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Walking and Running Control of Small Size Humanoid Robot "HAJIME ROBOT"

Hajime Sakamoto [1] and Ryohei Nakatsu [2]

School of Science and Technology, Kwansei Gakuin University
2-1 Gakuen, Sanda-shi, Hyogo, 669-1337, Japan
[1] sakamoto@hajimerobot.co.jp, [2] nakatsu@ksc.kwansei.ac.jp

Abstract: This paper describes the walking and running control of HAJIME ROBOT. Walking control consists of walking logic and vibration control using gyro sensors. Trajectory tables of each direction of X, Y, Z, and THETA make gait. The reference ZMP (Zero Moment Point) is a rectangular wave and it is always under the support foot. It is proved by measured ZMP. Running control consists of kick control and gain control. HAJIME ROBOT has won awards in RoboCup which is a worldwide soccer competition of robots.

Keywords: Humanoid Robot, Biped Robot, Walking, Running, RoboCup, HAJIME ROBOT

I. INTRODUCTION

A small size humanoid "HAJIME ROBOT" has been developed for ROBO-ONE and RoboCup. ROBO-ONE is a battle competition of biped robots. RoboCup is a worldwide soccer competition of autonomous robots. [1][2]

High mobility is required for a battle robot and a soccer robot. HAJIME ROBOT achieved high speed walking in all directions and running. This paper describes the walking control of HAJIME ROBOT which consists of walking logic and vibration control using gyro sensors.

II. SPECIFICATIONS

We developed a running humanoid robot "HAJIME ROBOT 15". A 3D design of HAJIME ROBOT 15 is shown in Fig. 1. The specifications of the robot are shown in Table 1. It is 36 [cm] in the height and 2.5 [kg] in the weight. It has a small body with high power servo motors. It has twenty DOFs (degrees of freedom) in total, twelve in the legs, and eight in the arms. Two axes crosses in the ankle joints and in the hip joints. It has a 32-bit controller SH2/7145 50MHz for motion control. It has gyro sensors and an acceleration sensor for motion control.

System configuration is shown in Fig. 2. The wireless R/C PROPO sends a command to the motion controller. The motion controller calculates the joint angles according to the command, and sends angle command to the servo motors. The walking and running control is calculated in the motion controller.

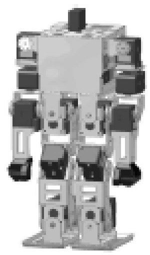

Fig. 1. HAJIME ROBOT 15

Table 1. Specifications

Height	36 [cm]
Weight	2.5 [kg]
DOFs	20
Frame	Aluminum plate
Actuators	Servo motors DX-117
Controller	32bit microprocessor SH2/7145 50MHz
Sensors	Gyro sensor x 3 Acceleration sensor x 3
Batteries	LiPo 22.2V, NiMH 6V
Communication	R/C PROPO
Features	Run, High-speed walk, Chinese exercises Tai-chi, punch, kick, getting up after falling, forward roll kick, backward handspring, victory pose, mortification pose, sidekick, back kick

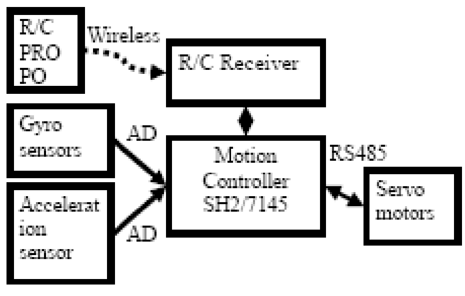

Fig. 2. System configuration

III. WALKING CONTROL

Walking control of HAJIME ROBOT consists of walking logic and vibration control. Walking logic is described in this chapter. Vibration control is described in chapter VI.

This walking control is developed for a small size HAJIME ROBOT. But HAJIME ROBOT 25 which is 1 [m] in the height can walk using the exactly same walking control.

1. Gait

First of all, the coordinate system is decided. The origin is the root of each leg. The forward is X, the rightward is Y, and the downward is Z. The rotation of X axis is roll, the rotation of Y axis is pitch, and the rotation of Z axis is yaw.

Trajectory tables of each direction of X, Y, Z, and THETA make gait. The angle THETA is the rotation angle of yaw. The trajectory table expands and contracts when normalized trajectory table is multiplied by the amplitude and the angle of walking parameters. The shape of the trajectory does not change even if the walking parameters change. It becomes flexible to correspond to all directional walking by separating in the direction of X, Y, Z, and THETA. The calculation load of CPU decreases when the controller has the normalized trajectory tables which have finished calculation.

2. Trajectory Tables

The calculation of normalized trajectory tables of X, Y, Z, and THETA is the following.

A. Right and Left : Y

Stepping on the place is the basis of walking. Assuming the robot is one mass, the reference ZMP (Zero Moment Point) is a rectangular wave like Fig. 3. The amplitude and period of the wave is $2*Y_{ZMPMAX}$ and 2*T, respectively. The equation of ZMP is expression (1). The answer is expression (2) and expression (3).

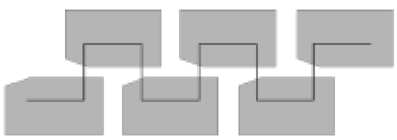

Fig. 3. Reference ZMP and footprints

$$Y_{ZMPMAX} = y(t) - \frac{H}{g}\ddot{y}(t) \qquad (1)$$

$$y(t) = C_1 * \exp(\sqrt{\frac{g}{H}} * t) + C_2 * \exp(-\sqrt{\frac{g}{H}} * t) + Y_{ZMPMAX} \qquad (2)$$

$$C_1 = C_2 = \frac{-Y_{ZMPMAX}}{\exp(\sqrt{\frac{g}{H}} * T/4) + \exp(-\sqrt{\frac{g}{H}} * T/4)} \qquad (3)$$

g : acceleration of gravity

H : height of center of gravity

T : walking cycle (half of period of rectangular wave)

Y_{ZMPMAX} : half of amplitude of rectangular wave

The size of trajectory table is n, for example, n = 0 to 500. The output of trajectory table y(t) is normalized from 0 to 1. The normalized trajectory table y(n) is shown in Fig. 5.

The ZMP during walking is the same as the ZMP during stepping on the place. It is because the velocity during steady walking is assumed to be constant and the acceleration is assumed to be 0. Fig. 3 shows the reference ZMP and the image of footprints.

Actually, when the robot begins walking or finishes walking, the acceleration is not 0. To keep balance of forward and backward ZMP, the length of forward stride and backward stride are changed during a few steps when the robot begins walking or finishes walking.

B. Forward and Backward : X

During steady walking, the acceleration is assumed to be 0. The normalized trajectory table of X is a straight line and is shown in expression (4) and Fig. 4.

$$x(n) = n/SIZE \qquad (4)$$

C. Up and Down : Z

When the robot lifts up the leg, expression (5) which is shown in Fig. 6 is used. When the robot takes down the leg, expression (6) which is shown in Fig. 7 is used. Because the leg should be lifted up and be taken down quickly to prevent from stumbling.

$$z_{up}(n) = 1 - \frac{\arcsin(1 - n/SIZE)}{\pi/2} \qquad (5)$$

$$z_{dw}(n) = \frac{\arcsin(n/SIZE)}{\pi/2} \qquad (6)$$

D. Rotation angle of yaw axis : THETA

The trajectory table of THETA is used the same as X. It is shown in expression (4) and Fig. 4.

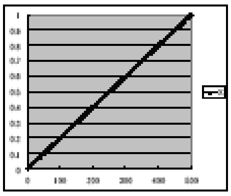

Fig. 4. X table

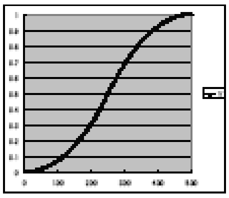

Fig. 5. Y table

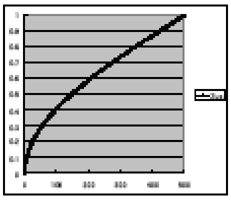

Fig. 6. ZUP table

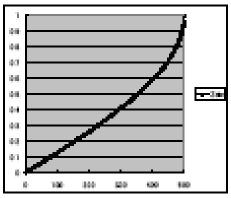

Fig. 7. ZDOWN table

IV. HIGH SPEED WALKING

High speed walking is dynamic walking. The gait is produced using trajectory tables described in chapter III. The right and left trajectory y(t) is shown in Fig. 8. The calculated ZMP trajectory is shown in Fig. 9. It is calculated by the trajectory y(t) and the height of center of gravity H using expression (1). The time axis is synchronized in Fig. 8 to Fig. 11 and the range is 0 [s] to 1 [s]. The calculated ZMP shows that ZMP is between 70 [mm] to 100 [mm] and is under the right leg during the time 0.15 [s] to 0.33 [s]. At this time, the upward and downward trajectory z(t) (Fig. 10) shows that right leg is 175 [mm] and is support leg. Left leg is 20 [mm] shorter than right leg and is swing leg. The trajectory z(t) shows that when the swing leg touched to the ground, the support leg is lifted up immediately. The trajectory x(t) shows that the robot is walking forward.

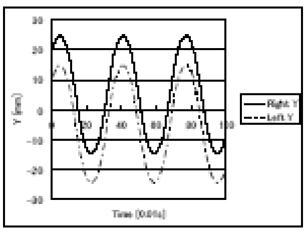

Fig. 8. Trajectory y(t)

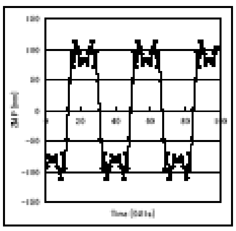

Fig. 9. Calculated ZMP

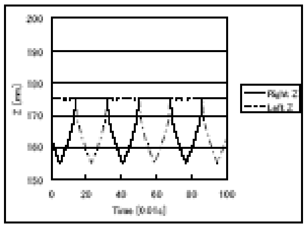

Fig. 10. Trajectory z(t)

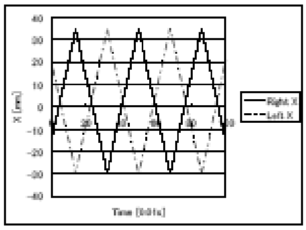

Fig. 11. Trajectory x(t)

V. MEASUREMENT RESULT OF ZMP

Measurement result of ZMP is shown in Fig. 12. It is calculated using force sensors under the foot and reference foot positions. The ZMP is a rectangular wave like Fig. 3.

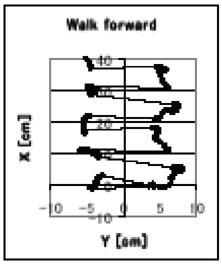

Fig. 12. Measured ZMP

VI. VIBRATION CONTROL

Vibration control is worked to reduce vibration of the robot while the robot is walking. The vibration controller is shown in expression (7). The angular velocity is measured using the gyro sensor. The controller multiplies the measured angular velocity by proportional gain and feedbacks to the servo motors of the ankles, hips, and shoulders. The angular velocities of roll and pitch are used for the servo motors of roll and pitch, respectively.

$$\theta_2 = \theta_1 - K * \omega \qquad (7)$$

θ_1 : *angle of joint before vibration control*
θ_2 : *angle of joint after vibration control*
K : *feedback gain*
ω : *angular velocity*

VII. RUNNING CONTROL

Running controller consists of kick control to jump in the air and gain control to land on the ground softly.

1. Kick Control

Only changing the timing of swing leg and support leg fails running. Kicking the ground and accelerating the body upward enables running. The trajectory z(t) is shown in Fig. 13. Solid line is right leg and the other line is left leg. The horizontal axis is time 0 [s] to 0.5 [s]. The parameters are stride 65 [mm] and period of one step 0.18 [s]. The calculated running speed is 361 [mm/s]. Left leg begins to down at the time 0.23 [s], right leg begins to kick at the time 0.27 [s]. In other words, the right leg kicks the ground 0.05 [s] before the left leg reaches to the ground. The kick is 17 [mm] in the length during 0.06 [s]. The right leg is lifted up immediately after the kick. The actual motion may be different from those reference data, because this kick is very fast and servo motors may not catch up exactly with those data.

2. Gain Control

High gain of servo motors is used to kick the ground. It is for fast and strong kick. Low gain of servo motors is used to land on the ground. It is for soft touch to the ground. The touching shock sometimes destroys the gears of servo motors. Gain control reduced thirty percent shock according to measured acceleration. The gain control is shown in Fig. 13. The dot line is gain control flag. The gain of right leg is low and the gain of left leg is high where the flag is lowest (153). The gain of left leg is low and the gain of right leg is high where the flag is middle (156). The gain of both legs is high where the flag is highest (159). The left leg is going down and the gain of left leg becomes low at 0.23 [s]. The gain of left leg becomes high after the left leg touched the ground at the time 0.34 [s].

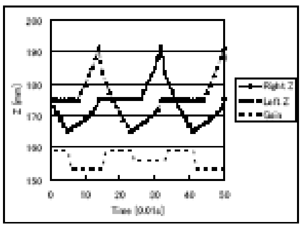

Fig. 13. Trajectory z(t) in running mode

VIII. RUNNING TEST

Running test using HAJIME ROBOT 15 was successful. The captured photos (15 [frame/s]) of the foot during running are shown in Fig. 14. The running motion was easily confirmed by our eyes.

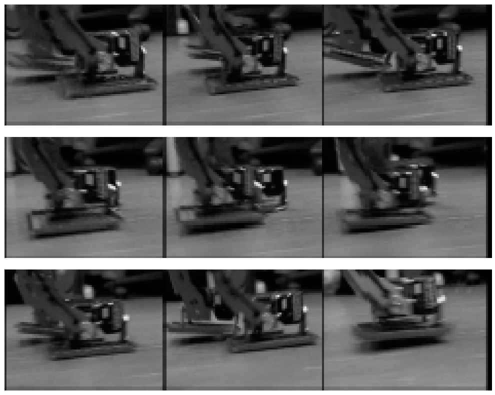
Fig. 14. Running test

IX. CONCLUSION

This paper described the walking and running control of HAJIME ROBOT. Walking control consists of walking logic and vibration control using gyro sensors. Trajectory tables of each direction of X, Y, Z, and THETA make gait. The reference ZMP is a rectangular wave and it is always under the support foot. It was proved by measured ZMP. Running control consists of kick control and gain control. Running test using HAJIME ROBOT 15 was successful.

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