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Colias-Φ: An Autonomous Micro Robot for Artificial Pheromone Communication

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***Abstract*—Ants pheromone communication is an efficient mechanism which took inspiration from nature. It has been used in various artificial intelligence and multi robotics researches. This paper presents the development of an autonomous micro robot to be used in swarm robotic researches especially in pheromone based communication systems. The robot is an extended version of *Colias* micro robot with capability of decoding and following artificial pheromone trails. We utilize a low-cost experimental setup to implement pheromone-based scenarios using a flat LCD screen and a USB camera. The results of the performed experiments with group of robots demonstrated the feasibility of *Colias-Φ* to be used in pheromone based experiments.**

***Index Terms*— autonomous, swarm robotics, micro robot, pheromone communication**

I. Introduction

Nature inspires fascinating phenomena to be used in solving and optimizing human problems. Many robotic subjects especially multi and swarm robotic researches have taken inspiration from the social behavior of insects and other animals [1]. These bio-inspired controlling mechanisms efficiently solve the problems which are beyond the capabilities of an individual robot. The success of a group in accomplishing a common task relies on the interactions among the members. In fact, inter-agent communication plays an essential role in the efficiency of the collective behaviors. Various communication mechanisms have been observed in social interactions of insects and other animals in nature. Pheromone-based communication is one of the most fascinating mechanisms which social insects use to interact within similar species [2].

Ants produce various types of chemicals (pheromones) for their different purposes. In general, the pheromone trail which is used in forging task has been mostly studied by computer scientists well known as the optimizing the shortest path selection between nest and food sources [3]. In swarm robotic [4], many studies have adopted the pheromone communication phenomenon as a bio-inspired approach to communicate between the agents [5], [6]. Fig. 1 shows our previously developed robots to be used in swarm robotics researches.

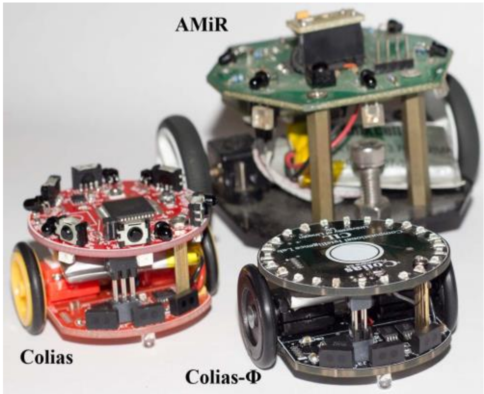

Figure 1. Colias-Φ, Colias and AMiR mobile robots developed for swarm robotic applications

Pheromone trail has been implemented with several artificial methods in robotic researches using simulated robots or real hardware robots with various media. In some researches [7], [8], chemical substances have been used. The advantages of the chemical pheromones are the ability of implementing characteristics such as evaporation, diffusion and reactivity due to the chemical reactions with the environment. However, the robotic platforms require complex designs and extra sensing abilities which are costly. Another disadvantage of the chemical pheromones is the difficulty in the control of the evaporation and diffusion rates. Moreover, utilizing continuous and long-term of the chemical pheromones in the laboratory environment would be harmful. Therefore, artificial media such as RFID [9], audio [10]-[12] and light [5], [13]-[15] could be the safe media to be used as the artificial pheromone and cue. Garnier et al. [16] presented an experimental setup for study on pheromone based communication with micro autonomous robots using the projected light. Earlier, the projected light was also used as a media to implement an artificial pheromone communication [17].

In our recent study, we introduced a communication system, COSΦ (communication system via pheromone) [18] as a novel pheromone communication system using visual pheromone trail. It can be implemented by a low-

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cost experimental setup using a basic digital camera and low-cost Colias-Φ micro-robot in a laboratory area. To implement the communication system (COSΦ), the robot must capable to sense the light intensity using its ambient light sensors and detect the pheromone trail which released by other robots. In this paper, we explain hardware specification of Colias-Φ and a swarm scenario which was used to investigate the feasibility of the robot.

The rest of this paper is organized as follows. In Section II, we introduce the hardware design and architecture. Following that, in Section III, we explain experiments setup with the developed robot. In Section IV, we discuss about experimental results in different settings. Finally, in Section V, we make a conclusion and discuss about future research directions.

II. Hardware Description

A. Main Processing Unit

Colias-Φ is a specific version of the Colias micro robot [19]. It is designed for pheromone-based experiments in swarm robotic researches. Hardware and control mechanism of Colias-Φ are explained in this section. Fig. 2 shows a Colias-Φ robot and its different modules. The robot uses two boards -- upper and lower -- which have different functions. The upper board has 24 LED lights utilized as indicators which show different states of the process. However, the lower board plays main processing role as well as low-level functions such as power management and motion control. Fig. 3 shows Colias-Φ architecture and its modules.

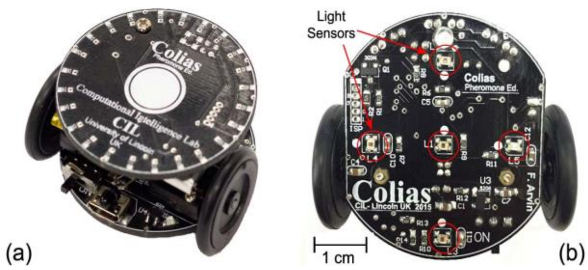

Figure 2. Colias-Φ micro robot platform developed for pheromone communication system

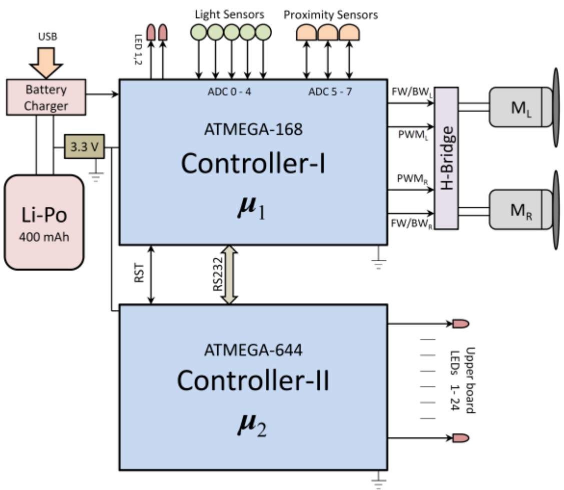

Figure 3. Architecture of Colias-Φ

B. Motion Control

Robot uses two wheels and a caster for its motion. The wheels are controlled by pulse-width-modulation technique for left and right wheels separately [20].

In nature, pheromone trail follower ants follow the trail with a simple trajectory plan (see Fig. 4). Ant moves on a curve to the left until its right antenna detects the pheromone trail, then the ant continues its motion with a turn to the right until its left antenna detects the pheromone trail [7].

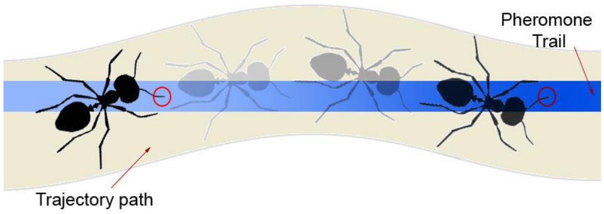

Figure 4. Trajectory of ants for following the pheromone trail

We use a similar motion approach seen in trail follower ants. Colias-Φ when is following a trail formed by artificial pheromones, controls its left and right motors based on light intensity readings from the left (I_L) and right (I_R) sensors. These two sensors act as ants' antennas. The robot tries to keep its position on a pheromone trail by changing the rotational speeds of its left and right motor. The rotational speeds are calculated as:

$$N_L = \frac{I_L - I_R}{\alpha} + u \tag{1}$$

$$N_R = \frac{I_R - I_L}{\alpha} + u \tag{2}$$

where I_L and I_R are the light intensity readings (between 0 and 255) from the left and right sensors, u is a forwarding speed and α is the rotational speed sensitivity coefficient. The rotational speed coefficient is tuned empirically to have a smoother motion.

C. Sensory System

Sensory system of Colias-Φ consists of three short-range infrared (IR) proximity sensors and five ambient light sensors. We place the proximity sensors in front of the robot with 120° angle for scanning the front side of the robot to detect obstacles and other robots [21]. The robot can detect the white body obstacles/walls within distance of 3±0.5 cm and it can detect the other robots within distance of 1±0.5 cm. As described before, the robot does not have any types of direct communications such as IR or wireless.

The lower board of Colias-Φ is equipped with 5 light intensity sensors that are faced to the horizontally placed LCD screen as shown in Fig. 2(b). These sensors read the intensity of light (I_i, where i refers to the position of the sensor at the bottom of the robot) varying linearly from 0 and 255. We mostly use I_L and I_R (left and right sensors) for controlling the motion of robot as shown in (1) and (2). In addition, we can attach a color RGB sensor when we need to implement different types of messages in pheromone system.

Table I shows the specification of Colias-Φ and two previously developed mobile robots, Colias [22] and AMiR [23].

TABLE I. COMPARISON OF THREE SWARM ROBOTIC PLATFORMS (AS SHOWN IN FIG. 1)

Robot / Modules	Description / Values
Colias-Φ:	
– Sensory System:	– Short-range proximity/ light/ RGB
– Power Consumption:	– 800 mW
– Motion:	– Wheel / Differential driven
– Size (diameter):	– ⌀ 4 cm , ↕ 2.5 cm
– Cost:	– £16
Colias [22]:	
– Sensory System:	– Short- & long-range IR, light
– Power Consumption:	– 2000 mW
– Motion:	– Wheel / Differential driven
– Size (diameter):	– ⌀ 4 cm , ↕ 3.5 cm
– Cost:	– £25
AMiR [23]:	
– Sensory System:	– Short- & long-ranges IR, light
– Power Consumption:	– 1000 mW
– Motion:	– Wheel / Differential driven
– Size (diameter):	– ⌀ 6.5 cm , ↕ 6 cm
– Cost:	– £65

III. EXPERIMENTS

In this section, we explain the experiments and the arena configuration. We also present a collective scenario to investigate the feasibility of the developed robot to be used in pheromone communication.

A. Arena Configuration

To implement the bio-inspired pheromone-based communication system, COSΦ (Communication System via Pheromone) [18], we use an arena with a size of 93x52 cm^2. We use a 42” LCD screen as the ground (as shown in Fig. 5) which robots move on. Using LCD screen gives us an opportunity to simply implement the pheromone-based swarm scenarios with complex and dynamic environments and interactions. Pheromone trails are displayed with a maximum illuminance of 420 lux and the system is controlled by a desktop PC.

Figure 5. Arena configuration for collective experiments

B. Swarm Scenario

To investigate the feasibility of the developed robot to be used in pheromone communication system, we implement a basic swarm scenario with Colias-Φ robots. In this scenario, we have two types of roles: i) leader and ii) followers. Follower robots move randomly and when they detect a pheromone trail, they follow this trail. The pheromone trail, which is a high-brightness constant width line, is laid by the leader robot. The leader robot moves forward with a constant speed of u in a random direction. When a follower robot detects a pheromone trail, it chooses a random direction (left or right) to follow the trail.

In general, pheromone trail has two basic parameters:

- Evaporation e_ϕ, that determines how quickly the pheromone strength fades over time
- Diffusion κ_ϕ, that defines the rate at which the pheromone is spreading,

where in this paper, we only test the effects of two evaporation delay (5 and 10 sec) in experiments with 3 and 6 robots and diffusion is $\kappa_\phi = 0$.

In all the swarm scenario experiments, we used one leader and different number of followers and different evaporation delay and each set of experiment is repeated 5 times.

C. COSΦ System

COSΦ (Communication System via Pheromone) [18] is a high precision, flexible and low-cost experimental setup, which provides a reliable and user friendly platform to study bio-inspired mechanisms. The proposed system consists of: i) a high precision visual localization system [24] which detects the positions of swarm robots and releases the visual pheromones on the LCD screen and ii) a lightweight (~20 g) micro-robot platform with a specific design enables reading the visual pheromone trails using its light sensors.

IV. RESULTS

We first evaluated the accuracy and feasibility of the localization system in tracking and pheromone trail releasing. The robots’ ability to follow the pheromone trail was also investigated. Fig. 6 shows the trajectory of three robots in a randomly selected experiment. The thick yellow line indicates the pheromone trail on the LCD screen which is the trajectory of the leader robot. Two dashed lines are the trajectories of the follower robots. The positions of the robots reveal that the two followers were able to follow the leader without any explicit direct communication (or neighboring position estimation) system.

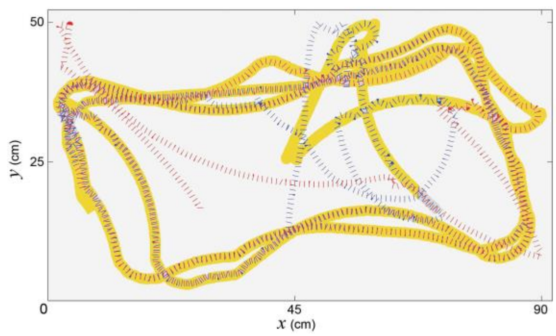

Figure 6. Trajectory of three robots. Leader (yellow shadow) and two follower robots (dashed lines with red and blue colors).

The observed results from experiments with three robots (one leader and two followers) are shown in Fig. 7.

The results show that the increase in the evaporation delay increases the number of follower robots on the pheromone trail. In longer evaporation delay, pheromone trail lasts longer than the shorter evaporation delay. Thus, the chance of the followers to meet the pheromone trail increases by increasing the e_ϕ.

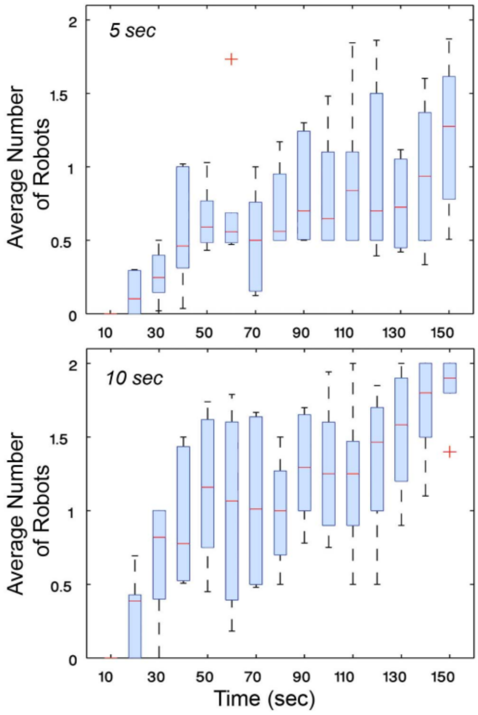

Figure 7. Average number of robots on the pheromone trail in different evaporation delays (e_ϕ= 5 and 10 sec) with 3 robots (one leader and 2 followers).

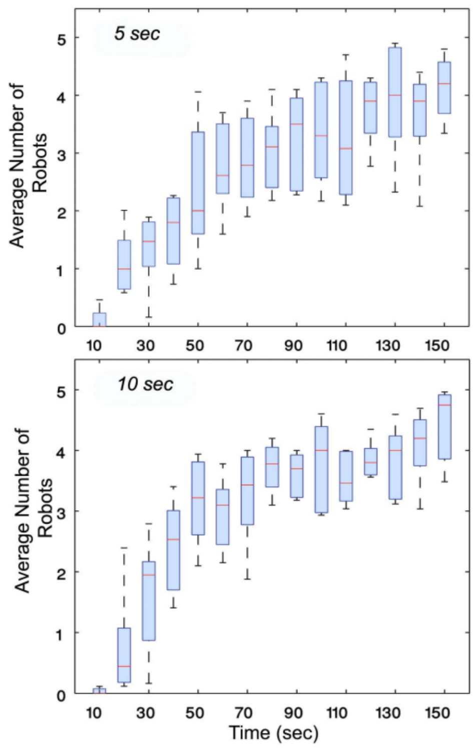

Figure 8. Average number of robots on the pheromone trail in different evaporation delays (e_ϕ= 5 and 10 sec) with 6 robots (one leader and 5 followers).

Fig. 8 shows the number of robots during experiments with six robots (one leader and five followers). We investigate the effects of two evaporation delays (5 and 10 sec). Similar to the previous configuration, increasing the evaporation delay resulted in increase the number of robots on the pheromone trail with increasing the tendency of the robots to follow the pheromone trail. We can also observe that the system reaches steady-state faster when the evaporation delay is 10 sec.

V. Conclusion

In this paper, we present a development of an open-platform micro-robot designed for pheromone-based communication experiments. It is a low-cost (£16) robot which can be simply replicated. Using a low-cost artificial pheromone experimental test bed which consists of an open-source motion tracking system and a low lost micro robot that moves on a horizontally placed LCD screen, we can have detail studies on behavior of individual robots and group behavior in static and dynamic environments. For the future work, we will add RGB sensor in center of the robot which is replaced with the middle light sensor. Therefore, we will have more flexibility with multiple types of pheromones and define different zones with different colors.

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