A Biped Humanoid Robot for Human-robot Coexistence

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Abstract. To explore an issue of a human-like motion, we have constructed a human-like biped robot called WABIAN-RII (WAseda BIped humANoid robot-Revised II) that has a total of forty-three mechanical degrees of freedom (DOF); two six DOF legs, two ten DOF arms, a four DOF neck, four DOF in the eyes and a torso with a three DOF waist. For human-robot symbiosis, the biped humanoid robot is required to have the ability capable of expressing its emotion and following a human motion. In this paper, we present a follow-walking control with a switching pattern technique and an emotion-based control with a motion parameter technique. Also, how to cancel moments generated by the motion of lower-limbs of the biped robot is described for a dynamic balance.

1 Introduction

To date, the issue of stable biped walking has been studied by many researchers [1–5]. A Waseda's walking-robot group has been engaged in studies of biped robots with human configuration from two viewpoints. One is an engineering viewpoint to elucidate the walking mechanism of humans. The other viewpoint is the development of anthropomorphic robots that become human partners in the next century.

The Waseda's walking-robot group succeeded in achieving a dynamic biped walking with a hydraulic biped robot WL-10RD in 1984 [6]. A hydraulic biped robot WL-12 having an upper body and a two-degrees-of-freedom waist was constructed to realize human-like motion in 1986. Also, the new control algorithm was developed to improve walking stability, which compensates for moment generated by the motion of the lower-limbs using the trunk motion. The dynamic biped walking was realized under external forces of unknown environment and on unknown walking surfaces [7, 8]. To adapt to human's living environments, the control method based on a virtual surface was introduced, which could deal with even and uneven terrain [9]. We developed a hydraulic biped robot WL-12RV that compensates for three-axis (pitch, roll and yaw axis) moment on a planned ZMP (Zero Moment Point) by the trunk motion and realized fast dynamic biped walking (the walking speed of 0.54 [s/step] with the step length of 0.3[m]) [10].

In 1992, we started the new project "humanoid" at HUREL (Humanoid Research Laboratory), Advanced Research Institute for Science and Engineering, Waseda University. This project aims at the development of an anthropomorphic robot that can share the same walking space with humans. WL-12RVII was developed, which was able to maintain a stable dynamic walking in unknown paths and stairs of human residential environments [11]. The dynamic walking was accomplished by the introduction of a new adaptive control method using mechanical hardware and software into the conventional biped walking control method using the trunk motion. In 1996, a biped humanoid robot with human configuration called "WABIAN" was developed under the following design plan to investigate cooperative dynamic walking and a collaborative work with humans:

- The size of the biped robot should be the average size of an adult Japanese woman to do a collaborative work with humans.
- The robot should walk at human speed.
- The robot should have a 3 DOF trunk and 6 DOF arms.
- The joints of the robot should use electric servomotors.
- A control computer and motor drives except power supply should be installed.

To realize human-robot symbiosis, humanoid robots are expected to have a flexible workability such as doing along with human motion in physical contact. There are many studies that deal with physical interaction problems in human-robot environments [12, 13]. However, there are no reports on the realization of physical dynamic interaction between a human and a life-sized humanoid robot based on various action models. A physical interaction between humans may be realized by the action of shaking hands, walking together hand in hand, and even dancing. From these cases, it is reasonable to suppose that the hand has an important roll in physical interactions with humans. Thus, under the circumstances of human-robot coexistence, our purpose for this research is to realize a locomotive following motion by a biped humanoid robot to human motion.

Recently, an issue of emotion expression for a smooth and natural communication has proposed by many researchers [14]. However, there are few researches on a human's walking behavior. Wallbott [15], and Barclay and co-workers [16] studied a person's character, sex and age from a person's gait. In addition, Montepare and co-workers [17] have explored human's emotions from a human's walking style. We are interested in emotion expression using the body motion and walking of a biped humanoid robot. This research also aims to clarify a human emotional behavior.

In this paper, we first describe a control algorithm to stabilize the dynamic walking of a biped robot. To achieve a human-like motion, a follow-walking control method and an emotion-based control method are proposed. The follow-walking control contains three parts:

- A following-motion control method of the upper-limbs.
- A motion planning method of the lower-limbs.
- A motion planning method of the trunk and waist.

Also, an emotion-based control method is based on the motion parameters of the biped robot.

2 Compensatory Motion

We have already proposed the control methods for the dynamic walking of biped walking robots: a model-based walking control (ZMP and yaw axis moment control), a model deviation compensatory-control and a real-time control of ZMP and yaw axis moment (external force compensatory control).

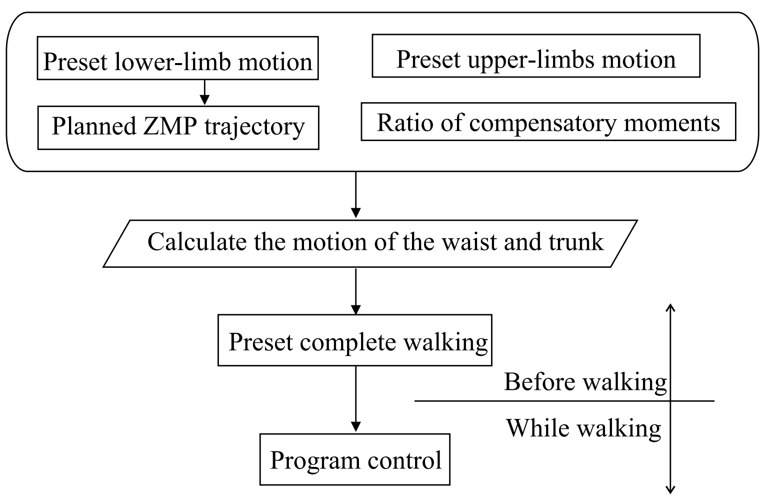

Fig. 1. Control structure of the biped robot

This section describes a reliable walking control approach for a biped humanoid robot to realize human-like motion. The control method consists of two main components as shown in Figure 1: a calculation of compensatory motion and program control. It is important for the biped robot to balance on the various environments. The combined motion of the waist and trunk compensates for not only the pitch axis and the roll axis but also the yaw axis moment around the preset ZMP before the biped robot starts to walk.

In brief, the algorithm automatically computes the compensatory motion of the waist and trunk from the lower-limbs planned arbitrarily, the time trajectory of ZMP, and the planned motion of the upper-limbs, in consideration of the ratio of compensatory moments. This is composed of the following four main parts:

- Modeling of the biped robot.
- Derivation of ZMP equations.
- Computation of approximate motion of the waist and trunk.
- Calculation of the strict motion of the waist and trunk by an iteration method.

The other component of the control method is a program control using a preset complete walking pattern transformed from the motion of the lower-limbs, the trunk, and the upper-limbs, while the biped robot is walking.

2.1 Modeling

The compensatory trunk and waist motions of a biped robot are calculated by using an approximate model. Then, a moment rate between the trunk and the waist is given to achieve human-like motion. A world coordinate frame $\mathcal{F}$ is fixed on the floor where the biped robot can walk and a moving coordinate frame $\bar{\mathcal{F}}$ is attached on the center of the waist to consider the relative motion of each part (see Figure 2). Also, five assumptions are defined to model the biped robot as follows:

- The biped walking robot consists of a set of particles.
- The foothold of the robot is rigid and not moved by any force and moment.
- The contact region between the foot and the floor surface is a set of contact points.
- The coefficients of friction for rotation around the X, Y and Z-axes are nearly zero at the contact point between the foot and the floor surface.
- The foot of the robot does not slide on the contact surface.

The moment balance around a contact point p on the floor can be written as

$$\sum_{i=1}^{n} m_i(\boldsymbol{r}_i - \boldsymbol{r}_p) \times (\ddot{\boldsymbol{r}}_i + \boldsymbol{G}) + \boldsymbol{T} - \sum_{j=1}^{n}(\boldsymbol{r}_j - \boldsymbol{r}_p) \times (\boldsymbol{F}_j + \boldsymbol{M}_j) = \boldsymbol{0}, \tag{1}$$

where m_i is the mass of the particle i. $\boldsymbol{r}_i$ denotes the position vector of the particle i with respect to the world coordinate frame $\mathcal{F}$. $\boldsymbol{r}_p$ is the potion vector of point p from the origin of $\mathcal{F}$. $\boldsymbol{G}$ is the gravitational acceleration vector, $\boldsymbol{T}$ is the moment vector acting on the contact point p. $\boldsymbol{F}_j$ and $\boldsymbol{M}_j$ denote the force and the moment vectors acting on the particle j relative to the frame $\mathcal{F}$.

The three-axis motion of the trunk is interferential each other and has the same virtual motion because the biped robot is connected by the rotational joints. Therefore, it is difficult to derive analytically the compensatory motions of the trunk and waist from Equation (1). To get the approximate solution analytically, we assume that

(a) the external forces are not considered in the approximate model,
(b) the upper body is modeled as a four-mass model,
(c) the moving frame does not rotate and
(d) the trunk and waist does not move vertically.

Each moment equation can be written by

$$m_t(\bar{z}_t - \bar{z}_{zmp})(\ddot{\bar{x}}_t - m_t g_z \bar{x}_t + m_w(\bar{z}_w - \bar{z}_{zmp})(\ddot{\bar{x}}_w - m_w g_z \bar{x}_w = -\hat{M}_y, \tag{2}$$

$$m_t(\bar{z}_t - \bar{z}_{zmp})(\ddot{\bar{y}}_t + m_t g_z \bar{x}_t - m_w(\bar{z}_w - \bar{z}_{zmp})(\ddot{\bar{y}}_w + m_w g_z \bar{y}_w = -\hat{M}_x, \tag{3}$$

$$m_t {R_t}^2 \ddot{\theta}_t = \hat{M}_z, \tag{4}$$

where $\bar{\boldsymbol{r}}_{zmp}$ is the position vector of ZMP with respect to the $\bar{\mathcal{F}}$. m_t and m_w are the mass of the trunk including the head and arms and the mass of the waist, respectively. $\bar{\boldsymbol{r}}_t = [\bar{x}_t \; \bar{y}_t \; \bar{z}_t]^T$ and $\bar{\boldsymbol{r}}_w = [\bar{x}_w \; \bar{y}_w \; \bar{z}_w]^T$ are the position vectors of the trunk and the waist, respectively. R_s is the radius of the trunk arm.

In Equations (2), (3) and (4), the moments $\hat{M}_x$, $\hat{M}_y$ and $\hat{M}_z$ are known values, which are derived from the motion of the lower-limbs and a time trajectory of ZMP. However, it is difficult to calculate

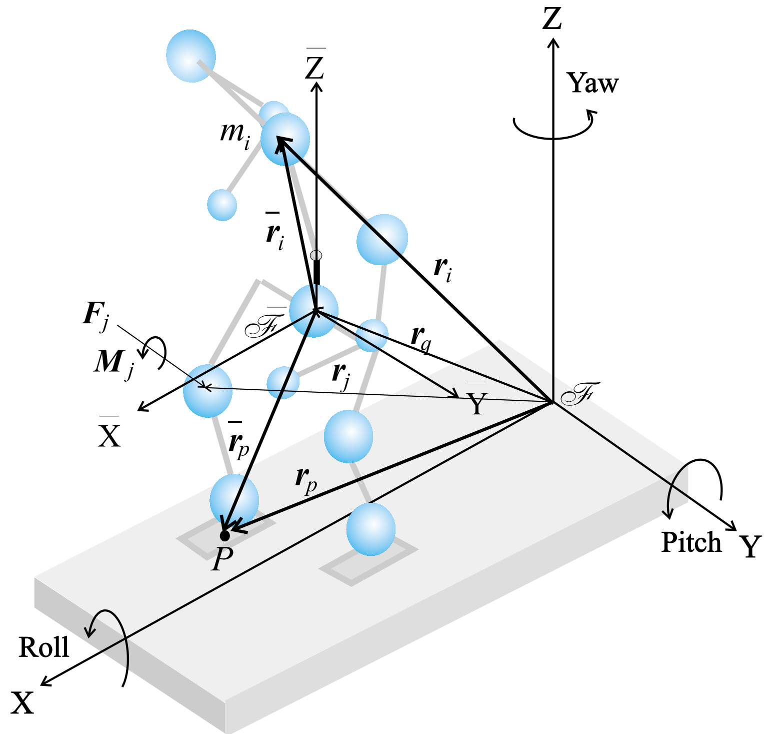

Fig. 2. Coordinate frames of the biped robot

the compensatory motion due to six unknown variables such as $\bar{x}_t$, $\bar{x}_w$, $\bar{y}_t$, $\bar{y}_w$, θ_t and θ_w. Each equation can be represented as a Fourier series. Comparing the Fourier transform coefficients of both sides of each equation, the approximate periodic solutions of the pitch and roll trunk and waist can be obtained easily. Also, this computation is applicable to the complete walking too. By regarding complete walking as one walking cycle and making static standing states before and after walking long enough, the approximate solutions of the compensatory trunk and waist for the complete walking can be derived.

2.2 Recursive Calculation

A recursive method is used to obtain the strict solutions of the trunk and waist motions. First, the approximate periodic solutions of the linearized Equations (2), (3) and (4) are calculated. Second, the approximate periodic solutions are substituted into the moment equation (1) of the strict biped model, and the errors of moments generated by the trunk and the waist motions are calculated according to the planned ZMP. These errors are accumulated to the right-hand side of Equations (2), (3) and (4). The approximate solutions are computed again. Finally, these computations are repeated until the errors fall below a certain tolerance level [10].

3 Follow-walking Motion

In this section, a compliance control for the uper-limbs is discussed and a walking pattern produced by unit patterns is discribed to follow a human motion.

3.1 Compliance Control

A follow-walking motion is realized by a human-follow walking method that selects and generates switchable unit patterns, based on the action model for human-robot interaction. The upper-limb's trajectory is decided by the force information applied on the robot's hand. Then, by judging the direction of the robot's tracking motion, the trajectory of the lower-limbs can be decided. For computing the upper-limb's trajectory, we use a virtual compliance control method. Figure 3 shows the coordinate system of the robot's arm. The equation of compliance motion of the robot'hand is written by

$$\boldsymbol{M}\frac{d\bar{\boldsymbol{v}}}{dt} = \bar{\boldsymbol{F}} - \boldsymbol{K}\Delta\bar{\boldsymbol{x}} - \boldsymbol{C}\bar{\boldsymbol{v}}, \tag{5}$$

where $\boldsymbol{M} \in \Re^{6\times 6}$ is the virtual mass matrix. $\boldsymbol{K} \in \Re^{6\times 6}$ and $\boldsymbol{C} \in \Re^{6\times 6}$ are the stiffness and damping matrices, respectively. $\bar{\boldsymbol{v}} \in \Re^6$ and $\bar{\boldsymbol{x}} \in \Re^6$ is the velocity and deviation vectors of the robot's hand, respectively.

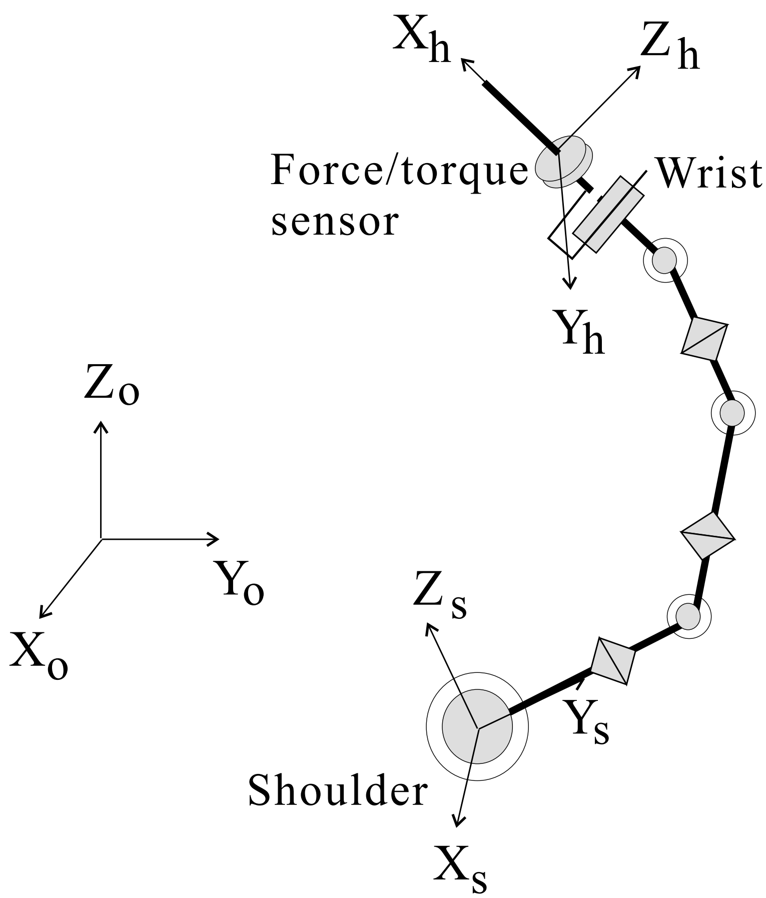

Fig. 3. The upper-limb's Model

In the case where our target is the full tracking ability of the hand like a method generally used in the direct teaching of an industrial manipulator, the stiffness components may be disregarded. Also, when the control loop time we apply is very short (5[ms]), we may think of the virtual mass as equal to zero. Therefore, the hand velocity can be obtained with respect to the hand coordinate frame $\{h\}$ as

$$^h\bar{\boldsymbol{v}}_h = \boldsymbol{C}^{-1}\bar{\boldsymbol{F}}. \tag{6}$$

Figure 4 shows a control system for the follow motion of its upper-limb. We can find the hand velocity with respect to the shoulder frame $\{s\}$:

$$^s\bar{\boldsymbol{v}}_s = {}^s\boldsymbol{R}_h\, {}^h\bar{\boldsymbol{v}}_h, \tag{7}$$

where ${}^s\boldsymbol{R}_h$ is the rotation matrix of the frame $\{h\}$ relative to the frame $\{s\}$.

To calculate the joint angle velocity $\dot{\boldsymbol{\theta}} \in \Re^7$ from the hand velocity, the pseudo-inverse matrix $\boldsymbol{J}^+$ is used according to the redundancy of the arm; that is,

$$\dot{\boldsymbol{\theta}} = \boldsymbol{J}^+\, {}^s\bar{\boldsymbol{v}}_s, \tag{8}$$

where

$$\boldsymbol{J}^{+} = \boldsymbol{J}^{T}(\boldsymbol{J}\boldsymbol{J}^{T})^{-1}.$$

where $\boldsymbol{J}$ is 6×7 Jacobian.

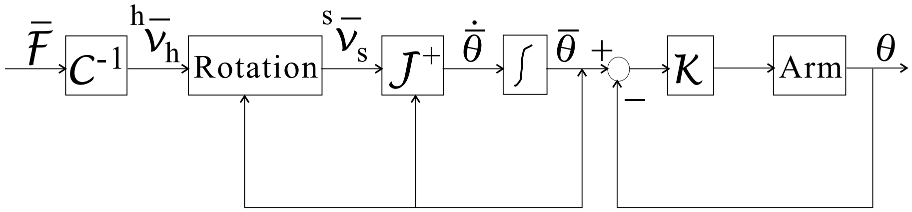

Fig. 4. Control system for the upper-limb

3.2 Follow Walking Pattern

The biped robot recognizes the guiding direction of human motion by the above arm control system, and then decides the next walking pattern while synchronizing it with the preset walking condition. In a case where no pattern is selected, we program to let the preset condition be continued by the biped robot.

In addition, we know from the transfer functions of ZMP equations that the above control method doesn't cope with initial value problem and doesn't satisfy the law causality, because of characteristics of the Lorenz function. From the simulation and experimental tests, we know that the trunk compensation motion begins to move earlier than the shift of ZMP on the floor. This means that the trunk compensation affects one or more steps before and after in a pattern time. To solve these problems, a method is described below.

(a) The motion patterns of the lower-limbs are given as unit patterns, which have one before and one after gait attributes of a step pattern (in consideration of the trunk's motion dynamics). By combining some simple and selective patterns, it is possible to realize a following motion by a biped robot similar to a human. The unit patterns that are combined from three gait patterns (forward step pattern, backward step pattern, marking time pattern) and are computed to have a continuous position, velocity and acceleration of its trajectory, are calculated off-line.

(b) The trunk compensatory motion relative to the moment generated by the lower-limbs is computed off-line, and it gives the biped robot sets of unit patterns in the same way as the lower-limb's patterns. Through experiments, we could clarify that in circumstance of movable margin of the trunk's angle, the ZMP shift caused by the upper-limbs' smooth motion could be ignored. This was done so that the change in attitude of the upper-limbs could be disregarded to make the control technique more simply.

Even during a high-speed motion, it is possible to make a unit pattern of the trunk motion by taking into account only one-step before and after of a unit pattern as an attribute. The unit patterns were created using a software simulator, and include indexes for pattern searching and attribute of current, before and after steps. These unit patterns are preloaded as one-step long angle data in the computer memory of the biped robot.

4 Emotion Expression

To identify a human walking in certain emotions, three walking styles of the biped humanoid robot are considered: happy, sad and angry walking. The motion patterns of the lower-limbs and upper-limbs for locomotion and the combined motion patterns of the waist and trunk for cancellation of produced moments are described in this section. Also, the motion parameters that play an important roll in making emotional walking patterns are discussed.

4.1 Emotional Walking Pattern

To make the walking patterns capable of expressing human-like emotions, the initial and final states of the waist, trunk, head, leg and arm should be given. In a happy emotion, the states are as follows:

- The middle and final x-positions of the foot are set as 0.15[m] and 0.078[m], respectively.
- The initial and final accelerations of the foot are 0.05[m/s^2], respectively, and the y-position of the foot is -0.2[m], and the orientation of the roll axis of the foot is -20[deg].
- The initial angle of the yaw axis of the foot is set as 30[deg].
- The z-position of the waist in the middle of the swing phase is set as -0.1[m] for the waist to move up and down.
- The angle of the roll axis of the waist in the middle of the swing phase is -10[deg]. The initial and final angular velocities are -1.0[deg/s] and 1.0[deg/s], respectively.
- To shake largely the pitch axis, the ratio of the pitch and roll moments between the trunk and waist is 0.7. The angles of the pitch and roll axes of the head are -10.0[deg] and 10.0[deg], respectively.
- The ratio of the pitch angle of the shoulder to the yaw angle of the trunk is 2.5.

On the basis of these conditions, the positions and orientations of the foot, waist and head $\boldsymbol{x}_{foot} \in \Re^6$, $\boldsymbol{x}_{waist} \in \Re^6$ and $\boldsymbol{x}_{head} \in \Re^3$ can be determined by a polynomial. In making a smooth motion, at least seven constraints are required. Three constraints come from the selection of the initial and final values:

$$\boldsymbol{x}(t_0) = \boldsymbol{x}_0, \ \boldsymbol{x}(t_f) = \boldsymbol{x}_f, \ \boldsymbol{x}(t_m) = \boldsymbol{x}_m, \tag{9}$$

where t_0, t_m and t_f are the initial, intermediate and final times of a step, respectively.

The position and orientation $\boldsymbol{x}$ have an additional four constraints that are the zero initial and final velocity and acceleration:

$$\dot{\boldsymbol{x}}(t_0) = \boldsymbol{0}, \ \dot{\boldsymbol{x}}(t_f) = \boldsymbol{0}, \ \ddot{\boldsymbol{x}}(t_0) = \boldsymbol{0}, \ \ddot{\boldsymbol{x}}(t_f) = \boldsymbol{0}. \tag{10}$$

These seven constraints are satisfied by a polynomial of six degree. The sixth order polynomial is written as

$$\boldsymbol{x}(t) = \boldsymbol{a}_0 + \boldsymbol{a}_1 t + \boldsymbol{a}_2 t^2 + \boldsymbol{a}_3 t^3 + \boldsymbol{a}_4 t^4 + \boldsymbol{a}_5 t^5 + \boldsymbol{a}_6 t^6, \tag{11}$$

and the velocity and acceleration along the path are clearly

$$\begin{aligned} \dot{\boldsymbol{x}}(t) &= \boldsymbol{a}_1 + 2\boldsymbol{a}_2 t + 3\boldsymbol{a}_3 t^2 + 4\boldsymbol{a}_4 t^3 + 5\boldsymbol{a}_5 t^4 + 6\boldsymbol{a}_6 t^5, \\ \ddot{\boldsymbol{x}}(t) &= 2\boldsymbol{a}_2 + 6\boldsymbol{a}_3 t + 12\boldsymbol{a}_4 t^2 + 20\boldsymbol{a}_5 t^3 + 30\boldsymbol{a}_6 t^4. \end{aligned} \tag{12}$$

Combining Equation (11) and Equation (12) with seven constraints, we can specify a linear set of seven equations ($\boldsymbol{a}_0 \cdots \boldsymbol{a}_6$). The desired positions and orientations of the waist obtained from Equation (11) are changed by the compensatory motion control algorithm to compensate for the moments produced by the motion of the head, lower-limbs and upper-limbs during the walking. In addition, the compensatory trajectory of the trunk is obtained by the iteration method, depending on the ratio between the compensation moments of the trunk and the waist and the initial position and orientation of the trunk. Also, the arm trajectory is defined using forward kinematics, depending on the shoulder position and orientation.

4.2 Motion Parameters

In order to obtain effective motion parameters for emotions, we analyze the variance of the motion parameters. In happy emotion, the biped robot should
(1) walk with a long step,
(2) lift its foot and put it down vertically like a M-shaped walking,
(3) turn the toes outward,
(4) move the waist up and down using knee joints,
(5) rotate the waist using the hip joints,
(6) shake the head and upper trunk side-to side greatly,
(7) move the head and upper trunk front-to-back greatly and
(8) swing the arms according to the walking largely.

Combining the motion parameters and the gait characteristics, thirty-two walking patterns for the emotion are made. The variability of a set of n measurements (the number of walking patterns) is proportional of SS (sum of squares of deviations).

$$SS = (sum\ of\ squares\ of\ all\ y\ values) - CM = \sum_{i=1}^{p}\sum_{j=1}^{n_i}(y_{ij} - \bar{y})^2$$
$$= \sum_{i=1}^{p}\sum_{j=1}^{n_i} y_{ij}^2 - CM = SST + SSE, \quad (13)$$

where y_{ij} and $\bar{y}$ denote the variance of a sample of ij measurements and the mean of a sample, respectively. The terms CM and SST denote the correction for the mean and the sum of squares for treatments, respectively. The term SSE denotes the sum of squares for errors. These quantities are written as.

$$CM = \frac{(total\ of\ all\ observations)^2}{n} = \frac{(\sum_{i=1}^{p}\sum_{j=1}^{n_i} y_{ij})^2}{n} = n\bar{y}^2,$$
$$SST = \sum_{i=1}^{p} n_i(\bar{T}_i - \bar{y})^2 = \sum_{i=1}^{p}\frac{T_i^2}{n_i} - CM,$$
$$SSE = SS - SST, \quad (14)$$

where T_i is the treatment totals.

When the null hypothesis is true, the mean square for treatments (MST) and the mean square for error (MSE) both estimate the same quantity. When the null hypothesis is false, MST will probably be larger than MSE. F probability distribution is given as a test statistic to test the hypothesis $\mu_i = \mu_j$ against the alternative, $\mu_i \neq \mu_j$.

$$F = \frac{\nu_e\, SST}{\nu_t\, SSE}, \quad (15)$$

where ν_e, ν_t are percentage points of distribution.

If the computed value of F_α ($\alpha 5 = 0.05$ or $\alpha 1 = 0.01$) exceeds the critical value F_α, there is sufficient evidence to reject the null hypothesis and conclude that a real difference does exist in the expected response in the group of subjects.

5 Experiments

We have demonstrated the quasi real-time follow walking and emotional walking to confirm the validity of the control methods. In this section, the hardware and software of the experimental system are described briefly, and the experimental results are presented.

5.1 System Description

To explore human-like motion, a forty-three mechanical degrees of freedom WABIAN-RII with a human configuration has been constructed as shown in Figure 5. The height of the WABIAN-RII is about 1.84[m] and its total weight is 127[kg].

Duralumin, GIGAS (YKK Corporation) and CFRP (Carbon Fiber Reinforced Plastic) are mainly employed as structural materials of the WABIAN-RII. The body and legs are driven by AC servo motors with reduction gears. The neck, hands and arms are actuated by DC servo motors with reduction gears, but the eyes by DC servo motors without reduction gears. A force/torque sensor is attached to the wrist of the WABIAN-RII.

The WABIAN-RII is controlled by a PC/AT compatible computer PEAK-530 (an Intel MMX Pentium 200[MHz] CPU processor) which are govern by an OS, MS-DOS 6.2/V (16-bit). TNT DOS-Extender SDK (Ver.6.1) is employed to extend the OS to a 32-bit. It has three counter boards with each 24-bit 24 channels, three D/A converter boards with each 12-bit 16 channels and an A/D converter board with differential 12-bit 16 channels to interface with sensors. The joint angles are sensed by incremental encoders attached at the joints, and the data are taken to the computer through the counters. All the

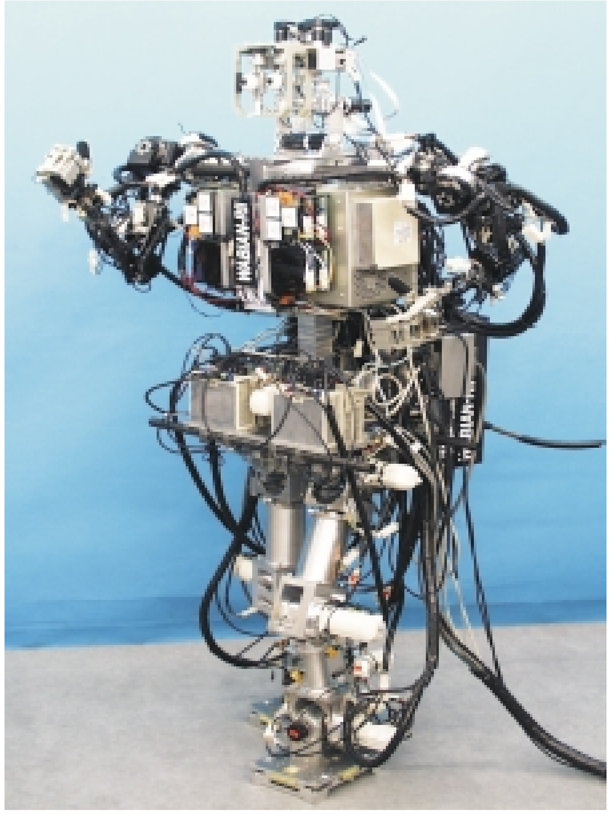

Fig. 5. Photo of the WABIAN-RII

computations to control the WABIAN-RII are carried out by the control computer and the control program that are written in C language. The servo rate is 1[kHz]. The computer system is mounted on the back of the waist and the servo driver modules are mounted on the upper part of the trunk. The external connection is only an electric power source.

5.2 Experimental Results

Figure fig.follow.exp and Figure fig.happy.exp show a part of scenes of follow walking and emotional walking, respectively. In both walking experiments, the walking with 26 steps is realized with the step time of 1.28[sec/step] and the step width of 0.15[m/step]. The emotional walking is evaluated by ten undergraduates as two steps (not agree or agree). Table 1 shows the evaluation of emotional walking. The agreement rates in the happy and sad walking are 90 percent and 80 percent, respectively. On the other hand, the agreement rate in the angry walking is 50 percent due to the joint limitation of the WABIAN-RII. These results clarify that the switching pattern and motion parameters are effective for the follow walking and emotional walking, respectively.

Table 1. Evaluation of three emotional walking

Walking style	Agreement
Happy walking	90
Sad walking	80
Angry walking	30

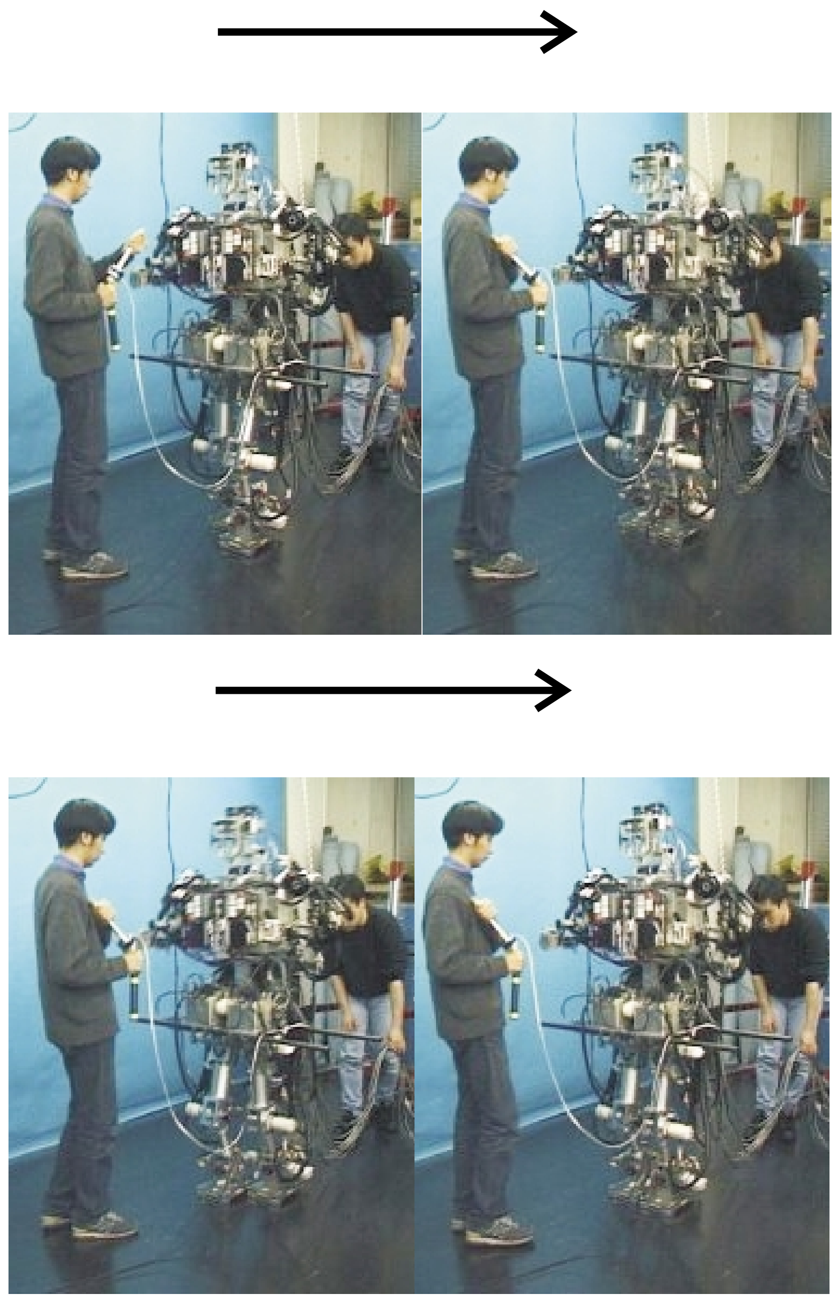

Fig. 6. Human-follow walking experiment

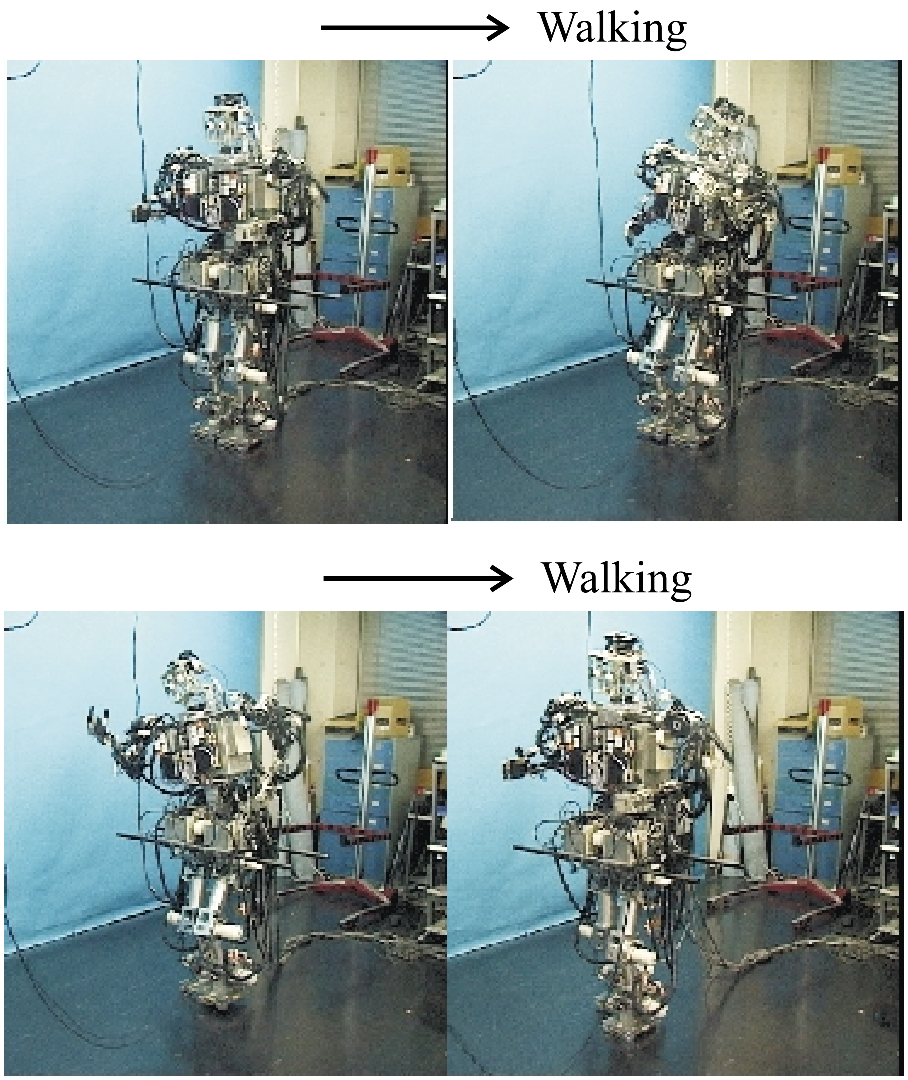

Fig. 7. Happy walking experiment

6 Conclusions

There are many challenging aspects in building a biped humanoid robot that can interact and cooperate naturally with humans. To realize human-like walking such as the emotional walking and the follow walking, a pattern switching method and a parameterization of the walking motion are proposed. The follow walking and the emotional walking are confirmed by experiments.

In order to deal with various interaction and emotion, the biped humanoid robot needs more degrees of freedom. Emotional behavior including facial expression will be studied to communicate more smoothly and naturally.

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