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Author(s)	Oka, Daichi; Kamimura, Tomoya; Nakamura, Yuma et al.
Citation	The 11th International Symposium on Adaptive Motion of Animals and Machines (AMAM2023). 2023, p. 41-42
Version Type	VoR
URL	https://doi.org/10.18910/92257
rights	
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Bounding of a Two-Legged Robot Using CPG-based controller Inspired by a Cheetah Simple Model

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1 Introduction

Animals use many degrees of freedom of their entire body to perform efficient and sophisticated locomotion. Understanding animal locomotion and applying it to robot design and control can facilitate the development of better robots. However, animal locomotion is a complex dynamic phenomenon resulting from interactions between the body, nervous system, and environment. Therefore, understanding the entire dynamic principles of locomotion from observation alone is difficult. So far, many studies using simple dynamical models have shown that the passive nature of the body plays an important role in the emergence of locomotion [1, 2]. It has also been shown that motor control by the nervous system in animals can be reproduced using simple oscillator models [3, 4]. However, the simple model is a simplified version of the actual phenomenon. It is crucial to develop robots based on these models and verify the validity of the findings to determine if they are still dominant when accounting for additional factors.

We have investigated the principle of the cheetahs' high-speed running by utilizing the motion of its spine using a simple dynamical passive model [5], whose legs are represented by prismatic springs. In this study, we develop a quadruped robot platform to validate our findings of simple model. The robot is designed to reproduce the passive nature of the model, and a simple neural oscillator model is used for control.

2 Methods

In this study, we develop a robot that reproduces the passive dynamics of the body of a simple model. To replicate the springy legs of the model, a high back-drivability motor was used to control compliance. The RMD-X8 (MyActuator), a brushless DC motor with a low reduction ratio (1:6), was used.

The legs required two degrees of freedom (DOF) to move forward and backward, as well as to expand and contract, hence they were designed as 2-DOF links. Both motors were placed in the trunk, with the proximal link driven directly and the distal link driven by a timing belt. To construct the torso, we used a single aluminum frame. The robot was constrained in the sagittal plane above the treadmill. The power source was placed outside the robot body.

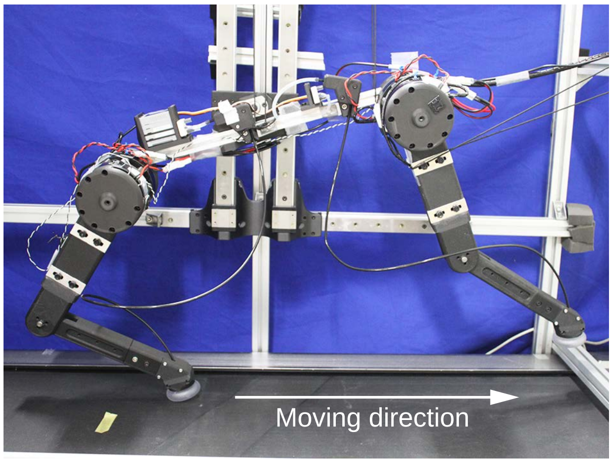

Figure 1: Fore and hind two-legged robot.

A simple oscillator is used as a CPG model in this study, with each fore and hind limb having a phase oscillator that was kept opposite through feedback. The touchdown was detected using a pressure sensor on the toe of the leg, which triggered phase resetting. ϕ_1 and ϕ_2 are the phase angles of fore and hind legs, respectively. The phase angular velocities of oscillator ϕ_i $(i = 1, 2)$ were given as follows:

$$\dot{\phi}_1 = \omega + \varepsilon \sin(\phi_2 - \phi_1 - \pi) - \phi_1^{\mathrm{td}}\delta(t - t^{\mathrm{td}}) \qquad (1)$$

$$\dot{\phi}_2 = \omega + \varepsilon \sin(\phi_1 - \phi_2 - \pi) - \phi_2^{\mathrm{td}}\delta(t - t^{\mathrm{td}}) \qquad (2)$$

where ω and ε are constant and $*^{\mathrm{td}}$ represents the variables at touchdown timing.

The shoulder and hip joints were position-controlled with the target angle switching depending on the phase of the CPG. The target angle was set to the touchdown and liftoff angles for $0 \leq \phi_i < 2\pi\beta$ and $2\pi\beta \leq \phi_i < 2\pi$, respectively, where β represents the duty rate, and we set $\beta = 0.3$.

The elbow and knee joint were position-controlled with the low gain PID control to reproduce the compliant characteristics of the simple spring-mass model. The target angles

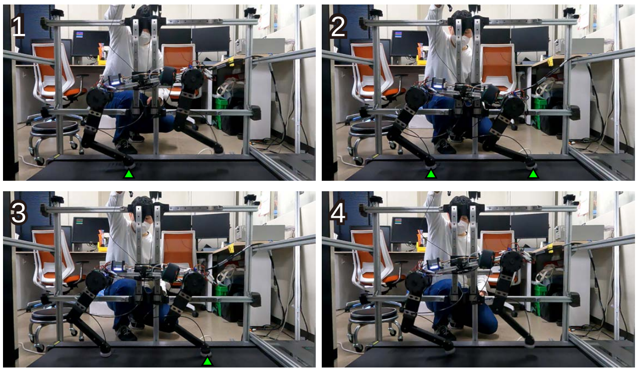

Figure 2: Snapshots of running on treadmill. Triangles indicates legs in contact.

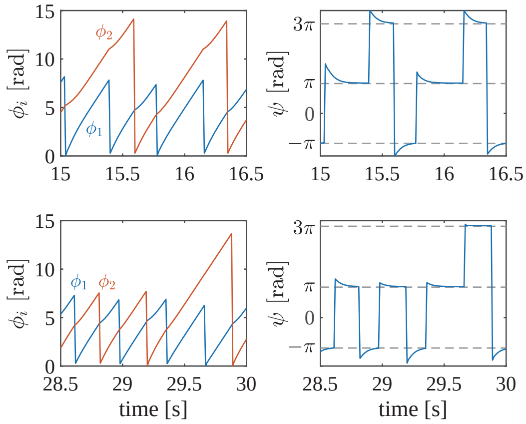

Figure 3: Time profiles of phase angles ϕ_i (left) of fore and hind legs and phase difference ψ (right) before (top) and after (bottom) switching to bounding gait.

were set to the initial position and not changed depending on the stance conditions of each foot.

3 Results

We developed a fore and hind two-legged robot as shown in Fig. 1. The robot has 5.1 kg body weight and 480 mm leg length. The robot was able to run on a treadmill, including flight phases, at a speed of 1.6 km/h for approximately 40 seconds.

At the beginning of running, during one cycle, the fore leg touched the ground twice while the hind leg touched it only once. However, at a certain point in time, the motion switched to a bounding gait where the fore and hind legs alternately touched the ground once during one cycle. Snapshots of the running after transition is shown in Fig. 2. The time profiles of phase angles of the CPGs and phase differences are shown in Fig. 3. Before the transition, the hindlimb was unable to lift off, resulting in a large phase angle each cycle. In such case, the phase difference exceeded π then converged to 3π due to the controller design. However, after the transition, the fore and hind legs alternately touched down and lifted off, with phase resetting occurring at an appropriate phase angle and the phase difference converged to $\pm\pi$.

4 Discussion

We developed a two-legged robot with fore and hind legs that have elastic properties, based on a simple model. We implemented a simple control system based on the phase of the CPGs, which allowed the robot to run on a treadmill without requiring a precisely defined foot trajectories.

The robot also showed a transition to bounding during locomotion, which indicates that a limit cycle was generated through the interaction between the body, nervous system, and environment, as predicted by the simple models. However, the leg control in our study did not exactly match the model dynamics, since the knee joints only functioned as rotational springs and did not produce spring forces along the leg axis, as in the models [2, 5].

The results suggested that it is required to improve our CPG model. Using the current CPG, the phase difference converged to $(2n-1)\pi$ (n is positive and negative odd number). In the future study, we change the controller to produce the appropriate locomotion.

Additionally, despite the robot being capable of running with flight phases, its running speed was quite low, with a Froude number of only 0.04. To increase the robot's speed, we plan to conduct experiments to optimize important parameters such as trunk length, touchdown angle, and angular frequency of CPGs.

Furthermore, we would like to implement a body joint to reproduce spine bending motions as shown in cheetahs' high-speed running [5].

Acknowledgement

This study was supported in part by JSPS KAKENHI Grant Numbers JP21K14104 and JP22H01445.

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