Insect-Machine Hybrid System for Understanding and Evaluating the Sensory-Motor Control*

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Abstract—Insect-machine hybrid system is an experimental system which has a mobile robot as its body. The robot is controlled by the insect through its behavior or the neural activities recorded from the brain. As we can arbitrarily control the motor output of the robot, we can intervene at the relationship between the insect and the environmental conditions.

I. INTRODUCTION

Adaptability to changing circumstances is a key feature of animals. Insects are well suited for multidisciplinary studies in brain research involving a combined approach at various levels, from molecules to single neurons to neural networks, behavior, and modeling. Insect-machine hybrid system is an experimental system which has a mobile robot as its body. The robot is controlled by an insect’s behavior (i.e., insect-controlled robot [1]) or the neural activities recorded from the brain (i.e., brain-machine hybrid system [2]). As we can arbitrarily control the motor output of the robot, we can alter the relationship between the insect and the environmental conditions. This system will contribute to evaluate the adaptability of behavior, and to a better understanding of the dynamics of the neural networks that generate adaptive behavior under real circumstances. Focusing on sensory-motor control by sex pheromone in the silkmoth, Bombyx mori, we present the behavioral strategy for odor-source orientation and its neural mechanisms as well as a novel approach using an insect-machine hybrid system for evaluating and understanding adaptive behavior in insects.

II. INSECT MACHINE HYBRID SYSTEM

A. Odor Source Orientation Behavior in Insect

Male silkworms exhibit a characteristic zig-zagging pattern as they walk upwind toward the pheromones released by conspecific females. Upwind walking toward a pheromone source is largely controlled by an internally generated steering program. Once initiated by a single puff of pheromone, the moth exhibits a programmed sequence of walking consisting of brief bouts of straight-line walking and zig-zag turns followed by looping. Upon stimulation, male moths exhibit straight-line walking. Upon the loss of pheromone stimulation, males exhibit zig-zagging walking with a significant increase in time between each turn followed by looping. This programmed sequence of movements is reset and restarted from the beginning in response to pulsed pheromonal stimulation. Therefore, with increasing frequency of stimulation as it nears an odor source, the path of a moth becomes straighter with repeated straight-line walking. In contrast, if the frequency of stimulation decreases, the path becomes a complex combination of zig-zagging and looping.

B. Insect-Controlled Robot (ICR)

In order to evaluate the behavioral capabilities of insect, a mobile robot driven by a genuine insect was fabricated. The ICR is a two-wheeled robot equipped with behavioral measurement, signal processing and motor control subsystems. A male silkworm is used as a ‘driver’. The ICR enables us to appropriately manipulate the bias quantitatively at arbitrary times. We are able to put the moth into an extraordinary situation in which the moth is required to change its behavior, using adequate sensory-motor systems for successful orientation.

C. Brain-Machine Hybrid system (BMHS)

To understand the neural basis of adaptive behavior, recording dynamic activities of a brain during behavior is required. For this purpose we fabricated the BMHS which is a mobile robot driven by steering (command) signals recorded from the brain. We selected the activities of the neck motor neurons in the 2nd CNb corresponding to walking of the silkworm as steering signals for controlling the robot. Using the BMHS we could record moment to moment neural activities for the first time from the brain during unintentional conditions by turning bias under real circumstances.

III. CONCLUSION

Understanding neural mechanisms for pheromone-source localization is one of the most accessible approaches for understanding mechanisms of how reliable and robust biological systems control behavior despite environmental perturbations. The first implementations have started to appear in the area of odor-source localization as ‘insect-machine hybrid system’, coupling biological information processing to artificial effectors. This system will contribute to evaluate the adaptability of behavior, and to better understanding of the dynamics of the neural network.

REFERENCES