Verification of trajectory generation of bipedal walking robot

Naoki Masuda, Masanori Sugisaka
Dept. of Electrical and Electronic Engineering, Oita University
700 Dannoharu Oita 870-1192 Japan.
Email:*msugi@cc.oita-u.ac.jp*

Abstract

A bipedal walking robot and a humanoid robot are developed in various research organizations in recent years, and research towards utilization is done. Under the environment which has irregular ground or various road surface, also the bipedal walking robot and human, working and living together, need to be studied, so that the bipedal walking robot will be able to respond to multiple conditions. By doing so, it was considered that generating the walking orbit which can respond to the walking movement on the irregular ground which is the purpose of this research have been achieved. In this paper, using a simulation, the walk orbit in leveling is generated and it verifies whether it can walk with the level of differences created virtually.

1. Introduction

A bipedal walking robot and a humanoid robot are developed in various research organizations in recent years. Currently, research organization is working toward the utilization of this technology and manage to attract public society. By studying and learning from biological model, in this case human, is the direction of the bipedal walking robot. You may say that the dynamic bipedal walking in reproducible leveling was realized at present although having to be regarded as an actual thing like the directions of bipedal walking robot or humanoid. However, the technical study of bipedal walking robot movement been conquered completely [1][2].

On the other hand under the environment which has irregular ground or various road surface, also the bipedal walking robot and human, working and living together, need to be studied, so that the bipedal walking robot will be able to respond to multiple conditions. There are various methods, [3][4] such as using the linear inverted pendulum mode which fixed ZMP, in orbital generation of the irregular ground, using moment as $N = 0$. However, in order to perform an irregular standpoint line, the orbit control of the center of gravity is indispensable first. And there are some which fix the height of the center of gravity and the height of the ground [5], and are generating the orbit by the research which is carrying out orbit control of the center of gravity. However, I fix the position and the ground of the center of gravity, and think that the walk in the irregular ground is not possible. Then, by paying attention to the center of gravity vibration by the velocity which is one of the fall reason, target velocity was set up and it is considered as controlling, advancing or translation velocity to converge on the target velocity. This is operating ZMP and controlling the center of gravity, and is transposing the problem which determines the orbit of the center of gravity to the problem which determines the orbit of ZMP.

By doing so, it was considered that generating the walking orbit which can respond to the walking movement on the irregular ground which is the purpose of this research have been achieved. In this paper, using a simulation, the walk orbit in leveling is generated and it verifies whether it can walk with the level of differences created virtually.

2. Generation of orbit

2.1 The equation of a strict model [5]

First, gravity and the anti-power of a floor act on a bipedal robot. The anti-power and the moment of a floor can be described using the position of ZMP (Zero Moment Point), the inertia power of the whole body, and the gravity which are defined on floor. Balance of the circumference of the X-axis and Y-axis on the basis of the center of gravity uses the next equation.

$$\begin{aligned} N_y &= m(x_{cg} - x_{ZMP})(\ddot{z}_{cg} + g) - m(z_{cg} - z_{gnd})\ddot{x}_{cg} \\ N_x &= -m(y_{cg} - y_{ZMP})(\ddot{z}_{cg} + g) + m(z_{cg} - z_{gnd})\ddot{y}_{cg} \end{aligned} \qquad (1)$$

Here, $N := [N_x, N_y, N_z]^T$ is the moment which acts on the circumference of the center of gravity. And L is the angle quantity of motion of the circumference of the center of gravity. And $[x_{cg}, y_{cg}, z_{cg}]^T$ is a center of gravity position. And $[x_{ZMP}, y_{ZMP}, z_{gnd}]^T$ is in ZMP. m is the mass of the whole body. g is the size of gravity acceleration.

2.2 Assumption

Approximation is taken as assumption conditions is one and it is the moment N of the circumference of the center of gravity produced by change of a posture. The anticipation value $\tilde{N}(t)$ is calculated beforehand.

$$N \cong \tilde{N} \qquad (2)$$

Since a moment is not correctly obtained until it determines actual movement, an error is included in an anticipation value. However, if the influence which it has on ZMP of the error is settled in the grade which does not jump out of a support leg, it is thought that the problem by approximation will be produced as a result.

The next equation will be obtained, if the above assumption is applied to the equation (1) of the model.

$$\begin{cases} \ddot{x}_{cg} = a(x_{cg} - x_{ZMP} - \dfrac{\widetilde{N}_y}{mg}) \\ \ddot{y}_{cg} = a(y_{cg} - y_{ZMP} + \dfrac{\widetilde{N}_x}{mg}) \end{cases} \quad (3)$$

The center of gravity generation is performed based on the equation (3) of an approximation model.

2.3 The formulization in question

The center of gravity orbit is a problem which attains the center of gravity position and center of gravity velocity of the specification with the appointed time, and is expressed with the next equation.

$$\begin{cases} \begin{bmatrix} x_{cg}(t_0+T) \\ \dot{x}_{cg}(t_0+T) \end{bmatrix} = \begin{bmatrix} \overline{x_{cg}} \\ \overline{\dot{x}_{cg}} \end{bmatrix} \\ \begin{bmatrix} y_{cg}(t_0+T) \\ \dot{y}_{cg}(t_0+T) \end{bmatrix} = \begin{bmatrix} \overline{y_{cg}} \\ \overline{\dot{y}_{cg}} \end{bmatrix} \end{cases} \quad (4)$$

Here, $t = t_0$ is the time specification of $t = t_0 + T$ at the present time. For specified center of gravity position $(\overline{x_{cg}}, \overline{y_{cg}})$ and the appointed center of gravity velocity by $(\overline{\dot{x}_{cg}}, \overline{\dot{y}_{cg}})$ above equation will become as shown below.

$$\begin{cases} \begin{bmatrix} \overline{x_{cg}} \\ \overline{\dot{x}_{cg}} \end{bmatrix} = e^{TA} \begin{bmatrix} x_{cg}(t_0) \\ \dot{x}_{cg}(t_0) \end{bmatrix} + \int_0^T a e^{(t-\tau)A} h_x(t_0+\tau)\, d\tau \\ \begin{bmatrix} \overline{y_{cg}} \\ \overline{\dot{y}_{cg}} \end{bmatrix} = e^{TA} \begin{bmatrix} y_{cg}(t_0) \\ \dot{y}_{cg}(t_0) \end{bmatrix} + \int_0^T a e^{(t-\tau)A} h_y(t_0+\tau)\, d\tau \end{cases} \quad (5)$$

Since a center of gravity position and ZMP have the relation of the equation(3), by ZMP operation,it shows that a center of gravity position is controllable. By applying ZMP, center of the gravity orbit can be obtained. However, the range which can operate ZMP with the behavior is limited inside a support leg.

3. Simulations

3.1 Orbit marking

In order to decide the position of a leg, the target orbit of the imagination body is considered. The position of a leg is arranged along this target orbit. A target orbit makes the starting point a position, velocity, a present angle, and present angular velocity. And in order to make it converge on the target speed and target angular velocity which were specified, it is made constant angular acceleration and constant acceleration. And an orbit which becomes uniform angular velocity and uniform velocity from the middle is made.

Moreover, the length of the grounding term one of the both legs and the length of the grounding term of both legs are decided beforehand. It asks for the time of the center of both the leg grounding term according to the schedule. And a landing position is decided near the point in the time on a target orbit.

3.2 Modeling

By aiming at the orbital generation, the simplified model is used. A front is the X-axis, a horizontal axis is the Y-axis and, as for this model, the vertical axis is the Z-axis. A hip joint is 3flexibility, a knee joint is 1flexibility and, as for flexibility, the leg joint has 2flexibility. (Fig.1)

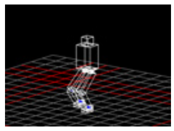


Fig.1 Bipedal walking robot model

3.3 An environmental setup of the irregular ground

An environmental setup of the irregular ground creates the level differences of height (0.1[m] and 0.05[m]) virtually as the first phase. Moreover, sidewall is made leveling.

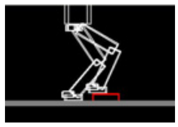


Fig.2 The irregular ground

3.4 Walking conditions of the model

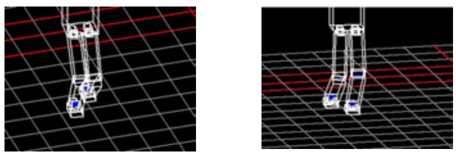
The conditions of the model of the bipedal walking robot are shown below.

- Time in one step＝0.5[s]
- The rate of both legs grounding term in one step＝0.2[s]
- Maximum acceleration＝0.4[m/s^2]
- Maximum angle acceleration＝3.0[rad/s^2]
- Distance from the target orbit to the landing position of a leg ＝0.02[m]

4. Results

4.1 Walking pattern and Advancing translation velocity to target velocity, Velocity of center of gravity

Fig.3 is the walking pattern at the time of leveling. A closed example and Fig.5 show the displacement of center of gravity velocity to Fig.4 for the advancing translation velocity to target velocity.



(a) Right leg grounding term (b) Left leg grounding term

Fig.3 Waking pattern (Height of ground = 0.0[m])

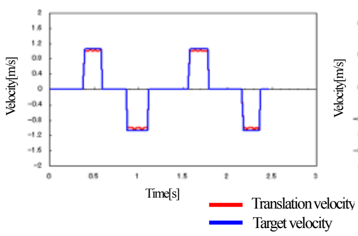


Fig.4 Advancing translation velocity to target velocity

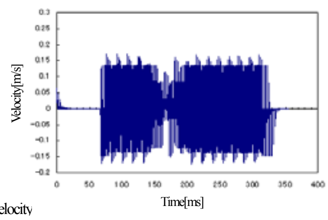


Fig.5 Velocity of center of gravity

The walk pattern was able to obtain the walk stabilized mostly. Although target velocity is not as expected, by referring to Fig.3, it turns out that acquaintance and uniform velocity are mostly maintained at target velocity. Although Fig.4 is a figure showing the velocity of the center of gravity, it turns out that it is walking maintaining a certain fixed center of gravity velocity. Therefore the stabilized walking pattern is studied.

In case the height of the ground goes up, which the level difference is 0.05[m] as shown in Fig.6. And Fig.8 show the displacement of center of gravity velocity to Fig.7 for the advancing translation velocity to target velocity.

(a) from front view (b) from side view

Fig.6 Form of a walk (Height of ground = 0.05[m])

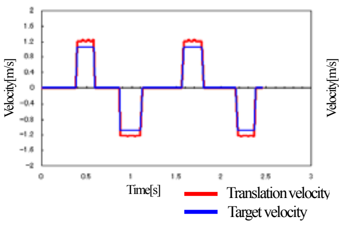


Fig.7 Advancing translation velocity to target velocity

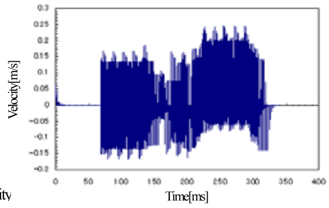


Fig.8 Velocity of center of gravity

Although the walk pattern was shaky, it was maintaining the walk orbit. Since the center of gravity movement was the range which a support leg can bear, the walk orbit which overcomes the level difference of 0.05[m] was generable. By referring to Fig.7, it turns out that advancing translation velocity is over a few to target velocity compared with the walk at the time of leveling. Although center of gravity velocity was carrying out the velocity rise at the moment of going up a level difference, the width is the width of the inside which can be walked and seldom affected the walk pattern. (Fig.8)

Next, walk form in case the height of the ground goes up the level difference which is 0.1[m] is shown in Fig.9. And Fig.11 show the displacement of center of gravity velocity to Fig.10 for the advancing translation velocity to target velocity.

(a) from front view (b) from width view

Fig.9 Form of a walk (Height of ground = 0.1[m])

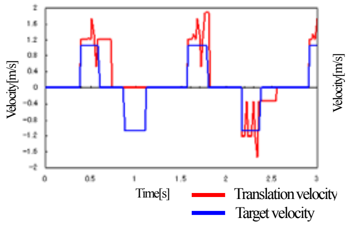


Fig.10 Advancing translation velocity to target velocity

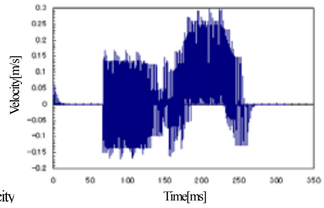
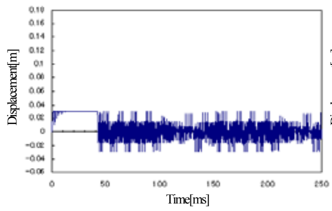


Fig.11 Velocity of center of gravity

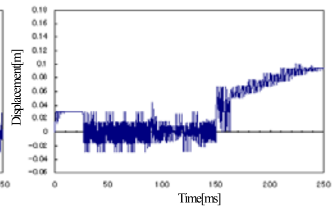
For the walking pattern, the model collapse at the beginning, because putting the left leg on the difference level and carrying the right leg. Although it has balancing translation velocity to target velocity, it has balancing translation velocity clearly beyond target velocity. Moreover, center of gravity velocity has generated a double velocity, when rising a level difference as compared with the walk at the time of leveling. Therefore, I think that the rise of this velocity caused a fall. It is observed that this double velocity caused the model to fall.

4.2 Displacement of the center of gravity (Form by each road surface)

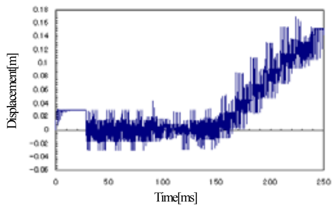
The displacement of the center of gravity position in each road surface form is shown in Fig.12.



(a) Height of ground = 0.0[m]



(b) Height of ground = 0.05[m]



(c) Height of ground = 0.1[m]

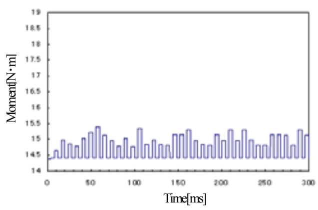
Fig.12 Displacement of the center of gravity

The displacement of the center of gravity position in each road surface is compared. Since the displacement of an almost fixed center of gravity position is shown at the time of leveling, as walking pattern, it turns out that it is possible within the limits. Moreover, it is considered that this vibration occurred since the contact power of the sole and the floor in sidewall is vibrating. Next, for 0.05[m] and 0.1[m], when the center of gravity position rises at a level difference in both, the center of gravity position is changed completely. If by comparing these two levels, although change of a center of gravity position may be sharp at the moment of rising level difference at 0.05[m], after that, the change of a center of gravity position will not be much, and it turns out that there is none. However, while rising the level difference of 0.1[m], it can grasp that it is intense in center of gravity movement. Too, the rise of center of gravity velocity led to change of a center of gravity position. And it turns out that a result to reverse was brought.

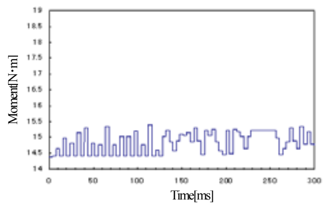
4.3 Displacement of Moment

The displacement of moment in each road surface form is shown in Fig.13.

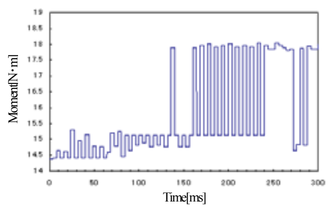
It turns out that the moment in the height 0[m] and 0.05[m] of the ground is maintaining fixed width mostly, and there is no influence of center of gravity portion. However, it has generated clearly, and by comparing the moment of the circumference of the center of gravity in 0.1 [m] with 0[m] and 0.05[m], 3 [Nm] it has slight a difference. It is the moment produced since this had advancing translation velocity clearly beyond target velocity, and since the influence which the error has on ZMP has jumped out of the support leg, I think that it is the cause of a fall. You have to control generating of this moment.



(a) Height of ground = 0.0[m]



(b) Height of ground = 0.05[m]



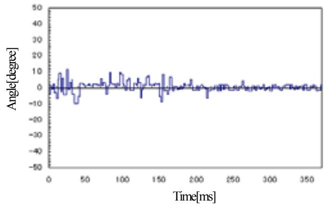
(c) Height of ground = 0.1[m]

Fig.13 Displacement of Moment

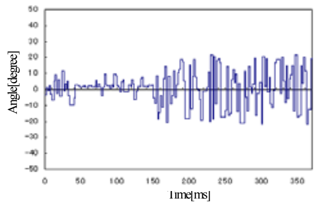
4.4 Displacement of Hip Angle

The displacement of the waist angle of Hip Angle in each road surface form is shown in Fig.14.

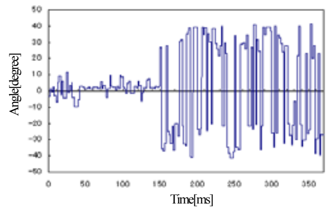
When the height of the ground is 0[m] as it understands, even if it sees a Fig.14, the difference of the maximum angle is 10[degrees], when it is 0.05[m], it is 20[degrees], and in the case of 0.1[m], it is 40[degrees]. The angle at the time of 0[m] and 0.05[m] is the displacement of the angle within the limits which can maintain a walk pattern. However, at the time of 0.1[m], since the displacement of a center of gravity position had become large as the displacement of the center of gravity position of the foregoing paragraph also showed, displacement of the angle of the waist was enlarged for it as a method of prevention. And it was going to do by force and is going to maintain the walk pattern at an angle of the waist. It is one of the causes of moment generating.



(a) Height of ground = 0.0[m]



(b) Height of ground = 0.05[m]



(c) Height of ground = 0.1[m]

Fig.14 Displacement of Hip Angle

5. Conclusions

From this research, it is observed when the height of the ground was 0 [m] and 0.05 [m], the orbit of the walk which follows a target orbit was able to be generated. However, since the moment of the circumference of the center of gravity occurred, 0.1 [m] brought a reverse result. In addition, since the contact power of a sole and a floor occurred, the burden of each joint supporting a robot became large, and a result which affects the vibration and the walk orbit in a center of gravity position was brought. From research observation, for the moment control produced by velocity rise, velocity control is performed and the moment of the circumference of the center of gravity is controlled. Also, you have to consider generation of the orbit which performs an interference check etc to the contact power of a sole and a floor.

Reference

[1]Inoue,H.,Tachi,et.al : "Overview of Humanoid Robotics Project of METI", Proc.Int.Symp.Robotics, pp.1478-1482, 2001.

[2]Nishiwaki,K.,Sugihara,T.,et.al : "Designand Development of Research Platform for Perception-Action Integration in Humanoid Robot:H6", Proc.Int.Conference on Intelligent Robots and Systems, pp1559-1564, 2000.

[3] Kajita, S. and Tani, K., : "Control of Dynamic Biped Locomotion Based on Realtime Sensing of the Ground Profile" , Journal of the Robotics Society of Japan, vol.14, No.7, pp.1062-1069, 1996. (in Japanese)

[4]Kajita,S., : "Real-time Dynamic Walking Control of a Biped Robot Using the Linear Inverted Pendulum Mode" ,Report of Mechanical Engineering Laboratory No.171,1996. (in Japanese)

[5]Shino,et.al : "Real-time orbital generation of a bipedal robot" , Tokyo institude of Techology project newmanoid,2001.(in Japanese)