Insects adjust body and appendages to traverse cluttered obstacles

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I. Introduction

Legged robots still cannot agilely move on cluttered terrain. In contrast, insects like cockroaches are excelled at navigating rough terrain with large or cluttered obstacles [1]. Understanding the physical principles of how the cockroaches traverse such complex terrain is promising to give insight in creating agile robots.

Recently, we found that discoid cockroaches traversed a layer of grass-like beams by transitioning from the "pitch" to "roll" mode [2]. In the "pitch" mode, the cockroach pitched up its body against the beams and tried to ram through. In the "roll" mode, the cockroach rolled its body into the gap between two beams. Using a potential energy landscape approach, we found that the transition emerged when the system crossed a barrier to jump from a "pitch" local minimum basin to a "roll" basin with the help of kinetic energy fluctuation from body oscillation. However, we also observed that the mode transition happened before the energy barrier became lower than the kinetic energy fluctuation level. This suggested that the animal used active sensory feedback to control transition [3].

Here, we tested the hypothesis that the cockroach actively senses the obstacles and adjusts its body and appendages to facilitate mode transition and beam traversal.

II. Methods & Results

We challenged a discoid cockroach ($N = 3$ animals, $n = 36$ trials) to traverse a layer of high-stiffness beams ($K = 2.5$ mN·m/rad). We recorded and measured the animal's active adjustments on the head, abdomen, and legs.

We observed that the cockroach adjusted its body and appendages in four ways when it explored around the beam or rolled into a gap, compared to approaching the beams. (1) It flexed head up and down repeatedly (Fig. 1A) while searching round the beams or rolling. (2) It sometimes flexed its abdomen (Fig. 1B) when it was in the middle between two beams. (3) It sprawled the hind legs outward (Fig. 1C) when it pushed against the beams, and inward before rolling. (4) It extended one hind leg and retracted the other (Fig. 1D) before rolling.

We speculated that these active adjustments facilitated the mode transition and beam traversal. (1) Flexing the head helps sense the terrain shape and physical properties and to lead the body into the gap. (2) Abdomen flexion helps propel the body forward and lower terrain resistance. (3) Reducing the leg sprawling angle reduced rolling stability. (4) Extending one hind leg and retracting the other generate roll torque.

We recently created a robot (Fig. 1E) as a robophysical model to systematically study the mechanism how force sensing and feedback control improve transition and traversal performance. To mimic the cockroach's head and abdomen flexion, we designed that two parts of the robot were able to flex around the middle part. In addition, to mimic the active control on the leg motion affecting the body motion when interacting with the terrain, we added underactuated force control to the robot's yaw, pitch, and roll directions. We also added force-torque sensors to sense the ground reaction forces. We will use this robot to systematically study how to close the loop using force sensing information to better make locomotor transitions to traverse the obstacles.

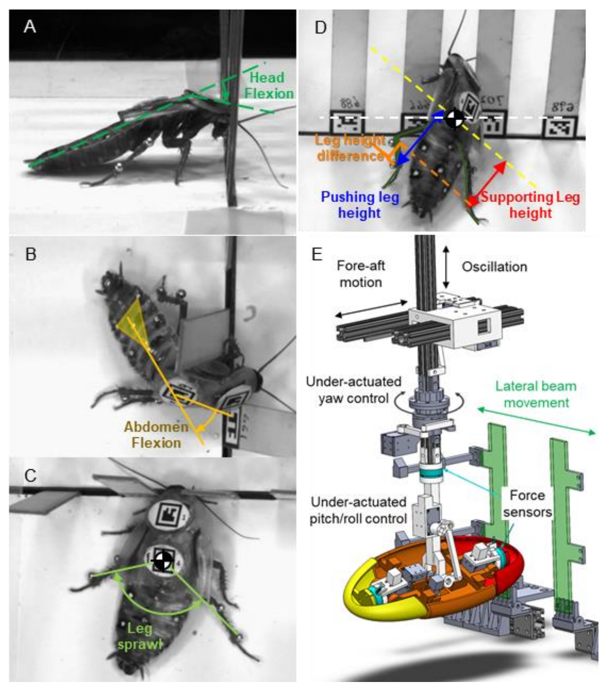

Fig. 1. A. Cockroach flexing its head. B. Cockroach waving its abdomen. C. Cockroach sprawling its legs outward. D. Cockroach extended one hind leg and retracted the other. E. Cockroach-inspired robot.

References

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