Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2015, 7(3):537-542

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Motion planning for humanoid robot based on arm

Zhong Qiu-bo[1,2], Zhao Jie[1] and Tong Chun-ya[2]

[1]State Key laboratory of Robotics and System, Harbin Institute of Technology, Harbin, China
[2]School of Electronic and Information Engineering, Ningbo University of Technology, China

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ABSTRACT

Gait planning of humanoid robot is a hotspot at robotic field. The problem that swing arms have an effect on gait during the walking and running is analyzed in this paper. Standing on the view of energy, a special pendulum model established on the motion of swing arms is used to analyze the effect about swing and angular velocity of arms to gait planning. The experiment indicates, the optimal swing angle and the optimal swing speed facilitate the stability and validity of gait planning in the humanoid robot motion.

Key words: Humanoid Robot; Arms moving; Motion planner; Pendulum

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INTRODUCTION

Humanoid robot has the similar structure with people and both walk depending on the feet, always is the hot topic in robotics area [1]. It has the similar human connecting-rod and joint to support the body, imitating human's walking through joint motions to achieve gait moving goal. Human is used to oscillating arms, robot has learned this. Human usually walks with arms tandem, whichever the oscillating arms mode is, only needs a little movement of shoulders, however, the energy cost varies very much. By "pendulum movement mode", oscillating arms can counteract the force of impelling body whirlling, helping to support parts of force on feet, but robot's arm oscillating through electric motors' force on shoulders, with the intercoordination of arms and weight shifting[2], so we can design the speed of electric motors output and maximum deflection to compensate the gait movement stability.

The most common way of gait planning of Humanoid Robot is the criterion that Vukobratovic came up called ZMP(Zero Moment Point)[3], based on COP(Center of Pressure)[4], FRI(Foot-Rotation Indicator)[5] and GZMP(General Zero Moment Point)[6] to judge the gait movement stability. In the research of gait planning, the planning based on geometrical constraint is widely used, and it succeed in actual walking in the situation of planning walking speed is not very fast[7]. This passage is based on MF robot as experiment terrace, using the basic of achieving essential gait goal, changing the arms' oscillating of humanoid robot, researching its effect on stability.

GAIT PLANNING FOR ROBOT

The way of robot's walking is the same to human, because of the friction force's reciprocity between floor and feet. However, in the process, the interface between feet and floor will produce rotation applied moment.It is generally supposed that floor acting force is able to balance the robot's self-torque. But when the floor friction coefficient is very small, or the moving speed is too fast, the balance will be broken and affect the gait movement stability. If considering using upper parts of the body's moving to compensate the torsion, this will be a feasible method to perfect the gait stability. Document[8] showed that arms compensation is better than trunk compensation at the angle of energy in Arms/Body Moving planning research.

1.1 Torque analysis

If robot's center of mass is in the geometric centre namely waist,abstracting all the electric motors for mass's centre, abstracting link for streak,ignoring its mass, planning its motion trajectory, when robot is moving in the frame of axes down the locus orbit, which illustrated in Figure 1.

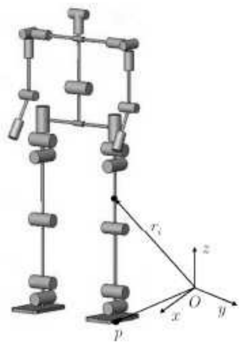

Fig. 1 Humanoid robot model

Learning from the method of supporting legs, torque-balance, we can come up:

$$\sum_{i=1}^{n}[m_i(r_i - p)\times(\ddot{r}_i + g) + M_{ci}] + T_p = 0^{[8]}$$

Among these, mi means the mass of the first parts; r_i, $\ddot{r}_i$ and M_{ci} separ 才 ately mean the first parts' molar center position vector, acceleration and torque; p means the touch contact between supporting feet and floor's position vector; g means acceleration of gravity; T_P means the applied moment that floor act on robot at the point of p; n means the number of parts. Choose point p as point ZMP, learning from the direction of Z axis's torque when the robot is moving.

$$M_Z = \sum_{i=1}^{n}[m_i(r_i - p)\times(\ddot{r}_i + g) + M_{ci}]_z^{[8]} \tag{1}$$

If M_Z is over the floor, it will lead to the result that gait loses its balance, effecting on body's moving. Because robot's arms oscillating depends on shoulders' electric motors, but document[8] had explained that oscillating arms can strengthen the system's stability. Based on this, we can consider to use the shoulder's electric motors torque to balance the torque that robot produces when moving, if the shoulder's electric motors torque output is P2.we can come up:

$$M_Z = P_2 \tag{2}$$

According to the actual electric motors torque output formula: $T = 9550 \times P / V$

T means torque output, P means the power of motors, V means the output speed namely linear velocity，η means coefficient. Put them into the formula(2) ， then we can come up:

$$M_Z = \eta(9550 \times P / V) \tag{3}$$

Because no matter the robot is walking or running, it all moves in one period. So actually I only need to consider to compensate for one-period T, it can guarantee that the following gait is steady. Take actual into consideration, it has compensating errors, if gait circles more, the errors will be enlarged, this finally will affect the gait's stability. This passage ignores the errors.

1.2 oscillating arms' energy analysis

Imitate the human's walking to build one action model, which can be illustrated in Figure 2:

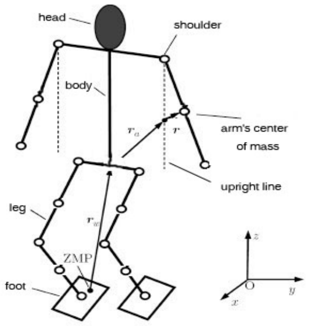

Fig. 2 Robot action model

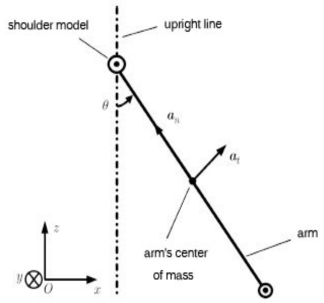

Fig. 3 Oscillating arms model

After analyzing arms' movement discipline, we can find that arms are circling the shoulders in in-plane of XOZ. When human is walking, natural arms are steering, when human is running, arms are flexual, during designing the MF humanoid robot's gait, no matter the robot is walking or running, arms are steering. So we don't consider the flexual state.

We can learn after abbreviating the effect that oscillating arms makes on body torque:

$$M_{2z} = -2m_2 r_{ay} \ddot{r}_x \quad [8] \tag{4}$$

The same, swing arm is a periodic motion. θ means the turn angle of arm circled shoulder. at means the tangential vector of swing arm acceleration and an means the normal component of swing arm acceleration. As shown in Figure 3, we only need to analysis the energy consumed during one cycle period T. Based on the energy consumed formula of swing arm proposed by the document[6], $\Delta E_\alpha = \sum_{k=1}^{n-1} \left| E_{K+1} - E_K \right|$.

Due to swing arm need to consume energy, the swing arm must be caused by work of shoulder's motor. So the work of the motor equals the energy consumed of swing arm. Assume that this energy coefficient as η , the arm length as L, a formula about the energy consumed as following:

$$\Delta E_a = 2\eta \cdot (\frac{P}{V} \times \theta \cdot \pi \times L / 180°) \tag{5}$$

ARM MOTION COMPENSATION

Via the analysis standing on torque angle and energy, it can be concluded that gait stability is greatly affected by the swing arm speed *V* and the swing arm range θ. How to achieve the stability of optimization gait via adjusting *V* and θ. A optimal solution can be calculated by using the formula (3)-(5):

$$2\eta(\frac{P}{V} \times \theta \cdot \pi \times L / 180°) = \sum_{k=1}^{n-1} \left| E_{K+1} - E_K \right| \tag{6}$$

$$\eta(9550 \times P/V) = \sum_{i=1}^{n} [m_i(r_i - p) \times (\ddot{r}_i + g) + M_{ci}]_z \tag{7}$$

Simplify the formula (6), (7):

$$\frac{\theta}{V} = \frac{\sum_{k=1}^{n-1} \left| E_{K+1} - E_K \right| \cdot 180°}{2\eta \cdot P \cdot \pi \cdot L} \quad V = \frac{\eta \cdot 9550 \cdot P}{\sum_{i=1}^{n} [m_i(r_i - p) \times (\ddot{r}_i + g) + M_{ci}]_z}$$

The sub-step-design model is adopted to gait planning on the robot MF. The dynamic gait action is implemented by executing several sub-form actions continuously. In the several gait action models, there is a optimal situation about how to compensate the rotation torque and position arm action in which sub-form gait. The gait of this paper is designed as a cycle period subdivided into 5 steps. Flow Figure as shown in figure 4:

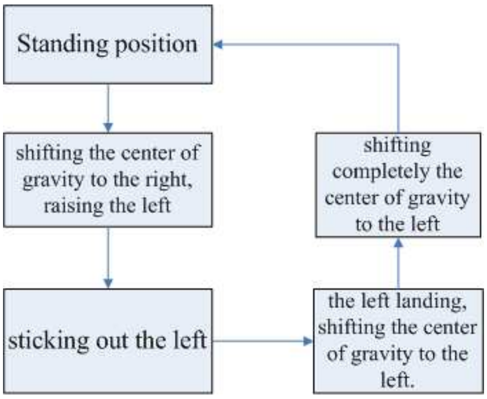

Fig.4 The flowchart of gait planning for robot

Based on observation of human walking and analysis about flow Figure, when a person sticks out his left leg, the rotation torque will be produced and compensated by swing arm. The rotation torque will disappear when recovering to standing position, so arms are allowed to recover to original state. Therefore the compensation of swing arm is added to gait flow Figure as shown in figure 5:

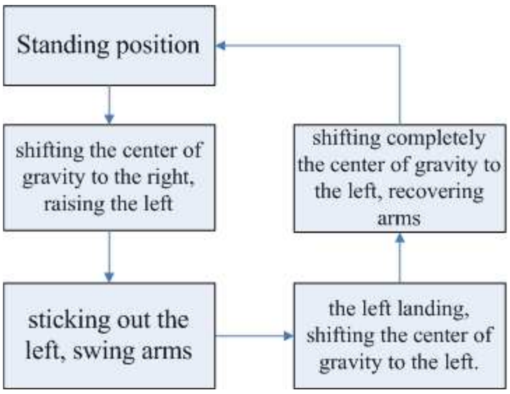

Fig.5 the flow Figure about the compensation of swing arm

EXPERIMENTAL SECTION

MF robot as shown in figure 6, there are 16 degrees of freedom in total. Each leg has 5 degrees of freedom contained ankle, knee etc. Each arm has 3 degrees of freedom contained shoulder etc. The output torque of the motor is 9 kg•cm. The output speed of the motor can be configured in application from 0 to 15. Considering the whole coordinate and algorithm design, the speed of swing arms should be equal to average speed of the all motors. The angle of swing is set from 0 to 45 degrees. Figure 6 show the right of robot walking. Figure 7 show the side of robot walking.

The experiment is executed on a hard blanket with a big friction factor. During the running and walking, the static model of swing arm is fast due to the small range of swing and equable change of center of gravity. Whether running and walking is distinguished by the executing speed of the other static action model. Every speed V and angle is tested about 10 times, walk steps at least 10. Robot is not fallen in 8 of 10 regarded as stability.

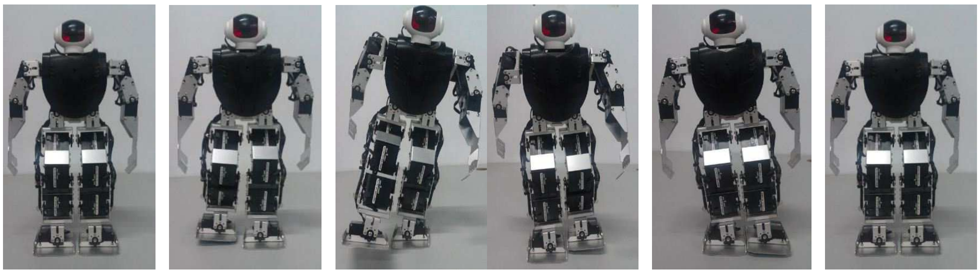

Fig. 6 The compensation on the right view

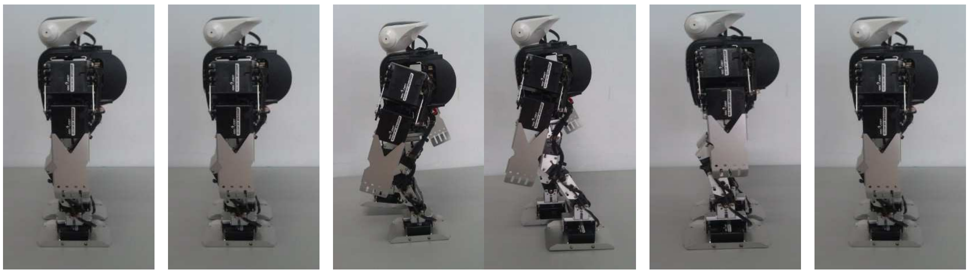

Fig. 7 The compensation on the side view

In figure 8, the walking cycle period is divided into three curves. Rotation torques is compensated during the rise and descends part.

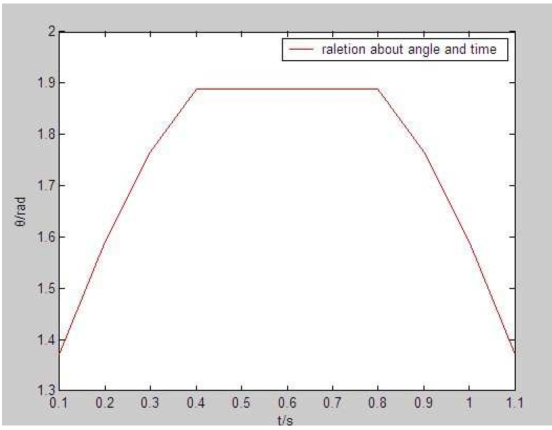

Fig. 8 The relation of angle and time

CONCLUSION

More research about the swing angle and speed of arms during the walking and running, we use an energy and output torque viewpoint to analyze the whole motion. Based on torque output by the motor of shoulder, the compensation for torque produced on the motion is settled, and stability of the whole system has improved. The result data proves the validate and rationality of the proposed approach.

Acknowledgements
This material is based upon work funded by Natural Science Foundation of China under Grant No.61203360, Zhejiang Provincial Natural Science Foundation of China under Grant No.LQ12F03001, LQ12D01001, LY12F01002, Ningbo City Natural Science Foundation of China under Grant No.2012A610009, 2012A610043, State Key Laboratory of Robotics and System (HIT)Foundation of China under Grant No.SKLRS-2012-MS-06, China Postdoctoral Science Foundation under Grant No.2013M531022

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