Comparison of signal processing methods for the utilization of insect antenna as odor sensor

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1 Introduction

Many animals utilize the chemical properties of their surroundings for cognition or decision-making. Insects that have smaller nervous systems than mammals are similarly able to utilize odor to perform important tasks such as searching for feeding and identifying mating partners and predators [1]. One of the reasons an insect is able to use odors so well is that it possesses excellent olfactory organs. Most insects have olfactory organs in the antennae of their heads and are known to respond to multiple odors. The antenna of an insect is expected to be utilized as a substitute for odor sensors because it is much more sensitive than engineering odor sensors and responds differently depending on the type of odor. Previous studies have employed insect antennae for odor identification [2] or as a drone's olfaction [3]. In these studies, the electric potential response of antennae to an odorant called EAG (electroantennography) is measured and used as a substitute for odor sensors. The signal-to-noise ratio of EAG is much lower than that of odor sensors because EAG is a kind of physiological response. For that reason, although signal processing for EAG is important to extract the desired signal, there has been little discussion on signal processing in past studies. In this study, therefore, we experimentally verify a signal processing method for the stable use of the insect antenna as the odor sensor. Specifically, we apply signal processing that is inspired by the behavior of the antennal lobe, the primary olfactory center in the insect brain. In addition, we investigate the effectiveness of signal processing suitable for EAG by conducting actual odor source localization experiments.

2 Signal Processing Methods for EAG

This study aims to improve the stability of using insect antennae as an odor sensor by a signal processing method that takes after the neural response of the antennal lobe. It has been reported that the antennal lobe connected to the antennae responds transiently to a single odor stimulus and gradually attenuates [4]. Moreover, it has been reported that the response changes depending on the history of previously received odor stimuli [5]. Based on the above, we focused on an exponentially weighted moving average (EWMA), which is an averaging process that exponentially changes the weighting of a weighted moving average. EWMA emphasizes recent data and does not completely truncate old data, allowing it to filter signals while relying on past history. The equation of EWMA is as follows (Eq. 1);

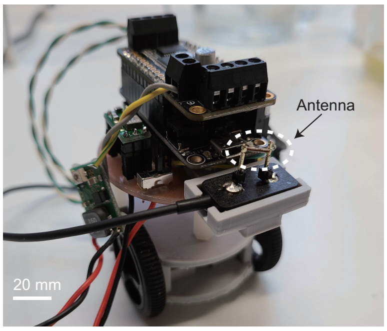

Figure 1: An insect-sized robot equipped with an antenna.

$$y_k = (1-\alpha)y_{k-1} + \alpha x_k \tag{1}$$

where y_k and x_k are the output and input at time k, respectively, and α is the smoothing factor. The α is a free parameter that allows us to adjust the degree to which past information is used. We investigated the localization success rate by varying the α from 0.1 to 0.9 through simulation and 0.2 was found to be the highest; therefore, we utilized 0.2 in the experiment.

The surge-zigzagging-loop algorithm [6] that can be localized only by odor information was employed in this study. We set a threshold value for the output value y_k of Eq. 1 and estimated the timing of odor detection because the algorithm switches its behavior depending on the timing of odor detection. The threshold value was determined based on the value obtained for 5 seconds in an odorless environment.

As a signal processing method for comparison, we employed the low pass filter (LPF) and differential value for

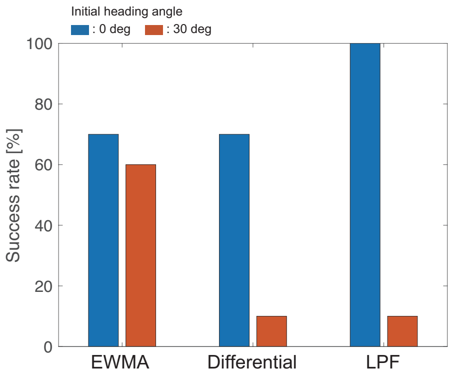

Figure 2: The success rate of each condition.

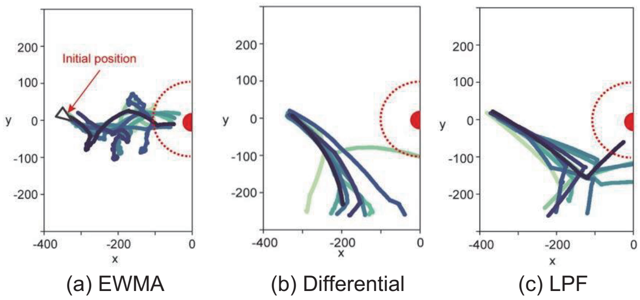

Figure 3: Localization trajectory at initial heading angle of 30 degrees.

EAG. In these methods, a threshold value is also set to obtain the odor detection timing. As in the above methods, the threshold value was determined based on the value in the odor-free environment.

3 Odor source localization experiment

3.1 Experimental conditions

A self-made insect-sized differential two-wheeled robot was utilized in the experiment (Figure 1). An antenna was isolated from an adult male hawkmoth, *Manduca sexta*. The antenna of the hawkmoth was connected to a compact amplifier (gain: 1000×) via a conductive gel (Spectra 360, Parker Laboratories, USA).

The experimental field was conducted inside a wind tunnel, and the wind speed in the wind tunnel was 0.35 m/s. We utilized linalool as an odor source. The robot started the experiment from a position 300 mm away from the odor source. Moreover, we investigated the localization performance against the degree of the arrival of odor depending on the initial condition by setting two initial heading angle conditions: 0 and 30 degrees. Ten trials were conducted for each condition.

3.2 Results

The localization success rate and trajectory for each condition are shown in figures 2, 3. In the case of EWMA, the localization success rate is more than 60% regardless of the initial posture, but the localization performance varies greatly depending on the initial heading angle when differential values and LPF are used. The trajectory in figure 3 is for the condition in which the initial heading angle is tilted by 30 degrees. In the case of EWMA, the robot moves to the odor source while modifying its behavior appropriately, but in most of the other conditions, the robot moves out of the odor plume and fails in its search. The results suggest that the sensory-motor balance can be improved by modifying the signal processing of the sensory organs to imitate the antennal lobe, and that appropriate behavioral decisions can be made.

4 Conclusion

In this study, we experimentally verified the effect of signal processing similar to the response of an antennal lobe on EAG, aiming at the stable use of an insect antenna, which is an excellent odor sensor. We employed EWMA as a signal processing method that can take into account the past history of EAG. Experiments on odor source localization showed that EWMA provides more stable localization performance than the conventional method of applying differential values or LPF to EAG, without being affected by the ease of obtaining odor information. This suggests that it is possible to modulate the sensory-motor balance by applying appropriate signal processing.

In the future, we contribute to the further promotion of the engineering use of insect antennae by conducting a comprehensive investigation of their applicability to other insect antennae and the extent to which past historical information can be used.

Acknowledgments

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