

# A Novel Trajectory Planning of Robot Imitating Human's Walking and Movement

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## Abstract

In this paper, a zero moment point (ZMP) coupling trajectory planning method was proposed, which aimed at the instantaneity and effectiveness of constraints for the robot's behavior. Firstly, based on the analysis of the stability of the robot at the same time, guarantee the walking stability of ZMP boundary conditions was calculated. Secondly, we took the natural gait as a reference, and the robot moving trajectory of each joint was calculated under the circumstance of guaranteeing the continuity of the robot movement conditions by polynomial fitting. Furthermore, after we set parameters combined with actual proportion of the human body, a humanoid robot with 10 degrees of freedom model was established, and the smooth trajectory when it walked along straight or curve was calculated. Finally, the MATLAB simulation results show that the trajectory has good smoothness and continuity, as well as zero moment point coupling method was verified validity in robot path planning.

Keywords: HUMANOID ROBOT; ZERO MOMENT POINT; GAIT PLANNING; POLYNOMIAL FITTING

## 1. Introduction

Bipedal humanoid robot is one of the most cutting-edge robotics research problems, it is not only related to the nonlinear coupling, multi-sensor information control technology, but also the control of complex electromechanical system dynamics modeling, simulation technology and hybrid systems wait. It is a mechanical, electronic, computer, bionics, multi-sensor fusion technology and artificial intelligence, and other subjects on the issue of the integration of artificial intelligence. You can replace humans in some radiation, dust, toxic and other harsh environments; carry out independent operations [1-3]. Bipedal walking robot is perhaps the most appropriate sport, but because of the foot of a small biped robot leads to easy to fall, so for stability considerations are also an important part of research biped robot.

Its studied the robot in the single support period, ZMP trajectory should be located within the support leg to ensure the stability of biped robot walking

without falling [4-6], to meet this condition are many ways to generate walking track. Amos Albert multi-particle inverse pendulum model (MMIPM), by calculating the robot's ZMP equation obtained walking track. Using inverse pendulum model (IPM), taking into account the situation on the focus point inverted pendulum dynamics model to calculate the trajectory based on reversible, but this method can have a greater ZMP error. its was biped robot in ensuring the quality of the distribution and movement of the human body to keep under consistent conditions, through the use of human walking data to produce an effective and stable foot path [7] who according to the footprint constraints, cubic spline interpolation footprint expression, and then use the third-order spline interpolation cycle track hip movements, thus ensuring high stability of the robot [8-9].

In this paper, a complete walking robot in the process of changing the characteristics of speed, through sampling and analysis of bipedal walking

robot of some specific points, plan a reasonable five gait[10-11]. Then from the forward and lateral planes robot gait planning, and ankle, hip and knee trajectory mathematical model. In considering the range of variation ZMP stable region, the plan out of the joint smooth trajectory curve. Finally, MATLAB simulation software had establish a humanoid robot model to calculate the trajectory of each joint and ZMP, and by walking robot animation of the robot to go in a straight line and curve walking gait effect.

**2. ZMP Stability Analysis and Calculation**

**2.1. ZMP Stability Analysis**

ZMP concept is composed of scholars Vukobratovic Yugoslavia, who in 1972 first proposed. ZMP (Zero-Moment Point, ZMP) refers to the intersection of robot movement suffered gravity and inertia force of the force of the extension line and the ground. From the kinetic point of view, the balance of the whole system is a necessary condition for the ZMP falls included all support points convex polygon.

Static walking means walking at any instant, the robots are in a state of static equilibrium, that the robot is always the focus of the projection on the ground within the support surface, so when the robot is stationary or static balance, projection, and ZMP coincides with its center of gravity in the ground, as shown in Figure 1. From the kinetic point of view, a necessary condition for equilibrium of the whole system is to contain all support points fall ZMP convex polygon. Humanoid robot dynamic walking, as long as the ZMP had support polygon located, regardless of where the center of gravity of the projection, the robot can remain stable, as shown in FIG.

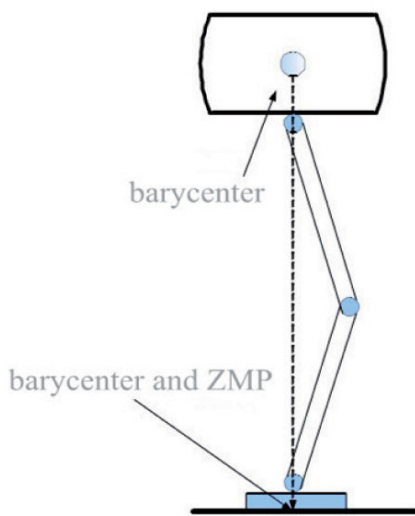


Figure 1. Focus of the projector and ZMP

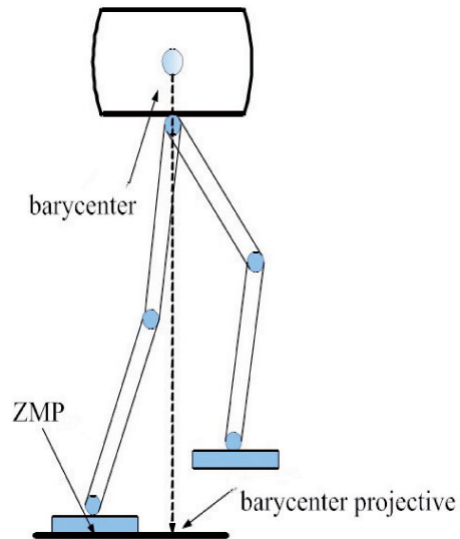


Figure 2. Walking projection and ZMP

**2.2 ZMP Calculation**

According to D'Alembert's principle [12], the robot suffered inertial force on x, y, z direction of the force of inertia force, namely:

$$F = \begin{bmatrix} F_X \\ F_Y \\ F_Z \end{bmatrix} = - \sum m_i \begin{bmatrix} \ddot{x}_i \\ \ddot{y}_i \\ \ddot{z}_i \end{bmatrix} \tag{1}$$

In the above formula,  $F_X$ ,  $F_Y$ ,  $F_Z$  represent the x, y, z direction inertial force,  $m_i$  is quality of the link,  $\ddot{x}_i$ ,  $\ddot{y}_i$ ,  $\ddot{z}_i$  respectively, each link centroid x, y, z direction acceleration, ZMP calculate the coordinates obtained.

$$\begin{bmatrix} x_{ZMP} \\ y_{ZMP} \end{bmatrix} = \begin{bmatrix} \frac{\sum m_i [(\ddot{z}_i + g)x_i - \ddot{x}_i z_i]}{\sum m_i (\ddot{z}_i + g)} \\ \frac{\sum m_i [(\ddot{z}_i + g)y_i - \ddot{y}_i z_i]}{\sum m_i (\ddot{z}_i + g)} \end{bmatrix} \tag{2}$$

When calculating the ZMP of the robot, you can use the entire robot as a particle or a link to each particle as a robot program, proven to each link of the robot as a method to calculate the particle decreases ZMP error, so we use this algorithm in a later simulation program[13-14]. Experiments show that if the use of the following methods seeks ZMP, this method can greatly shorten the run time.

After calculating the ZMP position to determine whether or not fall within the stable ZMP region, if in a stable region, according to point formula to the straight line distance to determine the distance be-

tween the boundary of the ZMP, which is the minimum required to stabilize the ZMP from the zone boundary. According to this distance can understand the planning gait stability margin.

In the trajectory planning process, try to realize walking humanoid robot, for below normal gait analysis, combined with the natural gait of the robot joint trajectory planning. In order to ensure the continuity of the robot gait and smoothness, polynomial curve fitting method robot trajectory planning, so that the position of each part of the velocity and acceleration during a walk in a row [15-16].

**2.3. General Gait Planning**

As shown, CD stage shown in Figure 3 and Figure 4 is the single support period, OC stage is the support of the feet. In OA stage, not turning right foot, left foot is rotated around the heel; in the AB phase, the right foot is rotated around the toe, left foot is rotated around the heel, to the B state left foot touch the ground; in BC stage, this time left foot touch the ground, stopped spinning, and continue to turn right; when CD stage, right foot step forward.

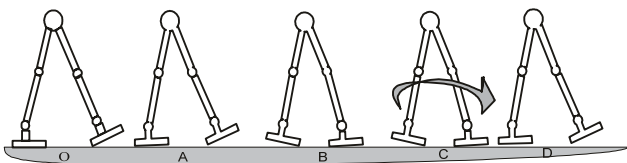


Figure 3. Robot gait

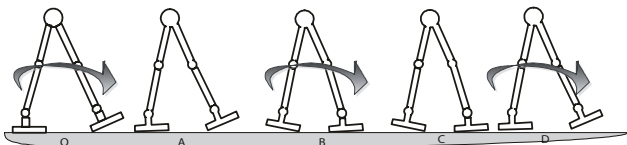


Figure 4. Walk straight

Figure 5 is a plan view of the ground all the figures (x-axis and y-axis is the plane) on the direction of the arrow for the direction of the robot forward, rectangular  $F_{11}F_{12}F_{13}F_{14}$  and rectangular  $F_{21}F_{22}F_{23}F_{24}$  are right and left angle with the ground zero and the ground contact range. The shaded region of ZMP has stable region of each stage.

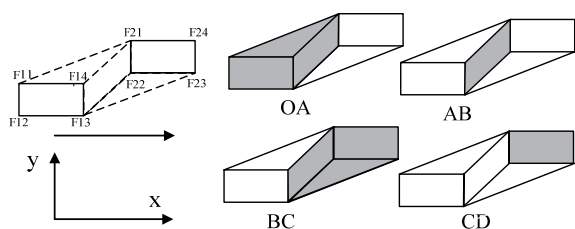


Figure 5. ZMP stable region walking process

**2.4. Feet and Ground Angle Change**

Robot during walking, the foot angle with the ground has been changing [17]. But overall the angle of the foot and the ground contact can be divided into three distinct phases ( $t_1-t_2$ ;  $t_2-t_3$ ;  $t_3-t_4$ ), and then press the three phase of the cycle. Following a foot for the study, and another addition to the different than the same time the stage is circulating in the three phases. The various stages of the foot and the ground had schematic diagram shown in Figure 6.

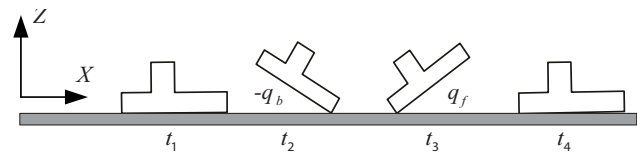


Figure 6. Change the angle

In figure 6, the angle between the ground and is provided for the foot, leaving the front of the foot, the foot around the toes make initial velocity becomes zero rotational acceleration,  $t_1$  time starts to rotate,  $t_2$  time off the ground, then the foot with the ground angle of  $-q_b$ , after leaving the ground, the foot is rotated around the ankle,  $t_3$  time heel, the ground, the feet and the ground angle of  $q_f$ , heel to the ground, around the heel feet do the final velocity deceleration becomes zero,  $t_4$  moments feet fully touch the ground.

Prescribed time period  $t_1 \sim t_2$ , the angle between the foot and the ground

$$q_1(t) = \frac{-q_b(t - t_1)^6}{(t_2 - t_1)^6} \tag{3}$$

Prescribed time period  $t_2 \sim t_3$ , the angle between the foot and the ground:

$$q_3(t) = a_0q + a_1qt + a_2qt^2 + a_3qt^3 + a_4qt^4 + a_5qt^5 \tag{4}$$

Which by formula (6) can be obtained  $a_0q - a_5q$ ,  $t_3 \sim t_4$  period specified, the angle between the foot and the ground

$$q_2(t) = \frac{q_f(t_4 - t)^6}{(t_4 - t_3)^6} \tag{5}$$

$$\begin{bmatrix} 1 & t_2 & t_2^2 & t_2^3 & t_2^4 & t_2^5 \\ 0 & 1 & 2t_2 & 3t_2^2 & 4t_2^3 & 5t_2^4 \\ 0 & 0 & 2 & 6t_2 & 12t_2^2 & 20t_2^3 \\ 1 & t_3 & t_3^2 & t_3^3 & t_3^4 & t_3^5 \\ 0 & 1 & 2t_3 & 3t_3^2 & 4t_3^3 & 5t_3^4 \\ 0 & 0 & 2 & 6t_3 & 12t_3^2 & 20t_3^3 \end{bmatrix} \begin{bmatrix} a_{0q} \\ a_{1q} \\ a_{2q} \\ a_{3q} \\ a_{4q} \\ a_{5q} \end{bmatrix} = \begin{bmatrix} -q_b \\ -6q_b / (t_2 - t_1) \\ -30q_b / (t_2 - t_1)^2 \\ q_f \\ -6q_f / (t_3 - t_1) \\ 30q_f / (t_3 - t_1)^2 \end{bmatrix} \quad (6)$$

Based on the above, you can find the left and right in different stages of expression.

### 3. Each Joint Trajectory Planning

#### 3.1. Ankle Trajectory Planning

To simplify the model calculations, located around the ankle does not swing along the x-axis robot forward, left ankle joint during walking in the y-axis of coordinates and the coordinates of the size of the right ankle joint is equal to a predetermined left ankle joint in the y-axis direction coordinates  $W_d / 2$ , the coordinates of the right ankle joint is  $-W_d / 2$ , where  $W_d$  is a distance around the hip. Figure 7 is a side view of the foot,  $D_{ab}$  represents the distance to the foot of the ankle,  $D_{ah}$  represent ankle plantar surface of the projection distance to heel,  $D_{af}$  represent ankle plantar surface of the projection distance to toe.

#### 3.2. Hip Trajectory Planning

To simplify the planning, hip during walking the same height (ie coordinate z direction is unchanged),

$$x_{hip}(t) = a_{0xh} + a_{1xh}t + a_{2xh}t^2 + a_{3xh}t^3 + a_{4xh}t^4 + a_{5xh}t^5 + a_{6xh}t^6 \quad (7)$$

Can be obtained by the above provisions

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & t_d & t_d^2 & t_d^3 & t_d^4 & t_d^5 & t_d^6 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 2t_d & 3t_d^2 & 4t_d^3 & 5t_d^4 & 6t_d^5 \\ 0 & 0 & 2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 2 & 6 & 12t_c^2 & 20t_c^3 & 30t_c^4 \\ 0 & 0 & 2 & 6t_d & 12t_d^2 & 20t_d^3 & 30t_d^4 \end{bmatrix} \begin{bmatrix} a_{0xh} \\ a_{1xh} \\ a_{2xh} \\ a_{3xh} \\ a_{4xh} \\ a_{5xh} \\ a_{6xh} \end{bmatrix} = \begin{bmatrix} x_{hipst} \\ D_s + x_{hipst} \\ D_s / t_D \\ D_s / t_D \\ 0 \\ a_{xhip} \\ 0 \end{bmatrix} \quad (8)$$

#### 3.3. Knee Trajectory Planning

In the model of the robot, the robot's legs set length  $L_{th}$ , calf length robot is  $L_{sh}$ , depending on the position of several sections obtained above the hip

$$\begin{cases} x_{knee} = x_{hip} + L_{th} \sin(\angle P_2 P_1 P_4) = x_{hip} + L_{th} \sin(\angle P_2 P_1 P_3 + \angle P_3 P_1 P_4) \\ z_{knee} = z_{hip} - L_{th} \cos(\angle P_2 P_1 P_4) = z_{hip} - L_{th} \cos(\angle P_2 P_1 P_3 + \angle P_3 P_1 P_4) \end{cases} \quad (9)$$

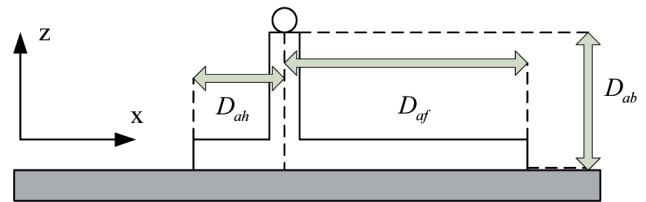


Figure 7. Foot side view

the hip is not about the z-axis (the whole walking around during the forward plane coincides with the hip).

In the x direction of advance provision coordinate hip time 0 to  $x_{hipst}$ , the time  $t_D$  coordinates for  $D_s + x_{hipst}$ ; provision hip speed time 0 to time  $t_d$  and average speed, the  $D_s / t_D$ ; predetermined time 0 and  $t_D$  hip acceleration time is 0,  $t_c$  time acceleration  $a_{xhip}$ .

Hip track located in the x direction is

joint and the position of the ankle, according to a certain relationship between them, that is knee position can be determined.

#### 4. Simulation Analyses

Use previous gait planning method, combined with the natural gait given specific values of certain parameters, then the formula according to previous analysis obtained using MATLAB calculated for each joint and ZMP trajectory, with animated visual display of the adoption of this article gait simulation algorithm planning. Process rod-shaped diagram and ZMP stable region had biped robot gait plan view of FIG. 8, as shown in Figure 9.

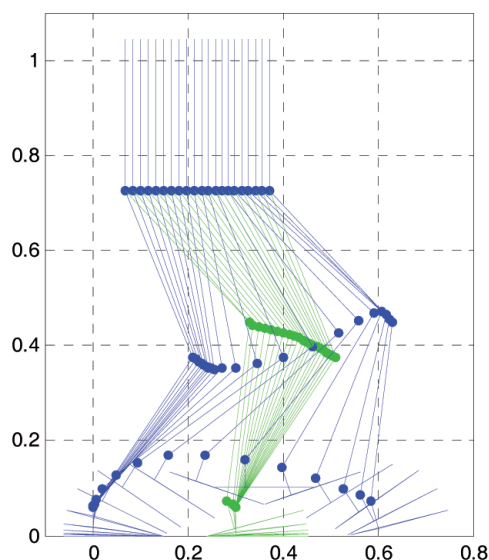


Figure 8. Walking rod-shaped diagrams

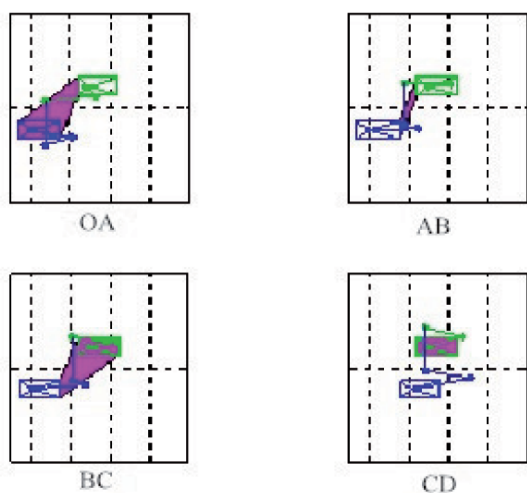


Figure 9. ZMP stable regions walking a plan view

#### 5. Conclusions

In this paper, the polynomial method to map out the joint biped walking humanoid robot of the track, to ensure the speed of the robot to walk and continuous condition during acceleration, so that the robot remains smooth gait steady. After the simulation, the results show that this method can plan the basic

humanoid robot walking gait. In this paper the parameters on the assumption that the robot is walking on level ground, this is just a special place bipedal walking robot in the future in order to make the biped robot have a wider space, we must let the robot can walk on rough, uneven on the ground, this is the main direction of our future research.

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## Research on the Distributed Big Data Management of Bank Based on the Three-tier C/S model

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### Abstract

Designing and implementing an effective three-tier client/server system to support the new business paradigm is the focus of this document. To fully realize the potential of the three-tier architecture, this paper makes the middle layer easily accessible to multiple front-ends. The middle tier is running on a separate machine. This allows it to be accessible to multiple clients and it provides for the maximum performance. A prototype system was built using the business transaction of a certain Commercial Bank as the case studies. The experiment result shows that the three-tier client/server system has better performance in distributed big data management.

Keywords: DISTRIBUTED BIG DATA MANAGEMENT, THREE-TIER C/S MODEL, DISTRIBUTED SYSTEM FOR BANK.

### 1. Introduction

The term client/server originally applied to software architecture that described processing between two programs: an application and a supporting ser-

vice. At that time, the client program and the server program did not have to be physically separated – they could be calling and called programs running on the same computer. Thus, originally, the client/server