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Experimental investigation of the effects of periodic intake on odor source localization behavior of silkmoth

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Abstract: In this study, we experimentally verified the relationship between periodic odor intaking and localization performance of an adult male silkmoth, which uses female sex pheromone as a cue for localization behavior. The adult male silkmoth is able to localize to a female by walking with strong flapping when it receives sex pheromones with antennae on its head. Although the silkmoth can not fly, it uses flapping to obtain propulsive force and to actively intake odor in its own direction. The flapping frequency is not always constant and is modulated depending on the situation. However, the relationship between frequency modulation and localization behavior is still unclear. We employed an insect-machine hybrid system to generate a periodic odor intaking that is equivalent to the flapping of wings, and measured the relationship between the odor intaking and behavioral changes during the odor source localization. The results suggest that it is important not only to increase the odor intake frequency but also to make a big difference in the airflow between odor interception and intake.

Keywords: periodic odor intake, odor source localization, insect-machine hybrid system, male silkmoth

1. INTRODUCTION

In this study, we employed an insect-machine hybrid system to investigate the relationship between periodic odor intake generated by the flapping of an insect's wings and its odor source localization behavior. We focus on an adult male silkmoth, which localizes a female relying on a sex pheromone. When the adult male silkmoth detects a female sex pheromone, it can localize to the female by walking [1]. The silkmoth moves with its wings flapping vigorously, not for flight, but to actively intake odor in its own direction [2]. This unique behavior enables efficient localization to the female, but it is still debatable whether the mere phenomenon of active odor intake contributes to efficient localization behavior. The silkmoth modulates its flapping frequency between 20 and 30 Hz during localization behavior, which may be important for female localization [3]. Therefore, we constructed a device that simulates the flapping of the silkmoth wings and experimentally investigated the relationship between odor intake frequency and behavioral changes.

2. CONSTRUCTION OF INSECT-MACHINE HYBRID SYSTEM

Fig. 2 shows an insect-machine hybrid system employed in this research. As shown in Fig. 2, the insect-machine hybrid system can measure the movement of an insect installed at the top of a sphere, and moves by reflecting the movement of insects. A device that can simulate odor intake by the flapping of wings is placed in front of the insect. This device consists of a small fan and a solenoid, and by opening and closing the solenoid at high speed, it is possible to periodically shut off and intake odors. Using airflow visualization techniques, we measured the airflow generated by the device and found that it can perform periodic intake at a maximum of 25 Hz, as shown in Fig. 2. By placing this device in front of a silkmoth whose wings have been physically removed, it is possible to induce periodic fluctuations in odor intake similar to the flapping of wings, and to measure changes in localization behavior.

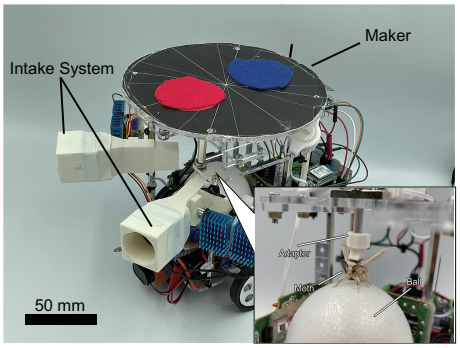

Fig. 1. Insect-machine hybrid system.

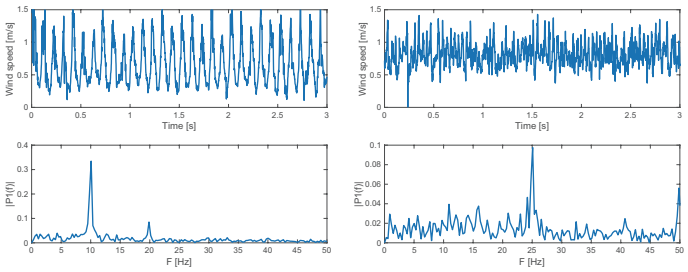

Fig. 2. Flow velocity change due to periodic intake.

The control period of the insect-machine hybrid system was 10 ms, and it was set to move at the same speed as the silkmoth.

† Shunsuke Shigaki is the presenter of this paper.

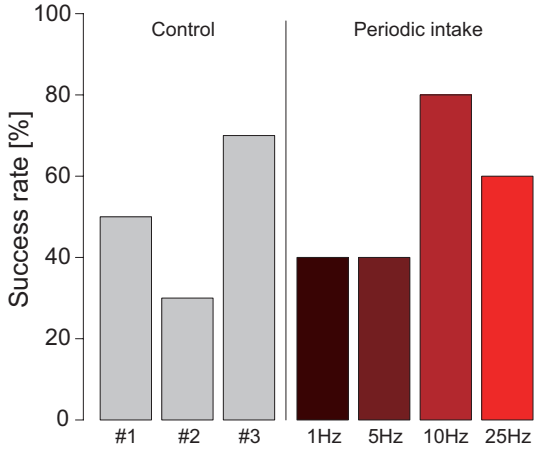

Fig. 3. Localization success rate of each condition.

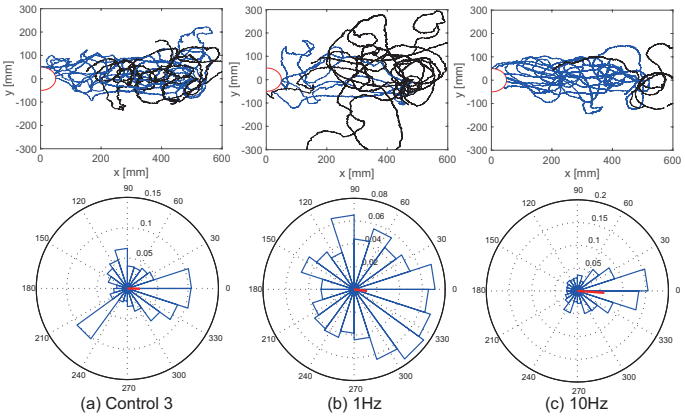

Fig. 4. Trajectory and posture angle histograms. The 0-degree direction of the posture angle histogram indicates the upwind direction.

3. ODOR SOURCE LOCALIZATION EXPERIMENTS

3.1. Experimental design

We investigated the relationship between periodic intake and modulation of the localization behavior of a silkmoth by conducting actual odor source localization experiments using an insect-machine hybrid system. The following seven conditions were used in the odor source localization experiments.

1. Control A: Intact conditions. The wings of the silkmoth are not removed and a periodic intake device is not installed.
2. Control B: No intake device.
3. Control C: Continuous odor intake.
4. Condition 1: Intake frequency: 1 Hz
5. Condition 2: Intake frequency: 5 Hz
6. Condition 3: Intake frequency: 10 Hz
7. Condition 4: Intake frequency: 25 Hz

For Control B, C, and Condition 1–4, experiments were conducted with the wings of the silkmoth physically removed.

The origin of the experimental field was the odor source, and the insect-machine hybrid system was placed 0.5 m away from the odor source. Successful localization was defined as when the system completely contacted the odor source. We set a time limit of 180 seconds, and failure was defined as no localization after the time limit had elapsed. Experiments were conducted using 10 silkmoths for each condition.

3.2. Results

The localization success rate for each condition is shown in Fig. 3. Gray bars represent the Control condition, and colored bars indicate periodic odor intake. The figure shows that the periodic odor intake at 10 Hz resulted in a higher localization success rate than continuous intake or high-frequency intake such as 25 Hz.

The localization trajectories and changes in posture angle for the lowest localization success rate of 1 Hz, the highest success rate of 10 Hz, and continuous intake were found to move more linearly with higher-frequency intake (Fig. 4). However, the posture angle histogram showed that when we set the continuously intake, it moved linearly, but the frequency of moving in the downwind direction increased. These results suggest that not only strong odor intake, but also intaking odors at high frequency with sharpness is effective for odor source localization behavior of the silkmoth.

4. CONCLUSION

In this study, we measured the relationship between periodic odor intake and odor source localization behavior in an adult male silkmoth using an insect-machine hybrid system. The insect-machine hybrid system was equipped with an intake device that simulates the effect of odor intake generated by the flapping of the silkmoth wings. This device was capable of periodic intake at a maximum of 25 Hz. Localization experiments were conducted using the insect-machine hybrid system under seven different conditions, suggesting that continuous intake or high-frequency intake does not necessarily improve odor source localization performance.

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REFERENCES

[1] R. Kanzaki, N. Sugi and T. Shibuya, ”Self-generated zigzag turning of *Bombyx mori* males during pheromone-mediated upwind walking”, *Zoological Science*, Vol. 9, pp. 515–527, 1992.

[2] C. Loudon and M. A. Koehl, ”Sniffing by a silkworm moth: wing fanning enhances air penetration through and pheromone interception by antennae”, *Journal of experimental Biology*, Vol. 203, pp. 2977–2990, 2000.

[3] R. Yanagisawa, S. Shigaki, K. Yasui, D. Owaki, Y. Sugimoto, A. Ishiguro and M. Shimizu, ”Wearable Vibration Sensor for Measuring the Wing Flapping of Insects”, *Sensors*, Vol. 21, No. 2, 2021.