Indirect cooperation between mobile robots through an active environment

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Abstract. In this work we study indirect robots' perception and cooperation by enabling a way of communication through the environment. It consists in paving the floor with communicating tiles, each one beeing connected to its neighbors and implementing an autonomous process. This regular network constitutes a grid world in which robots can read and write information. So bio-inspired models using marking of the environment, such as digital pheromones, can be implemented with real robots. We present experimental results showing the interest of the approach in multi-robot problems, by using message diffusion and pheromone evaporation processes.

Key words: digital pheromones, autonomous and collective robots, environment based models

1 Introduction

In this paper we aim at using the physical environment as it is done by living systems, i.e. as a medium of indirect communication and cooperation. This approach is well known in social insects self-organisation, where agents mark their environment for them and others [1, 12].

Interactions between robots and their environment has been considered recently through the deployment of sensors [7, 10]. It consists in using technologies provided by ambiant intelligence to implement multiagent models or means of communication for robots.

For this purpose, we propose to pave indoor floors with communicating tiles. A tile is defined to ensure communication with its adjacent neighbors, and to store simple information that can be read/write by an agent present on the tile. As a consequence tiles can be exploited to implement bio-inspired model and any algorithm computing by diffusion through the environment. In this paper we consider real robots interacting with the tiles, and show through experiments that bio-inspired MAS model could be implemented with autonomous robots.

The paper is organised as follows. Section 2 discusses existing work concerning the design of active environment.Then in Section 3 we abstract the proposed tile model. Section 4 presents the experimental device defining the robots and the active environment. In Section 5 we show a first experience allowing robots to mark digital pheromones in the environment, then Section 3 presents a model for message diffusion through the tiles and shows experimental results. Finally we conclude the paper by discussing perspectives of the work.

2 Related work

Transmitting information through the environment is a common approach in reactive multi-agents systems. We can quote digital pheromone techniques [12], potential field computation and cellular automata based environment [6]. Note that some deliberative agent models consider a discrete representation of the environment, to compute tasks such as path planning or policy learning (Markov Decision Process, etc.). So, designing the environment as a grid can provide a flexible and smart way to deploy or extend these algorithms.

T. Watanabe [8] and G. Theraulaz [3] teams have proposed devices allowing to display digital pheromones on the ground and over robots by using a projector situated above the system. This kind of centralised advice allow to implement passive environments on small experimental area. It does not allow to study active marking as it is the case with numerous bio-inspired models (e.g. models studied in Sections 5 and 6).

Recently, several models using passive RFID tags have been proposed to manage artificial pheromones [5] and tasks of a robot such as navigation [11] and localization [9]. We note from these works that tags are placed at regular distance (i.e. on a lattice) and over or inside the floor. This organization as a grid allows to define robots behavior exploiting this invisible structure.

Finally, this review led us to propose an original model dedicated to the implementation of active environments. It consists in a regular network of active nodes, which are embedded in the physical floor. These nodes are simple processors able to execute the Intelligent Tile model we introduced and simply simulated in [13]. We focus in this paper on experimenting the approach with real robots and defining a new algorithm for message diffusion.

3 Tiles Model

Tiles arrangement As in most discrete models, we set tiles identical and with a squared topology. Their size must be adapted to support just one person or one robot at once. They have to be positioned regularly as a grid over the floor. In practice, the interaction between robots and the tiles can be physical (sensors, contact) or wireless (radio, light, etc.).

We consider that neighbouring tiles are only known and addressed through their relative direction to the current tile: $\{N, S, E, W\} = \mathcal{C}$ (in a 4-connexity model).

Tile's functionning A tile is an autonomous, reactive and communicating entity. It can communicate with a carried robot, and with its neighboring connected tiles, up to four, see Fig. 1a. A tile holds:

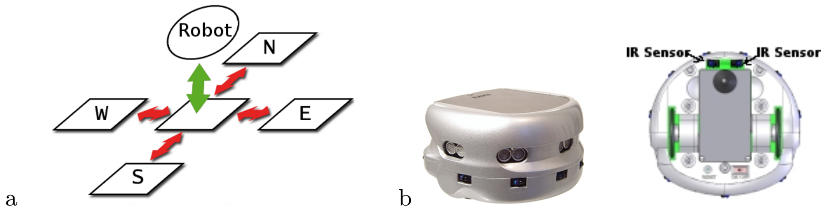


Fig. 1. a. Possible communications of a tile, b. Khepera III robot

- a (limited) memory to store information,
- a main process answering to requests from its neighbouring tiles or a robot,
- a secondary process which allows to manage the activity of the environment.

The tile's main process routines do not use blocking operations, as a tile must be able to answer agent's requests in real time. The main process is designed to store received messages in a FIFO queue and to treat them as they come.

To add pro-activity to the tiles we define a secondary process. It can manage recurrent activity of the environment, such as a pheromone evaporation process at a fixed frequency.

4 Experimental device

4.1 Khepera III robots

Khepera III are autonomous robots, embedded with an Intel processor (XSCALE 400MHz) and a Linux OS. They can communicate with a Wifi card. They are fitted with infrared sensors and an odometry measure. Figure 1b presents the robot and its sensors.

For now we limit robots moving to motion from a tile center to another. It corresponds to a classic displacement in a discrete MAS model. We plan to extend this choice to free motions over the tiles. In any case, a single assumption must be kept: a robot is connected to only one tile at a time. This assumption is easy to ensure with simple motions between tiles centers. Each time a robot crosses/detects a tile junction, it sends a message to the server to cause the connexion changing.

We consider that each robot has **no global positionning, nor coordinate information**. They only start from the center of a tile while being directed to the south.

Any moving consists in (1) changing the direction (N,S,E,W) (2) going forward up to a constant distance. Such an approach does not need any external control, robot's odometry is sufficient to perform it. However, odometry errors cumulates and robots can quickly stem from tile centers. Then we use tile's border detection to manage odometry correction (not detailed in this paper).

4.2 Environment

We defined a representation of the tiles on the floor to allow a physical perception of a the tiles crossing. Communications between robots and tiles is done through a Wifi communication between robots and the emulator of tiles.

The concurent acces to a tile by several robots is managed by messages between robots and the target tile. The target tile grants only one access at a time, by giving the access to the first received reservation message. Details of this mechanisms are given in [13]. It is important to note that it will be systematicaly executed when robots will decide to go to a new tile.

5 Digital Pheromone experimentation

In this section we aim at evaluating a pheromone based model with robots marking on the tiles. For this purpose, we consider a simple ant-patrolling algorithm, called EVAP, using pheromone dropping and evaporation [4].

Algorithm 1: Behavior of an EVAP agent in a grid

while *true* **do**
  Find cell x of $Neighborhood$ with the lowest value
  (in case of a tie, make some random choice)
  Move to cell x
  $Q_{pheromone}(x) \leftarrow Q_{Max}$

Algorithm 2: EVAP's Environment Algorithm

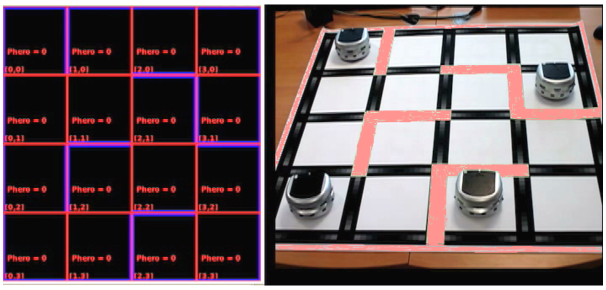
foreach *cell* $v \in$ *Environment* **do**
  $Q_{pheromone}(v) \leftarrow \rho.Q_{pheromone}(v)$

The environment is in charge of the evaporation process (see Algorithm 2). It consists in reducing pheromone quantity at a given frequency ($\rho \in]0,1[$ is the rate of evaporation). Agents' behavior is defined by Algorithm 1. According to their local perception they perform a pheromone gradient descent and drop a fixed quantity Q_{max} of pheromones — marking their visit — .

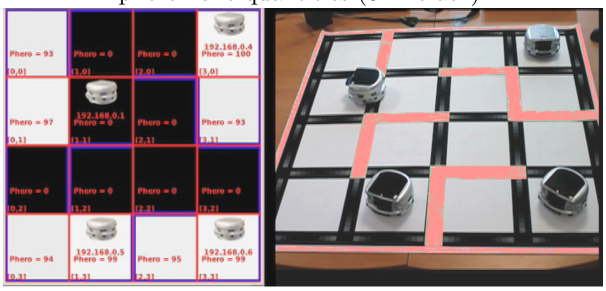
As the environment evaporates the pheromone, the remaining quantity in a cell represents the elapsed time since the last visit. So the agent behavior is defined by moving locally to the cell that has not been visited from the longest time (see details and performances of the patrol in [2, 4]).

5.1 Results

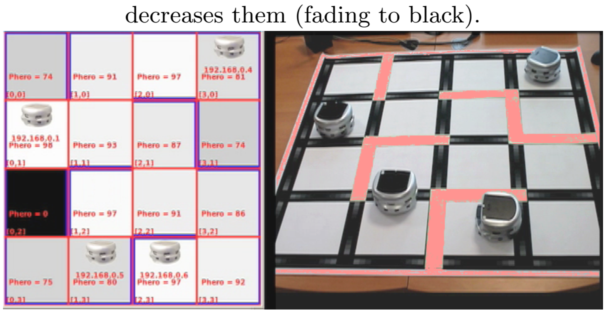
We defined an experimental setting of a 4x4 tiles environment, and disconnected some neighboring tiles to define walls in order to form a maze. We placed four robots to experiment the model. $Q_{max} = 100$, $\rho = 0.99$, and evaporation is computed every $1s$.



a. Snapshot of the initial state (4 robots) and the emulator interface, showing pheromone quantities (0 = black).



b. Snapshot at 7s, robots drop quantity 100 of pheromone (white), then evaporation decreases them (fading to black).



c. Snapshot at 15s, it remains one non visited cell, the robot on left has started to go on it.

Fig. 2. EVAP execution with 4 robots and 16 interconnected Tiles

Figure 2 presents three snapshots from a movie of the experiment, showing on left the emulator interface and on right the current state of the robots. In the real environment, walls i.e. disconnected tiles are represented in red color. In the emulator interface tiles are filled with a color representing the pheromone quantity (from 0 in black to 100 in white), values are also written. Walls are represented in blue. The movie of this experiment can be seen at *http://tiles.domire.net* (evap.mov).

First snapshot shows the initial state of the environment, no pheromones have been dropped. Second snapshot show the state of the system when robots finished to visit two cells and start to go on a third. They dropped pheromones in visited cells, which begin to evaporate. At the third snapshot, agents have nearly explored the environment. One can see the pheromone field as a color shading. Its evolution is computed regardless of the robots processes. It is possible to add or remove a robot without having to stop the other robots or the evaporation process.

We let the experiment to continue for minutes, we observed that robots patrolled all the environment while being well distributed. We obtained a global behavior quite similar to the theoretical/simulated EVAP model [2]. However, there exists differences between the robotic and the computer executions. Indeed, in the theoretical or simulated case, agent transitions from a cell to another have equal duration. With robots, changing its direction can take different time following the angle to reach, and robots can have slim speed differences. As a consequence it can prevent the system to converge to a stable cyclic behavior as in the theoretical model [4].

6 Signal diffusion experimentation

In this section we define a distributed algorithm in order to diffuse signals/messages through the tiles. We conduced experiments with robots using such a diffusion to deal with the dynamic path-planning problem.

6.1 Diffusion algorithm

Diffusion relies on the local connexion between tiles. We just add a propagation mechanism that exploits the tiles reactivity. The idea is to define a specific diffusion message that must be relayed by the tiles. This specific message is defined by 3 arguments: $spread\_This(message, nb_{hops}, [path])$, where

- *message* is the contents to communicate (a string),
- nb_{hops} is the number of hops (between 2 tiles) still possible for the message, it is initialized to the maximum expected distance of diffusion,
- *path* (optional) stores the path followed by the message since its origin, as a string composed of N,S,E,W letters.

To start a diffusion the source (tile or robot) sends a *spread_This* message to its 4 neighborings.

When receiving such a message, a tile executes the following algorithm:

A. Before to propagate the message, the *path* argument is extended by adding the direction it comes (N, S, E or W).

B. Each tile receiving a message propagates it to its neighbours (except to the tile which relayed the message) **if**

1. nb_{hops} is non null and the contents is new
2. for a known message, if nb_{hops} is greater (giving a shortest path to the origin)
3. for a known message, if the message is too old (see below).

Details of B.1 : As a same message will generally arrive several times from different paths, see figure 3.a, it is necessary to propagate only once. It requires that each tile stores the propagated messages in order to compare their contents to new ones. As a consequence, stored messages must be removed after a delay (or a memory limit).

Details of B.3 : If the topology of the grid changes, it is necessary to ignore old messages to update their paths. So we set a delay, very short, to update tiles' information in real time.

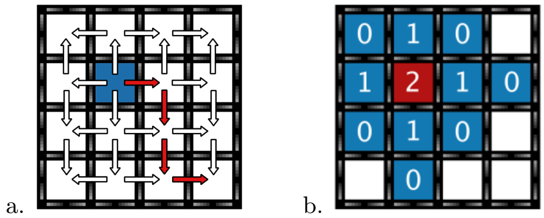


Fig. 3. Principle of message diffusion

Figures 3.b illustrates the diffusion mechanism for a message with an initial nb_{hops} set to 2. Only nb_{hops} values are marked in cells.

6.2 Experiment : Calling for help in a maze

We consider a robot that want to recruit all others situated under a certain distance (30 hops). This robot will diffuse regularly, at frequency f_e, a "help" signal through the tiles. Other robots will receive this message from their current tile. Then they will use the *path* argument to go to the source. They only have to follow the direction given by the *path*, reading it from the end.

We present an experiment involving one static robot diffusing a "help" message and five mobile robots following the messages' paths (see intial state in fig. 4.a). The diffusion is performed with a f_e frequency of $10Htz$. Update of values (delay for old messages) is set to 0.5s.

The different steps of the resolution are presented with snapshots of a movie recorded during the experiment. The movie can be seen at *http://tiles.domire.net* (diffusion.avi).

Figure 4.a shows the begining of the experiment, when the calling robot (or source) diffuses the 'help' message. Values of nb_{hops} received by the tiles are written in the tiles (the emulator interface allows to see these values but their snapshots are to big to be shown here).

One can see that these values could be used by robots to find the shortest path to the source. Robots do not need to ask these values to the tiles as the *path* argument of each *spread_This* message holds the shortest path. Figure 4.b

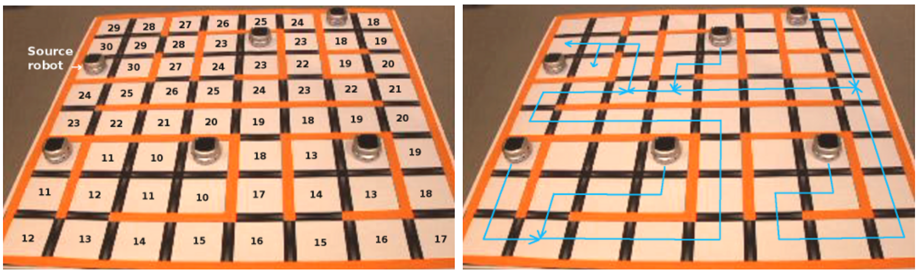


Fig. 4. a. Initial robots position, in each tile the value of nb_{hops} from the received message is written showing the first diffusion, b. *path* argument received by each robot is drawn.

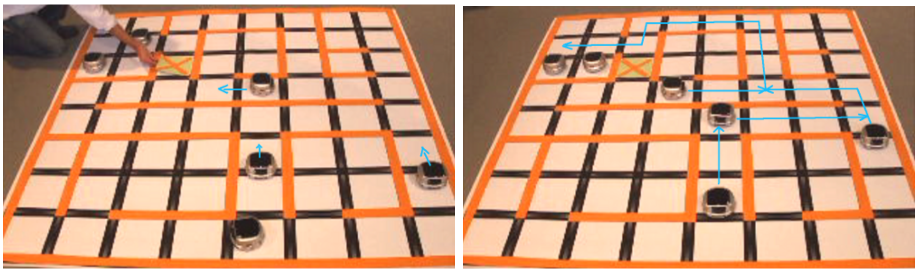


Fig. 5. a. Addition of an obstacle (tile blocked up), b. Dynamic replaning obtained from the last diffusion and updating

illustrates the *path* argument received by each tile/robot. Robots starts to follow them.

After a while, an obstacle is added on a tile (see the cross on figure 5.a), making the concerned tile to be switch off. As a consequence, after un short delay (0.5 s), all tiles, and then robots, have updated their 'help' message where the *path* argument takes into account the new maze topology. So they change their route to the source (see figure 5.b).

7 Conclusion and future works

In this paper we tackled the problem of implementing active environments in the real world and to allow their use with autonomous robots. A solution relying on the intelligent tiles model, that supposes the floor is paved with interconnected nodes, has been investigated.

Robots can communicate with their current tile through a wireless communication with a tiles emulator. This plateform allows to experiment the proposed model, by verifying its main assumptions: robots and tiles are independant processes (and asynchronous), they use only local tile communications and have no information about their global positioning or coordinates (which are not required by the system).

Experiments with two models, relying on digital pheromone and message diffusion, have shown the robotics feasibility and the robustness of the proposed approach. Now, we need to continue to evaluate the model while to prepare the design of a first electronic prototype of the tiles.

The system is really decentralized and open. As a consequence it has the property of scalability, which is necessary to envisage a deployment in large indoor environments (factory, hospital, nuclear plants, home, etc.) and with numerous mobile robots or humans. Indeed we plan to equip people with a PDA-like device to interact with tiles. Applications to help people in navigating or communicating seems important.

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