Dynamic Walking of a Biped Robot

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Abstract - This paper mainly deals with the dynamic walking of a biped robot. At first, in order to walk in various environments, it is desirable to adapt to such ground conditions with a suitable foot motion, and maintain the stability of the robot by a smooth hip motion. A method to plan a walking pattern consisting of a foot trajectory and a hip trajectory is presented. The effectiveness of the proposed method is illustrated by simulation results. Secondly, the paper brings forward a balance control technique based on off-line walking pattern with real-time modification. At last, the concept of Zero Moment Point (ZMP) is used to evaluate dynamic stability.

Key Words : Dynamic walking, walking pattern, stability, balance control, ZMP

1. Introduction

Recently there has been much interest in dynamic walking in biped robotics. Human beings usually employ a dynamic gait when walking as it is faster and more efficient than static walking.

Several methods for dynamic gait generation of biped robots have been introduced in previous works, such as geometry planning, fuzzy control, neutral network system, genetic algorithm and natural dynamics. However, these methods can't offer complete solution for the full locomotion cycle. And in the practical application, each of these methods has some disadvantages that are hard to overcome[1]. In this paper, a new approach to dynamic walking pattern is studied. And it also brings forward a control method to ensure the robot stable while walking.

Stability is a basic requirement of gait generation for the biped robot. For static stability, it just requires that the center of gravity(CG) is within robot support area. However, for dynamic stability, the CG may lie outside of the support region. Most biped walking planing has been achieving dynamic stability. A popular method called ZMP has been used as a criterion of walking stability[2].

The aim of this research is to design, build and implement a robot to achieve dynamic waking. This paper is structured as follows. The next section describes a proposed method for planning dynamic walking pattern. Section 3 proposes a balance control technique .Section 4 introduces the ZMP criterion. The last section summarizes and concludes the paper.

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2. dynamic walking pattern

1. Mechanical Model of Biped Robot

The characteristic of dynamic motion of biped robot are closely related with it's mechanical structure. In order to achieve desired performance like human beings, a good mechanical design following human body structure is needed first. the mechanical design can be divided into three phases[3]:

a. Study the structure of human body and determine the specifications of the biped robot.

b. Select the materials and components to satisfy the desired specifications.

c. Comprehend the characteristic and specifications of the components and design the architecture details.

2. walking cycle

The dynamic walking pattern can take statistics data of human locomotion[4] supplied by physician. The main work focuses on statistics data transformation to the joint of robot. However, we take feasible mathematics analysis method to plan waking pattern in this paper.

We consider a biped robot with a trunk. Each leg consists of a thigh, a shin, and a foot, and has six degrees of freedom(DOF): three DOF in the hip joint, one in the knee joint, and two in the ankle joint.

Biped walking is a periodic phenomenon. A complete walking cycle is composed of two phases: a double-support phase and a single-support phase. During the double-support phase, both feet are in contact with the ground. This phase begins with the heel of the forward foot touching the ground, and ends with the toe of the rear foot leaving the ground. During the single-support phase, while one foot is stationary on the ground, the other foot swings from the rear to the front.

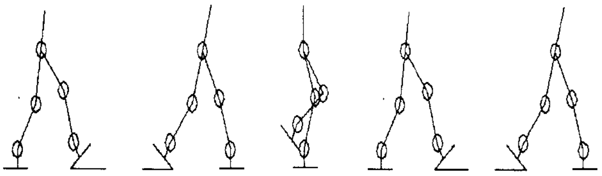
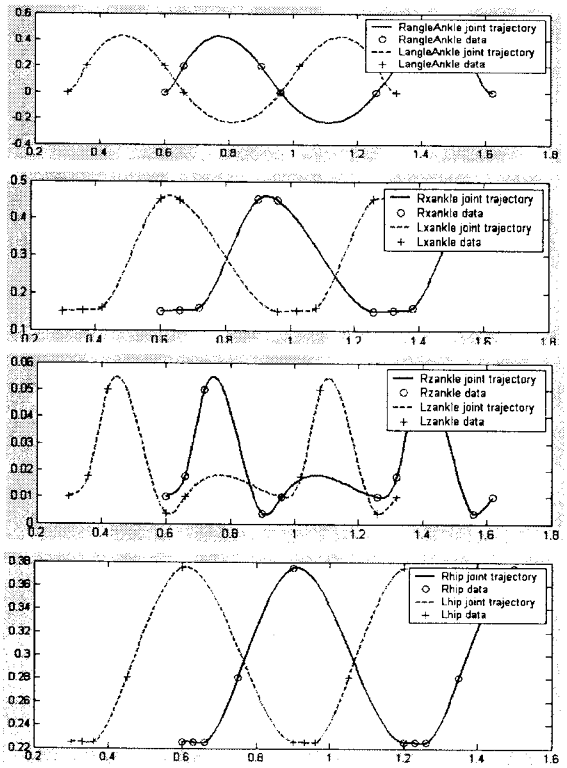


Fig.1 walking cycle

3. foot and hip trajectory

To be able to walk stably in various environments, such as on rough terrain, up and down slopes, or in regions containing obstacles, it is necessary for the robot to adapt to the ground conditions with a foot motion, and maintain its stability with a torso motion[3]. Lateral motion is similar with sagittal motion. Only sagittal motion is discussed in this work.

First, we formulate the constraints of a foot trajectory, and generate the foot trajectory by 3rd order spline interpolation. By setting the values of constraint parameters, it is easy to produce different typed of foot motion by varying the values of constraints parameters. Then, we formulate a hip trajectory using a 3rd order periodic spline function, and derive the hip trajectory with high stability. From the viewpoint of stability, xh(t) is the main factor that affects the stability of biped robot walking in sagittal plane. Finally, the effectiveness of the proposed method is illustrated by simulation examples.



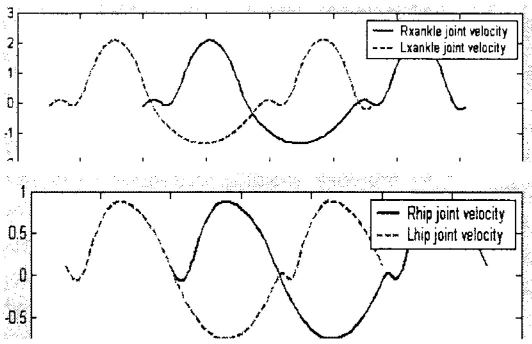


Fig2-7.Ankle and hip joint trajectories and their related velocities along x direction.

4. actuator specification--motor torque

To compute the required actuator specifications such as torque and velocity, it is necessary to accurately formulate and solve the equations of the kinematics and dynamics of the robot mechanisms Fig.8. Here, the mathematical model for robot is established, including the joint coordinate, determination for link parameters and derivation of kinematics and dynamics equations.

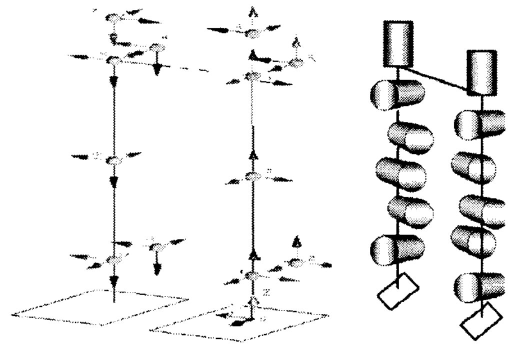


Fig.8 Body coordinate based on D-H rule

Dynamic Analysis not only considers the effect of velocity and acceleration, but also needs to think about torque.

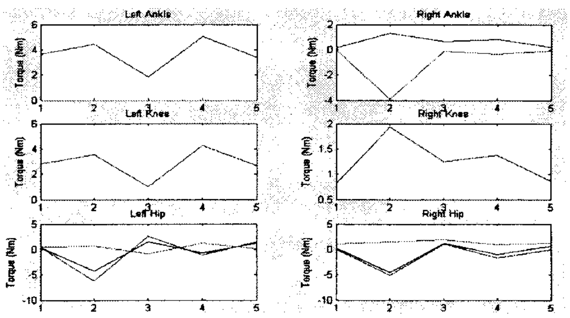


Fig.9 Joint torque.

The output curves of the joint torque demonstrate the chosen motor and the whole robot frame feasible.

3. ZMP and Robot Stability

The stable criterion is still the general one: the ZMP poison must be restricted within the support area strictly

The ZMP is defined as the point on the ground where the sum of all the moments of active forces equals zero. If the ZMP is within the contact polygon between the feet and the ground, the biped robot is stable. ZMP coordinates are computed using a model of the robot and information from the joint encoders. ZMP equations are as follows:[5]

$$x_{zmp} = \frac{\sum_{i=1}^{n} m_i (z_i + g_z) x_i - \sum_{i=1}^{n} m_i (\ddot{x}_i + \ddot{g}_x) z_i}{\sum_{i=1}^{n} m_i (z_i + \ddot{g}_z)}$$

$$y_{zmp} = \frac{\sum_{i=1}^{n} m_i (z_i + g_z) y_i - \sum_{i=1}^{n} m_i (y_i + \ddot{g}_y) z_i}{\sum_{i=1}^{n} m_i (z_i + \ddot{g}_z)}$$

where(Xzmp,Yzmp,0) is the coordinate of the ZMP, (Xi,Yi,Zi) is the mass of link i, g is the gravitational acceleration.

A method using six-axis force sensor to measure actual ZMP is presented. The best position to install sensors is under the ankle, that is, the nearer the ground is the better. here, the sensor is installed inside the feet[6].(s is six-force sensor, p is actual ZMP point)

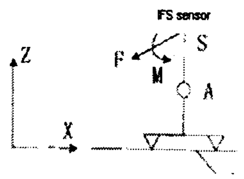
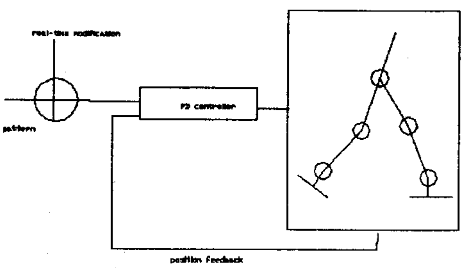


Fig.10 Installing of six-axis force sensor schematic

Based on D'Akanbert's Principle, we can get the formulas for computing actual ZMP

4. Balance Control

Since a biped robot tends to tip over easily, stable and reliable biped walking is a very important achievement. In this paper, we propose a balance control method based on an off-line planned walking pattern with real-time modification[7]. For this study, however, the embedded PD controller inside each RC servomotor is to take control tasks when the reference value of each joint is commanded in an open-loop fashion. the structure of balance control is shown in Fig11.



5. Summary and Conclusion

In this paper, the walking motion of the biped can be determined by the hip and foot trajectory. Cubic polynomial is used to generate the hip and swing foot trajectory. The control strategies were designed based on the specific character of robot. Zero Moment Point criterion is used to ensure the stability

We can find this solution of gait-programming its feasible from the track curves of joints, the ZMP curve, the output curves of the joint torques and other results of the simulation performed with Matlab.

With the method mentioned in this paper, the future work is to use one software called Yobotics Simulation Construction Set for motion simulation and applies to real robot for achieving dynamic walking based on the proposed method.

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Reference

[1] Kai Xu, Ken Chen, Jinsong Wang, Li Liu, Dongchao Yang, Jiandong; "A New Method of Gait Generation for A Biped Walking Robot", *Proceedings of the IEEE-RAS International Conference on Humanoid Robots*,2001

[2] Zhe Tang.."Trajectory Planning for Smooth Transitioin of a Biped Robot",*Proceedings of the 2003 IEEE International Conference on Robotics & Automaiton,* Sept14-19,2003.

[3] Ruixiang Zhang, student Member, IEEE, Prahlad Vadakkepat, and Chee-Meng Chew, "Development and Walking Control of a Biped Robot", *jrnl.*

[4] "Normal Human Locomotion(part I and II)". assets/css/styles-ie.css

[5] Kemalettin Erbatur, Akihiro Okazaki, Keisuke Obiya, "A Study on the Zero Moment Point Measurement for Biped Walking Robots", *IEEE*,2002

[6] Liu Li,Wang Jin-song,Chen Ken,Yang Dong-chao, Zhao Jian-dong. "Actual ZMP measurement for force-moment sensors based humanoid robot",*Robot*, Vol,23,No.5, Sept, 2001.

[7] Qiang Huang,Kenji Kaneko, Kazuhito YoKoi, Shuuji Kajita,ect., "Balance Control of a Biped Robot Combing off-line Pattern with Reail-time Modification",*Proceedings of the 2000 IEEE, International Conference on Robotics & Automation San Francisco, CA* .April 2000.

[8] Robotics(control, Sensing, Vision, and Intelligence), K.S.Fu, R.C.Gonzales and C.S.G.Lee.

[9] Qiang huang, "Planning Walking Pattedsrns for a Biped Robot," *IEEE transactions on robotics and automation,* Vol,1,No.3, June 2001.