Investigation of male searching for female silkworm using an artificial pheromone in free-space environment

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Abstract. A male insect can exhibit interesting motions and behaviours when it detects the female pheromone. The behaviour shown by a male insect is frequently used for nature-inspired robotics research especially for various applications such as teleoperated and autonomous source locating robots. In this research, we investigate the male searching for female behaviour by changing the source of pheromone using an artificial pheromone. This research is conducted by using three male insects, where, each insect performs three trials and the chosen environment is a free-space environment. The three male insects perform satisfactorily without having any hurdle in a free-space scenario using artificial pheromone. It is concluded that the motion behaviour of insects can be applied in the real robot for searching mission.

1. Introduction
Searching for food, mates, and escaping from a predator by using the olfaction systems are the important behaviours in insects and is called as the searching behaviour. Naturally, insects depend on their sensory systems to obtain the necessary information to guide their motion [1]. The capability of an insect to decode the complex information is outstanding. They can simply translate the information and convert it into a motion straightforwardly. As the insects can exhibit the straightforward motion, the researchers were attracted to investigate the insect behaviour and taking them as the biological inspiration for searching behaviour such as ground robot [2], and aerial robot [3] both for autonomous or operated/teleoperated by insect [4,5].

In some studies, the best-studied insect model is the silkworm, Bombyx mori, and fruit fly, Drosophila melanogaster [6]. Where, the investigation of searching behaviour similarly to real male searching for female insects already conducted both using real pheromone [5,7,8] or artificial pheromones with a bit of modification on insect genetic [4,9] which makes the insect adapt to a light source [4]. In the case of obtaining the female insect is difficult. Thus, artificial pheromone can be an alternative solution to overcome the limitation of female insect availability.

In particular, the insects show a straightforward behaviour when they detect the pheromone. Based on [4-5,7,9] the silkworm was chosen because it shows the best model for searching behaviours. In this study, we investigate the behaviour of silkworm when it searches the artificial pheromone location and finds the searching effectiveness with comparison to a mini quadrotor.

This paper is organized in the following. Section 2 describes the problem in this study. The proper selection for the insect is described in section 3. The investigation and the experimental setup is given.
in section 4. The result of this study is given in section 5, where the comparison result between insects and the mini quadrotor will be elucidated. The conclusion and future works are given in section 6.

2. Problem statements
This study aims to observe the behaviour of an insect motion in searching the artificial pheromone of the female. In the rest of this paper, we will define the artificial pheromone of the female as the gas source. The idea of conducting this research is to show the effectiveness of searching the gas source by an insect that will have an impact when the implementation is changed by using a robot. In this study, two points are pointed out to obtain the research objective.

The first point of this study is the proper selection of the insect that can be a model of searching for the gas source. Various insects might exhibit unique olfaction behaviour. However, to obtain the best-insect model, the proper justification is needed with a clear parameter description.

The second point is the implementation of a behaviour model into a robot. The insect’s motion behaviour will be implemented to a robot for the comparison of whether the motion can be implemented or too difficult to be implemented. In this study, we select a mini quadrotor as a target implementation. The behavioural model is injected to a quadrotor as the algorithm to search the gas source. The quadrotor platform for this study is Parrot Mini-drone Mambo, from Parrot Inc. The purpose of using the quadrotor in this study is to show whether we can apply the insect behaviour to a robot effectively or not.

3. Selection of the insect for male searching for a female pheromone study
In this study, we select an insect as the searching model. Insects show simple natural behaviour, for detecting a signal through its olfaction systems, yet effective in recognizing the complex substance [10]. As an example, when the insects are searching for the food or mate using their olfaction systems, they will execute the command to search their objective immediately. Particularly, we can see the pattern of insect behaviour is rather straightforward.

In general, we choose the silkworm as the model for gas source searching as it exhibits a straightforward motion such as surge, zigzag, and loop when they detect any gas information [7]. A male silkworm can exhibit an interesting motion and behaviours when it detects the female pheromone, otherwise, it will remain stationary in its position that makes the silkworm as the best model for this study.

The silkworms we employ in this study are adult silkworms. To obtain healthy silkworm, the treatment must through several parameters.

- The number of days to categorize the silkworm as an adult is 3 – 5 days [11].
- The temperature of the refrigerator to keep the adult silkworm is 23° - 28° [12]. Where we select the temperature 26° [11] to avoid the imperfect of an adult silkworm.
- Relative humidity approximately 50% - 60%. (4) The silkworm shows no irregular growth such as producing faces frequently compared to another individual.

4. Experimental design
This section describes the experimental setup. After we have selected the silkworm based on section 3. Then, the proper validation from our investigation, the setup is described as follow:

- The number of silkworms used in this study is three males. Each male conduct three trials.
- The number of mini quadrotor trials is ten times.
- The artificial pheromone used is a bombykol with 100 ng. Other details of bombykol can be found in [11].
- No time limit for insect, but 100 seconds for validation using mini quadrotor.
- The area dimension for insect perform their motion is 0.5 m x 1.0 m. The area for mini quadrotor is 1.0 m x 3.0 m. The area is free from obstacle.
- The wind speed is approximately 0.65 m/s.
The experimental design detail is shown in Figure 1.

**Figure 1.** Experimental setup of this study.

5. Result and discussion
The experimental result of the silkworm searching for the gas source is shown in Figure 2.

**Figure 2.** Three kinds of trajectory of three male silkworms. (a) The trajectory of moth 1, (b) The trajectory of moth 2, (c) The trajectory of moth 3.

The result obtained from three male silkworms when performing a search motion toward the gas source. The three silkworms exhibit a 100% searching in a free-space area. From the results of Figure 2, all three males’ silkworm which represented in figure (a),(b), and (c) have no difficulty to search the gas source even though the source of the pheromone was not directly exhibited by a female silkworm. From Figure 2, the pattern of the silkworm’s trajectory less like the trajectory described in Kanzaki, et al. [7]. Although in the real experiment the trajectory result is similar with [7], where the pattern is surge-zigzag motion.

The next step is to implement the searching behaviour of the silkworm into the mini quadrotor to investigate the performance and effectiveness in searching using the insect behaviour with the same area configuration. The result is shown in Figure 3. The success ratio in a mini quadrotor shows 70% of success from ten trial with the given constraint in the previous section. The possibility of the success ratio on mini quadrotor is lower than the real silkworm and this is due to the limitation defined in the experimental design. On the other hands, silkworm moth does not give any external due to its motion cause by its natural behaviour. Therefore, from the validation result, we can see that the male searching for female by silkworm can be implemented to a robot platform such as mini quadrotor that we use for this study.
6. Conclusion
This paper presents an investigation of male searching for female using artificial pheromone. Where, the experiment shows a 100% success ratio which means there is no problem encountered by three male silkworms in the free-space environment. The trajectory shows the pattern of zigzag motion, however, in the visualization from camera the silkworm is less-like zigzag. Albeit the problem of likeliness of trajectory pattern, the motion of silkworm is indeed straightforward where we can design the motion to mini quadrotor. The future work of this study will focus on observing the way to improve the performance of searching the gas source using mini quadrotor after we obtain the pattern of silkworm’s trajectory.

References
[1] Bell W J 1990 Searching behavior patterns in insects Annu. Rev. Entomol. 35 447–67
[2] Hernandez Bennetts V, Lilienthal A J, Neumann P and Trincavelli M 2012 Mobile robots for localizing gas emission sources on landfill sites: is bio-inspiration the way to go? Front. Neuroeng. 4 20
[3] Neumann P P, Hernandez Bennetts V, Lilienthal A J, Bartholmai M and Schiller J H 2013 Gas source localization with a micro-drone using bio-inspired and particle filter-based algorithms Adv. Robot. 27 725–38
[4] Shigaki S, Fikri M R, Hernandez Reyes C, Sakurai T, Ando N, Kurabayashi D, Kanzaki R and Sezutsu H 2018 Animal-in-the-loop system to investigate adaptive behavior Adv. Robot. 32 945–53
[5] Ando N, Emoto S and Kanzaki R 2013 Odour-tracking capability of a silkmoth driving a mobile robot with turning bias and time delay Bioinspir. Biomim. 8 16008
[6] Goldsmith M 2001 Bombyx mori Encycl. Genet. 231–3
[7] Kanzaki R, Sugi N and Shibuya T 1992 Self-generated zigzag turning of Bombyx mori males during pheromone-mediated upwind walking Zoolog. Sci. 9 p515-527
[8] Gomez-Marín A, Stephens G J and Louis M 2011 Active sampling and decision making in Drosophila chemotaxis Nat. Commun. 2 1–10
[9] Kuwana Y, Nagasawa S, Shimoyama I and Kanzaki R 1999 Synthesis of the pheromone-oriented behaviour of silkworm moths by a mobile robot with moth antennae as pheromone sensors Biosens. Bioelectron. 14 195–202
[10] Kohl C and Wagner T 2006 Gas Sensing Fundamentals Springer Ser. Chem. Sensors Biosens.
[11] Shigaki S, Okajima K, Sanada K and Kurabayashi D 2019 Experimental Analysis of the Influence of Olfactory Property on Chemical Plume Tracing Performance IEEE Robot. Autom. Lett. 4 2847–53
[12] Rahmathulla V K 2012 Management of climatic factors for successful silkworm (Bombyx mori L.) crop and higher silk production: a review *Psyche (Stuttg).* 2012