RFID Digital Pheromones for Generating Stigmergic Behaviour to Autonomous Mobile Robots

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Abstract: During the past years, the price of RFID tags have constantly dropped, while their technical performances increased. Along with the constant interest of the researchers for the problems of swarm intelligence, this opens a wide area of applications based on the use of RFID tags as storage media for digital pheromones, aimed to mediate the communication between various agents. A simple method to define digital pheromones as data structures and to simulate the evaporation process of the natural pheromones is described. This paper describes an experiment where RFID tags storing digital pheromones, deployed in an indoor environment, are used to define a dynamic path to be followed by autonomous mobile robots. The robots sense the pheoromones in the environment by means of a dual antenna, just like ants do, and a fuzzy controller governs the left-right movement thereof. The experimental results prove that the idea of using digital pheromones to control the movement of autonomous mobile robots is entirely feasible, even with very simple robots. This opens new possibilities to improve robot to robot and human to robot interaction. The idea of enabling mobile robots with new "senses", and thus going beyond the antropomorphic paradigm in robot control, seems to be productive.

Keywords: Digital pheromones, RFID, mobile robots, fuzzy controller, stigmergy.

1. Introduction

The performances of the RFID technology are so impressive, that some researchers, like Franco Zambonelli et al. in [1] envision the possibility of spraying microcomputers in the environment to create complex, self-organizing structures. This illustrates the growing interest of the researchers for the swarm intelligence and stigmergy.

A comprehensive study [2], conducted by Tony White for the Canadian Department of National Defence, identifies hundreds of significant works in this field, and there are many others.

While the general topics of swarm intelligence and RFID are very well covered in the literature (see for example [3] and [4]), there are however relatively few studies directly describing the use of RFID tags as a means to store digital pheromones aimed to guide mobile robots for tasks like path planning, object tracking, or other cooperative tasks.

One of the most interesting works with this subject is [5], which deals with the problem of object tracking by autonomous mobile robots. This paper is particularly interesting because it offers an elegant solution to the problem of digital pheromone reinforcement/evaporation, by adding a time stamp to the data structure which defines the intensity of the pheromone. This time stamp is read by the agent that senses the pheromone, and compared with its own real time clock. Based on the "age" of the latest record, each agent computes and updates the intensity of the pheromone.

This paper describes an experiment aimed to prove that RFID tags deployed in the environment, storing digital pheromones, can easily define paths to be followed by autonomous robotic agents. Robots are controlled in a way that emulates the foraging behaviour of the social insects. This simple solution can be, in some circumstances, a valuable alternative to complex environment mapping and path planning algorithms.

Our experiment is, at this time, limited to a software simulation, but this simulation uses the kinematic model of the real robot Pioneer3-DX, from MobileRobots Inc. [6], and the whole application is written in ANSI C, so that it is easily portable to an embedded controller carried by the robot. In section 3, we include the schematic of a possible embedded structure canable to execute the tasks described here.

The paper is structured as follows:
Section 2 introduces the concept of digital pheromone and shows the RFID implementation thereof. Section 3 presents the kinematic model of the robot and suggests

a possible structure of an embedded device suitable for a phisical implementation of the experiment. In section 4 is presented the fuzzy controller that governs the movement of the robot. Section 5 presents the experimental results, while section 6 is reserved for general discussions and conclusions.

2. RFID tags and digital pheromones

Basically, RFID tags contain a nonvolatile memory (usually 0.5-8k EEPROM), whose content is accessible to a so-called "reader" via a contactless radio link. Both read and write operations are possible.

Their main advantages are that they are powered by the radio frequency wave generated by the reader, so that they do not have the battery-exhaustion problem, and the very low cost. A reader can access the information stored in a RFID tag from a distance ranging from a few centimeters (ISO14443) to up to 1m (ISO15693). See details in [4] and [7].

At a cost of only a few cents per tag, hundreds or thousands of such tags can be deployed in the environment, and a variety of agents – human or robotic – carrying appropriate readers can access the information stored in the internal memory of the tags.

Pheromones are chemical markers that most social insects (and other species) spread in the enviromnemt in order to send messages and modulate the behaviour of the other individuals of the colony. The term "pheromone" was introduced in 1959 by Karlson and Luescher in [8], and the mechanisms of inter-individual coordination between ants by means of pheromones was explained in 1959 by Pierre-Paul Grassé in [9].

Ant foraging is the most common example of pheromone-mediated intercoordination. When an ant finds food, it starts spreading pheromone on its way back to the nest, thus creating a trail that indicates the way to the food source to the other ants. Each ant using the same path reinforces the pheromene trail.

When the food source is exhausted, in the absence of reinforcement, the natural evaporation makes the trail disappear. This process of indirect coordination between agents by means of a trace left in the environment by an action, which stimulates similar subsequent actions is called stigmergy (Grassé [9]).

RFID tags seem to be the ideal solution to create digital pheromones for use with robotic agents and other applications of stigmergy. However, due to their passive nature, RFID tags cannot simulate by themselves the process of natural evaporation. Therefore, we have adpoted the following solution: the actual digital pheromone consists in a counter, which can be incremented or decremented, and a time stamp.

Every time an agent accesses the information in the tag, it reads this time stamp, compares it with its own real time clock and decides whether to increment or decrement the counter, based on the "age" of the current record. Then, it overwrites the record, storing the computed value of the counter, and a new time stamp. Figure 1, shows the data structure stored by the RFID tags, illustrating the idea of the implementation of digital pheromones.

AGENT ID	TYPE	PHEROMONE INTENSITY COUNTER	TIME STAMP

Fig. 1 Data structure defining the digital pheromone

The counter that gives the intensity of the digital pheromone is read and updated by every agent at discrete time moments T_i, according to the expression (1).

$$C_{n+1} = C_n + Qf(T_{n+1} - T_n) \qquad (1)$$

where:

$$f(t) = \begin{cases} +1 & \text{for } t < \Delta t \\ -\operatorname{int}\left(\dfrac{T_{n+1} - T_n}{\Delta t}\right) & \text{for } t > \Delta t \end{cases} \qquad (2)$$

Q is a positive constant, representing the quantum of reinforcement/evaporation of the pheromene int(x) is the integer part of x, and Δt is the evaporation constant. T_{n+1} is the current time according to the real time clock of the agent, and T_n is the time stamp of the previous record, read from the tag.

The field "Agent ID" is was included to prevent multiple successive reinforcements of the pheromone by a slow moving agent, and the field "Type" is reserved for future use, because it may be interesting in some situations to define multiple types of pheromones to induce different behaviours to the population of agents.

3. The robotic agents

Real ants sense the pheromone trail by means of two antennas, and they constantly correct their trajectory according to the differential intensity of the pheromene "smell". We propose a similar sensing structure for the robotic agents, with two laterally placed RFID readers, as shown in figure 2.

With this placement of the RFID readers, each robot will create/reinforce a double trail of digital pheromones. This improves the overall robustness of the system to the situations of broken pheromone trails.

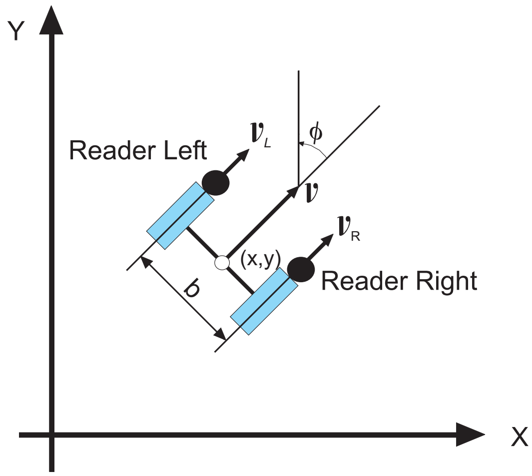

Fig. 2 Kinematic schematic of the robot

Our simulation program uses the kinematic model of the Pioneer3 robot presented in detail in our previous work [10]. With the notations in figure 2, this is sinthetically expressed in (3).

$$\begin{bmatrix} x' \\ y' \\ \phi' \end{bmatrix} = \begin{bmatrix} \frac{-\sin\phi}{2} & \frac{-\sin\phi}{2} \\ \frac{\cos\phi}{2} & \frac{\cos\phi}{2} \\ -\frac{1}{b} & \frac{1}{b} \end{bmatrix} \begin{bmatrix} v_L \\ v_R \end{bmatrix} \quad (3)$$

The actual control of the Pioneer3 robot is performed by sending commands via the serial communication interface, according to a proprietary protocol.

The command VEL2, for example, allows the control unit to specify distinct values for the speed of the left and right wheels of the robot. With this feature, a command VEL2(v_L>v_R) means right turn, VEL2(v_L<v_R) means left turn, and VEL2(v_L=v_R) means simple translation forwards.

A possible structure for the embedded control unit, suitable for this application is presented in figure 3.

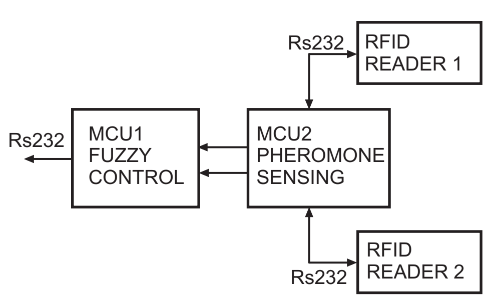

Fig. 3 Suggested structure of the embedded controller

The suggested structure of the embedded controller of the robot uses two microcontrollers: MCU1 controls the motion of the robot by means of a fuzzy controller and sends commands to the robot via the RS232 interface, while MCU2 holds the real time clock of the system and periodically sends interrogations to the RFID readers. The computed values of the intensity of the pheromone are presented to the main microcontroller as two analog signals.

4. The Fuzzy Controller

A simple fuzzy controller can solve the problem of the robot movement by processing a set of logic statements like this: "if the pheromone level sensed by the right reader is LOW, and the level of pheromone sensed by the left reader is HIGH, then v_L must be LOW and v_R must be HIGH".

Assuming that there are only two fuzzy subsets (LOW and HIGH) for the domain of variation of the pheromone level, one can choose membership functions like those depicted in figure 4.

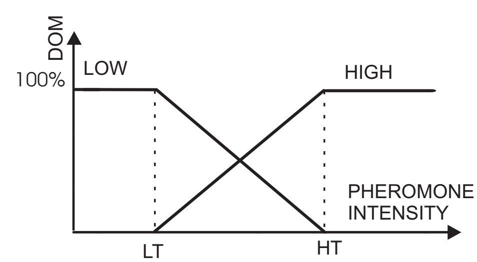

Fig. 4 Membership functions for pheromone levels

With this assumption, the whole rule base that describes the behaviour of the fuzzy controller is summarized in table 1.

Table 1 The rule base of the fuzzy controller

		RIGHT PHEROMONE LEVEL	
		LOW	HIGH
LEFT PHEROMONE LEVEL	HIGH	LL	HL
	LOW	LH	HH

The fuzzy controller generates crisp values for v_L and v_R by processing the fuzzy rule base, according to (4).

$$v_{OUT} = \frac{\sum_{i=1}^{K} z_i S_i}{\sum_{i=1}^{K} z_i} \qquad (4)$$

where:

$$zi = \min(PIL_i, PIR_i) \qquad (5)$$

Si is the corresponding singleton value of the fuzzy output, and K is the total number of rules in the rule base. PIL_i, PIR_i are the degrees of membership of PIL(t) and PIR(t) to the domain corresponding to the cell i. PIL(t) and PIR(t) are the pheromone intensity functions for the left and right reader respectively. (see [10] and [11] for details on the implementation of the fuzzy controller).

5. Experimental Results

General assumptions

a. The RFID tags are uniformly ditributed in the environment, at a distance so that one and only one tag can be accessed at any moment by each of the readers.
b. An initial pheromone trail is marked on the pheromone array, serving as target path for the robots (see figure 5)

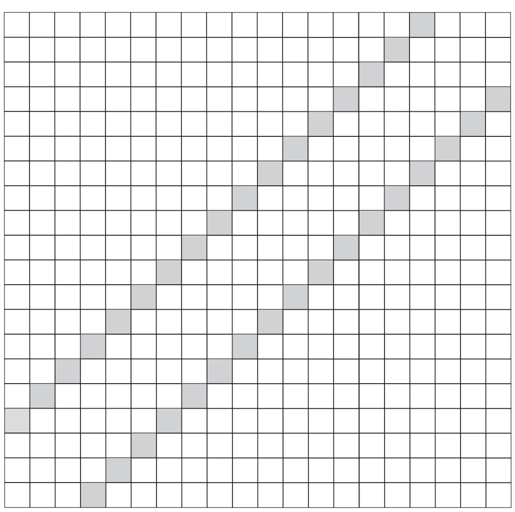

Fig. 5 Initial conditions of the experiment

Note that in figure 5 and subsequent each cell of the array contains a RFID tag. White cell have the concentration of pheromone equal to zero. Gray cell have higher pheromone concentrations – the darker shades indicate higher concentrations.

Figure 6 depicts the trajectory of the first robot crossing the pheromone area, by showing the successive positions of the axis connecting the two RFID readers as dark segments.

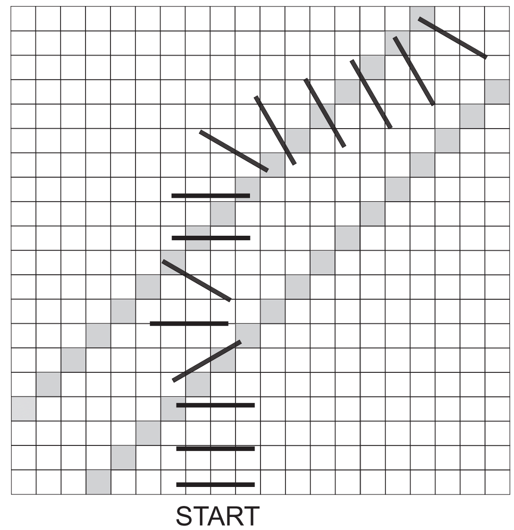

Fig. 6 Trajectory of the first robot

After having 50 robots crossing the pheromone area, and considering the effect of evaporation, the pheromone trail looks like the image in figure 7.

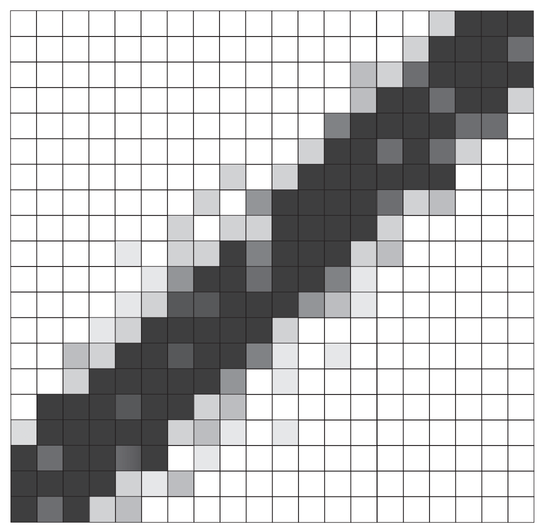

Fig. 7 Pheromone trail after 50 robots

And the trajectory of a robot through this environment is much closer to a straight line (see figure 8).

Note that better performances can be easily obtained by improving the fuzzy controller, e.g. by choosing three fuzzy subsets (Low, Medium, High) for the domain of variation of the concentration of pheromone. Also, in some applications, it is possible to abandon the strict stigmergy scenario and to have a human operator define more complex initial conditions for the experiment by creating thicker pheromone trails.

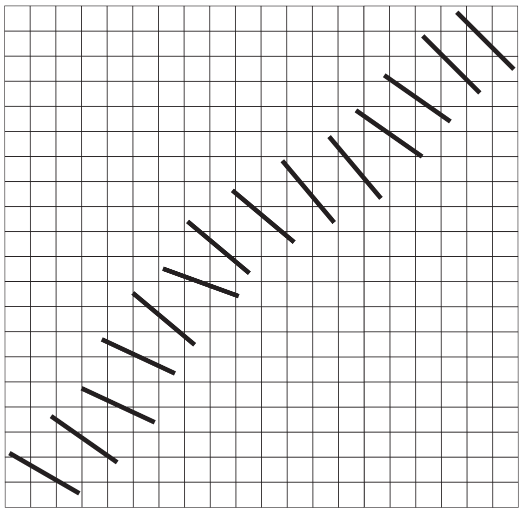

Fig. 8 Trajectory with higher pheromone density

6. Discussion

This simple experiment clearly demonstrates that RFID based digital pheromones can be easily used to define dynamic paths for guiding mobile robots. In some situations, this can be an efficient and cost effective alternative to complex environment mapping and path planning algorithms. It is part of our research effort aimed to develop low cost embedded solutions for robot control.

The main weak point of this experiment is that it is limited to a software simulation, but we believe it can be easily reproduced with embedded hardware.

Further research is required to diversify the robot-environment interaction with new scenarios (e.g. “danger ahead – don’t cross this line”) or to improve human - robot interaction.

Since the memory capacity of the commercially available RFID tags is now much higher than the few bytes required by the digital pheromone used in this experiment, it would be possible to use this resource either by defining different “types” of pheromones, or by storing more complex mapping information about the environment.

This experiment only simulates the foraging behaviour of the ants in a robotic context, but there are much more aspects concerning swarm intelligence that can be explored with this simple experimental setup.

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