\ \sum \tau = 0 \Rightarrow R_x.L' = (F_L - F_R).L \end{cases} \quad \overset{L'/L=k}{\Rightarrow} \quad \begin{cases} F_L = (R_y + kR_x)/2 \\ F_R = (R_y - kR_x)/2 \end{cases} \quad (1)$$

The vector (FL, FR) is a force vector that must be simulated by the wheels so that an observer perceives a force vector (Rx, Ry) affecting the movement of the robot. The force vector (FL, FR) is mapped to a feasible speed vector (VL, VR). We used k=1 in our application. Bigger k values create sharper turnings since Rx is magnified.

4.2. The Arbiter

The mathematical model of the mixed-aggregation asks for a stochastic state machine that at each time step (here 500 ms) selects the next macro-action among *move*, *turn*, and *stop* action set (Fig.5). These actions are mapped to reactive behaviors in hardware processor. If the robot is moving near periphery, the *move* action means *wall-*
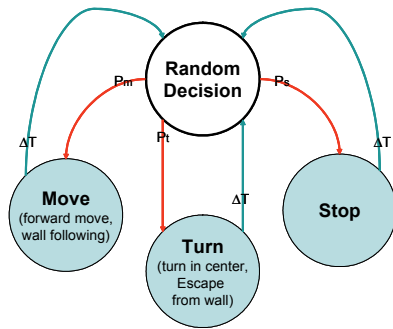
Fig. 5. The finite state machine for mixed-aggregation

following behavior and *turn* means *escaping-from-wall*. In the center of the arena they mean regular *obstacle-avoidance* and regular *turning* respectively.

Actions are selected based on a probability table. Entries of the table assign a probability to each macro-action based on the state of the robot, i.e. position, shelter type, and number of cockroaches and/or robots around. The probability table is extracted by extensive statistical data gathering on real cockroaches using visual tracking software and adapted to create similar behavior to the cockroaches.

5. Results

Based on the discussed facts, the detection algorithm combines the different responses of the top and bottom IR sensors, the local communication and the linear camera to distinguish the cockroaches from the arena walls and the robots. Here we show some test results.

5.1. Cockroach and Wall Detection

Fig.6 displays the accuracy of the detection algorithm implemented on the InsBot. These results were obtained by manually analyzing 900 different situations of a movie taken by the overhead camera and information of the wireless communication interface. For cockroach detection the distance is measured from the robot (body-border) to the closest point of the cockroach body (excluding legs and antennas).

Fig. 6 confirms that cockroaches are visible from 2.5cm, but optimal detection is only reached when they get
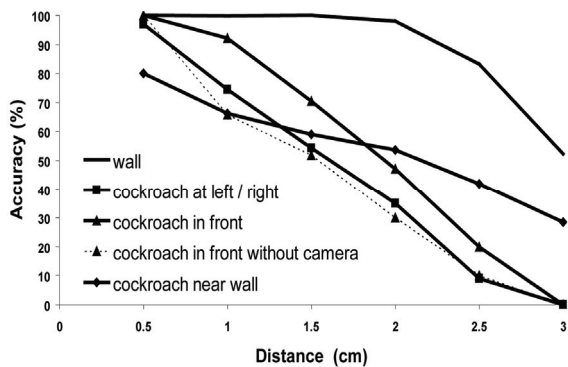

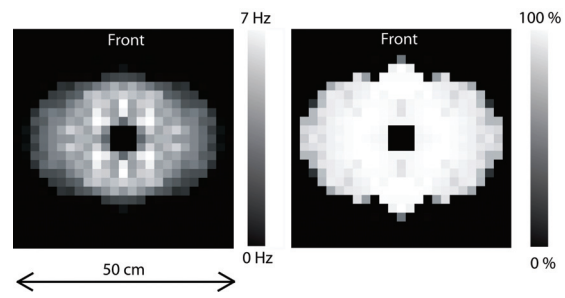Fig. 6. Cockroach/wall detection accuracy vs. robot-cockroach/wall distance

Fig. 7. Local communication between 2 robots. Left: communication rate. Right: success rate

closer to the robot. The better performance in front side is due to introducing the linear camera. The dashed curve represents the same result without the use of the linear camera. It is clear that the detection accuracy is close to detection in left/right side. This graphics also shows that the walls are detectable at further distances than the cockroaches with higher accuracy thanks to their better reflective properties.

The rather poor performance of the cockroach detection at even short distances comes from several facts: Firstly, certain parts of the cockroach's body are less visible than the others. Its head well reflects the IR signals, whereas the rear side of its body composed of thin horizontal wings reflects the IR signals upwards. Also some positions around the robot are not well covered by IR sensors. Better performance is achieved by adding the linear camera as the graph with diamond marks shows.

5.2. Robot Detection

Robot detection mainly depends on the reliability of local communication protocol which is rather difficult to characterize. Communication rate depends on the distance and the relative orientation of the robots. Fig. 7 (left side) shows communication rate between two robots. Each point represents the number of the received messages by a fixed robot from another one in different distances and orientations during a 30s test. Brighter points correspond to higher rates. Fig. 7 (right) shows the success rate i.e. the percentage of correct messages out of the received ones. The success rate is rather high (70-100%) even where the baud rate is low.

6. Conclusion

In this paper details of the perception and the behavior implementation of the miniature robot InsBot were explained. Due to the limits in the size of the robot, and the required long-time autonomy, the hardware parts and processing algorithms have been highly optimized. Different problems arisen from the imposed simplifications and limited sensory information were explained and the solutions were described.

The sensor fusion methods combined with heuristic rules that came from our knowledge about the experimental setup allowed the robots to have a good discrimination among different objects in the environment. Cockroaches

and walls are now detected using the IR proximity sensors mounted in different heights around the robot.

To have less collisions and more friendly behavior with cockroaches, a linear camera was introduced on the front side of the robot that enhanced the detection quality.

A simple local-range communication protocol through IR sensors was established for robot detection. However more investigation is necessary to completely solve the raised problems. Using local communication introduces noise on the proximity value of sensors of other surrounding robots. The noise disturbs the detection procedure and we are working on appropriate filters to reduce it.

We also explained the scalable and reusable architecture of behaviors. The layers start from some primitive low-level behaviors. The higher layers combine the behaviors in lower layers and build new behaviors. We have distributed the behavior layers between two processors, hardware and behavior processors. The hardware processor provides a library of reactive behaviors. The behavior processor provides the possibility to combine the behaviors in the library and compose more complex even deliberative behaviors.

Biological experiments showed that the robots are accepted by the colony of the cockroaches and that the mixed-society of robots and cockroaches has statistically close behavior to a pure cockroach society. The results of the experiments will be submitted to biology conferences.

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