Real-time Trajectory Adaptation for a Biped Robot with Varying Load

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Abstract: This paper proposes suitable gait generation for dynamic walking of biped robot with varying load in real time. Author proposes the relationship between ZMP(Zero Moment Point) and measurement from FSR(Force Sensing Register). Simplifying this relationship, it is possible to reduce the computational time and control the biped robot in real time. If the weight of the biped robot varies in order to move some object, then joint trajectories of the the biped robot must be changed. When some object is loaded on the biped robot in it's home position, FSRs can measure the variation of weight. Evaluating the relations between varying load and stable gait of the biped robot, it can walk adaptively. This relation enables the biped robot to walk properly with varying load. The simulation is also represented in this paper which shows proposed relationships.

Keywords: biped robot, ZMP, humanoid, varying load

1. Introduction

The biped robot is the most suitable to work in human environment. But there are many difficulties in applying the biped robot to real working area because of terrain ground, external forces and obstacles. The most important problems in biped robot are stability for various environment and difficulty in real-time control. A number of studies for stability of biped robot were developed. Most of these studies used the ZMP as a criterion to determine the stability of biped robot. There is two methods to get the ZMP. Mostly, ZMP is obtained from the joint encoders. This method is accurate. But the ZMP computation spends a lot of time, because it needs the whole information of joints. Another method for obtaining the ZMP is to use force sensor instead of joint encoders. As put the FSR(Force Resister Sensor) on the foot of robot, the ZMP is computed directly[1].

In resent years, using the ZMP method or other methods, biped robots can walk alone excellently. But finally, the biped robot have to walk not only alone but also with some payload[4]. Using FSR, the variation of the load is computable and it is correctable the ZMP errors caused by varying load. In this paper, the relations between the information from the FSR and the ZMP is mentioned, and the proper adjustment of the ZMP is proposed when the payload is changed on the supposition that the biped robot has its reference ZMP and joint trajectories.

The concepts of ZMP and FSR are introduced at first. In section 4, the diagram of control and the controller design are proposed. In section 5, the simulation result is represented. Finally, conclusion is followed.

2. Zero Moment Point

ZMP(Zero Moment Point) is a point on the ground where the sum of moments around **P** by gravity, inertia force of robot and external force[9].

According to the D'Alambert's Principle, the ZMP condition

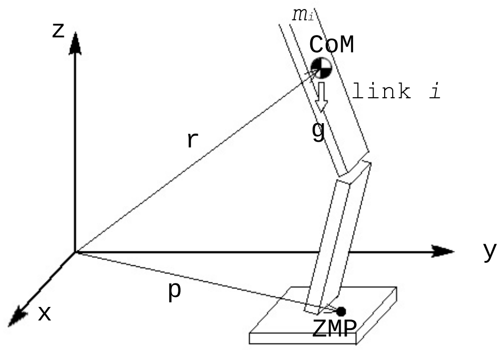

Fig. 1. The coordinate frame for ZMP

is found to be

$$\sum_i (\mathbf{r_i} - \mathbf{p}) \times \mathbf{m_i}(\ddot{\mathbf{r}}_\mathbf{i} - \mathbf{g}) = \mathbf{M_p} \tag{1}$$

where m_i is the mass of link i, $g = \begin{bmatrix} 0 & 0 & g_z \end{bmatrix}^T$ is the gravitational acceleration and $M_p = \begin{bmatrix} 0 & 0 & M_z \end{bmatrix}^T$ is moment at point **P**. Solving (1), each components of ZMP can be obtained as

$$p_x = \frac{\sum_i m_i(\ddot{z}_i - g_z)x_i - \sum_i m_i\ddot{x}_i z_i}{\sum_i m_i(\ddot{z}_i - g_z)} \tag{2}$$

$$p_y = \frac{\sum_i m_i(\ddot{z}_i - g_z)y_i - \sum_i m_i\ddot{y}_i z_i}{\sum_i m_i(\ddot{z}_i - g_z)} \tag{3}$$

3. Force Sensor Resistor

FSR is very suitable for biped robot because of its thickness and weight. When it is under pressure, its resistance is changes almost linearly in log scale. Fig.2 illustrates this property and basic structure.

In order to compute the ZMP from FSR, 4 FSRs are placed under the each foot of robot as fig.3. ZMP from forces acting on FSRs during SSP(Single-Support Phase) can be cal-

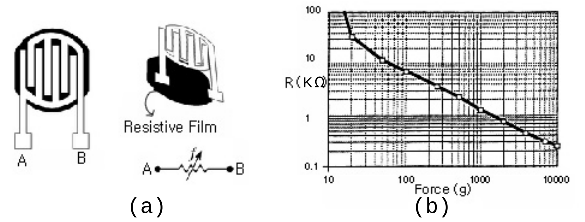

Fig. 2. (a)Diagram of FSR (b)resistance as a frnction or force for FSR

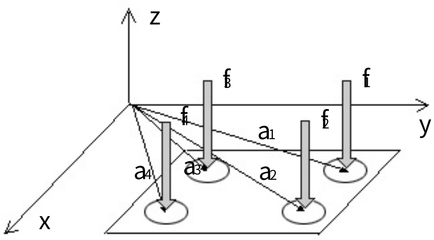

Fig. 3. The coordinate frame and placement for FSR on robot feet

culated as

$$p'_x = \frac{\sum_i f_{si} a_{xi}}{\sum_i f_{si}} \tag{4}$$

$$p'_y = \frac{\sum_i f_{si} a_{yi}}{\sum_i f_{si}} \tag{5}$$

4. Controller

This paper proposes a controller to adjust ankle joint so that the ZMP from FSR follows the reference ZMP. There is assumption that the robot has already joint trajectory and reference ZMP. In other words, proposed controller is applicable to the biped robot that can walk with no load. The information from the FSR is used for calculation of load and ZMP. The calculation of load is measured at home position before walking. Then the controller computes proper hip joint trajectory by using the mass of load, the calculated ZMP from FSR, reference ZMP and reference hip trajectory. When the load M_L is loaded on the trunk, the P'(ZMP from FSR (4) and (5)) deviates from P(reference ZMP (2) and (3)).

$$\begin{aligned} p'_x &= \frac{\sum_i f_{si} a_{xi}}{\sum_i f_{si}} \\ &= \frac{(m_0 + M_L)((\ddot{z}_0 - g_z)x_0 - \ddot{x}_0 z_0)}{(m_0 + M_L)(\ddot{z}_0 - g_z) + \sum_i m_i(\ddot{z}_i - g_z)} \\ &+ \frac{\sum_i m_i(\ddot{z}_i - g_z)x_i - \sum_i m_i \ddot{x}_i z_i}{(m_0 + M_L)(\ddot{z}_0 - g_z) + \sum_i m_i(\ddot{z}_i - g_z)} \end{aligned} \tag{6}$$

$$\begin{aligned} p'_y &= \frac{\sum_i f_{si} a_{yi}}{\sum_i f_{si}} \\ &= \frac{(m_0 + M_L)((\ddot{z}_0 - g_z)y_0 - \ddot{y}_0 z_0)}{(m_0 + M_L)(\ddot{z}_0 - g_z) + \sum_i m_i(\ddot{z}_i - g_z)} \\ &+ \frac{\sum_i m_i(\ddot{z}_i - g_z)y_i - \sum_i m_i \ddot{y}_i z_i}{(m_0 + M_L)(\ddot{z}_0 - g_z) + \sum_i m_i(\ddot{z}_i - g_z)} \end{aligned} \tag{7}$$

Because p'_x and p'_y are formed same, only p_x and p'_x are considered. Adjusting link 0 trajectoy(x_0, $\ddot{x}_0$, z_0 and $\ddot{z}_0$) to new trajectory(x_0^*, $\ddot{x}_0^*$, z_0^* and $\ddot{z}_0^*$) which satisfy following equations, the ZMP_{fsr} can keep the reference ZMP ZMP_{ref}.

$$(m_0 + M_L)((\ddot{z}_0^* - g_z)x_0^* - \ddot{x}_0^* z_0^*) = m_0((\ddot{z}_0 - g_z)x_0 - \ddot{x}_0 z_0) \tag{8}$$

$$(m_0 + M_L)(\ddot{z}_0^* - g_z) = m_0(\ddot{z}_0 - g_z) \tag{9}$$

Equation (8) lead to a second order differential equation as follow

$$\ddot{x}_0^*(t) + C_1(t)x_0^*(t) = C_2(t) \tag{10}$$

where $C_1(t) = \frac{g_z}{z_0^*(t)}$ and $C_2(t) = \frac{m_0}{(m_0+M_L)z_0^*}(z_0(t)\ddot{x}_0(t) + g_z x_0(t))$. To simplify this differential equation, let us assume that $z_0(t)$ and $z_0^*(t)$ are same constant value c_z. Actually, hip joint moves very little about z axis. Finally, we have

$$\ddot{x}_0^*(t) + \frac{g_z}{c_z}x_0^*(t) = \frac{m_0}{(m_0 + M_L)c_z}\{c_z\ddot{x}_0(t) + g_z x_0(t)\} \tag{11}$$

Using Runge-Kutta method, the solution $x(t)^*$ of differential equation (11) is easily computed in robot processor. Similarly, $y(t)^*$ is obtained from

$$\ddot{y}_0^*(t) + \frac{g_z}{c_z}y_0^*(t) = \frac{m_0}{(m_0 + M_L)c_z}\{c_z\ddot{y}_0(t) + g_z y_0(t)\} \tag{12}$$

Then the joint trajectory must be computed to move the hip joint trajectory from $x_0(t)$ to $x_0^*(t)$. Adjusting only ankle joint trajectoy, hip joint trajectory can change effectively.

$$\begin{bmatrix} \dot{x}_0^* \\ \dot{y}_0^* \\ 0 \end{bmatrix} = \begin{bmatrix} \dot{x}_0 \\ \dot{y}_0 \\ 0 \end{bmatrix} + J_v5(q)\Delta\dot{q_5}(t) + J_v6(q)\Delta\dot{q_6}(t) \tag{13}$$

$$\begin{bmatrix} \dot{x}_0^* - \dot{x}_0 \\ \dot{y}_0^* - \dot{y}_0 \\ 0 \end{bmatrix} = \begin{bmatrix} J_v5(q) & J_v6(q) \end{bmatrix} \begin{bmatrix} \Delta\dot{q_5}(t) \\ \Delta\dot{q_6}(t) \end{bmatrix} \tag{14}$$

$J_{vi}(q) \in \mathbf{R}^{\mathbf{3}\times\mathbf{1}}$ denotes ith column of Jacobian Matrix. Joint 5 and joint 6 are ankle joint. Using this equation, $\Delta q_5(t)$ and $\Delta q_6(t)$ are computed.

5. Simulation result

The simulation is illustrated when a proper reference ZMP, calculated ZMP from FSR and hip trajectory arbitrarily. If some load was added on biped robot, the trajectory of hip joint must be corrected properly in order to the real ZMP tracks the reference ZMP. Using proposed method, adequate hip joint trajectory can be computed as the load M_L is varying(M_L = 20, 40 and 60)(fig.5-7). Choosing the Δt for solving differential equation (11) and (12) properly, the computational time can be taken less than the sampling time of FSR. So, it can be accomplished that controlling the biped robot.

6. Conclusion

This paper proposed FSR method for ZMP and a controller that adapts hip joint trajectory as load is varying. The performance of the proposed method is well shown in the computer simulation, which shows the proper hip trajectory

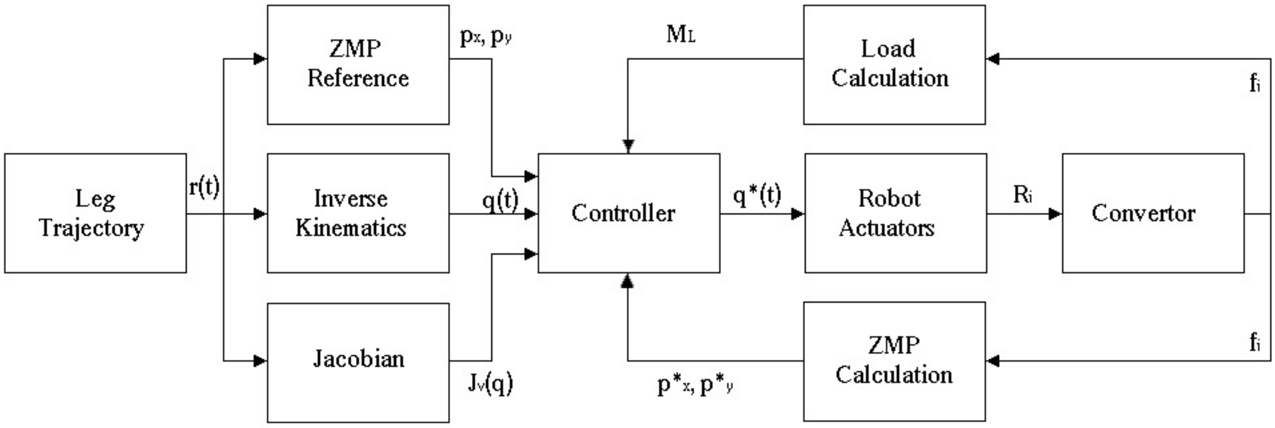

Fig. 4. Block diagram of whole system of biped robot

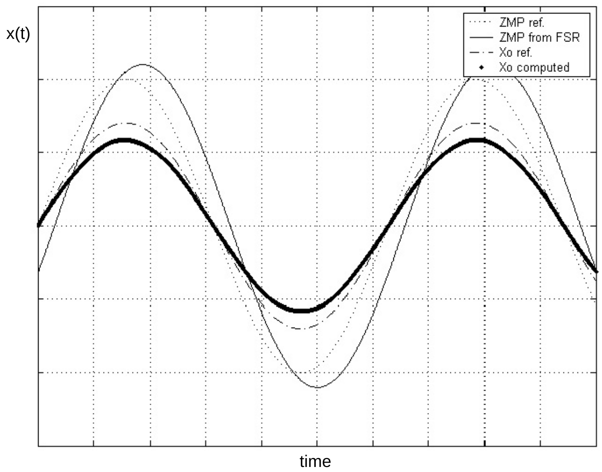

Fig. 5. The adjusted $x_0^*(t)$ trajectory($M_L = 20$)

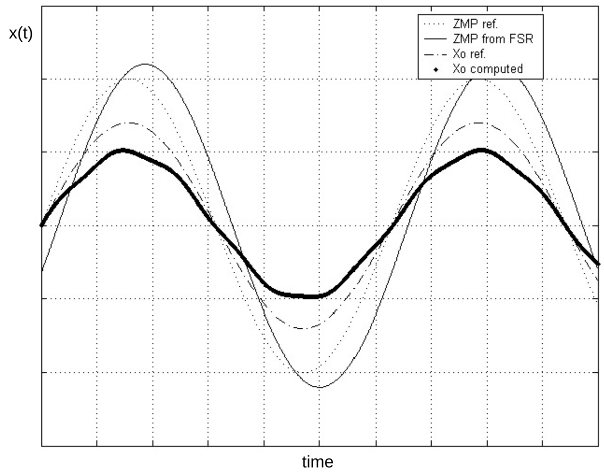

Fig. 6. The adjusted $x_0^*(t)$ trajectory($M_L = 40$)

as the load is changing. The proposed controller did'nt consider the external disturbance and the joint torque constraints.

Currently, a biped robot is being made in order to implement this method to the real manipulator. In the future study, the disturbance and the torque constraint will be considered in the real robot applying the proposed method.

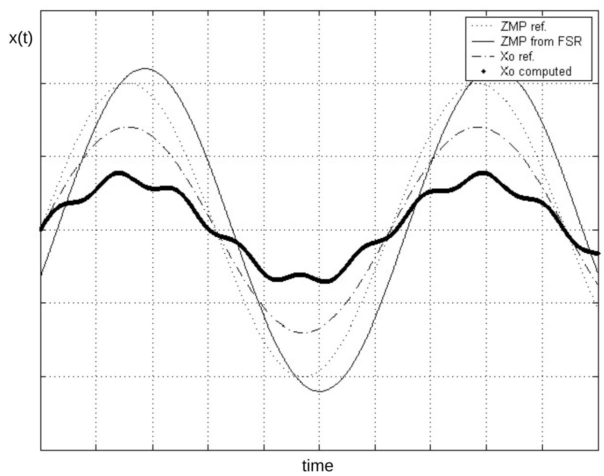

Fig. 7. The adjusted $x_0^*(t)$ trajectory($M_L = 60$)

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