

# Apollo 3D Humanoid Simulation Team Description

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**Abstract.** *Apollo3D* is a team in RoboCup soccer simulation 3D league. The target is to build a nice team with wonderful skills and good cooperation among players. This paper briefly describes efforts of Apollo 3D Soccer Simulation Team during past year. Based on the solution of inverse kinematics of a leg by combining analysis method with numerical method, trajectory planning method is used to implement the humanoid robot walking skill in a 3D simulation environment, and also Omni-directional walk under certain conditions is achieved.

**Keywords:** RoboCup soccer simulation; inverse kinematics; trajectory planning; humanoid robot

## 1 Introduction

Recently, increasing interest has been shown in the exploration of humanoid robot, which is a new interdisciplinary domain combining mechanism with electron, computer science, materials science and sensor. Thus, to some extent, it represents the level of the development in high technology of a country. The study of humanoid robot has become a significant subarea of robotics. A growing number of investigation and exportation has been devoting into this domain and many notable achievements have been made.

Biped walking pattern is one of the most difficult problems in the humanoid robot area, and there exists no ideal algorithm for a generalized walking scenario. In section 2, the humanoid robot model is presented. The method for planning walking patterns is presented in section 3. The simulation results are presented in section 4. It is followed by conclusion and future work in section 5.

## 2 Humanoid Robot Model

The NAO humanoid robot is designed by Aldebaran Robotics in France. The device is 57 cm high and weighs 4.5 kilograms (about the size of a 6 month old baby).



Fig. 1. Real Nao Model

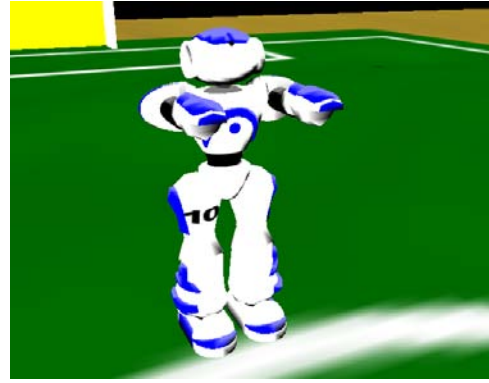


Fig. 2. Nao in Simulation

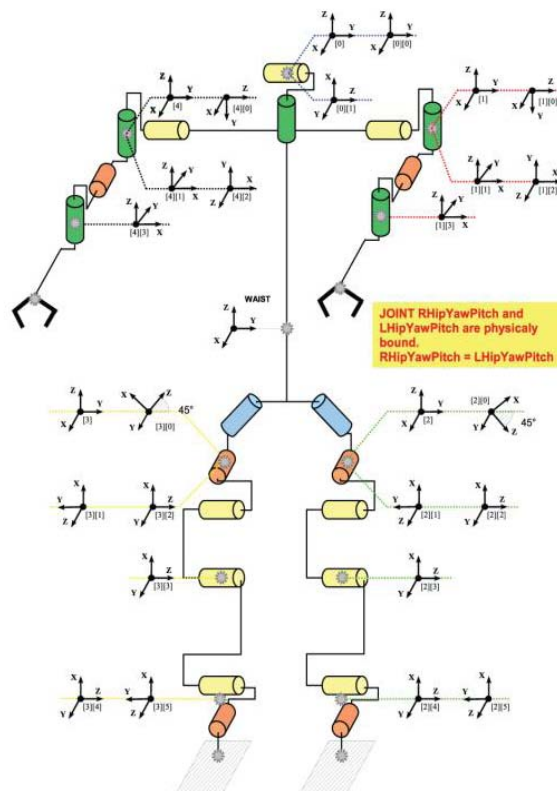


Fig. 3. Nao Joints Map

Name	Parent	Translation	Mass	Geometry	Name	Anchor	Axis	Min	Max
neck	torso	0, 0, 0.09	0.05	Cylinder L: 0.08 R: 0.015	Hj1	0, 0, 0	0,0, 1	-120	120
head	neck	0, 0, 0.065	0.35	Sphere 0.065	HJ2	0, 0,-0.005	1,0, 0	-45	45
shoulder	torso	0.098, 0, 0.075(r) -0.098, 0, 0.075(l)	0.07	Sphere 0.01	AJ1	0, 0, 0	1,0, 0	-120	120
upperarm	shoulder	0.01, 0.02, 0(r) -0.01, 0.02, 0(l)	0.150	Box 0.07, 0.08, 0.06	AJ2	-Translation	0,0, 1	-95(r) -1(l)	1(r) 95(l)
elbow	upperarm	-0.01, 0.07, 0.009(r) 0.01, 0.07, 0.009(l)	0.035	Sphere 0.01	AJ3	0, 0, 0	0,1, 0	-120	120
lowerarm	elbow	0, 0.05, 0	0.2	Box 0.05, 0.11, 0.05	AJ4	-Translation	0,0, 1	-1(r) -90(l)	90(r) 1(l)
hip1	torso	0.055, -0.01,-0.115(r) -0.055, -0.01,-0.115(l)	0.09	Sphere 0.01	LJ1	0, 0, 0	-0.7071,0, 0.7071(r) -0.7071,0,-0.7071(l)	-90	1
hip2	hip1	0, 0, 0	0.125	Sphere 0.01 0.07, 0.07, 0.14	LJ2	0, 1, 0	1,0, 0	-45(r) -25(l)	25(r) 45(l)
thigh	hip2	0, 0.01, -0.04	0.275	Box	LJ3	-Translation	1,0, 0	-25	100
shank	thigh	0,0.005,-0.125	0.225	Box 0.08, 0.07, 0.11	LJ4	0,-0.01, 0.045	1,0, 0	-130	1
ankle	shank	0, -0.01,-0.055	0.125	Sphere 0.01	LJ5	0, 0, 0	1,0, 0	-45	75
foot	ankle	0, 0.03,-0.035	0.2	Box 0.08, 0.16, 0.03	LJ6	0,-0.03, 0.035	0,1, 0	-25(r) -45(l)	45(r) 25(l)
Torso			1.2171	Box 0.1, 0.1, 0.18					

Table. 1. Nao Parameters

### 3 Planning Walking Patterns

#### 3.1 Foot Trajectories

Assuming that the period necessary for one walking step is  $T_c$ , the time of the  $K$ th is from  $kT_c$  to  $(k+1)T_c$ ,  $k=1,2,\dots,K$ .  $K$  is the number of steps. To simplify our analysis, we define the  $K$ th walking step to begin with the heel of the right foot leaving the ground at  $t = kT_c$ , and to end with the heel of the right foot making first contact with the ground at  $t = (k+1)T_c$ . In the following, we discuss only the generation of the right foot trajectory. The left foot trajectory is same as the right foot trajectory except for a  $T_c$  delay.

Letting  $q_b$  and  $q_f$  be the designated angles of the right foot as it leaves and lands on the ground respectively. Assuming that the entire sole surface of the right foot is in contact with the ground at  $t = kT_c$  and  $t = (k+1)T_c + T_d$ , we get the following constraints:

$$\theta_a(t) = \begin{cases} q_{gs}(k) & t = kT_c \\ q_b, & t = kT_c + T_d \\ -q_f, & t = (k+1)T_c \\ -q_{ge}(k), & t = (k+1)T_c + T_d \end{cases} \quad (1)$$

where  $T_d$  is the interval of the double-support phase,  $q_{gs}(k)$  and  $q_{ge}(k)$  are the

angles of the ground surface under the support foot, particularly  $q_{gs}(k) = q_{ge}(k) = 0$  on level ground.

The following constraints must be satisfied.

$$x_a(t) = \begin{cases} kDs, & t = kT_c \\ kDs + l_{an} \sin q_b + l_{af}(1 - \cos q_b), & t = kT_c + T_d \\ kDs + L_{ao}, & t = kT_c + T_m \\ (k+2)Ds - l_{an} \sin q_f - l_{ab}(1 - \cos q_f), & t = (k+1)T_c \\ (k+2)Ds, & t = (k+1)T_c + T_d \end{cases} \quad (2)$$

$$z_a(t) = \begin{cases} h_{gs}(k) + l_{an}, & t = kT_c \\ h_{gs}(k) + l_{af} \sin q_b + l_{an} \cos q_b, & t = kT_c + T_d \\ H_{ao}, & t = kT_c + T_m \\ h_{ge}(k) + l_{ab} \sin q_f + l_{an} \cos q_f, & t = (k+1)T_c \\ h_{ge}(k) + l_{an}, & t = (k+1)T_c + T_d \end{cases} \quad (3)$$

Where  $Ds$  is the length of one step,  $kT_c + T_m$  is the time when the right foot is at its highest point,  $l_{an}$  is the height of the foot,  $l_{af}$  is the length from the ankle joint to the toe,  $l_{ab}$  is the length from the ankle joint to the heel,  $h_{gs}(k)$  and  $h_{ge}(k)$  are the heights of the ground surface which is under the support foot, particularly  $h_{gs}(k) = h_{ge}(k) = 0$  on level ground.

Since the entire sole surface of the right foot is in contact with the ground at  $t = kT_c$  and  $t = (k+1)T_c + T_d$ , the following derivative constraints must be satisfied:

$$\begin{cases} \dot{\theta}_a(kT_c) = 0 \\ \dot{\theta}_a((k+1)T_c + T_d) = 0 \end{cases} \quad (4)$$

$$\begin{cases} \dot{x}_a(kT_c) = 0 \\ \dot{x}_a((k+1)T_c + T_d) = 0 \end{cases} \quad (5)$$

$$\begin{cases} \dot{z}_a(kT_c) = 0 \\ \dot{z}_a((k+1)T_c + T_d) = 0 \end{cases} \quad (6)$$

To generate a smooth trajectory, it is necessary that the first derivative (velocity)

terms  $\dot{X}_{a(t)}$ ,  $\dot{Z}_{a(t)}$  and  $\dot{\theta}_{a(t)}$  be differential, the second derivative (acceleration) terms  $\ddot{X}_{a(t)}$ ,  $\ddot{Z}_{a(t)}$  and  $\ddot{\theta}_{a(t)}$  be continuous at all  $t$ , including all breakpoints  $t = kT_c$ ,  $kT_c + T_d$ ,  $kT_c + T_m$ ,  $(k+1)T_c$ ,  $(k+1)T_c + T_d$ .

To satisfy constraint (1)–(6), and the continuity conditions of the first derivative and the second derivative, the order of the polynomial will be too high and its computation is difficult using polynomial interpolation. Therefore, we obtain the foot trajectory by third-order spline interpolation.

### 3.2 Hip Trajectory

From the viewpoint of stability, it is desirable that hip motion parameter  $\theta_h(t)$  is constant when there is no waist joint; in particular,  $\theta_h(t) = 0.5\pi$  rad on level ground. Hip motion  $Z_h(t)$  hardly affects the position of the ZMP. We can specify  $Z_h(t)$  to be constant, or to vary within a fixed range. Assuming that the hip is at its highest position  $H_{hmax}$  at the middle of the single-support phase, and at its lowest position  $H_{hmin}$  at the middle of the double-support phase during one walking step,  $Z_h(t)$  and  $X_h(t)$  has the following constraints:

$$z_h(t) = \begin{cases} H_{hmin}, & t = kT_c + 0.5T_d \\ H_{hmax}, & t = kT_c + 0.5(T_c - T_d) \\ H_{hmin}, & t = (k+1)T_c + 0.5T_d \end{cases} \quad (7)$$

$$x_h(t) = \begin{cases} kDs + x_{ed}, & t = kT_c \\ (k+1)Ds - x_{sd}, & t = kT_c + T_d \\ (k+1)Ds + x_{ed}, & t = (k+1)T_c \end{cases} \quad (8)$$

## 4 Results

Set the parameters before the simulation:

Ds	0.16 m	Lan	0.035 m
Tc	0.2 s	Laf	0.08 m
Td	0.04 s	Lab	0.08 m
Tm	0.1 s	Lao	0.08 m
Qgs	0 m	Lth	0.1201 m
Qge	0 m	Lsh	0.1 m
Qb	0.2 rad	Hgs	0.015 m

Qf	0.2 rad	Hge	0.015 m
Hmin	0.23 m	Hao	0.03 m
Hmax	0.23 m		

Table.2. Parameters of the biped robot

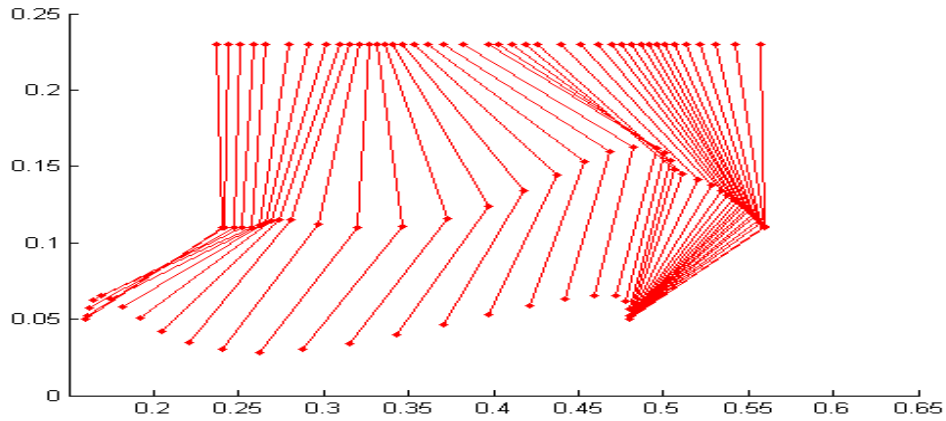


Fig.4. Foot and Hip tratory



Fig.5. Simulation Result

## 5 Conclusion and Future Work

Humanoid robot research is a popular and trends in robot research, many researchers and engineers focus their research on this field. The planning method in this paper based on given parameters, it is not easy to implement this method to general robots. Our further future will focus on this field as well as the improve the stability of walking patterns.

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