Physical Deployment of Digital Pheromones Through RFID Technology

Marco Mamei, Franco Zambonelli
Dipartimento di Scienze e Metodi dell'Ingegneria
Università di Modena e Reggio Emilia
Via Allegri 13 – Reggio Emilia– ITALY
mamei.marco@unimore.it, franco.zambonelli@unimo.it

ABSTRACT
We describe and evaluate a system for enforcing stigmergic interactions in the physical world by deploying pheromones in RFID tags.

Categories and Subject Descriptors
I.2.11 [**Artificial Intelligence**]: Multiagent Systems; C.2.4 [**Computer-Communication Systems**]: Distributed Systems; C.3 [**Special Purpose and Application-based Systems**]: Smartcards.

General Terms
Algorithms, Design, Experimentation

1. INTRODUCTION
Stigmergic interaction, exhibited by social insects to coordinate their activities, has recently inspired a vast number of computer-science applications. In these works, application components (i.e. agents) interact by leaving and sensing artificial pheromones (i.e. markers) in a virtual environment. Such pheromones can encode and describe application-specific information to be used to achieve specific tasks.

From a general perspective, the strength of stigmergy interaction is rooted on two key points: *(i)* it completely decouples agent interactions (that are mediated by pheromones) making it suitable in open and dynamic scenarios where agents do not know each other in advance and can come and go at any time; *(ii)* it naturally supports application-specific context awareness, in that pheromones provide agents with an application-specific representation of their operational environment (e.g. in ant-foraging, pheromones provide a representation of the environment in terms of paths leading to food sources).

Despite these promises, the number of actually implemented systems exploiting pheromones for coordinating activities of distributed agents situated in a physical environment has been very limited so far. The great majority of the proposals have been implemented in simulated environments, only few of them have been concretely implemented by deploying pheromones in shared virtual data spaces, and very few realize pheromones by means of ad-hoc physical markers (special ink, metal dust, water on brown-kraft-paper, etc.). All these approaches are better described and properly referenced in the extended version of this paper [1]. In our opinion, none of them propose valid solutions to actually spread pheromones in real-world everyday environments.

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The reason for these missing implementations is rather natural: discarding centralized – not scalable – solutions, and still-to-come and costly sensor networks, it is not easy to find a suitable distributed infrastructure on which to store digital pheromones.

Inspired by this challenge, we propose a pervasive computing version of pheromone deployment based on RFID tags. The key idea of our approach is to exploit the fact that RFID tags can be written on-the-fly by suitable wireless devices, i.e., RFID readers (that are indeed also writers). On this basis, RFID readers, carried by a human or embedded in a robotic agent, could deploy pheromone trails across the environment, by storing the pheromone values in the RFID tags located there, as the user/robot roams across the environment. Relying on such an implementation, a wide range of application scenarios based on pheromone interaction can be realized ranging from multi-robot coordination to monitoring of human activities.

2. PHEROMONES IN RFID TAGS

2.1 RFID Technology
Advances in miniaturization and manufacturing have yielded postage-stamp-sized radio transceivers, called Radio Frequency Identification (RFID) tags, that can be attached unobtrusively to objects as small as a toothbrush. The tags are wireless and battery free. Each tag is marked with a unique identifier and provided with a tiny memory, up to some KB for advanced models, allowing to store data (our test-bed implementation comprise tags with a storage capacity of 512bit). Tags can be purchased off the shelf, cost roughly €0.20 each and can withstand day-to-day use for years (being battery-free, there have no power-exhaustion problems).

Suitable devices, called RFID readers, can access RFID tags by radio, for read and for write operations. The tags respond or store data accordingly using power scavenged from the signal coming from the RFID reader. RFID readers divide into short- and long-range depending on the distance within which they can access RFID tags. Such distance may vary from few centimeters up to several meters.

Given this technology, our scenario requires that a number of places in the environment (e.g. doors, corridors, etc.) or unlikely-to-be-moved objects (e.g. beds, washing machines, etc.) are tagged with RFID tags. Tagging a place or an object involves sticking an

RFID tag on it, and making a database entry mapping the tag ID to a name. In the following, we refer to these tags as *location-tags*.

It is important to remark that, in the near future, the scenario of having pheromones spread everywhere will come for free. Everyday objects will all be tagged with RFID directly from the factory for a number of other applications (e.g. stock control, inventory, etc), the same as happens today with barcodes.

2.2 Application Example

Let us shortly describe a concrete application to test our approach. It consists in an agent-based application to easily find everyday objects (glasses, keys, etc.) forgot somewhere in our homes. The application allows everyday objects to leave virtual pheromone trails across our homes to be easily found afterwards. Overall, the application work as follows:

- The objects involved in the application need to be tagged. For sake of clarity, we will refer to these tags as *object-tags* to distinguish them from the *location-tags* identifying places and spread in the environment.
- Agents (either robotic or humans) are provided with a handheld computing device, connected to a RFID reader, and running an agent-based application.
- The agent-based application can detect, via the RFID reader, *object-tags* carried by the user. In addition, it can write the object ID into the available memory of near *location-tags*.
- This allows the object to leave a pheromone trail across the *location-tags* in the environment.
- When looking for an object, a user can instruct the agent to read in-range *location-tags* searching the object's pheromone in their memory. If such pheromone is found, the user can follow it to reach the object current location.
- Once the object has been reached, if it moves with the user (i.e. the user grabbed it), the agent automatically starts spreading again the object associated pheromone, to keep consistency with the new object location.
- This application naturally suits a multi-users scenario where an user (or a robot), looking for an object moved by another user, can suddenly cross the pheromone trail the object left while moved by the other user.

Clearly, this description is oversimplified and overlooks lot of important details, to be found in the full version of this paper.

3 EVALUATION

3.1 Application Deployment

The actual implementation of our approach consists in tagging places and objects within our department. Overall, we tagged 100 locations within the building (doors, hallways, corridors, desks, etc.) and 50 objects (books, laptops, cd-cases, etc.). Locations have been tagged with ISO15693 RFID tags, each with a storage capacity of 512 bits (each tag contains 30 pheromone slots, 1 byte each). Objects have been tagged with ISO14443B RFID tags, each with a storage capacity of 176 bits (each tag contains only the object ID).

A wirelessly accessible server holds a database with the associations between tag IDs and places' and objects' description (i.e. ID 001 = Prof. Smith's office door). In addition, we set up three HP IPAQ 36xx running Familiar Linux 0.72, J2ME (CVM – Personal Profile). Each IPAQ is provided with a WLAN card and a M21xH RFID reader. The IPAQ can connect, via WLAN, to the database server to resolve the tag ID into the associated description. Each IPAQ runs the described agent-based application. Finally, a mobile robot searching for objects autonomously, has been realized by installing one of our wireless IPAQ (connected to a RFID reader) on a Lego Mindstorms robot. The IPAQ runs an application controlling the RFID reader and the robot movement. This latter point has been realized by connecting, via IR, the IPAQ to the robot CPU (the RCX Lego brick) enabling the IPAQ to access robot's sensors and actuators.

To test on the large scale, we also realized a Java-based simulation of the above scenario, to test on the large scale. The simulation is based on a random graph of places (each associated to a *location-tag*), and on a number of objects (each associated to an *object-tag*) randomly deployed in the locations-graph. Each simulated tag has been simply realized by an array of integer values. A number of simulated agents wander randomly across the locations-graph collecting objects, releasing objects, and spreading pheromones accordingly. At the same time, other agents look for objects in the environment eventually exploiting pheromone trails previously laid down by other agents.

3.2 Simulation Experiments

For the sake of comparison, we compared 2 search algorithms: in *random-search*, an agent randomly explores the locations-graph disregarding pheromones. In *follow pheromone*, the agent perceives pheromones in a local RFID tag together with the directions in which they increase (by perceiving nearby tags). The aggregated results of the simulation experiments are in Table 1, and relate to a scenario of 2500 tagged places, with 500 objects, and 10 agents populating this environment. The Table reports the number of places visited on average (i.e. number of *location-tags* perceived) before finding an object, for the two different search methods. The results are averaged over 100 simulated experiments and verified – on a smaller scale – on the real implementation.

It is easy to see how our *follow pheromone* method is very effective: the number of places to visit before reaching an object is dramatically reduced if compared to *random search* (where about half of the 2500 places are to be visited).

	Random Search	Follow Pheromone
Number of Visited Places Before Finding an Object	**1230**	**334**

Table 1. Number of places visited to finding a specific object, for the two search methods

4 REFERENCES

An expanded version of this paper [1], there included a proper discussion of related work and all relevant references, can be found at www.agentgroup.unimore.it

[1] M. Mamei, F. Zambonelli, "Spreading Pheromones in Everyday Environments via RFID Technology", 2nd IEEE Symposium on Swarm Intelligence, IEEE CS Press, June 2005.