Antbots: A Feasible Visual Emulation of Pheromone Trails for Swarm Robots

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Abstract. In this paper we present an experimental setup to model the pheromone trail based foraging behaviour of ants using a special phosphorescent glowing paint. We have built two custom addons for the e-puck robot that allow for trail laying and following on the glowing floor, as well as a way for the robots to mimic the ants capability of using polarization patterns as a means of navigation. Using simulations we show that our approach allows for efficient pathfinding between nest and potential food sources. Experimental results show that our trail and sun compass add-on boards are accurate enough to allow a single robot to lay and follow a trail repeatedly.

Keywords: swarm robotics, ant foraging, pheromone trails, biomimicry.

1 Introduction

Ants have the ability to find the shortest possible path between food sources and their nest collectively by laying pheromone trails on the ground [1,14]. These pheromones have shown to be involved specifically in the recruitment and navigation of ants between food sources and the nest. The foraging behaviour has long been of particular interest not only in the field of biology, but also in swarm robotics [4]. These kinds of collective abilities can be applied to real-life problems such as traffic, route-planing or the travelling salesman problem as well [5].

The collective behaviour of social insects and stigmergy-based communication remain to have a strong influence on the field of collective robotics. There have been several approaches to model the pheromone-based trail laying and trail following behaviour of ants in experimental settings using robots.

By means of chemical sensors and alcohol-depositing robots [10]. This is a very realistic imitation of the pheromone-based trails of ants. However, the chemical sensors used in this setup and the combination of robotics and substances such as alcohol have been shown to be very unreliable and not very practical.

Drawing lines onto the floor using pen and paper [12]. In this scenario each robot is equipped with a pen, with which it is able to draw solid thin lines onto the ground. Although a decay of these trails is archieved by using a special kind of disappearing ink, the trails layed by these robots remain thin in comparison

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to the robots. This does not provide a close analogy to the biologically inspired behaviour of ants.

Laying trails of heat [9]. This method promises an extremely flexible way to model the foraging behaviour of ants by laying trails of residual heat onto normal surfaces such as carpets or tiles. One problem is that the electrical generation of heat is not possible even on bigger mobile robots because of constraints in battery power. The researchers stored heat in the form of paraffin wax to lay trails instead. This presents an additional difficulty for experimental use and dynamically adjusting the strength of the trail is not possible.

Using robot-tracking and a projector setup, in which each robot is able to lay trails by being tracked using a camera suspended above the arena [7]. A computer superimposes 'virtual pheromones' by projecting them onto the arena floor. This system does not present a fully autonomous way for the robots to lay and follow trails, and a a central unit, an external computer, is needed. However, this system provides a very flexible way to modify parameters of the pheromones, such as decay and diffusion.

Emitting ultraviolet light onto a phosphorescent paint, and thus laying luminous green trails on the arena floor. This method of modelling ant trails has been published for use in an artistical context [2]. In this setup, the arena floor is coated with a special phosphorescent glow-paint that glows in the dark for several minutes after being stimulated by an external UV light source. By attaching UV-LEDs to the mobile robots, they can leave glowing trails on the ground. The idea is that because of the constant decay in brightness, the green glow that eminates from the floor can be seen as an analogy to the evaporating pheromones ants utilize in their trail following.

In this paper we extend and improve on the idea of using glow-paint to mimic ant trails. It presents a completely autonomous way for the robots to lay trails. Using specially developed sensors and actuators allows us to combine the glowing floor and robots in a unique and reliable way.

2 Materials and Methods

2.1 Base Robot: E-Puck

The e-puck robot [3] (see Fig. 2), was developed at the EPFL in Switzerland. It utilizes a Microchip dsPIC microcontroller at its core, and has two stepper motors for actuation. Several red and green LEDs placed in and around the casing of the robot can be used to quickly display what state the robot is in at a particular time. The e-puck features a number of different sensors, most important for our experiments are eight proximity sensors and a color CMOS camera. The proximity sensors are infrared receivers and transmitters placed around the body. They allow the measurement of distance between the robot and obstacles. Additionally they can differentiate between obstacles like walls and other robots by means of active and passive sensing. The camera on the e-puck has a theoretical resolution of 640×480 pixels, but only a part of this frame can be grabbed at runtime with a high enough framerate (40×40 pixel color image at approx. 4 frames per second).

2.2 Glow-Paint Floor

The synthetic raisin paint used to coat the arena floor contains small grains of phosphorescent material that react instantly to ultraviolet light and glow in the dark with a characteristic decay time T, as the intensity decreases like $I(t) = I_0 \exp(-t/T)$. In our experiments we have used the onboard camera tilted downwards for trail detection and trail following. Figure 1 presents intensity measurements over time for the onboard e-puck camera from the point of view of the robot. Figure 2 shows the robots' field of vision on the floor. The line-following algorithm is based on a line-following Braitenberg vehicle.

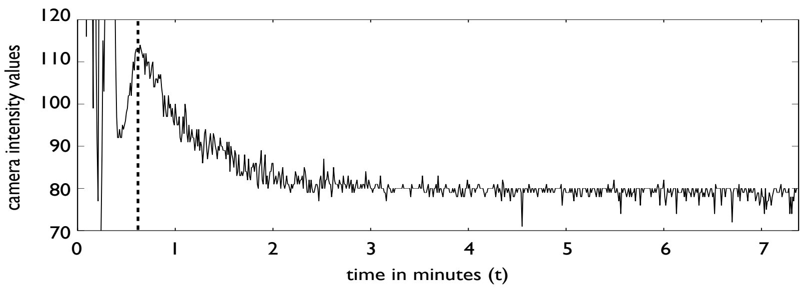

Fig. 1. Intensity measurements from the onboard e-puck camera over the course of approx. 7 minutes for the green color channel, directly polled from the robot, while standing still and the camera is pointed at one spot on the coated floor. Ambient light was at complete darkness. Before the dashed line ($t = 0$ to $t \approx .5$) the floor is being exposed to direct UV-LED light, explaining the irregular peaks, and is at its maximum glowing capacity shortly thereafter at $t \approx .6$. This curve combines the characteristic decay of the phosphorescent paint and the camera's response curve.

2.3 Nest, Food and an Artificial Sun as a Navigational Aid

Analogous to nest and food sources in ant foraging, we have chosen LED light sources with different colors for our experiments. The robots can distinguish between the objects by comparing the different color channels of the camera. The nest has been chosen to be red, and food sources are blue. Each one is made of transparent plastic covers with LEDs underneath.

Ants derive directional information from polarization patterns to navigate back to their nest from food sources [8]. This behaviour has been described for the desert ant *Cataglyphis fortis* in great detail [6]. To emulate this ability we have chosen a red light source positioned in a corner above the arena. Figure 3 shows a diagram of our experimental setup.

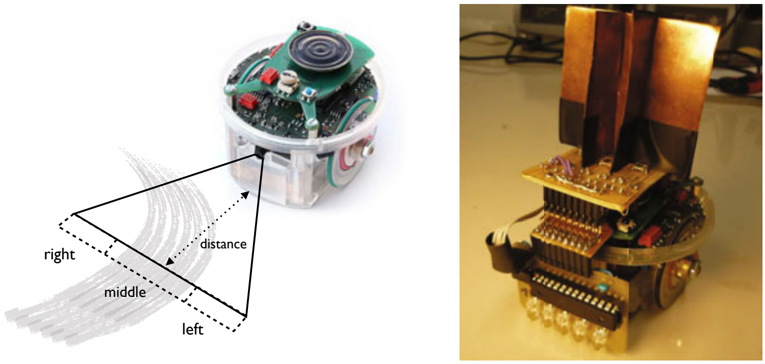

Fig. 2. Left: Diagram showing how far and how wide the field of view of the camera is on the floor. Dashed lines represent the sectors used for the line following algorithm: The robot calculates the brightness of the green color channel for each of the three sectors. When the leftmost sector is the brightest it turns right and vice versa. If the middle sector is the brightest it moves straight ahead. Distance from robot is approximately 4.5 centimeters. **Right**: e-puck robot equipped with our trail-laying (front) and sun compass extension board (top).

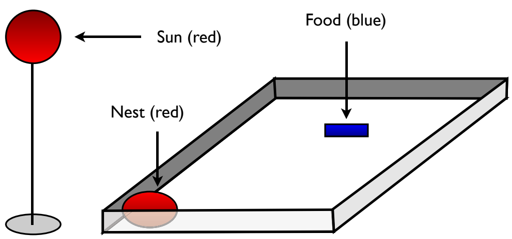

Fig. 3. This diagram shows the experimental setup used in our experiments. Depicted are the artificial sun suspended above the arena, the nest and a foodsource.

Each robot can detect from which direction this emulated sunlight is coming from using a specially designed ‘sun compass’ add-on board (see Fig. 2 right). In our experiments the nest has been placed in the same corner as this artificial sun, so the robots simply have to drive towards it to find their nest.

2.4 Add-on Boards: Trail-Laying and Sun Compass Extension

To utilize the experimental setup described above, the e-puck base robot needed several extensions (see Fig. 2). A special circuit board was added to provide the robot with five UV-LEDs pointed directly to the floor. The add-on uses a dedicated ATMega8 MCU [13] for independent control over brightness for each LED using pulse-width modulation. This board is attached on the back of the robot for a minimum distance of LEDs to the floor and thus the maximum amount of energy reaching the floor.

An additional board featuring six photodiodes that measure light intensity (red wavelengths in particular) is attached to the analog-digital comparer of the MCU. It is located on top of the robot and the sensors point upwards. Three small rectangular sheets of copper have been added to allow the 'artificial sun' to cast shadows on the sensors that don't point towards the light (see Fig. 2 right). By calculating which sensor has the highest value the robot is then able to face the artificial sun and readjust its direction during its trip to the nest, if necessary.

2.5 Simulation Using Netlogo

In order to explore parameters and the efficiency of our experiment, we have built a simulator (see Fig. 4) using the multi-agent programmable modeling environment *NetLogo* [11], developed at the Northwestern University in Illinois. In NetLogo *agents* are the equivalent of robots, and the arena is made up of tiles, so called *patches*.

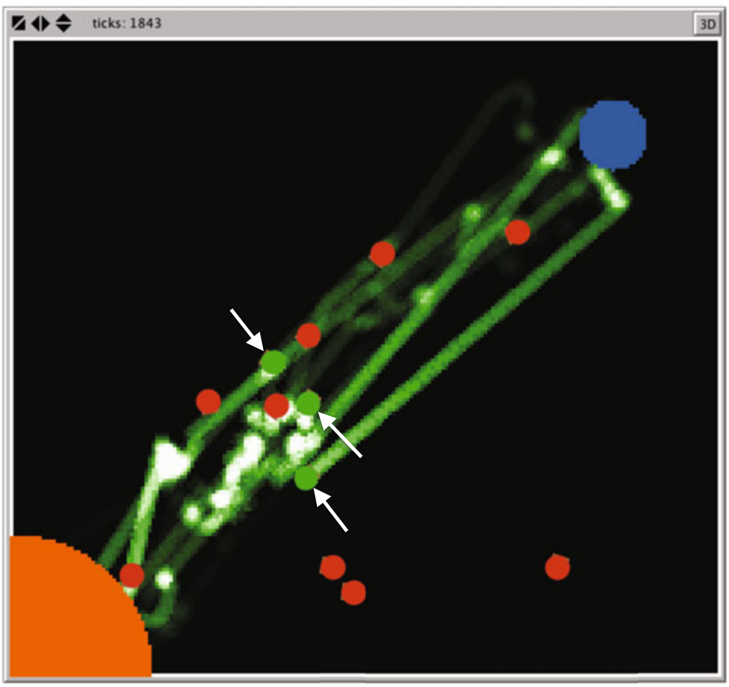

Fig. 4. Screenshot of a simulation run. The nest (orange) is located on the bottom left, a foodsource (blue) in the top right. Agents are either red (searching for food) or green (searching for the nest, marked with arrows here) depending on their state. Green trails show the pheromone paths between food and nest.

To resemble our experimental setup as closely as possible, we have programmed the eight proximity sensors of the e-puck robot into the simulation. These sensors have been implemented actively and passively in order to be able to differentiate between walls and other agents and to allow for a sufficient approximation of the obstacle avoidance of real robots. Our sun compass sensor was also implemented in the simulator by calculating where the nest is in relation to the agent. The resulting angle is categorized into six different general directions to approximate the sun compass. The agents leave a predefined amount of virtual pheromones on the patch they are currently on. The simulator then computes different shades of green in order to visualize the amount of pheromone on each patch for every time step. Nest (bottom-left) and foodsource (top-right) are orange and blue circles respectively. The camera, used for trail-following, is emulated by reading out pheromone levels (shades of green) in front of the individual agent at three different angles.

In contrast to most other ant trail multi-agent simulations, ours models the actual sensoral attributes of the e-puck robots, and actual properties of the glowing floor. The obstacle avoidance algorithm employed in the simulation is based on and closely resembles the actual e-puck behaviour. This is crucial in order to be able to tell from the simulational results how efficiently multiple robots should be able to complete the path finding task.

2.6 Control Program

The algorithm used in both the simulations and experiments has two basic states. The robot is either searching for food, or searching for the nest. The two states have several subtasks that are ordered by priority and executed in that order. For example, *only* if a robot can distinguish a light trail in front of it, will it try following it.

The two states and their tasks are as follows:

1. Search for food sources (not laying trails, UV-LEDs turned off)
   (a) If the camera registers food (blue), the individual turns 180° and switches to state 2.
   (b) Basic obstacle avoidance, only registers walls or other non-robot objects.
   (c) If the camera registers a green trail (distinguished by contrast in relation to the different camera sectors), follow it. If the sun compass registers that the robot is heading directly to the nest turn 180° .
   (d) Correlated random walk.
2. Search for the nest (laying trails, UV-LEDs turned on)
   (a) If the camera registers the nest (red), the individual turns 180° and switches back to state 1.
   (b) Basic obstacle avoidance, registers non-robots as well as robots and avoids them.
   (c) If the camera registers a green trail (contrast) follow it. If the sun compass registers that the nest is directly behind the individual, turn 180° .
   (d) Follow the sun compass and constantly adjust the trajectory so that the frontmost sensor has the highest value.

3 Results

In order to investigate the attributes and capabilities of our approach, we have run several simulations. They show how a robot swarm of up to twelve robots can achieve better efficiency in finding food and carrying it back to the nest using trails equivalent to the ones on the glowing floor. To measure the accuracy in line-following and of the sun compass on an actual robot, we have carried out test trials using a single robot.

3.1 Foraging Efficiency in Simulation

To measure the efficiency of the setup we count how many times a virtual agent has travelled from food to nest, i.e. how many times it has 'delivered' a unit of food to the nest. Each time an agent completes this task, a global counter variable is increased by one. We have conducted each run with and without pheromone trails and three times in repetition each to eliminate errors. The test runs were run for 2000 time steps. The arena size was fixed at 200×180 patches, while one agent is 7 patches in diameter. The decay properties of the arena floor were set to be consistent with a real-world scenario (see Figure 1). In Figure 4 the layout of the simulated arena can be seen. Figure 5 shows the results of the simulation for 4, 6, 8 and 12 agents in a fixed-size arena. Solid lines indicate efficiency of pheromone-aided robot swarms and dashed lines are from simulation runs without pheromones.

In all of the simulation runs the efficiency is greatly enhanced when utilizing pheromone trails. When four agents where in the arena, pheromone aided robots delivered 8 units, versus only 3 in the test run without pheromones. Six agents archieved 10 with, and 2 without pheromones, eight agents brought 22 vs. 6 and twelve agents 23 vs. 8 units to the nest. This shows that even with a very dense population robots, and the many resulting collisions, a great improvement of efficiency can be archieved using the phosphorescent trails.

3.2 Experiments with the e-Puck Robot Add-Ons

To test our sensor boards, we have conducted the following experiments each with three repetitions and a varying distance between foodsource and nest: The e-puck robot is placed in the middle of the arena and pointed towards the food source. When switched on, it drives straight ahead until its camera recognizes the blue foodsource. It then turns 180° and uses its sun compass sensor to navigate back to the nest. When it has reached the nest it turns 180° and tries to follow its own trail back to the foodsource. This process is repeated for the duration of the experiment. By measuring how often the robot looses the trail we can determine the reliabilty and the limits (in length of trail) of our line-following approach. Note that three components are being evaluated in this process: The camera (for trail-detection), the UV-LED extension (for trail-laying) and the glow-paint floor (how long the trail lasts). In each of our experiments the sun compass always found a nearly straight path back to the nest (see Fig. 6).

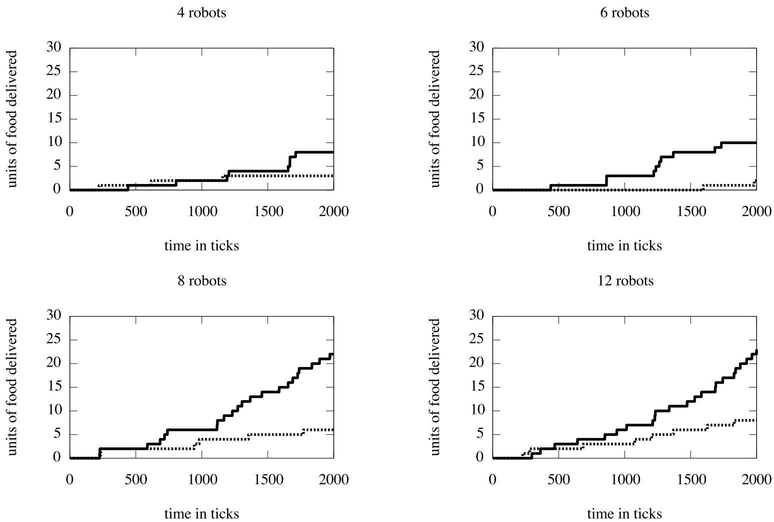

Fig. 5. Efficiency measurements for 4 different simulation runs. Top-left shows 4 robots, top-right 6, bottom-left 8, bottom-right 12. Solid lines are with pheromones turned on, dashed lines represent runs without pheromones. The plots show the sum of units of food delivered to the nest. The efficiency of the agents that could utilize the pheromone trails is greatly increased.

Table 1. Results of experiments carried out with a single robot with varied distances between nest and food

arena size	distance food to nest	food delivered	track lost	time on trail
1m×1m	1.3m	21 units	2 times	82%
1.5m×1.5m	1.6m	10 units	6 times	67%
2m×2m	2.3m	3 units	4 times	49%

We varied the distance of food to the nest for each experiment and repeated them three times each for 15 minutes. Table 1 shows the test results numerically.

With a distance of 1.3 meters from food to nest and a 1m×1m arena, the robot lost track of its trail two times on average. It returned from the foodsource to the nest 21 times and spent 82 percent of the time on the track otherwiese doing a correlated random walk in search of food or using its sun compass to find the nest. Overall line-following reliability was sufficient to keep the glowing trail stable at all times.

Next, the distance was increased to 1.6 meters. The robot lost its trail 6 times on average and brought ten units of food to the nest. It was on the track 67 percent of the time. While the robot lost track of his trail more often, he still succeded in keeping one central trail glowing throughout the experiment.

When the distance was 2.3 meters, most of the time the robot lost its trail halfway to the foodsource, which resulted in inefficient search of the arena using

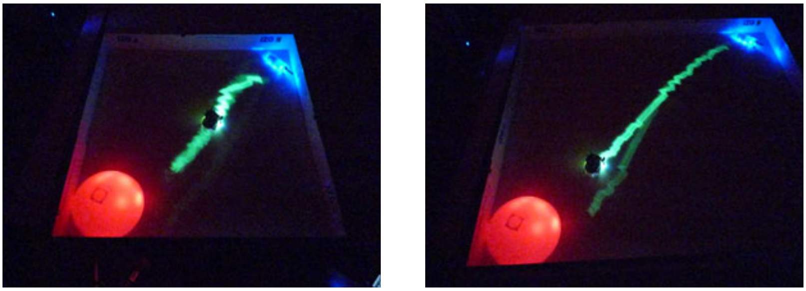

Fig. 6. Left: Photograph showing the trail laid by the robot in a 1m×1m arena and a distance of 1.3m between food (top-right) and nest (bottom-left). The robot is on its way back from the food source pointing towards the nest and is following its own line. **Right**: Same setup in a 1.5m×1.5m arena. Distance between food and nest is 1.6 meters. The robot has lost its track about halfway to the nest and is laying a new one beside the 'old' one.

the correlated random walk. In this case the decay of the phosphorescent floor is too high. Overall it managed to bring back 3 units of food and laid three separate trails on the ground.

4 Discussion and Outlook

In this paper we have introduced an experimental setup to model the foraging behaviour of ants using robots. We have developed solutions to combine a phosphorescent arena floor and robots to lay and follow glowing trails. Additionally we have introduced a novel sensor to mimic the ants capability of using polarization patterns to derive directional information and to navigate back to their nest. Using simulations we have shown that the use of these phosphorescent trails leads to an efficiency increase in collecting units of food and to aid path finding between a food source and the nest. Experimental results show that our newly developed sensors are realiable enough for the robot to navigate to the two spots reliably.

In the future we plan on conducting experiments with more than one robot, in order to transfer the presented simulation into real life. Figure 7 shows a contrived photograph of how this could look like. Collision avoidance between robots is not reliable enough at the moment and needs further investigation.

Our sun compass has proven itself to be very reliable in finding the nest. In combination with the artificial sun, it presents a very cost-effective solution to get directional information inside of a robot arena.

We will explore the capabilities of our sun compass in more detail and introduce more complex behaviours that utilize it, such as remembering the path travelled to the foodsource by the heading in relationship to the sun, also imitating the ants capability to remember their travelled path [6]. In such a scenario the sun could be moved before and during the experiment to show how, just like

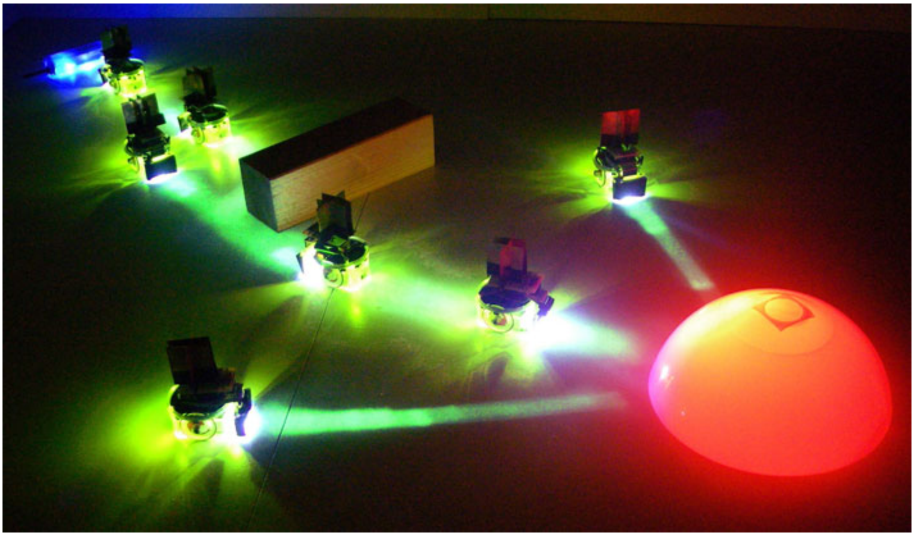

Fig. 7. Contrived photograph of how the glowing floor and our sensors should be used in the future. Two robots leave the nest to search for food, the remaining robots navigate to and from the nest around an obstacle.

in real life, individuals alter their paths accordingly, and steadily adapting to the new position.

Additionally, we will introduce obstacles and multiple food sources in order to explore how the robots optimize the paths in between. The robots could also adopt a tandem behaviour so that they lead each other on pheromone paths to optimize speed and to minimize collisions.

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