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A FRAMEWORK FOR CREATING MIXED ROBOT FORMATIONS WITH PHYSICAL AND VIRTUAL AGENTS

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Abstract: This paper proposes a solution for creating mixed formations with virtual and physical agents and describes a framework for studying stigmergy in such formations. The central element of the solution is the concept of virtual pheromones, defined as engrams created by the agents not in the environment, but in a map of the environment, stored by a pheromone server. This map acts like a shared memory area for all the agents, embedding information usable for defining paths and actions, and is dynamically updated by the server, which is in permanent communication with the agents, through a radio link. A model of the virtual pheromone is proposed, describing the spatial diffusion, and evaporation. Possible uses of this concept for controlling the real-time motion of the agents are explored.
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Keywords: Virtual pheromones, pheromone server, spatial diffusion, controlling the real-time motion.

1. INTRODUCTION

Afterwards, a great number of scientific papers proposed various methods for creating *artificial pheromones*. Some researchers propose solutions based on spreading chemicals in the environment, just like ants do. (Purnamadjaja 2007, and Genovese 1992). Others (Payton 2005) use short-range infrared transceivers to relay messages between mobile robots, while others (Mamei 2005, Susnea 2008) propose the use of RFID tags, deployed in the environment, to store some data structures, interpreted as *digital pheromones*.

The term *"virtual pheromone"* was mainly used in connection with software agents (Szumel 2006).

In all of the above implementations, artificial pheromones are psysical, chemical or informational entities *distributed* in the environment, thus having the benefit of the intrinsec robustness of any decentralized multi-agent system.This paper presents a centralized approach on using artificial pheromones, wherein virtual pheromones are engrams created by the agents *not in the environment, but in a map of the environment, located in a pheromone server*.

In this approach, the agents use their own localization system to periodically report their position to the pheromone server, via a radio communication link. When the pheromone server receives a data packet containing the current position of an agent, it locates the agent on the internal map, then computes the pheromone concentrations for that particular position, and sends back to the client a response packet containing this data. Thereafter, the agent acts as if it had its own differential pheromone sensors, and adjusts its position so that it gets as close as possible to the pheromone trail. The system can operate with fixed, predefined paths embedded in the pheromone map, or, when multiple agents are involved, it can modify the pheromone concentrations as if the agents would leave pheromone trails on their way, just like real insects do. In this last case, the pheromone paths stored by the server dynamically change as agents move through the environment, creating a realistic emulation of a natural swarm.

Beyond this introduction, this paper is structured as follows:

- Section 2 proposes a model of the virtual pheromones
- Section 3 contains a description of an experiment where physical agents follow a virtual leader by means of a pheromone server.
- Section 4 presents some experimental results, and
- Section 5 is reserved for discussion and future work.

2. A MODEL OF THE VIRTUAL PHEROMONES

Natural pheromones are chemical substances released in the environment by some insects and other animals, in order to influence the behavior, and sometimes even the physiology of other members of the same species.

Ant foraging is the most common example of pheromone-based interaction. When an ant finds a food source, it starts spreading pheromone on its way back to the nest, leaving a trail that indicates the path to the food to the other ants. Every ant that senses the pheromone trail tends to follow the existing path and reinforces the pheromone trail by spreading additional pheromone.

On the other hand, the pheromone is subject to evaporation, and, when the food source is exhausted, in the absence of reinforcement, the trail disappears. This indirect coordination between agents by means of modifying the environment by an action, which stimulates similar subsequent actions, in a positive feedback process, is called *stigmergy* (Grassé 1959).

Any model of the natural pheromones should address at least the following aspects:

- Spatial diffusion.

Pheromone diffusion gradients provide valuable navigational information and also encode useful information about obstacles that obstruct pheromone propagation. Normally, insects sense the pheromone by means of two movable antennas located on the sides of the head. This allows the insect to sense the spatial gradients of the distribution of the pheromone.

- Superposition of the effects of multiple pheromone sources.

The overall intensity of the pheromone, sensed at a given point, is a result of the superposition of the effects of multiple pheromone sources. Figure 1 illustrates this mechanism.

- Evaporation.

The intensity of the pheromone effect decrease with time. This process reduces obsolete or irrelevant information, and also provides the colony with a mechanism to find the shortest path to the food. If two or more paths of different lengths are available between the nest and the food source, longer paths require more time for the ants to reach their target. The process of evaporation reduces the intensity of the pheromone on longer paths, and therefore more ants tend to choose the shorter path. Eventually, the shortest path is used by most of the ants, and longer paths disappear. See figure 2 for an illustration of this process, as explained in the so-called double bridge experiment (Deneubourg 1990).

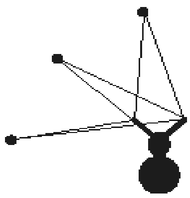

Fig. 1 An illustration of the spatial diffusion and superposition.

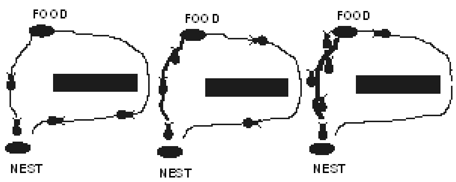

Fig. 2 The double bridge experiment

The spatial diffusion can be modeled with (1):

$$p(x)=\begin{cases} p_0\left(1-\dfrac{x}{\sigma}\right) & 0<x<\sigma \\ 0 & x\geq\sigma \end{cases} \tag{1}$$

where $p(x)$ is the pheromone intensity sensed at the distance x from the source, and σ is the maximum distance at which the pheromone source p_0 is detectable.

The evaporation can also be described by a simple, linear function of time (2).

$$p(t)=p_0\left(1-\frac{t}{\tau}\right) \tag{2}$$

By combining (1) and (2), the pheromone intensity along the x axis can be described by the equation (3)

$$\overline{p}(x,t)=\begin{cases} p_0\bar{\imath}\left(1-\dfrac{x}{\sigma}\right)\left(1-\dfrac{t}{\tau}\right) & 0<x<\sigma \\ 0 & x\geq\sigma \end{cases} \tag{3}$$

where $\bar{\imath}$ is the unit vector of the x axis.

Using (3), the effect of N pheromone sources, located at the distances d_1, d_2, ... d_N from a point R (x_0,y_0,θ_0) can be expressed by:

$$\overline{P}=\sum_{k=1}^{N}p_0\bar{\imath}_k\left(1-\frac{d_k}{\sigma}\right)\left(1-\frac{t}{\tau}\right) \tag{4}$$

The equation (4) is the model of the pheromones, we have used in our experiments.

The resulting intensity of the pheromones can be sensed with two "virtual antennas", located laterally on each side of the agent, at the distance b from each other.

The coordinates of the right (R) and left (L) antennas are given by (5).

$$\begin{aligned} x_R &= x_0-\frac{b}{2}\sin\theta_0 \\ y_R &= y_0-\frac{b}{2}\cos\theta_0 \\ x_L &= x_0+\frac{b}{2}\sin\theta_0 \\ y_L &= y_0+\frac{b}{2}\cos\theta_0 \end{aligned} \tag{5}$$

Knowing the position (x_0,y_0,θ_0) of an agent, and the distribution of pheromone sources, the server can compute with (4) and (5) the intensities of the pheromone P_L, P_R at the level of each antenna. Since the virtual antennas are assumed to be located symmetrically along the axis of the agent, the difference $(P_L\text{-}P_R)$ can be used as an expression of the positioning error with respect to the pheromone trail.

Once the values of P_L, and P_R are reported back to the agent, this acts as if it had its own differential pheromone sensing system.

Note that all the calculations are executed by the server. This greatly reduces the computational load at the level of the control system of the agent, which may lead to drastic cost reduction thereof.

3. AN EXPERIMENT FOR MIXING PHYSICAL AND VIRTUAL AGENTS

3.1 *Objective*

The main objective of the experiment described in this section is to demonstrate the feasibility of the idea of creating cooperative formations including physical and virtual agents.

The simplest cooperative behavior – “follow the leader” - was selected, with the difference that the leader was a simulated, virtual robot, (simulated with MobileSim) while the follower was a physical robot, namely the robot Pioneer3-DX. Both the robot and the simulator MobileSim are manufactured by MobileRobots Inc. (MobileRobots, 2000).

The pheromone server was implemented with a desktop computer, connected through a IEEE 802.11g WLAN with the agents.

3.2 *Experimental Setup*

The structure of the equipment used in the experiment is presented in figure 3.

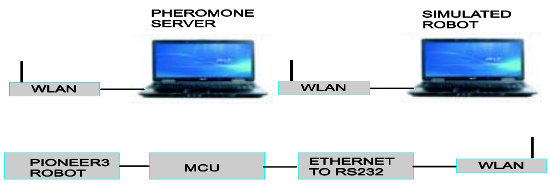

Fig. 3 The Experimental Setup

The motion of the simulated robot was manually controlled. A low cost/low power microcontroller unit (MCU) implemented a fuzzy controller for path following, by generating reference values for the speeds v_L, v_R of the left and right wheels of the differential drive robot, based on the pheromone intensities P_L, P_R, reported by the server. See (Susnea 2008b) for details on the fuzzy controller.

3.3 *Notes on the Actual Implementation*

The environment map used was a simple 2D grid map whose nodes were linked with a data structure containing information about pheromone source (if any) and a time stamp. Each cell of the map corresponds with a square area in the real world (see figure 4).

A special software application was written to generate and manage such maps. See figure 5 for a snapshot of the GUI of the map editor.

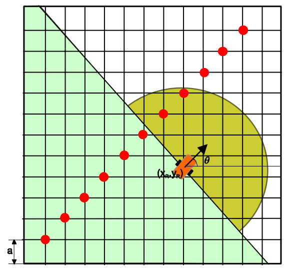

Fig. 4 The grid map embedding information on the pheromone distribution

The robot’s sensitivity to pheromones was assumed to be directional, so that only a 180 degrees circular sector ahead of the robot is “visible” for the pheromone sensing antennas.

In the first phase of the experiment, the robots were instructed to follow a pre-defined pheromone trail. This was used to tune the FLC for path following and to test the communication functions.

In the second phase of the experiment, the pheromone trail was generated by recording successive positions of the simulated robot, and the physical robot was instructed to follow the pheromone trail created by the virtual leader.

In both cases, the pheromone trace was assumed to be time-invariant – the evaporation was not taken into consideration.

The environment was assumed to be a horizontal plane with no obstacles. The odometric system of the robot was used for position estimation.

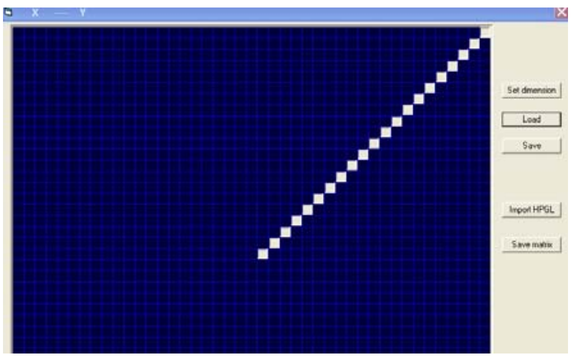

Fig. 5 Snapshot of the GUI of the map editor

4. EXPERIMENTAL RESULTS

Figures 6 and 7 present the actual path of a simulated robot, recorded with MobileSim, superposed with the corresponding pheromone distribution map for pre-defined paths.

The path used for recording the evolution of the robot in figure 8 was generated by a virtual leader robot, manually controlled.

In all cases, the follower robot was controlled by a fuzzy logic controller implemented on a low cost microcontroller.

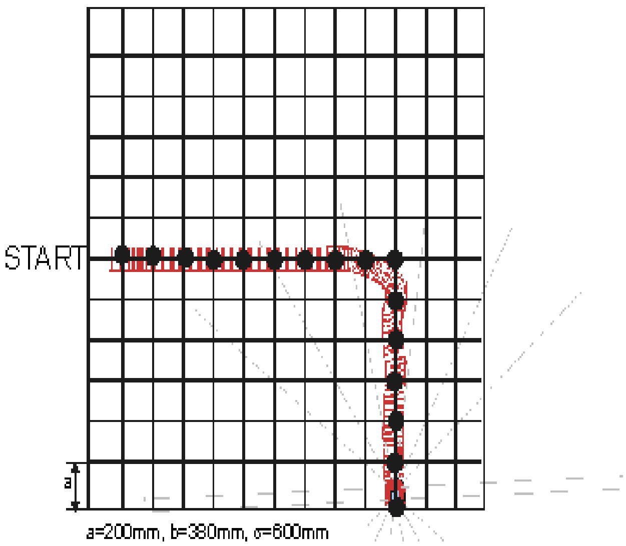

Fig. 6 Recorded path vs pheromone distribution

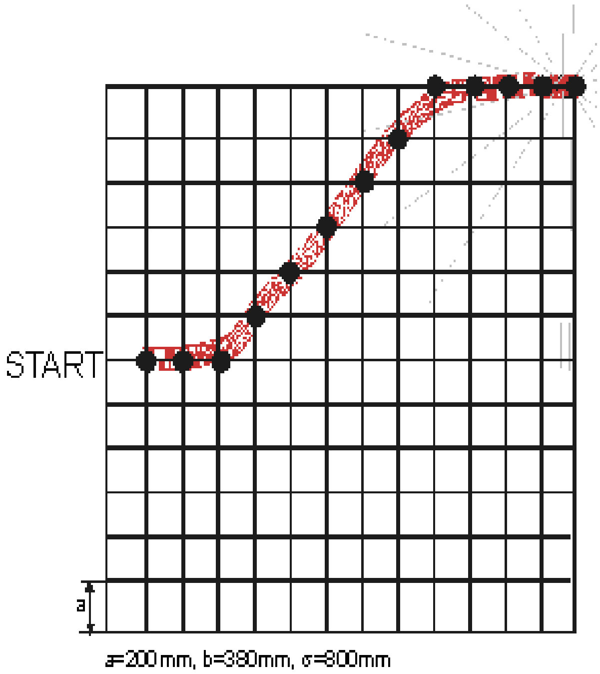

Fig. 7 Recorded path vs. pheromone distribution

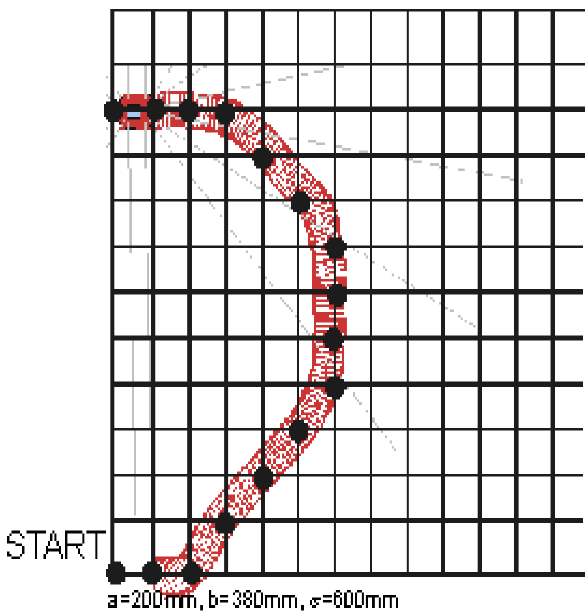

Fig. 8 Recorded path vs. pheromone distribution

5. DISCUSSION AND FUTURE RESEARCH

This centralist approach has been criticised and a-priori rejected (Parunak 2002) for lack of robustness in case the pheromone server fails. However, this limitation can be easily eliminated by using a second backup server, which executes all the operations of the main server, except responding to the queries of the robot clients. If the main server fails to communicate for a specified time-out delay, the backup server automatically assumes the communication tasks. There are, instead, several important advantages of this method:

- It distributes the computational load between the server and the agents, thus allowing very simple control structures for the agents. This results in drastic cost reduction thereof.
- Convenient pheromone distribution maps, obtained, for example, in an Ant Colony Optimization process, can be saved for later use. Virtual agents can be used in the optimization process, and the results are immediately available for use with physical robots.
- Multiple pheromone types can be defined (e.g. “stay away from this area”, “find and pick a load”, “drop the load here” etc.).
- Virtual leader-robots, with high speed and maneuerability can be sent in real-time to influence and guide formations of physical robots.
- This method is applicable to control any type of military, civil, and industrial service robots. Existing robots can be easily modified to suit this control method.

One major drawback of the proposed method is that it relies on the agent’s localization system. For outdoor applications the GPS locators can give satisfactory results, but indoors a localization system better than dead reckoning must be implemented. Further research is needed in the following directions:

- Define a method to embed information about the obstacles in the pheromone distribution maps, and describe how obstacles influence pheromone diffusion.
- Experiment with other types of pheromones.
- Identify other possible applications of the method.

REFERENCES

[1] Beni, G., Wang, J. (1989) Swarm intelligence in cellular robotic systems, *Proceedings of NATO Advanced Workshop on Robots and Biological Systems*, Tuscany, Italy, , pp:26–30

[2] Bonabeau. E., Dorigo M, and G. Theraulaz, *(*1999) *Swarm intelligence: from natural to artificial systems.* , Oxford University Press, 2004

[3] Deneubourg, J.-L., Aron, S., Goss, S. and Pasteels, J. M. (1990), The self-organizing exploratory pattern of the Argentine ant, *J. Insect Behav***. 32,** pp:159- 168.

[4] Dorigo M et al. (1996) The ant system: optimization by a colony of cooperating agents. *IEEE Trans Syst Man Cybernet* 26(1), , pp:29–41

[5] Karlson, P., Lüscher, M. (1983) Pheromones: a new term for a class of biologically active substances. *Nature* 183, pp. 55-56

[6] Grassé P.P. (1959) La Reconstruction du nid et les coordinations inter-individuelles chez Bellicositermes Natalensis et Cubitermes sp. La theorie de la stigmergie: essai d’interpretation du comportement des termites constructeurs. *Insectes Sociaux*, 6

[7] Genovese, V., Dario, P.,Magni, R., & Odetti, L. (1992), Self organizing behavior and swarm intelligence in a pack of mobile miniature robots in search of pollutants. In *Proceedings of the IEEE/RSJ international conference on intelligent robots and systems*, Raleigh, NC, 1992, pp. 1575–1582

[8] Mamei M., F. Zambonelli, (2005) Physical deployment of digital pheromones through RFID technology, *Swarm Intelligence Symposium*, 2005. SIS 2005.

[9] Parunak V.D., Purcell M., O’Connell R. (2002), *Digital pheromones for autonomous coordination of swarming UAV’s,. Available online: http://www.newvectors.net/staff/parunakv/AIAA-2002-3446.pdf* [Online]

[10] Payton D., R. Estkowski, M. Howard,

(2005) Pheromone robotics and the logic of virtual pheromones", in *Swarm Robotics*, Springer, 2005, pp: 45-57

[11] Purnamadjaja A.H, Russell R. A, (2007) Guiding robots' behaviors using pheromone ommunication *Journal of Autonomous Robots*, Vol. 23 (2), Kluwer Academic Publishers Hingham, MA, USA, 2007, pp: 113 – 130

[12] Susnea I., G. Vasiliu and A. Filipescu, (2008a) RFID Digital Pheromones for Generating Stigmergic Behaviour to Autonomous Mobile Robots, *Proceedings of the 4th WSEAS/IASME International Conference on dynamical systems and control (CONTROL'08),* Corfu, Greece, October 26-28, 2008, ISSN: 1790-2769.

[13] Susnea, I.; Filipescu, A.; Vasiliu, G.; Filipescu, S. (2008b), Path following, real-time, embedded fuzzy control of a mobile platform wheeled mobile robot**,** *Automation and Logistics, 2008. ICAL 2008. IEEE International Conference* Volume 1 , Issue , 3 Sept. 2008, pp:268 – 272