Analysis of locust's unique gait mechanism focusing on leg length difference

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1 Introdution

There are many insects around us. Although they are smaller than human and other animals and have only a limited nervous system, they show various locomotion with high adaptability in different uncertain circumstances. Such insects' unusual behaviors with a little arithmetic capacity have attracted interests not only by biologists but also by many robot engineers and been extensively studied. However, in many previous studies, the leg size, shape, and power of all six legs have been identical. On the other hand, many actual insects have differences in the structure of the forelimb, middle leg, and hind leg, especially in that of lengths. It is considered that this asymmetry greatly influences the realization of adaptive locomotion based on the interaction between the environment and the body by insects.

Therefore, in this research, to investigate the influence of leg length difference on walking, we focus on locusts(Figure 1) which has strong asymmetry in the forelimb, middle leg, and hind leg and shows a unique gait specific to the locust besides jump or fly. Firstly, we measure the gait of some insects including locust. Next, by reproducing the measured gait particular to locust in the numerical simulation, we explore the locust's unique gait mechanism.

2 Analysis of insects gait

First, we measured the gait of locust. Besides, to compare with it, we also measured the gait of stick insects(*Phasmatodea*) which has almost no difference in the structure of each leg and cricket (*Grylloidea*) which has a little different structure of each leg.

Figure 1: *Nomadacris succincta*

We recorded their walkings on flat ground with a high-speed camera whose frame rate was 120 [fps]. From recorded movies, touch down and lift off of each leg were discriminated and gait charts were created. Figure 2 shows the obtained gait charts. Figure 2a, 2b and 2c show the result of locust, stick insects and cricket respectively.

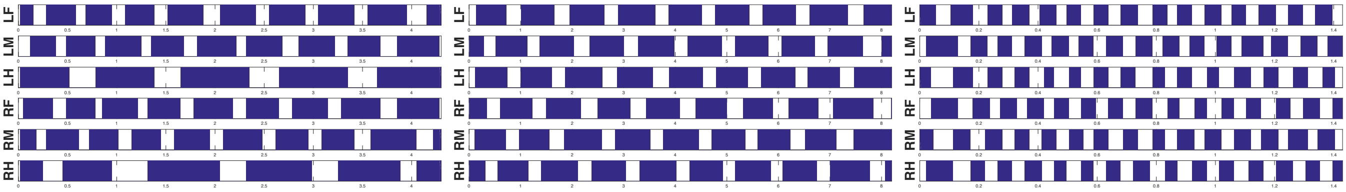
From these figures, it is confirmed that stick insects and cricket synchronized LF, LH and RM legs and synchronized the remaining legs in antiphase(Figs. 2(b), (c)). This gait is the tripod gait which is one of typical gaits and is used at high-speed walking of many insects. On the other hand, locust showed significantly different gait from stick insects or cricket(Figure 2(a)). Focusing only on the touchdown timing of the hind leg, LH is synchronized with LF and RM, and RH is synchronized with LM and RF. This relation is the same combination as tripod gait. However, it can be confirmed that the forelimb and middle leg are moving in a period of 2 while the hind legs move by 1 period. This gait is a locust specific gait. In this paper, this unique gait is called **Locust gait**. The Locust gait is also found in not only locust but alto other grasshoppers [1]. The Locust gait enables to increase the stroke of the hind legs because the hind legs are longer than the front and middle legs. It seems that there is some relation between the long hind leg and the Locust gait.

3 Walking simulation of locust

Next, by reproducing the Locust gait confirmed by gait measurement experiment, we investigated the realization mechanism of Locust gait with a numerical simulation. Although an actual locust has a different structure also between fore-leg and middle leg, we focus on the difference between fore-leg, middle-leg, and hind leg as a first step.

3.1 Walking simulation environment using ODE

Figure 3 shows the size of the locust model prepared on the simulator using Open Dynamics Engine (ODE). The density of all components was set as 295.4[kg/m^3] and set as a rigid body. The values of size and density were obtained by measuring the actual locust. Each joint is a hinge joint having one degree of freedom, and it is possible to realize a targeted foot trajectory. In addition, to control each leg based on the ground reaction force, the sensors of the ground



(a) locust **(b)** stick insect **(c)** cricket

Figure 2: Gait chart obtained from walking mesurement experiments

reaction forces were attached to each leg.

3.2 Control method

In this study, we implemented the following control method;

$$\dot{\phi}_i = \omega - \sigma_1 N_i \cos\phi_i \tag{1}$$

$$\dot{l}_i = \sigma_2 M_i \tag{2}$$

$$\dot{T}_i = \sigma_3 M_i \tag{3}$$

Eq. 1 that was proposed by Owaki et al. [2], is the control method which expresses the time evolution of each phase oscillator of the ith leg. ω is the intrinsic angular velocity, and the second term represents the local sensory feedback with the feedback gain σ_1 and the vertical ground reaction force acting on the ith leg N_i. The control method has the effect of keeping being a support leg as the load applied to each leg increases. As a result, even though each phase oscillator is decoupled, proper inter-leg coordination through the body can be realized.

The phase of the oscillator corresponds to the previously designed foot trajectory. The legs are controlled to realize the corresponded trajectory. Although the previously designed foot trajectory was fixed in the previous study [2], we made it possible to change the foot trajectory while walking in this research. Eqs. 2, 3 are additional control methods for this purpose. M_i is the horizontal ground reaction force acting on the ith leg. l_i and T_i are the stroke length and period of ith leg respectively. σ_2, σ_3 are feedback gains. Eq. 2 is intended to obtain a more propulsion force by extending the support leg phase of the legs contributing to the propulsion. If the horizontal ground reaction force M_i is positive, the stroke length l_i is lengthened, whereas if it is negative the control method shortens l_i. Eq. 3 changes the period of phase oscillator so that the speed of foot during support leg phase does not change even if the stroke length l_i changes according to Eq. 2. That is, when the stroke length l_i becomes long, the period T_i also becomes long.

3.3 Result of walking simulation

Figure 4 shows the result of walking simulation with the proposed control method(Eqs. (1)-(3)). From this figure, it is confirmed that the period of the hind leg is gradually lengthened as compared with the front and middle leg, that is, the Locust gait was realized. To investigate the influence on the gait by the length of the leg, we conducted another walking simulation with the model in which the structure of the hind leg was similar to the front, middle leg. In this case, the period of the hind leg was not changed. We also confirmed that without the feedback of horizontal ground reaction the Locust gait could not be realized. These results suggest that the Locust gait is generated by the combination of leg length difference and feedback of horizontal ground reaction.

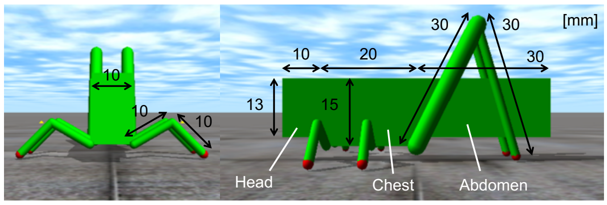


Figure 3: Size of locust model created on ODE

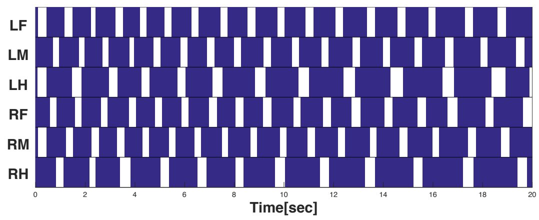


Figure 4: Gait chart with the proposed control method that feedbacks ground reaction force on the locust model

4 Conclusion

In this paper, to investigate the effect of leg length differences on gait, we analyzed locomotion of some insects including locust. From the measurement experiment, we could confirm the unique gait specific to the locust. Next, we realized the Locust gait on numerical simulation and found that leg length difference and the feedback of horizontal ground reaction force affected on the realization of the gait specific to the locust.

Acknowledgements

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References

[1] D.M Wilson. Insect walking. *Annual review of entomology*, 11(1):103–122, 1965.

[2] Dai Owaki, Takeshi Kano, Ko Nagasawa, Atsushi Tero, and Akio Ishiguro. Simple robot suggests physical interlimb communication is essential for quadruped walking. *Journal of The Royal Society Interface*, 10(78), 2013.