Connecting insect and machine: robotics facilitates biological analysis for adaptive behavior

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1 Introduction

In the study on neuroethology in which researchers seek the neural basis of animal behavior, the use of mobile robots have been a useful technique for validating sensory-motor models available from biological analyses. The most advantage of using mobile robots is that it enables us to validate models in a closed-loop among the brain, body and environment. Insects are the most successful model organisms for the use of robots because of their capabilities to behave adaptively in ceaselessly changing environments with their small nervous systems and bodies [1, 2]. Furthermore, robots implemented with such insect models will also be prototypes for exploring potential application to autonomous robots [3].

In contrast to the use of robots as a tool for model validation (i.e., to validate how much we understood the biological system), we have been directly using robots as an experimental tool for neuroethology [4]. Since robots are artificial systems, researchers can easily manipulate any of parameters of them, which is a great advantage of using robots if they are combined with the sensory-motor systems of insects and implemented into the closed-loop. For instance, if an insect drives a mobile robot as a controller, such "hybrid" robot is regarded as an organism in which researchers can easily manipulate the properties of its sensory-motor system. The manipulation of the sensory-motor systems of animals is an important technique to understand their function for behavior, which has been done by surgical, pharmacological and genetic techniques. I present here our recent studies on hybrid robots and their significance for biological analyses for adaptive behavior.

2 Insect-machine hybrid robot

2.1 Insect-controlled robot

The insect-controlled robot is a robotic platform for analyzing insect adaptive behaviors in a real world (Figure 1). A male silkmoth (*Bombyx mori*) is tethered inside an enclosed robot cockpit where an airflow containing an odor (female sex pheromone) is delivered to each side of the antenna. Once the moth received the pheromone, it performs odor tracking walking behavior on a spherical treadmill that acts as a handle of the robot car. The manipulation of the robot alters the sensory-motor control of the hybrid robot (regarded as an "organism"), and we can test its effect on behavior in a real environment. We elucidated sensory-motor control of the odor tracking behavior of the silkmoth by manipulating olfactory and visual input as well as the motor properties of the robot [5].

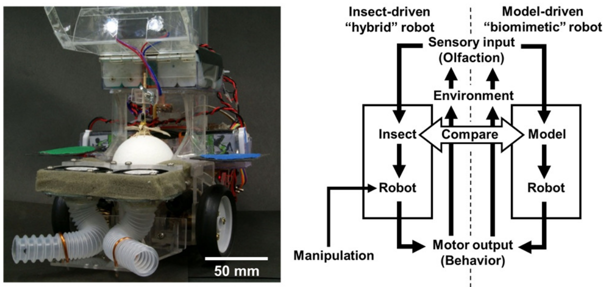

Figure 1: Insect-controlled robot and information flow of a hybrid and a biomimetic robots.

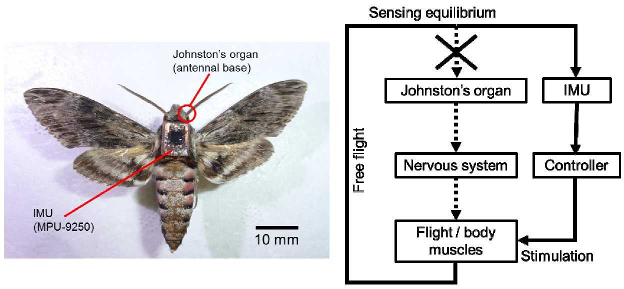

Figure 2: IMU-loaded hawkmoth and the concept of neuroprosthetic flight control.

2.2 Neuroprosthetic control of insect flight

We have been developing another insect-machine hybrid for flight control. Hawkmoths have gyroscopic organs at the base of the antennae (Johnston's organs), and their function is impaired by cutting or immobilizing the antennae [6]. Inspired from the recent development of micro air vehicles bearing small-sized inertial measurement units (IMUs) and controllers, we have been trying to replace the function of the insect's gyroscopic organ by an IMU for the identification of the flight control system *in vivo* [7]. We attached a small-sized IMU (MPU-9250, Invensense, San Jose, CA) on the dorsal thorax of an antennae-ablated hawkmoth (*Agrius convolvuli*). The instability of flight posture is monitored by a microcontroller based on the output from the IMU (sensory input), and electrical stimuli (motor output) are applied to flight or body muscles (Figure 2). The replaced artificial sensory-motor control would be comparable to the system that intact moths have if the antennae-ablated moth recovered flight stability.

3 Future directions

The hybrid robots are novel and seem to be completely different from conventional experimental tools in biology. However, the manipulability of the interaction among brain, body and environment of the hybrid robots is effective for analyzing the mechanism behind adaptive behavior. Furthermore, the hybrid robots will make us easier to compare the biological and artificial systems. The direct comparison between an intact insect and a "biomimetic" mobile robot is difficult because of differences in the sensory and motor systems (e.g. antenna vs gas sensor and hexapod vs wheels), while the hybrid robots provide common platforms bearing the same sensors and/or motor systems (Figure 1). The recent progress in small-sized and multifunctional electric devices will further promote the hybridization between insects and machines, which provides powerful tools for understanding adaptive behaviors.

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