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A Versatile Vision-Pheromone-Communication Platform for Swarm Robotics

Tian Liu[1], Xuelong Sun[1], Cheng Hu[2,1], Qinbing Fu[1,2], and Shigang Yue[2,1]

Abstract— **This paper describes a versatile platform for swarm robotics research. It integrates multiple pheromone communication with a dynamic visual scene along with real time data transmission and localization of multiple-robots. The platform has been built for inquiries into social insect behavior and bio-robotics. By introducing a new research scheme to coordinate olfactory and visual cues, it not only complements current swarm robotics platforms which focus only on pheromone communications by adding visual interaction, but also may fill an important gap in closing the loop from bio-robotics to neuroscience. We have built a controllable dynamic visual environment based on our previously developed ColCOSΦ (a multi-pheromones platform) by enclosing the arena with LED panels and interacting with the micro mobile robots with a visual sensor. In addition, a wireless communication system has been developed to allow transmission of real-time bi-directional data between multiple micro robot agents and a PC host. A case study combining concepts from the internet of vehicles (IoV) and insect-vision inspired model has been undertaken to verify the applicability of the presented platform, and to investigate how complex scenarios can be facilitated by making use of this platform.**

I. INTRODUCTION

Insects provide perfect models from which to develop swarm robotics systems. Biological studies have revealed that insects are able to perform complex tasks dynamically and efficiently with their compact yet efficient sensory systems. Their simple but practical neural systems have become a very important source of inspiration for many swarm robotics studies. Among these studies, communication via pheromones has attracted great interest and is now one of the major research areas. To carry out such research, we previously proposed a multiple pheromones communication platform named ColCOSΦ [1]. However, among the several sensing modalities utilized by insects, vision is another crucial and essential source of information. For example, locusts use their visual systems to detect collisions [2], [3], fruit flies use vision to acquire angular velocity[4], and ants/bees use vision cues to navigate [5]. However, a survey of the current research literature on insect-inspired swarm robot platform (see Table I) has shown that whilst some UAV swarm experiments [6] use sensory computation for calculating distances, the use of visual information has been limited to only a few ground-based swarm micro-robotic studies [7], [8]. One reason for this is that there are very few micro-robots (Table I) equipped with visual sensors. Another is that most of the experimental environments (Table I) consist of fixed-pattern arenas, in which it is difficult to provide varied visual stimuli easily and quickly. Furthermore, precise and dynamic control of visual information presented in the arena is also a challenging task for a swarm robotics platform. To address this challenge, we have proposed a new method for presenting a swarm robotics visual environment using LED panels to dynamically display visual stimuli to the arena enclosure.

A suitable platform for a swarm robotics study would make the experimental execution and analysis straight forward, and facilitate the grabbing of data from each swarm robot during the experiment. However, this is a challenge for micro-robots, especially in multiple micro-robot systems, due to limitations in computational resources and power consumption. To realize real-time data acquisition in swarm robotics, we have proposed and designed a bi-directional data transmission system between a PC and the swarm robots.

In summary, to facilitate developmental research in swarm robotics inspired by insects, this paper presents an experimental platform that not only integrates all the main functions of existing platforms (see a comparison in Table I) but also incorporates a dynamic visual environment. It inherits the strengths of our previously developed ColCOSΦ platform and incoporates the recently released Colias IV micro-robot [9] which has a vision sensor board, thus creating the first micro-robot experimental platform that can provide dynamic visual information, multiple virtual pheromones, real-time bi-directional data transmission and ID binding tracking. To verify the robustness of the platform, a case study has been conducted to demonstrate its viability, convenience, efficiency and future potential.

II. THE HOLISTIC PLATFORM

In terms of vision and communication systems the platform presented in this work represents a considerable leap forward when compared to the previous ColCOSΦ platform [1]. Combining these two subsystems leads to the latest version of our platform shown in Fig. 1. With RF wireless communication module and camera, Colias can now

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TABLE I

COMPARISON OF EXPERIMENT PLATFORM FUNCTION

Platform (Supported Robot)	Dynamic visual environment	Robot visual sensor	Communication	Pheromone	Comment
PΦSS [10] (Mona [11])	No	No	No	LCD display	Designed for virtual pheromone research, Cheap and convenient.
ARK [12] (Kilobot [13])	No	No	IR(download) LED(upload)	IR Data (Augmented Reality)	With AR technology, can experiment with large numbers of swarming robots, but limited ability to upload data from the robot.
Kilogrid [14] (Kilobot)	No	No	IR	IR Data	Extension of kilobot's communication capabilities.
ARDebug [15] (E-puck [16], Psi Swarm [17])	No	Equipped	WIFI or Bluetooth	IR Data (Augmented Reality)	Enables different robots to complete experiments together, with good compatibility.
Robotarium [18] (GRITSBot[19])	No	No	2.4G RF or WIFI	Projector	Can remote access to the robot via the Internet.
(This work)ColCOSΦ (**Colias** [9])	**Yes**	**Equipped**	**2.4G RF or Bluetooth**	**LCD display**	**Can provide dynamic visual environment.**

effectively grab information from visual surroundings, send its own data and receive remote commands. With a new embedded LED wall surrounding the arena, the whole system now can provide a wide range of visual information. The combination of improvements to the platform makes the study of vision-based swarm robotics, robots control in a dynamic and complex environment, and the coordination of multiple cues in a complex environment, easy to preform and repeat at low cost. The following two subsections will introduce these two new-added systems in detail.

A. *Wall display system*

Visual cues are often the most informative data that an organism can obtain from its surrounding environment. Hence, vision plays a vital role in both biology and robotic studies. However, in previous studies, the visual world has comprised either an unstructured open environment or has been kept regular and simple. These methods are inherently problematic since the dynamic complexity of the visual scene is hardly ever subject to control via parameters or configurations. In this work, we have upgraded the surrounding wall of the ColCOSΦ arena with an LED display system from which the visual elements can be accurately and readily maintained or refreshed in real time.

As illustrated in figure1, the wall display system is constructed using 22 (11×2) units of RGB LED blocks with approximately 20Dots per Inch (DPI) (size $200mm \times 150mm$). These are arranged vertically along the bottom display system forming a 3520×120 pixel screen. The height of the wall display is 150mm.

To further demonstrate the applicability and flexibility of the LED display system, for both robotic and insect studies, we show how the visual environment can be constructed in our platform as shown in Fig. 2. For robot navigation [20] and *Drosophila* visual place learning [21], one can display any kind of views on the LED screen and conduct systematic testing in different visual environments just by changing the image want to be displayed on the wall. For the heading direction system of *Drosophila* [22], [23], the closed-loop setup (where the moving speed of the fly is used to move the visual bar on the LED screen) can be implemented in our platform by combining the directional information derived from the localization system.

B. *Communication*

Creating the capability to transmit data between individual robots and the PC not only facilitates downstream back-tracking analysis of the experimental data but also permits remote control and the adjustment of collective parameters in real time. In the presented platform, communication between individual robots and the holistic platform is implemented by Radio Frequency (RF). The wireless communication is implemented using the NRF24L01p RF transceiver module. It is a small-package one-chip transceiver that uses 2.4G band and Gaussian frequency-shift keying (GFSK) modulation. Compared to other RF techniques such as WiFi and Bluetooth in which a stable connection that requires time-consuming handshake processes, this RF module, that works on the OSI link layer, can provide fast and flexible data transmission which is advantageous for ad-hoc networks in which the agents can join and leave the network freely.

The wireless module is shown in Fig. 1. In our work, one STM32F4-Discovery board developed by ST-Microelectronics with an attached RF module serves as the wireless access point (WAP), which communicates with the PC host (CoSwarm GUI) via a USB port. Inside the holistic platform, each robot is mounted with a Colias-eXconnect module that has been assigned with a unique address and configured to silent mode by default. It sends an acknowledging data packet that contains 32 bytes to the WAP only in response to periodic requests. In our application, one wireless access point monitors up to 10 robots simultaneously. The data rate of a single robot agent can be up to 20KB/s with an average power consumption of 5mW, which is adequate for periodic running status and algorithm data collection.

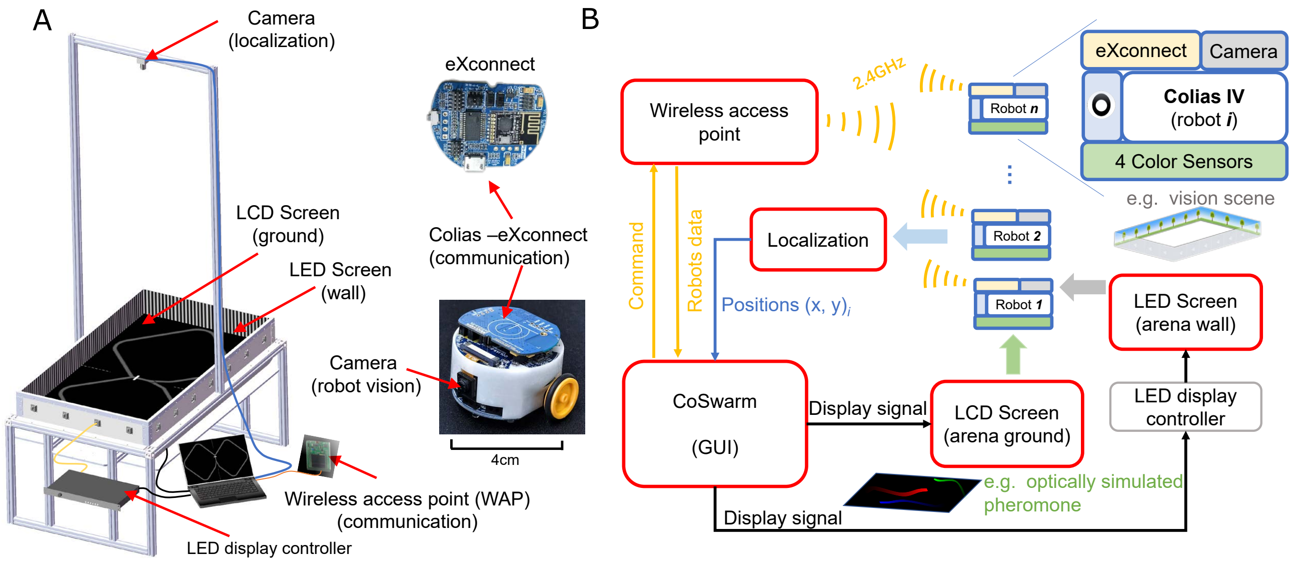


Fig. 1. The holistic platform. **(A)** The 3D constructed model of the arena and the picture of Colias-IV robots with the new developed communication module-eXconnect. **(B)** The schematic diagram showing the functions of each part of the presented platform and their interaction with robots.

To test the performance of the communication system, we put four robots at the center of the arena and then send motion commands to the robots via the PC host (i.e., CoSwarm GUI) to start the test. During the whole test period, data from the real-time sensor is transmitted to the host and plotted in the GUI as shown in Fig. 3. This test demonstrates that the communication system is reliable and stable and can work in real time.

III. CASE STUDY

In order to validate of the presented platform, a case study was designed aiming to test every component of the presented platform.

A. Scenario

As an emerging concept, the Internet of Vehicles (IoV) has gradually come to dominate the ongoing development of intelligent transportation systems. This is because it has many advantages, one of which is the collection of reliable real-time data from the internet [24]. The data can be shared among vehicles thereby helping to guide their selection of routes with lower flow density, and consequently improving transportation efficiency. To implement this concept on our platform we displayed, on separated areas of the arena wall, visual scenes with different complexities as assessed by an insect-inspired visual model - angular velocity detection model (AVDM) [25]. Tests have shown that this model has a higher response when planar rotation occurs within the environment using additional vertical bars in the visual field. Therefore we displayed nothing no one half the wall screen and a sine-wave gratings (a kind of classical visual pattern used to test insects vision based behavior) on the other half (see Fig. 4). The hypothesis was that in a robot with AVDM running, there should be a difference between the AVDM outputs when it is moving in the left and right parts (x-axis based) of the arena. Then inspired by the strategy from IoV, we use this difference to help the robot to navigate to the part of the arena with lower visual complexity (i.e., the side with nothing displayed on the wall and corresponding to the roads with low flow density in real life transportation). As the main target of this case study is to verify the applicability of the whole platform, we just simplify the logic of robot control by displaying simple simulated traffic lanes (see the roads with a diamond shape in Fig. 4) and setting a bifurcation where the robot should make a decision of turning left or right (white horizontal bar shown in Fig. 4). To guide the robots in their decision-making, a global variable P_L is defined as the possibility of turning left, meaning that with a higher value of P_L, the robot is more likely to turn left (see the algorithm of robot control in Algorithm 1).

The final step (to close the loop) is how to use the visually sensitive AVDM outputs to determine P_L. Intuitively, P_L is calculated by:

$$P_L = \frac{AVDM_R}{AVDM_L + AVDM_R} \tag{1}$$

where $AVDM_L$ and $AVDM_R$ are the mean value of the AVDM outputs from the robots running in the left and right side of the arena respectively. Whether the AVDM data should be taken as the left or right is based on the real-time position((x_i, y_i)) data of i^{th} robot from localization system, thus:

$$AVDM_L = \frac{1}{N_{x_i < length/2}} \sum_{x_i < length/2} AVDM_i \tag{2}$$

$$AVDM_R = \frac{1}{N_{x_i > length/2}} \sum_{x_i > length/2} AVDM_i \tag{3}$$

Subsequently, the robot's decision-making at the bifurcation can be guided by broadcasting P_L to all the robots via the RF communication system. The whole scenario is shown in Fig 4.

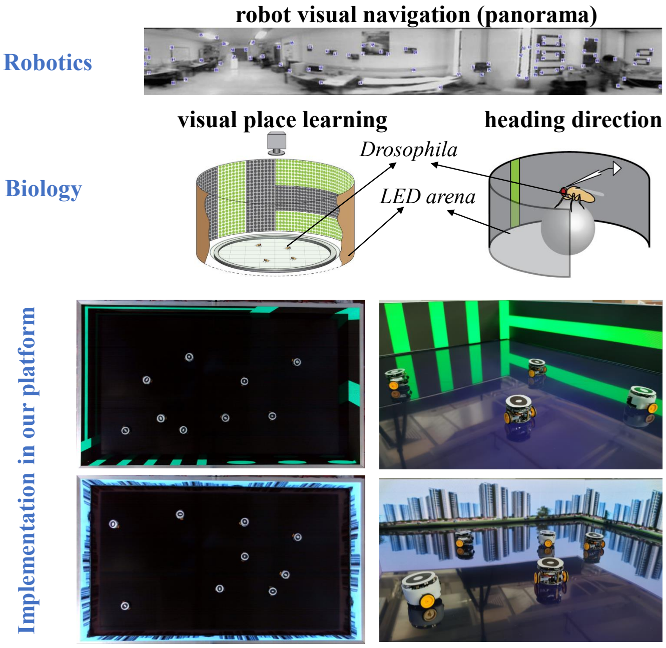


Fig. 2. Typical examples of research scenarios using visual imaging that can be readily implemented in the presented platform. The top figure depicts a robotics visual navigation area, adapted from [20], where a robot homing strategy employing panoramic views is presented. The middle figures are adapted from [21] and [22], and relate to biological studies of *Drosophila*, concerning visual place learning and heading systems which prevail in the insect community. The four figures at the bottom show how the above paradigms can be easily and flexibly implemented in our platform.

Algorithm 1: IoV simulation control strategy

```
while power on do
    if Is Image ready then
        process the AVDM algorithm;
    Detect obstacles in front;
    if No obstacle detected then
        Detect the bifurcation mark;
        if On the bifurcation then
            Turn to a direction according to the $P_L$ ;
            if rand $N(0,1) \leq P_L$ then
                Turn Left;
            else
                Turn Right;
        else
            Follow the track displayed on the arena;
    else
        Stop and wait for a while;
    Check Wireless mission flags;
    if Whether to send data then
        Send sensor data including AVDM results;
    if Has received command and data from PC then
        Update configuration including $P_L$;
```

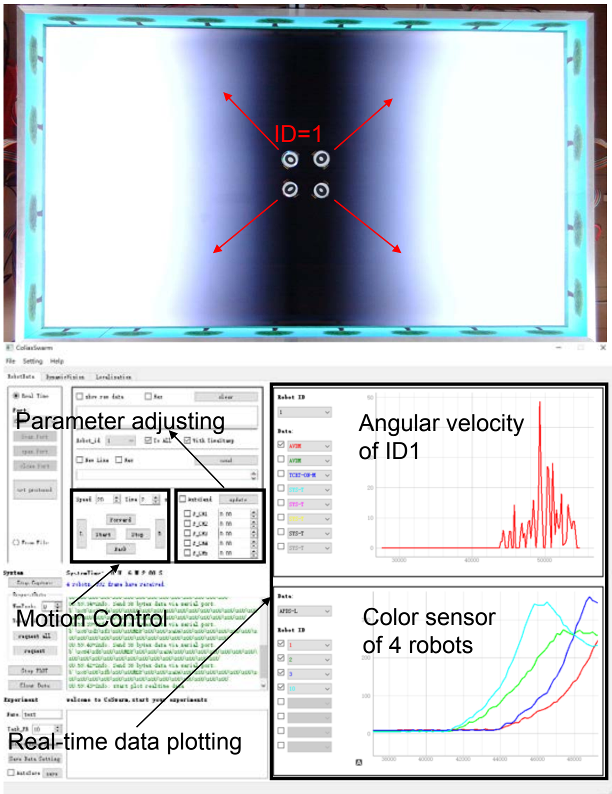
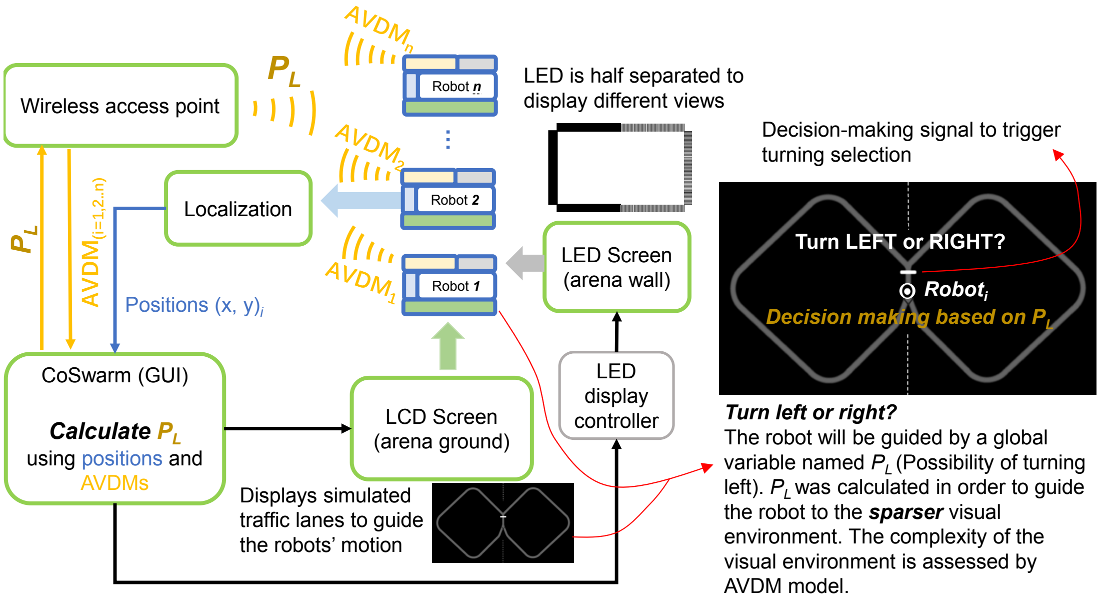


Fig. 3. The test of the communication system. The top picture shows the beginning of the test when four robots are placed in the center of the arena. Robots start to move in a straight line once they receive the command via the RF communication triggered by our pressing the start button in the motion control panel of the CoSwarm GUI. The data received from the robots is plotted on the GUI, here showing the angular velocity of robot ID=1 and all the values transmitted from the robot's color sensors. The accuracy of these values can be inferred by the fact that the brightness of the arena ground is higher at the corners.

B. Results

Fig. 5 shows the main process and results of the experiments. AVDM outputs with respect to robot positions (second row in Fig. 5) demonstrate the ability of AVDM to discriminate between the visual scenes on the wall display. Note that when the robot runs within the part of the arena with no visual pattern, AVDM outputs still occur because the robot has a wide field of view; it can still "see" things including other moving robots or the mirrored items on the LCD screen (arena ground). To assess the performance of broadcasting P_L to guide the direction taken bu the robot at the bifurcation, the value of P_L and 1min time interval x-position distributions has been plotted in Fig. 5. All the results lead to the conclusion that the whole processing loop is successfully closed. Firstly, P_L will rapidly change after the visual scene on the walls are swapped around, and conversely will become constant number in an unvaried visual environment (third row in 5). Secondly, the distribution of the robots' x-position suggests the robots are likely to turn towards the part of the arena exhibiting with sparser visual surroundings (fourth row in 5).

Results from the experiments above demonstrate that all



Turn left or right?
The robot will be guided by a global variable named P_L (Possibility of turning left). P_L was calculated in order to guide the robot to the ***sparser*** visual environment. The complexity of the visual environment is assessed by AVDM model.

Fig. 4. The scenario of the case study. All parts of the newly presented platform are involved: The RF communication system collects the AVDM outputs from robots and broadcasts P_L to the robots. Position data from their localization helps to determine whether the AVDM outputs of a specific robot belongs in left or right part of the arena. The LED screen wall displays different visual scenes and the LCD screen on the floor provides the optic cues for robot motion control.

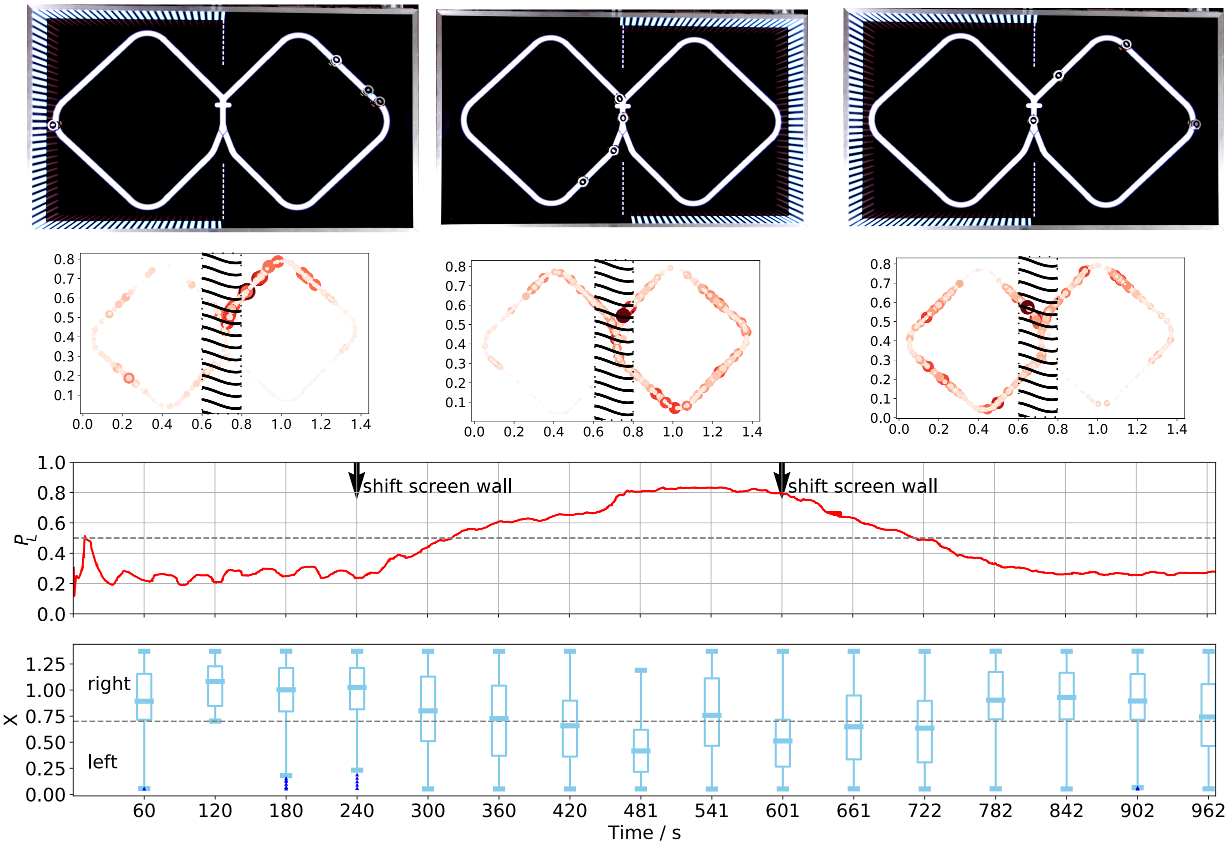


Fig. 5. Results of the experiment during which the wall screen has been shifted twice. The first row shows top-down screenshots of the arena along with the sine-wave gratings on different parts of the wall screen. The second row depicts the AVDM outputs with respect to robot position. Significant differences can be seen between the left and right parts. The shadowed area marks the data that are excluded from the calculation of P_L. The last two rows show the value of P_L and x-position distribution during experiments.

the sub-systems of the newly proposed platform are essential to the case study, thereby confirming its applicability and serviceability for further studies.

IV. Conclusions and Discussion

In this paper, a versatile swarm robotics experimental platform with the ability to simulate multiple pheromones, and to providing dynamic visual scenes and real-time communication and robot localization, has been presented. A case study combining the simulation of IoV and implementation of insect-inspired motion vision has been successfully undertaken, not only confirming the validity of the platform, but showing how complex scenarios are facilitated by making use of each part of this platform. Regarding future research, investigations into combining vision and pheromone sensing will continue. Many bio-inspired models such as the collision detection model LGMD [26] can be verified in this platform. It can simulate a city scenario, and the micro robots run with the LGMD model to test the efficiency of LGMD with very low-cost. Systematic investigation of other visual models including insect visual navigation [27] for a single robot can also be deployed and explored in this platform. Since this platform can be used to construct a complex environment containing multiple cues, studies of optimal cue integration and coordination can also be carried out [28], [27]. In addition, although the current wireless communication protocol is simple, it can be upgraded so that the remote monitoring and recording of a real-time view of the first-person perspective could be realized. This will greatly benefit the analysis of visual models.

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