Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Bipedal Walking Based on Body Dynamics Using Phase Oscillator: *Robustness against gentle Ascent*

To cite this article: T. Kinugasa *et al* 2018 *J. Phys.: Conf. Ser.* **1065** 172002

Bipedal Walking Based on Body Dynamics Using Phase Oscillator: *Robustness against gentle Ascent*

T. Kinugasa[1], T. Tada[1], Y. Yokoyama[1], K. Yoshida[1], R. Hayashi[1], and S. Fujimoto[1]
1-1 Ridai, Kita-ku, Okayama, Okayama 700-0005, JAPAN
E-mail: kinugasa@mech.ous.ac.jp

Abstract. This study aims at realizing a 3-D dynamic bipedal walking using two oscillators of a CPG approach based on its body dynamics. We have developed a 3-D biped that comprises flat feet with force sensors, ankle joints composed of ball joints surrounded by coil springs, telescopic knees, and active hip joints using a direct drive (DD) motor. We introduced the Owaki-Ishiguro method called 'TEGOTAE based approach' as ground contact information in the phase oscillator to the knee joint, and we achieved 3-D dynamic bipedal gait using RW06 only by the knee oscillation based on the phase oscillator. The bipedal walking was excited only by the knee oscillation, therefore, the gait was strongly affected by the body dynamics. This means that the gait might be affected strongly by disturbances, because passive dynamic walking, which achieved only by the body dynamics and interaction to environment, is not robust against such disturbances. In this study, therefore, we conduct some experimental tests to elucidate adaptability against ground variations.

1. Introduction

Passive dynamic walking [1] is emerged only by body dynamics of a biped and interaction to environment with body. The passive dynamic walking has an interesting characteristic of realizing a natural and energy efficient gait adapting to the environment according to its morphology. We assume that the body dynamics including the interaction to the environment stabilizes the bipedal gait implicitly. However, the passive dynamic walking and strategies based on the passive dynamic walking mechanism are not robust against disturbances mainly from the environment. In contrast, a central pattern generator (CPG), obtained by Biological findings, was introduced to control legged robots, and achieved various adaptive and robust locomotion including bipeds [2-5]. Some studies showed possibility of an adaptive three-dimensional (3-D) bipedal walking [5], however, there was no systematic design strategy for the coordination of oscillators excepting the studies for multi-legged robots by Owaki and Ishigro [6-11]. In addition, the CPG signal was used only for the desired trajectory of the tracking control of joints. The trajectory tracking control for the joints might neglect the body dynamics for the locomotion. For the problem, Hanamoto, et al [8], introduced some passive joints for a quadruped robot to achieve a dynamic locomotion. For the bipedal walking, the body is fundamentally supported by a foot and the center of the total mass goes outside of the foot print while the biped walks dynamically. Generally speaking, it is difficult to obtain a stable and dynamic bipedal walking with passive degrees of freedom that should be controlled by the body dynamics only. For the problem, we have developed a 3-D dynamic bipedal walking using two oscillators of a CPG approach based on the body dynamics. However, robustness or adaptability of the obtained gait was not evaluated. This study, therefore, aims at evaluating the

[1] Okayama University of Science

robustness or adaptability of the gait using the phase oscillator with ground reaction forces. First, we introduce our 3-D biped called RW06 that comprises flat feet with some force sensors, ankle joints composed of ball joints surrounded by coil springs, telescopic knee joints, and actuated hip joints using a direct drive (DD) motor. Next, we introduce the Owaki-Ishiguro method called 'TEGOTAE based approach' [10] as ground contact information in the phase oscillator to the knee joint. Finally, we conduct some experimental tests in order to elucidate robustness or adaptability of the biped.

2. 3-D Bipedal Walker RW06

We have developed a 3-D biped with ankle springs and flat feet, 'RW03', and realized 3-D passive dynamic walking gait [12]. We added a telescopic knee joint to RW03, and develop some 3-D bipeds, 'RW04' and 'RW05. We achieved 3-D dynamic bipedal gait for the bipeds on a horizontal surface using a forced oscillation by the knee joint [13]. In this section, we introduce a new biped, 'RW06' with hip actuators based on the previous bipeds.

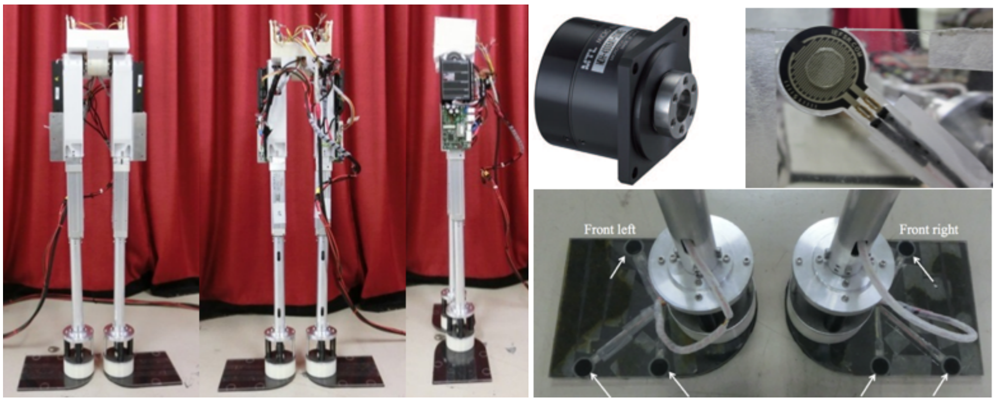

Figure 1. RW06 frontal view, rear view, and left side view, and DD motor and force sensor equipped on the sole.

2.1. RW06

Figure 1 shows the 3-D dynamic biped, RW06. RW06 is height of 900 mm, the total weight of 6.4 kg, the center of the total mass of 450 mm from the ground, and the eigenfrequency of 4.3 rad/s for a swing leg and 5.1 rad/s for the lateral oscillation, which are inherent characteristics of the previous bipeds. A direct-drive (DD) motor is implemented to a hip joint for back-drivable actuation as shown in figure 1. The DD motor can realize free oscillation of the hip joints using the back-drivability and generate an appropriate torque for walking, simultaneously, even though torso is controlled by the DD motors using a PD control law. This property ensures a torque control for the hip joints instead of usual trajectory tracking.

2.2. Phase Oscillator via 'TEGOTAE' Approach [10]

In the section, the previous method using the sinusoidal oscillation is extended to the phase oscillator based on 'TEGOTAE approach' [10]. The TEGOTAE approach uses the ground reaction force (GRF) as 'TEGOTAE', which means a good reaction from the target, i.e. the ground, for control of the phase. Eqs. (1) and (2) are extended to the phase oscillator given as the following equations:

$$\dot{\zeta}_i = \omega - \sigma N_i \cos \zeta_i \quad (1)$$

$$d_{di} = -A \sin \zeta_i + d_0 \quad (2)$$

Equation (1) shows the time response of the phase ζ_i of the left and right knees, where, N_i indicates the GRF measured by the ith force sensor as shown in figure 1, σ is the weight of the GRF of the foot sole. Equation (2) shows the desired trajectory for the knee oscillation. The both knee start the oscillation for the initial phase difference of zero. However, when the GRF in Eq. (1) provides force alternately caused by something such as an external oscillation, then the knee frequency of the stance leg decreases due to the second term of Eq. (1). The phase of the stance knee delays relative to the swing knee around the extended position. When the foot sole feels the GRF and the weight σ is enough large, the phase ζ_i converges to $3\pi/2$. Therefore, the knee tends to maintain the extended position when the leg touches to the ground. We expect that the bipedal gait is excited by the knee oscillation changing the phase with the GRF.

3. Experiment

We conducted performance tests that evaluated a kind of adaptability, climb-ability, for a gentle ascent. The angle of the ascent consisted of some aluminum board of 15 mm, and was 1.5 degrees. The length of the slope was 2 m. Two horizontal areas were connected to the slope. For the desired trajectory, the amplitude A and the angular frequency were 8.0 mm and 1.8 π rad/s, respectively. Figure 2 shows an experimental result. From the figure, RW06 could climb the gentle ascent.

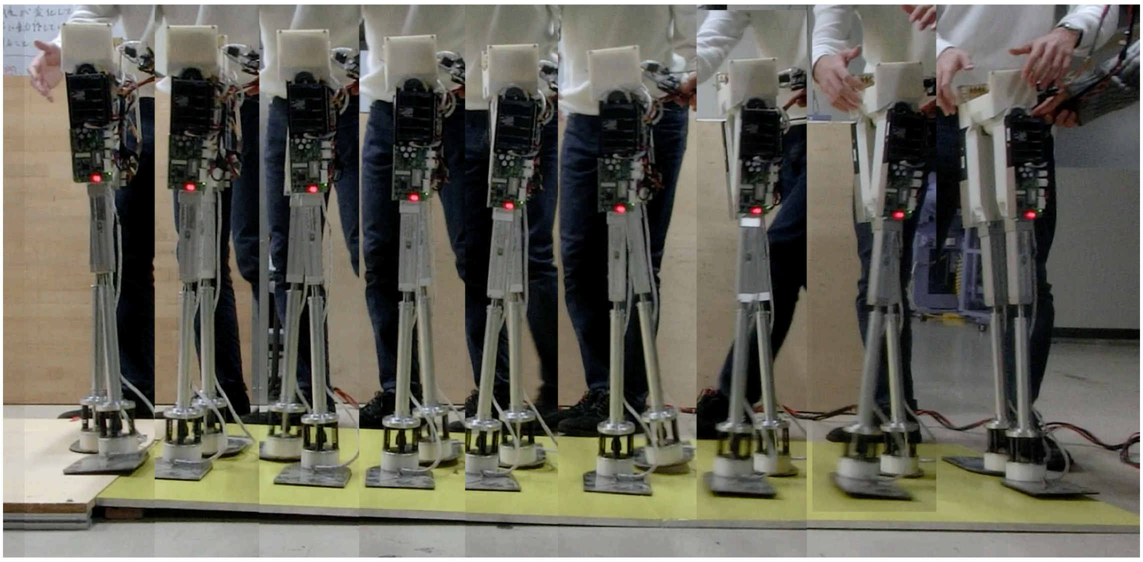

Figure 2. Walking gait of RW06 on a gentle ascent.

The left figure of figure 3 shows the relative angle between the both legs. In the figure, the stride decreases around 8s, it keeps the small stride of 7 degrees until 13 s, and RW06 steps on the same area from 14 s to 16 s. RW06 started climbing around 8 s and approached to the horizontal area around 14 s. After several stepping, it started walking forward again on the horizontal area, even though the stride was oscillatory. To clarify the foot stepping, the ground reaction forces of the both foot are shown in the right of figure 3. The ground reaction forces also decreased when RW06 started climbing, and it was lost when RW06 approached to the horizontal area. The force sensors located at the front of sole did not contact to the ground in the area where the slope angle discretely changed from 1.5 to 0. In the horizontal area, the ground reaction force was also oscillatory. The horizontal area was put on the floor that was not flat; and thus, the area was trembled because of the movement of RW06. We also conducted some experimental tests using the sinusoidal knee oscillation in order to compare the performance of the both methods, however, RW06 could not climb the same slope. Therefore, we can conclude that the phase oscillator using the ground reaction force had adaptability against gentle ascent.

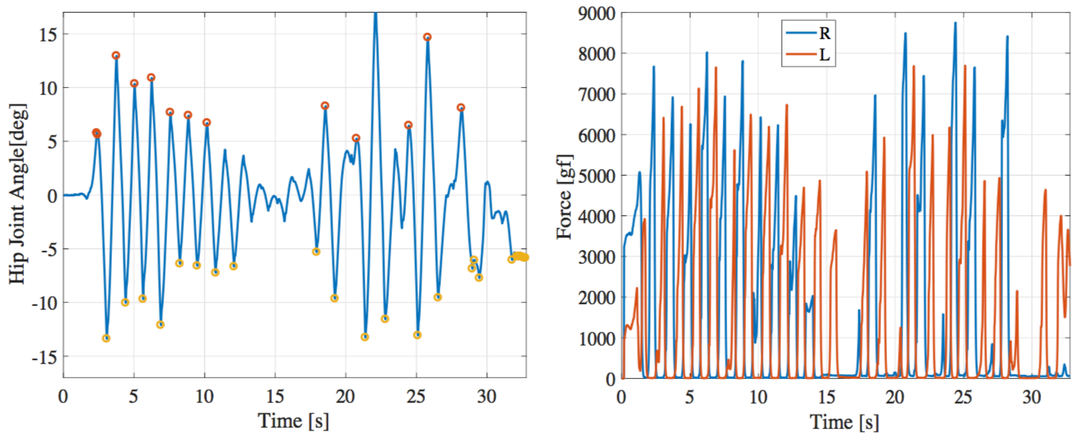

Figure 3. Hip joint angle (left) and ground reaction forces (right).

4. Conclusions

In this paper, we developed a 3-D biped 'RW06', designed a phase oscillator based on 'TEGOTAE' approach, realize 3-D dynamic bipedal gait, and evaluated adaptability against a gentle ascent. The gait was generated using body dynamics, because all degrees of freedom of the biped excepting knees and torso were passive. The previous strategy using a simple sinusoid explicitly could not climb the gentle ascent. It is important that the 3-D gait is emerged only using the phase oscillator of the knee joint and the body dynamics. For future works, we will elucidate the gait variation for angular frequency, amplitude, ground reaction force, and so on.

Acknowledgments

The authors are grateful to the Ministry of Education, Culture, Sports, Science and Technology of Japan for providing financial assistance under KAKENHI (Nos. 26420215 and 17k06281).

References

[1] McGeer T 1988, *CSS-IS TR* **88-02**.
[2] Taga T, et al 1991, *Biological Cybernetics* **65** 3 147-159.
[3] Geyer H and Herr H 2010, *IEEE Trans. On Neural Sys. and Rehabilitation Eng.*, **18** 3 263-273
[4] Yamasaki T, et al 2003, *BioSystem*, **71** 1-2 221-232
[5] Aoi S and Tsuchiya K 2005, *Autonomous Robots*, **19** 3 219-232
[6] Horikita S, et al 2016, *Proc. of 28th Symposium on decentralize system*, 116-119
[7] Yashitani N, et al 2016, *Proc. of ROBOMECH 2016*, 2A2-08a6
[8] Hamomoto M, et al 2016, *Proc. of ROBOMECH 2016*, 1A1-C10
[9] Owaki D and Ishiguro A 2017, *Scientific Reports* **7** 277
[10] Owaki D, et al 2017, *Frontiers in Neurorobotics*, **11** 29
[11] Kano T, et al 2017, *Bioinspiration & Bio-mimetics*, **12**
[12] Kinugasa T, et al 2009, *J. of Robotics Society of JAPAN*, **27** 10, 1169-1172
[13] Kinugasa T, et al 2015, *J. of Robotics and Mechatronics*, **27** 4, 444-452
[14] Kinugasa T, et al 2018, *Proc. of AROB 23rd 2018*, 703-708