Gait analysis of locusts walking on level, vertical, and ceiling planes

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1 Introduction

By altering their walking patterns, insects and other ground-dwelling species acclimate to and move rough terrain and unforeseen changes in the environment [1]. Several robotics engineers have been interested in this capability, which has been the focus of in-depth research [2]. Walking is famous for more than just its capacity to move rough terrain. For example, certain insects can climb up walls and ceilings. Locusts are one such insect. Locusts have huge and thick hind legs and their hind leg are considered to contribute to a significant jump. On the other hand, locusts also show a unique gait with skillful use of their hind legs [3]. Moreover, locusts can walk on smooth walls and ceilings in addition to uneven ground. Some locusts, notably Bombay locusts and katydids, have organs that resemble suckers on the tips of their legs. Figure 1 shows the enlarged leg tips of locust (*Nomadacris succincta*). Some research on sticky methods for an inclined plane has been conducted, and it is known that locusts use this organ to walk on level surfaces regardless of the slope of inclination [5, 6]. When locusts achieve locomotion by utilizing the peculiar foot tip structures, it is considered that they also change their gait. However, few studies have been conducted on gait changes on the inclined plane. In this study, we analyze how the locust gait changes when the angle of the inclined plane is changed.

2 Walking experiments

We conducted the walking experiment with *Nomadacris succincta* on the level, vertical, and ceiling plane. Locusts were placed on an acrylic plate and induced to walk in a near-straight line by light. The locust walking was recorded from the ventral side. The measurement experiments were conducted with ten animals, three trials for each under each experimental condition.

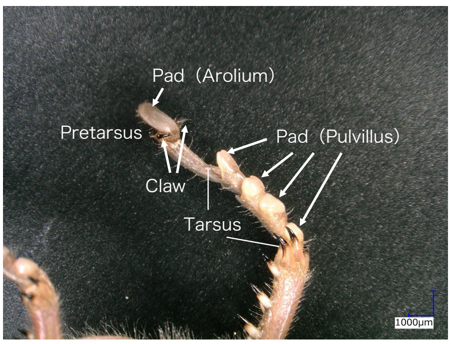
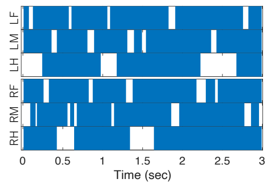
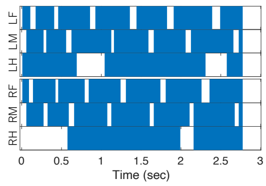


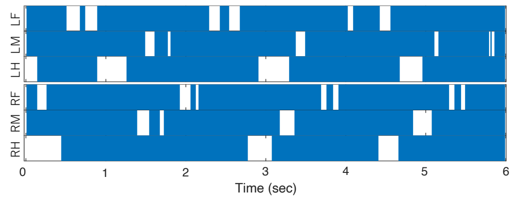
Figure 1: Structure of hind leg's tarsus.



(a) Two-period gait.



(b) Three-period gait.



(c) Wave gait.

Figure 2: The experimental results on the vertical plane.

Experimental results confirmed that locusts showed a variety of gaits. The front and middle legs move for two cycles while the hind leg moves for one cycle in the Two-period gait (Figure 2a). With a Three-period gait, the front and middle legs each move for three cycles, but the hind leg only moves once (Figure 2b). The wave gait is a movement pattern in which pairs of legs move sequentially from front to back, with the front leg moving as soon as the rearmost leg leaves the ground (Figure 2c). Moreover, a quadruped gait was also observed, in which the locusts only used their front and middle legs, never their hind legs. Other gait patterns, like inconsistent period gait, were observed. Table 1 lists the gait that was confirmed in all 24 trials. On the level and vertical planes, twp-period and three-period gait were often observed. On the level plane, the quadruped gait was also observed. On the ceiling plane, most locusts did not show a steady gait and the multi-period gait was not observed.

Figure 3a shows the mean value of grounded legs. The mean value of grounded legs was substantially higher when

Table 1: Frequency of each gait.

The type of gait	Wave	Two period	Three period	Quadruped	Others
Level	0 (0.00%)	20 (83.3%)	4 (16.7%)	4 (16.7%)	1 (0.412%)
Vertical	0 (0.00%)	5 (20.8%)	15 (62.5%)	0 (0.00%)	1 (0.412%)
Ceiling	2 (8.33%)	0 (0.00%)	0 (0.00%)	0 (0.00%)	22 (91.7%)

walking on the ceiling than when walking horizontally, according to a one-tailed t-test with a significance level of 0.5 percent. Additionally, to analyze the degree of the leg opening, the mean areas of a convex hull polygon enclosed by six feet and that by grounded feet were evaluated. Based on the two-dimensional coordinate from the experiment data, the mean convex hull polygonal areas were calculated. Figure 3b and Figure 3c show this result. One-tailed t-tests of the 0.5 percent threshold of significance were performed on the walking on the level and vertical plane. The result shows that the mean convex hull polygonal area was considerably bigger when walking vertically than when traveling horizontally. The mean convex hull polygonal area for walking on the vertical and ceiling surfaces was also tested using one-tailed t-tests with a significance level of 0.5 percent. It was shown that walking on the ceiling resulted in a significantly larger mean convex hull polygonal area than walking on the vertical surface. The mean convex hull support polygonal area showed the same results.

3 Conclusion

In this study, we measured the gait of locusts on level, vertical, and ceiling planes and quantitatively confirmed that the gait differs in each environment. Further research will involve the analysis of the difference in gait depending on the slope angle and surface conditions and clarifying the mechanism that produces the change in gait.

Acknowledgments

This study was supported by JSPS KAKENHI (grant numbers JP21H01276, JP22K19795, JP23K13280 and JP23H01435).

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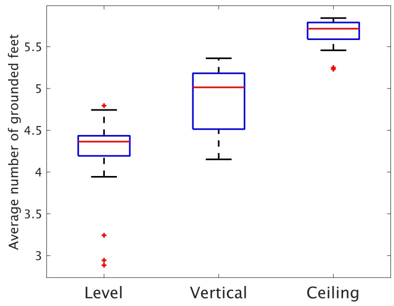
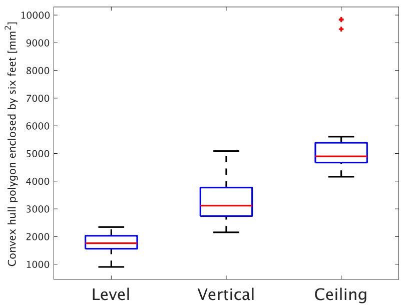
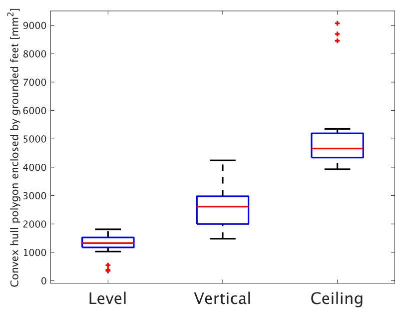


(a) The average of grounded feet.



(b) The distribution of the area of convex hull polygon enclosed by six feet.



(c) The distribution of the area of convex hull polygon enclosed by grounded feet.

Figure 3: The results of walking experiments.