Analysis and modeling of high-speed running motion of ghost crabs

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1 Introduction

The ghost crab, *Ocypode Stimpsoni*, is small-sized crab inhabiting warm *sandy* beaches (Fig. 1). As opposed to other types of crabs inhabiting *rocky* environments, it is often difficult for the ghost crabs to hide from their predetors on exposed beach, which implies they have two major choices to survive – *dig into underground* or *run faster* than the predators. Thus the ghost crabs are quite proficient in *excavation* and *high-speed running*. This study focuses on the latter; our purpose is to exploit high-speed running mechanism of the ghost crabs and reproduce it using artificial models, with potential application to develop fast-running multipedal robots. Based on the observations obtained in the previous works [1–3], we perform quntitative analysis of the running motion in detail and build a mathematical model to reproduce the motion, and to understand the underlying principle of the motion as well. In this work, all sample ghost crabs were collected in Wakayama and Okinawa, 2015–2016, Japan.

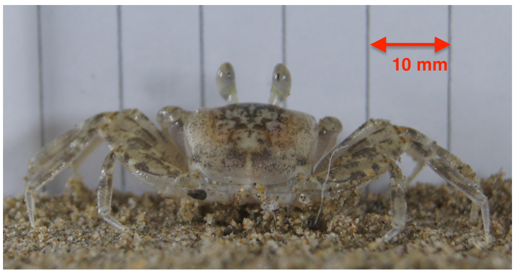

Figure 1: Overview of an *O. Stimpsoni*

2 Mechanical modeling of ghost crabs with linked structure

A ghost crab has a pair of claws and four pairs of legs (eight in total) for locomotion. Usually they use three pairs (F1-F3, H1-H3 in Fig. 2) in the so-called *tripod-gait* manner, where the two forelegs (F1, F3) on the both sides and the center hind leg (H2) move almost simultaneously, and so for the remaining three legs (F2, H1, H3). Based on our previous observation [3], we found out that the two tripod-groups are in *anti-phase periodic* motion, i.e., the phase gap between the groups is always kept around π[rad]. From now on, we focus on F3 and H3 as the representatives to characterize this motion.

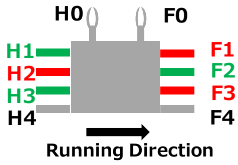

Figure 2: Reciprocal use of the legs in tripod running

Each leg is composed of 7 segments from anatomical point of view (Fig. 3), we approximate the structure as 3-links connected with two revolute joints and one spherical joint at the root, also based on our previous observation. Finally, we confine ourselves to discuss the motion in the transverse (vertical) plane, resulting in a serial 7-link model consists of the foreleg (the leading leg towards the running direction), the torso and the hind leg (the trailing leg), as shown in Fig. 4. Here we define some symbols to discribe the motion: γ denotes the attitude (the pitch angle) of the torso relative to the horizontal axis, $\theta_1, \theta_2, \theta_3$ denote the relative angles of the foreleg joints, and ϕ_1, ϕ_2, ϕ_3 are for the joints of the hind leg.

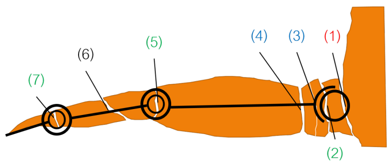

Figure 3: Each leg consists of 7 segments.

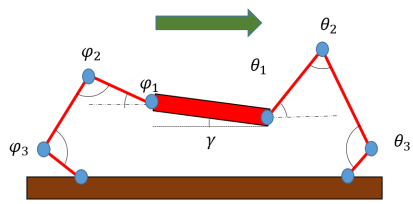

Figure 4: Transverse plane model: a serial 7-link model consists of the foreleg, the torso and the hind leg.

3 Motion analysis of high-speed running of ghost crabs

Based on the assumption proposed in the previous section, we analysed high-speed running motion of a sample ghost crab (taken at Wakayama, Japan, in October 2016) using an optical motion-capture system. Optical reflectors are attached to the four corners of the torso and the corresponding joints. Fig. 5 shows time variation of the joint angles, where the red vertical line indicates the instance of touching-down, while the blue vertical line indicates the instance of taking-off. Average running speed in the experimet of the crab was 0.50[m/sec].

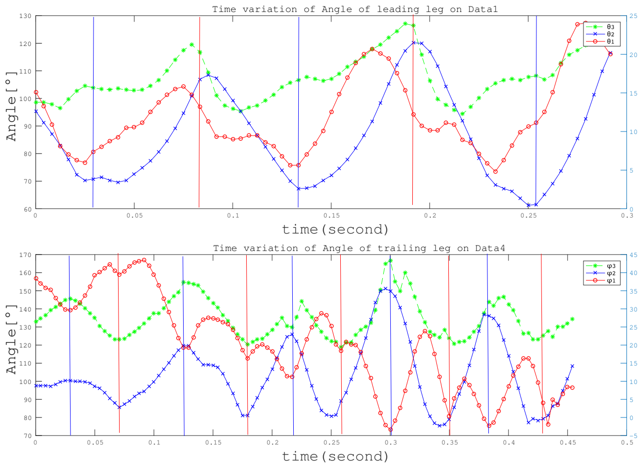

Figure 5: Joint angles. Top: foreleg(F3), Bottom: hind leg(H3)

We then discussed the relationships between motion of the all joints in detail to find out the law for coordinated control of the joints, although we omit them from this extended abstract due to the limitation of space.

4 Simulation with the reduced model

We performed some simulation to examine fidelity of the proposed approximated model in reproducing the running motion. Fig. 6 shows the $x-z$ (horizontal versus vertical) trajectory of *the end* of the legs, wehere the red curve shows *the actual* position directly obtained from the motion-capture system, while the blue curve shows *the simulated* position based on the transverse plane model. Note that it is not trivial that the trajectories coincide to each other. The coincidence justifies our approximation of the crab's motion into the 7-link model in the transverse plane.

Finally, we assembled the transverse plane model into a hexapod model, shown in Fig. 7. The torso is now modeled as a rectangular plate, which is connected to six 3-linked legs corresponding to F1-F3, H1-H3. Using the physical simulator (Open Dynamics Engine) and the joint data obtained in the previous section, we succeeded in reproduce the horizontal running motion at the speed of 0.32[m/sec]. The cofficient for horizontal friction was set to 0.7 and the cofficient of vertical restitution was set to 0.3.

5 Conclusion

In this paper, we focused on high-speed running motion of ghost crabs, as proposed a approximated model of their

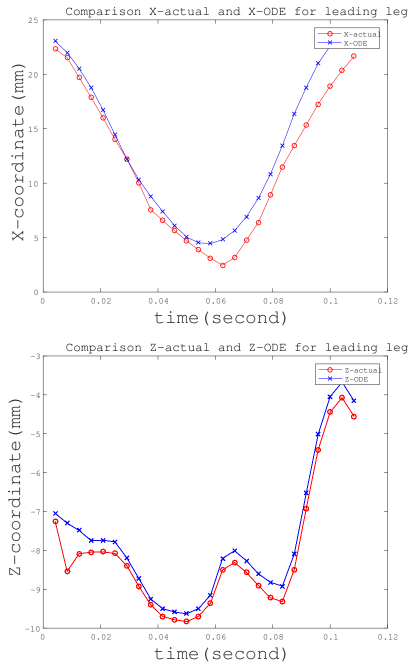

Figure 6: Physical simulation of the proposed reduced link model

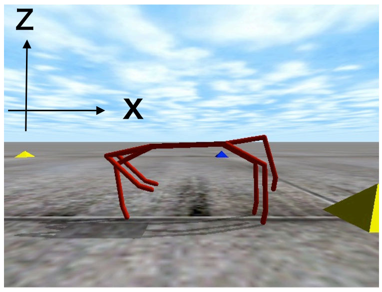

Figure 7: Physical simulation of the proposed reduced link model

structure using 7 serial links in the transverse plane, and assembled them into a 3-link hexapod model. Simulation results suggest fidelity of the proposed model to the real observation.

In the future work, we plan to extend our model to incorporate dynamical, force interaction between the links and the ground, and also granular physics of the ground to some extent.

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References

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