Modular Neural Control for Dung Beetle-like Leg Movements of a Dung Beetle-like Robot

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1 Introduction

When looking at multi-legged animals, we see that they can perform a variety of complex behaviors, i.e., walking, running, jumping in various environments. Biological studies have shown that these behaviors emerge from an underlying principle of locomotion [1]. However, we are still far from understanding the complete picture of this principle [1]. Many roboticists try to unravel this problem by developing controllers or biomechanical models that can mimic the movements of the animals. For example, Ijspeert et al. [2] developed a spinal cord model to control an amphibian robot that can adaptively perform both walking and swimming behaviors, like a salamander. Spröwitz et al. [3] designed compliant legs for cheetah-like locomotion. Recently, Nyakatura et al. [4] proposed an impressive integrative approach based on biomechanically relevant metrics to reconstruct the locomotion of tetrapod fossils. These kinds of works not only contribute to our biological understanding but also lead to advanced robotic technology.

Following this research line, we have developed a series of computational motor control for complex versatile behaviors, like walking and ball rolling, of hexapod robots based on dung beetles [5,6]. While our previous works show dung beetle-inspired walking and ball rolling, the detailed leg movements are still not completely similar to the leg movements of a dung beetle.

Thus, in this study, we propose a new modular neural control architecture that can mimic the leg movements of a dung beetle during walking. We evaluate the performance of the neural control on a new dung beetle-like robot (called ALPHA) based on the dung beetle *Scarabaeus galenus*. We compare the leg movements during walking of our robot with the dung beetle through gait diagrams and leg trajectories. This evaluation is used to quantify the similarity between the leg movements of our robot and the dung beetle. Due to the difference in size between the robot and the beetle, we normalize the leg trajectory for the evaluation. The evaluation shows that our control can generate the leg movements comparable to the ones observed from the beetle.

2 Methods

2.1 Leg movements of the dung beetle *Scarabaeus galenus*

In this work, we consider the leg movements during walking of the dung beetle *Scarabaeus galenus*. The beetle has six legs and each leg consists of three joints including body-coxa(BC), coxa-femur(CF), femur-tibia(FT) joints as shown in [7]. These joints are simplified and modeled as revolute joint in our dung beetle-like robot. Its leg movements are observed through video recordings. To mimic the dung beetle's leg movements, we analyze their walking gait and movement of each joint. From the observation, most of the time, the dung beetle walks with a tripod gait while each pair of legs step alternately. The BC-, CF-, and FT-joint angles of each leg are extracted by using a tracking technique described in [7]. The extracted joint angles and gait are used for developing neural control to mimic the movements on a dung beetle-like robot.

2.2 Modular neural control for dung beetle-like leg movements

Our modular neural control is based on our previous neural control mechanisms [6, 8]. It consists of the following neural networks or modules: a central pattern generator (CPG) network, CPG postprocessing (PCPG) networks, and velocity regulating networks (VRNs). The complete diagram of the neural control is shown in Fig. 1(a). The CPG network generates the rhythmic patterns from its neurons (C_1 and C_2) which drive the motor neurons ($BC_{0,...,5}$, $CF_{0,...,5}$, $FT_{0,...,5}$). The rhythmic output signals from the CPG network are preprocessed by the PCPG networks to further shape and smooth the signals. The output signals from the PCPG networks are then passed to the VRNs that regulate the amplitude of the signals before transmitting to the motor neurons ($BC_{0,...,5}$, $CF_{0,...,5}$, $FT_{0,...,5}$). All neurons are modeled as discrete-time non-spiking neurons and connected by synapses. These synaptic weights are here empirically adjusted to achieve the dung beetle-like leg movements.

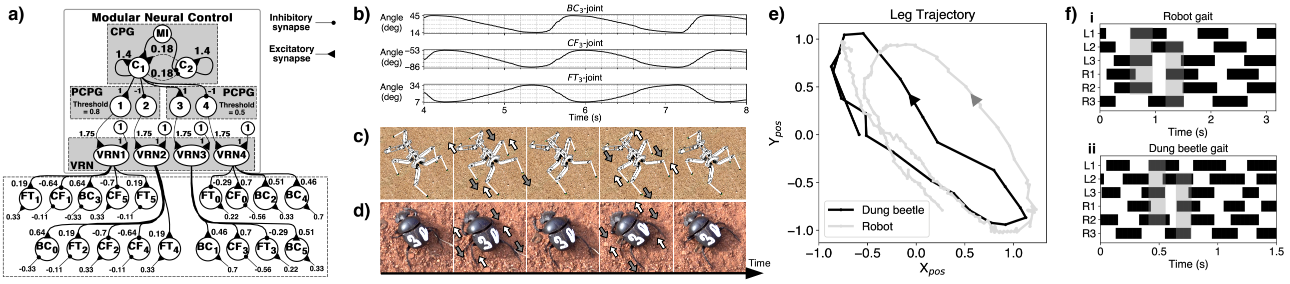

Figure 1: (a) Modular neural control for dung beetle-like leg movements. (b) Example of the BC-, CF-, and FT-joint angles of the right front leg generated by the control. (c) Snapshots showing the leg movements of the ALPHA robot during forward walking in V-REP simulator. (d) Snapshots showing the leg movements of the real dung beetle *Scarabaeus galenus* during forward walking. The video of these snapshots can be seen at `www.manoonpong.com/AMAM2019/SupplementaryVideo.wmv`. (e) Normalized leg trajectories of the right front leg relative to the body of the robot and the dung beetle. (f) Gait diagrams of the robot and the dung beetle.

3 Results & Discussion

Our modular neural control was tested on a dung beetle-like robot to perform forward walking. Figure 1(b) shows an example of BC-, CF-, and FT-joint angle movements during walking. Figures 1(c) and (d) show a comparison of the leg movements of our dung beetle-like robot generated by the neural control and the ones of the real dung beetle *Scarabaeus galenus*, respectively.

The detailed leg movements of the dung beetle-like robot, comparable to the real dung beetle, can be described as follows. During forward walking, the front legs extend outwards to reach the ground in the swing phase and retract inwards to its body in the stance phase. The normalized leg trajectories of the robot and dung beetle can be seen in Fig. 1(e). The hind legs are opposite; i.e., they flex inwards to its body in the swing phase and extend outwards to push the body in the stance phase. The middle legs show a combination of the front and hind leg movements; i.e., they retract inwards to its body rapidly and early during the stance phase in order to pull the body since in this period the legs are at an anterior position. Afterwards, they gradually extend outwards in order to push the body since in this period the legs are at a posterior position. The leg movements of the robot and the beetle are coordinated to form a tripod gait (Fig. 1(f)).

While our control architecture can generate kinematic leg movements, comparable to the dung beetle's leg movements, it cannot generate compliance as observed in the real beetle. Thus, this can be further improved by applying additional components, i.e., muscle models [9], to obtain compliance and natural movements; thereby, making it more realistic.

4 Conclusions

Modular neural CPG-based control for dung beetle-like leg movements of a dung beetle like-robot is presented in this study. The generated leg joint angle movements are extracted from video recordings of a real dung beetle. The experimental results show similarity between the robot leg movements and the real beetle leg movements during forward walking. The study suggests a possible neural mechanism underlying complex movements of a dung beetle and also provides a new approach for solving complex motor control problems of a system with many degrees of freedom.

For future work, we will extend the control architecture by introducing muscle models to achieve compliant and natural leg movements. We will also aim to achieve not only complex walking behavior but also ball rolling behavior.

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