Study of adaptability of an insect using the brain-machine hybrid system: Sensory feedback in odor searching behavior

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Abstract: We developed the brain-machine hybrid system as a new approach to investigate adaptability of insects. In this system, the mobile robot as a body was controlled according to the steering signals from the moth's brain. By changing the conversion rule from signals to robot behavior, we can intervene with the relationship between brains and environments. From the experiments, we observed that the moths on the robot responded correctively to forcibly given movement both while the robot was immobile and mobile in command signals. We also tested biased motor gain condition and compensative responses were also observed in these conditions.
Keywords: adaptability, brain-machine hybrid system, sensory feedback, insect, chemical plume tracking, cyborg.

1. INTRODUCTION

Insects can react appropriately to changing environmental conditions using their comparatively small brains. We call this ability as adaptability.

Male silkworm moths, *Bombyx mori*, orient toward conspecific females displaying a programmed behavioral pattern (straight-line walking, zigzagging turns and looping) upon detection of sex pheromone by their antennae. This behavioral pattern is repeated each time a pheromone plume is encountered resulting in localization of the goal.

In a previous study, it has been reported that the silkworm moth could compensate for motor asymmetry and show adaptive behavior in the orientation behavior to a pheromone source [1]. In that study, an insect-controlled two-wheeled robot was built to examine the adaptability. The robot moved based on the locomotion of the silkworm moth on a sphere mounted on the robot. Using the robot, artificial changes of motor gain could produce unintentional movements for the silkworm moth, and under these conditions, the silkworm moth could adapt to the new circumstances. Moreover, it was suggested that the silkworm moth used visual cues under these conditions.

Recently in the interdisciplinary field of neuroscience and robotics, closed-loop experimental systems that connect a brain with a robot have been developed [2]. We have suggested a new closed-loop experimental system, a brain-machine hybrid system that mounts a moth head on a robot as sensors and a controller. We constructed a brain-machine hybrid system using motor signals related to the steering behavior of the male silkworm moth for controlling a two-wheeled mobile robot. Using this system, we can acquire knowledge about adaptive processing in the brain by controlling the motor output of the robot.

2. BRAIN-MACHINE HYBRID SYSTEM

2.1 Selection of command signals

We recorded steering signals from neck motor neurons, 2nd cervical nerve b (2nd CNb). These neurons convey signals to regulate head swing [3]. Head swing angle and walking angular velocity are correlated [3].

We recorded the signals by sucking the cut end of the left and right 2nd CNbs into the glass microelectrodes by using syringes and acquired neural activities by using amplifiers. Signals from 2nd CNb contain five units that have different spike amplitudes. We chose units corresponding to the optic flow stimuli that induced head swing.

2.2 Setting a spike-behavior conversion rule

We set a spike-behavior conversion rule as we have already reported [4]. We assumed a two-wheeled mobile robot in a two-dimensional coordinate system. The forward velocities of the left and right wheels were calculated proportionally to the right and left spiking rate per 0.1 second. As a result, the angular velocities of the robot were calculated as the difference of right and left spike rate per 0.1 second.

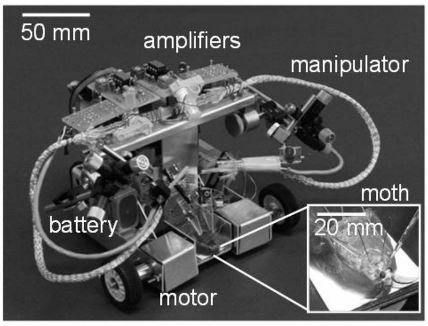

Fig. 1 Brain-machine hybrid system

2.3 Characteristics of the amplifiers

To amplify small signals recorded from nerves for use by the micro controller on a mobile robot (e-puck, EPFL), we made instrumentation amplifiers. We designed our instrumentation amplifiers with an input resistance of 100 MΩ, a gain of 80 dB (variable), a frequency bandwidth of 150 Hz – 3.2 kHz.

2.4 Experiments in a wind tunnel

To test the behavioral pattern and odor source orientation behavior of the hybrid system, we used an experimental wind tunnel (flow speed 0.7 m/s). The wind tunnel provided enough space (W 840 mm x H 300 mm x L 1800 mm) for the hybrid system (W 140 mm x H 60 mm x L 130 mm). In the wind tunnel, air puffs were regulated by electric valves operated by LabVIEW program.

Using the hybrid system, we observed the programmed behavioral pattern of a male moth following a single pheromone stimulus (bombykol 100 ng absorbed in a filter paper, 500 ms stimulus duration). By plotting angles formed between pheromone source direction from the hybrid system's start point and the longitudinal axis of the hybrid system, elements of the moth's programmed behavioral patterns (straight-line walking, zigzagging turns, and loop) were observed. Average angular velocity for 5 seconds was 9.57 degrees/s (before the stimulus) and 35.8 degrees/s (after the stimulus). Similar results were observed in 7 examples in 3 individuals.

We tested whether the hybrid system could orient and reach a pheromone source (bombykol 1000 ng) in the wind tunnel. We set the goal line 100 mm from the pheromone source. As a result, 10 successful examples in 7 individuals (in 24 trials) were observed.

3. RESPONSES ABOUT ADAPTABILITY

3.1 Responses to disturbances

As the initial step toward understanding the adaptability, we examined whether the activities of 2nd CNb changed responding to given disturbances. We gave disturbances as angular velocity and forward velocity, and the activities of 2nd CNb only responded to the angular velocity.

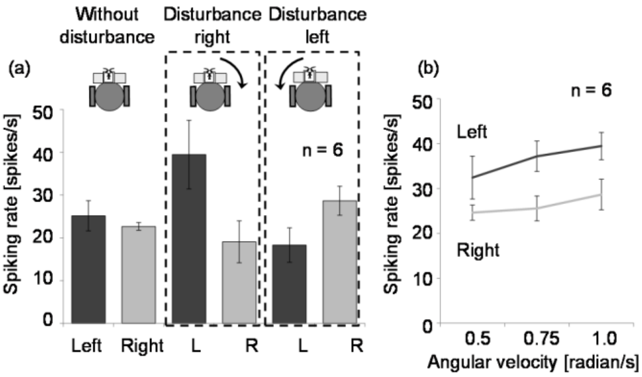

Fig. 2 Responses to angular velocity disturbances

They show compensative responses to keep the position of the hybrid system. Average spiking rates without the disturbances were 22.7 spikes/s (right) and 25.2 spikes/s (left). Average spiking rates of the contralateral 2nd CNb during the 1.0 radian/s disturbances were 28.7 spikes/s (right) and 39.5 spikes/s (left) (Fig. 2 (a)). These responses increased proportionally to the angular velocity (Fig. 2 (b)).

3.2 Biased motor gain conditions

We changed a conversion rule of the hybrid system to examine adaptability to the new conditions. We biased left and right motor by doubling the velocity. In those conditions, activities of the contralateral 2nd CNbs to the biased side excited and the activities of ipsilateral 2nd CNbs were inhibited, and in several examples the hybrid system still could reach the pheromone source.

4. CONCLUSION

We developed the brain-machine hybrid system. Using the selected command signals on the hybrid system, we reconstructed the programmed behavioral pattern and orientation behavior of a male silkworm moth. Moreover, we examined adaptability of a moth by giving disturbances and changing the spike-behavior conversion rule to make biased conditions. In these experiments, moths on the hybrid system showed compensatory responses to keep their position.

5. ACKNOWLEDGEMENT

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