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Lizard-like Robot with Decoupled Oscillator-based Control

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Abstract: Quadruped animals achieve remarkable mobility by integrating feedforward and feedback control in their decentralized motor control system. This study focused on understanding how local sensory feedback can coordinate whole-body motions of quadruped locomotion. Our previous work proposed a decoupled oscillator-based control for lizard-like walking. It confirmed that local sensory feedback establishes the coordination of the four legs and body trunk movements without neural communication between oscillators. In this paper, we developed a lizard-like robot and conducted a walking experiment for empirical validation. The resulting gait resembles the actual animal gait and establishes trunk–limb coordination similar to the simulation study.

Keywords: Legged locomotion, Quadruped robot, Central pattern generator, Sensory feedback

1. INTRODUCTION

Quadruped animals possess remarkable mobility by orchestrating whole bodily degrees of freedom, including the four legs, head, trunk, and tail, i.e., whole-body coordination. Such a well-coordinated behavior is mainly controlled by distributed neural networks, called central pattern generators (CPGs), and sensory feedback [1]. Based on the findings, many studies modeled the neural network for robot applications and understanding of animal motor control [2, 3]. These studies investigated whole-body coordination mechanisms using coupling oscillator models, where oscillators represent CPGs and inter-oscillator couplings allow for communication. However, the role of sensory feedback in whole-body coordination received less attention.

In this study, we aimed to understand the extent to which sensory feedback contributes to whole-body coordination. To focus on the effect of sensory feedback, we used a decoupled oscillator model without any neural connection between oscillators. Our previous models showed that a simple sensory feedback rule could generate inter-limb coordination [4], and as an extension, we proposed a model for lizard-like walking generating trunk–limb coordination [5]. In this paper, we developed a lizard-like robot with a single trunk joint to validate the extended model in the real world and conducted a walking experiment. The results showed that the lizard-like robot establishes trunk–limb coordination and generates a lizard-like walking gait similar to the simulation study.

2. ROBOT

2.1. Mechanical system

We developed a lizard-like robot (length: 0.24 [m], width: 0.21 [m], weight: 1.15 [kg]), which consists of a trunk segment and four limb segments, as shown in Figure 1. The trunk segment has a rotary actuator in the yaw direction for lateral body bending, and the limb segment has two rotary actuators, one for the yaw and another for roll directions, respectively. The yaw leg actuator contributes to the leg stroke from forward to backward, while the roll leg actuator moves the legs upward or downward. Each actuator was realized with servomotors (Dynamixel XM430-W350-R, ROBOTIS) controlled by a single-board computer (CoreMP135, M5Stack). The servo motors included current and angle sensors, which are used for local sensory information. The current value is regarded as torque information since it is proportional to the motor torque.

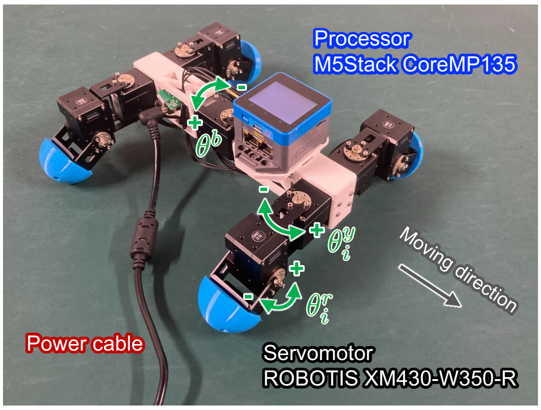

Fig. 1 Lizard-like robot.

2.2. Control algorithm

Our previous work proposed the control algorithm, and the details refer to [5]. The trunk and limbs have a phase oscillator for each, and the oscillator phases determine the target angles of servomotors:

$$\bar{\theta}^b = C_0^b + C_{\mathrm{amp}}^b \cos\phi^b, \tag{1}$$

$$\bar{\theta}_i^y = C_0^y - C_{\mathrm{amp}}^y \cos\phi_i, \tag{2}$$

$$\bar{\theta}_i^r = C_0^r - C_{\mathrm{amp}}^r \sin\phi_i, \tag{3}$$

where $\bar{\theta}^b$, C_0^b and C_{amp}^b denote the target angle, the offset angle, and the amplitude of the trunk joint; $\bar{\theta}_i^y$, C_0^y and C_{amp}^y denote the target angle, the offset angle, and the amplitude of the yaw actuator at the ith limb; $\bar{\theta}_i^r$, C_0^r and C_{amp}^r denote the target angle, the offset angle, and the amplitude of the roll actuator at the ith limb. The variables ϕ^b and ϕ_i represent the oscillator phase of the trunk

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† Shura Suzuki is the presenter of this paper.

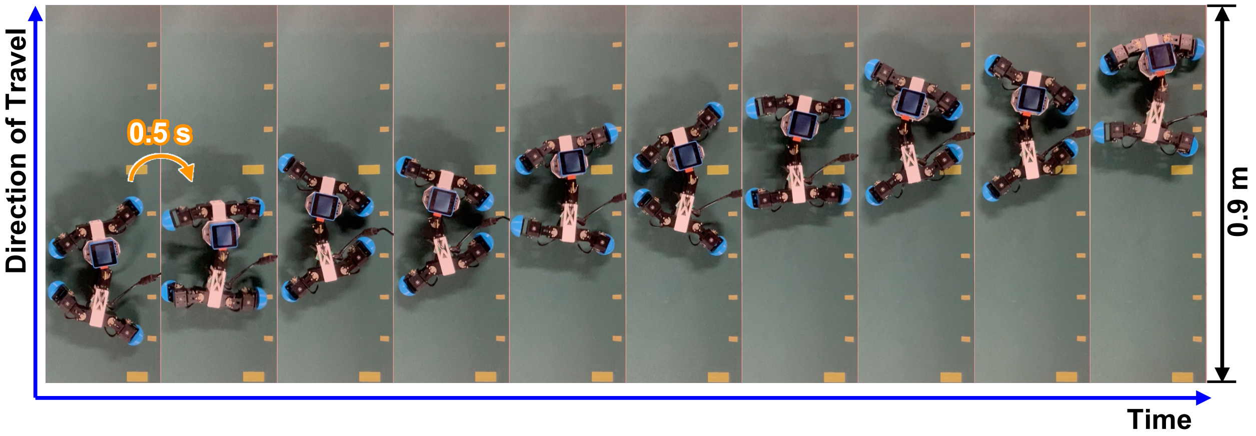

Fig. 2 Snapshots of walking experiment.

joint and the ith leg, respectively. The trunk joint bends right when $\phi^b = 0$ and left when $\phi^b = \pi$. The leg positions backward when $\phi_i = 0$ and forward $\phi_i = \pi$ by the yaw joint, and positions upward when $\phi_i = \pi/2$ and downward when $\phi_i = 3\pi/2$ by the roll joint.

The time evolution of the oscillator phase is described as follows:

$$\dot{\phi}^b = \omega - \sigma \tanh(\rho\tau^b) \cos\phi^b, \tag{4}$$

$$\dot{\phi}_i = \omega - \sigma \tanh(\rho\tau_i^r) \cos\phi_i, \tag{5}$$

where the variable ω represents the intrinsic angular velocity of oscillators, σ and ρ are the weights of sensory feedback, τ^b and τ_i^r represent the sensor values of servomotor current related to the generated torque at the trunk and the roll joint of the ith leg responsible for body support, respectively. Hyperbolic functions emulate the saturating response properties inherent in animal sensory systems, and ρ is related to the sensitivity.

The second term on the right side of Eqs. 4 and 5 is local sensory feedback inspired by our previous work [4]. This feedback ensures that the loaded actuator keeps the power stroke where the load continues to be applied. For example, the feedback modulates the trunk oscillator phase to $3\pi/2$ when the body trunk bends to the right ($\tau^b > 0$) and to $\pi/2$ when the body trunk bends to the left ($\tau^b < 0$). Similarly, it modulates the leg oscillator phase to $3\pi/2$ when the leg obtains the load ($\tau_i^r > 0$) for supporting the body.

3. RESULTS

We conducted the walking experiments on a stationary treadmill. The control parameters were determined referring to our previous work [5] as follows: $C_0^b = 0.0$ [rad], $C_0^y = 0.0$ [rad], $C_{off}^r = -\pi/3$ [rad], $C_{\mathrm{amp}}^y = \pi/6$ [rad], $C_{\mathrm{amp}}^r = \pi/6$, $C_{\mathrm{amp}}^b = \pi/6$ [rad], $\omega = 1.0\pi$ [rad/s], $\sigma = 0.8\pi$ [rad/s], $\rho = 0.1$ [a.u.]. The initial phases of all oscillators are set to $3\pi/2$.

Figure 2 shows the snapshots of the resulting gait patterns. The footfall pattern is the same as a lateral-sequence walking gait, in which the feet touch down in the order of right hind, right fore, left hind, and left fore. The lateral bending helps increase the stride length. These features correspond with those of the lizard walking gait [6]. The results show that the proposed controller can generate the lizard-like walking with trunk–limb coordination even in a real robot.

As future work, we will measure energy efficiency and traversability of various terrains. It clarifies the proposed controller's usefulness as a robot controller and how the local sensory feedback provides adaptive whole-body coordination in response to fields. Moreover, we will investigate the applicability of the controller for various morphologies using other types of animal-like robots.

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