Research about ZMP of biped walking robot

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Abstract

In this paper, ZMP (Zero Moment Point) of biped walking robot is explained. OpenHRP2 (AIST) is used for walking pattern simulation. The purpose of this research is to calculate the theoretical value and actual value of ZMP. Firstly, the reference ZMP of the robot is calculated from CoM (Center of Mass) and CoM position. Then, the actual ZMP of the robot is calculated from Force/Torque sensor value. Next, the reference ZMP is compared to the actual ZMP. Finally, the robot walking pattern behavior is controlled by restoring the actual value of ZMP to the theoretical value of ZMP.

1. Introduction

Recently, biped walking robots are widely known and concerned by mass media such as TV or magazines. People are interested in robots such as “ASIMO”, “QRIO” and “PINO”. Impressively, these robots are expected to be used for transportation device at complex environment such as steps. Therefore, biped walking robots are studied by many research institutions.

Two years ago, research of biped walking robot has been done for the first time in our laboratory. Then, in order to study biped walking robots, a robot composed of microcomputer and servo motors was developed. By assigning the command value of each joint or servo motors, “Static walking” of the biped robot was successfully done.

However, a lot of servo motors were broken because of overload during the experiment. In order to save the coot of servo motors, the robot walking pattern was verified using simulator.

In this research, ZMP concept is applied for “Dynamic walking”, so that “Static walking” will be successfully done by the actual robot. For this purpose, the theoretical value and the actual value of ZMP is calculated. Then, the robot walking pattern behavior is controlled by restoring actual ZMP value to theory ZMP value.

2. Simulation environment

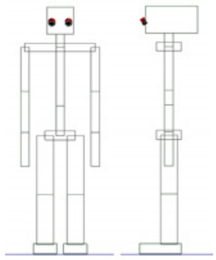
2.1 OpenHRP2

OpenHRP2 (AIST) is used for walking pattern simulation. OpenHRP2 is composed of “Dynamics server”, “Controller server” and etc. These servers are distributed object system that used CORBA (Common Object Request Broker Architecture). Each server is mounted as CORBA object.

Computer specification is Windows2000 for OS and AMD Athlon™ Processor (1000.04-MHz) for CPU.

2.2 Robot model

Robot model is created by 3D modeling language called VRML (Virtual Reality Modeling Language). Robot model that has been used for walking pattern simulation in this research is shown by Fig.1. One leg has 6 DOFs (Degree of Freedom), and 4 steps forward pattern is used for walking pattern of this robot model. This simple robot model is used for walking pattern simulation, so calculating the ZMP value of the robot is focused in this research.

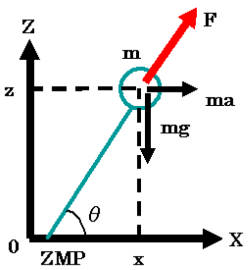


height	0.45[m]
weight	13[kg]
DOF	leg 6×2, arm 7×2, body 3 (total 29)
step	4[steps]

Fig.1 Robot model

3. Reference ZMP

3.1 ZMP simple model



F: force effecting mass point from floor
g: gravity
a: mass point acceleration effecting to direction of resultant of F and g.

Fig.2 Inverted pendulum model on sagittal plane

Inverted pendulum model on sagittal plane is shown as ZMP simple model by Fig.2. Firstly, Eq.1 is obtained from dynamic equation of horizontal and vertical direction about mass point.

$$
\begin{aligned}
m\ddot{x} &= f_x = |\mathbf{F}|\cos\theta \\
m\ddot{z} &= f_z - mg = |\mathbf{F}|\sin\theta - mg
\end{aligned} \tag{1}
$$

Secondly, Eq.2 is given by ZMP definition that total momentum around ZMP is zero.

$$zf_x - (x - ZMP)f_z = 0 \tag{2}$$

Finally, Eq.3 is derived from Eq.1 and Eq.2.

$$ZMP = \frac{m\{x(\ddot{z}+g)\} - z\ddot{x}\}}{m(\ddot{z}+g)} \tag{3}$$

By changing x to y, Eq.3 can adapt to lateral plane.

3.2 ZMP robot model

Eq.4 is obtained by expanding Eq.3 to each link of robot.

$$x_{ZMP} = \frac{\sum_{i=1}^{n} m_i\{x_i(\ddot{z}_i + g) - z_i\ddot{x}_i\}}{\sum_{i=1}^{n} m_i(\ddot{z}_i + g)} \tag{4}$$

where n is total number of piece of robot link. By replacing x with y, Eq.3 can adapt to lateral plane. It is shown as Fig.3 that the reference ZMP on sagittal plane is calculated by running the walking pattern simulation using Eq.4.

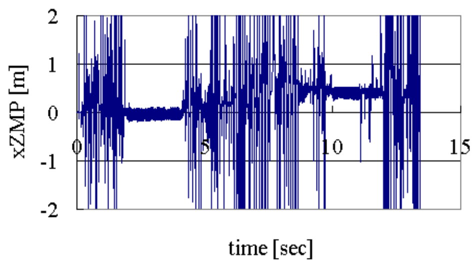


Fig.3 Reference ZMP on sagittal plane (used Eq.4)

It is shown as Fig.4 that the reference ZMP is widely oscillating in walking. It is cited as a factor that solutions are underspecified, so there are two variables (x, z). It is thought that optimization problem is solved. But, in this paper, it is decided that this problem is replaced with pseudo ZMP for simplicity. The following, pseudo ZMP is explained.

3.3 Pseudo ZMP

Eq.5 is given by representing gravity M of the whole robot in Eq.4.

$$x_{zmp} = \frac{M(g+\ddot{z})x - M\ddot{x}z}{M(g+\ddot{z})} \tag{5}$$

At this moment, attention should be paid to z direction of gravity position of walking pattern. By assuming that z direction of gravity position stays constant, z and $\ddot{z}$ in Eq.5 can be simply transformed into

$z = h_{ref}(const)$ and $\ddot{z} = 0$ in Eq.6.

$$x_{zmp} = \frac{gx - h_{ref}\ddot{x}}{g} \quad (6)$$

By changing x to y, Eq.3 can adapt to lateral plane.

Simulation results using Eq.6 is shown by Fig.4.

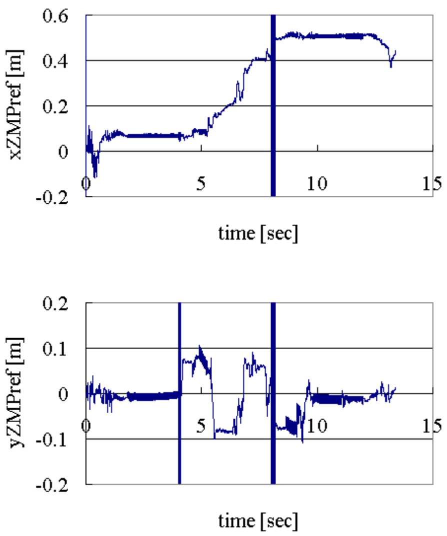


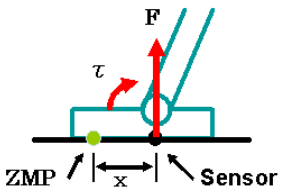
Fig.4 Pseudo ZMP using Eq.6

At x direction and y direction of ZMP, the results are displayed by Fig.4. It is taken that x direction ZMP moves to forward and y direction ZMP is shifting on supporting leg while the robot is walking. We understand that x and y ZMP are greatly amplified at about 4 and 8 seconds. From here, it is obtained that walking pattern of the robot does not go well and the robot movement on the floor taking extra time about 4 and 8 seconds. Therefore, $\ddot{x}$ of Eq.6 amplified widely by moving on the floor.

As described, theory value of ZMP of robot is calculated from gravity position and acceleration. This theory value of ZMP is called the reference ZMP.

4. Actual ZMP

In this topic, the actual ZMP is introduced. By A.Goswami, $ZMP = CoP$ (Center of Pressure) is verified in 1999. Therefore, ZMP is calculated by measuring CoP of sole. And so, it is thought that CoP, or ZMP, is measured from Force/Torque sensor value of sole of the robot.



F: vertical component of floor reactive force at sensor position

τ : torque at sensor position

x: distance between sensor and ZMP

Fig.5 Foot model of robot on sagittal plane

Foot model of robot on sagittal plane is shown by Fig.4. Moment of force around ZMP is expressed by Eq.7.

$$Fx - \tau = 0 \quad (7)$$

Eq.7 is rearranged to Eq.8.

$$x = \frac{\tau}{F} \quad (8)$$

The actual ZMP is calculated from x in Eq.8 and sensor position information. By replacing x with y, Eq.8 is able to be used for lateral plane.

Simulation result using Eq.8 is shown by Fig.6.

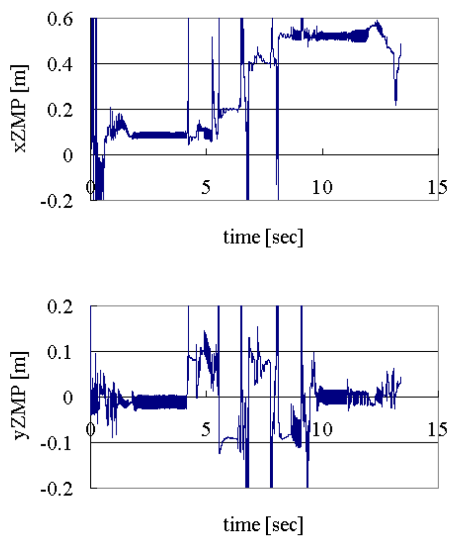


Fig.6 The actual ZMP using Eq.8 and sensor position information

The actual ZMP of x direction and y direction are shown as Fig.6. It is taken that x direction of ZMP moves to forward and y direction of ZMP is shifting on supporting leg while the robot is walking. We understand that x and y ZMP greatly amplified when supporting leg shifts on next leg. This is because F in Eq.8 becomes much lower to almost zero in changing supporting leg. Therefore, x in Eq.8 is made larger became F near to zero.

As described, measuring value of ZMP of the robot is calculated from CoP and sensor position information. This measuring value of ZMP is called the actual ZMP.

5. Comparing the reference ZMP with the actual ZMP

The reference ZMP calculated from Eq.6 is compared with actual ZMP calculated from Eq.8 for walking pattern simulation. Result of the comparison is shown by Fig.7.

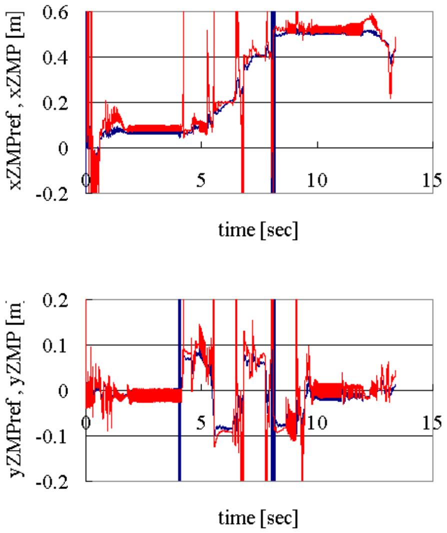


Fig.7 Comparing the reference ZMP with the actual ZMP

x direction and y direction are shown by Fig.7. It is understood that by comparing two graphs, two ZMPs follow the similar track. Comparing two ZMPs in detail, about x direction of ZMP, the actual ZMP when simulation starts and finishes, or in dumping and pumping hip, amplify in comparison with reference ZMP. This indication shows that the upper body of the robot is on the point of falling to back or front. At y direction of ZMP, it is also understood that the actual ZMP gets larger than reference ZMP at one leg supporting period. Also, this indication shows that the upper body of the robot leans to left or right.

6. Conclusion

In this paper, ZMP concept for "Dynamic walking" is observed. Firstly, the reference ZMP of the robot is calculated from CoM (Center of Mass) and CoM position. Next, the actual ZMP of the robot is calculated from Force/Torque sensor value. Finally, the reference ZMP is compared to the actual ZMP.

We understood that the reference ZMP and the actual ZMP used for walking pattern in this research have a slight difference in track. However, more stable walking pattern is obtained by bringing the actual ZMP close to the reference ZMP.

As for the future reference, it is thought that the actual ZMP is brought closer to the reference ZMP by using feed back control. For example, after actual ZMP is obtained around the reference ZMP by accelerating hip position according to error between the actual ZMP and the reference ZMP, walking pattern behavior of the robot is controlled by handling the reference ZMP. Finally, optimization problem should be overcome, too.

Reference

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