Proceedings of the 2017 International Conference on Advanced Mechatronic Systems, Xiamen, China, December 6-9, 2017

Trajectory Planning of NAO Robot Arm based on Target Recognition

Rui Zhai
School of Electric and Information Engineering
Zhongyuan University of Technology
Zhengzhou,China
Email:851247193@qq.com

Shengjun Wen
Zhongyuan-Petersburg Aviation College
Zhongyuan University of Technology
Zhengzhou,China
Email:wensj7062@163.com

Jing Zhu and Guangfu Guo
School of Electric and Information Engineering
Zhongyuan University of Technology
Zhengzhou,China
Email: 940825353@qq.com

***Abstract*—In order to grasp object by NAO robot arm, the position of target object is identified using NaoMarks and an optimal path of arm motion is considered by trajectory planning. Firstly, the kinematics model of the robot arm is established by using D-H modeling method, where D-H kinematic parameters are obtained through the structure analysis of NAO robot arm. Secondly, the target object is located by detecting Naomarks and combining with the Cartesian space and joint space. Trajectory planning is given using inverse kinematics. Finally, experimental results show that the NAO robot arm in motion is smooth, and NAO can grasp objects exactly.**

Keywords—trajectory planning; target recognition; kinematics model;

I. INTRODUCTION

The robot arm trajectory planning is a hot spot in the field of control. With the robot technology, in recent years, intelligent humanoid robot has achieved rapid development, the trajectory planning is not limited to research in the industrial manipulator. Moreover, the trajectory planning of intelligent humanoid robot arm plays an important role in the field of rescue and service. Jan Figat considered Naomarks and QR-code recognition by NAO robot vision to realize system hazard detection[1]. Tianzhu Lu proposed the strategy of using Naomarks to recognize objects indirectly[2]. Qiuyue Wang combines the Cartesian space with the joint space for the trajectory planning of the NAO robot arm, but the posture must be set in advance, and it is feasible only in a certain range[3].

The trajectory planning of the robot arm has two kinds, one is point to point operations (PTP), another is a continuous path operation. The point-to-point path planning just given the starting point and target point position, regardless of how the arm path arrived at the designated location. The continuous path planning need in the middle of the starting position and end position to add some key points, so that the arm movement according to path priority design. The trajectory planning method for robot arm can be performed in Cartesian space and joint space, in the Cartesian space planning system, more intuitive, easy to understand, but the inverse kinematics can produce joint, and easy to produce a singular position. The trajectory planning in joint space, need to give the starting point and ending point position of the robot arm, it can directly control each joint angle, and guarantee the uniqueness of the movement path, but the trajectory of the effectors are not intuitive. Of course, the two trajectory planning methods are required to ensure that the planned trajectory remains smooth and continuous [4-7].

Because trajectory planning is the basis of robot control, its performance is crucial to the robot's efficiency, motion stability and energy consumption[8-12]. Trajectory planning is divided into time optimal trajectory planning, energy optimal trajectory planning, impact optimal trajectory planning, and hybrid optimal trajectory planning[13]. The time optimal trajectory planning of robot refers to the shortest time as the performance index, and under the condition of meeting various constraints, the robot trajectory is optimized, so that the robot moves along the prescribed path for the shortest time[14-15].

The NAO robot which developed by Aldebaran Robotics company in 2012 is used as a platform to study the robot arm control, in this paper. Using NAO robot is H25 V5 version, it's 57cm tall and 5.4kg. As 25 degrees of freedom with NAO, it's agility, and can accomplish various humanoid movements, also has a inertial navigation device, in order to keep steady in mobile mode, a series of sensors can ensure it works correctly, and keep balance NAO better. It can be programmed on a variety of platforms and has an open programming framework, such as Linux, Windows or Mac OS, can be programmed using C++ or Python language.

Based on the above requirements, taking the NAO robot as the experimental platform, the kinematic model of NAO robot arm is established by D-H method, and an optimal trajectory is designed to make the arm reach the position of the target object. For the NAO robot, although its arm structure is complex, in this paper, the arm is simplified to two degrees of freedom mechanical arm.

978-1-5386-2602-3/17/$31.00/ ©2017 IEEE

II. KINEMATIC MODELING

A. Structure Analysis of the NAO Arm

The left arm of NAO has 5 degrees of freedom, a shoulder pitch and roll two degrees of freedom, the elbow has a yaw and roll, the wrist has a yaw. Among them, Pitch represents pitch, rotates around the X axis; Yaw represents yaw, rotates around the Y axis; Roll represents roll, and rotates around the Z axis, the structure of the left arm as shown in Fig. 1.

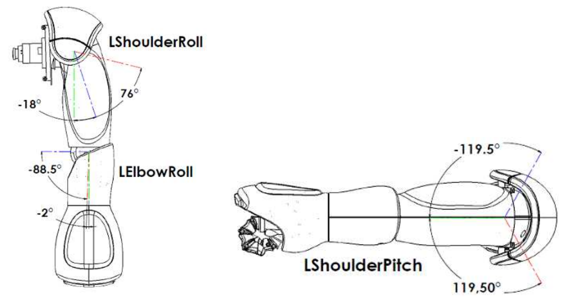

Fig. 1: The structure of the left arm

B. Kinematics Model

For the robot arm, kinematics describes the analytic relationship between the joint position and the end effectors position and direction, including arm position, velocity and acceleration and their derivatives with respect to time, do not need to consider the motion arm force, torque[10]. Study on kinematics of the manipulator including the forward kinematics and inverse kinematics, The forward kinematics of the manipulator describes the known angle of the joint of the manipulator and calculates the position and orientation of the end of the manipulator. For the problem of forward kinematics, its solution is uniquely determined, that is, the end position of the manipulator is uniquely determined after each joint variable is given.

The D-H method is a classical kinematic model describing the kinematic parameters of a robot arm, the transformation matrix is described by four parameters, α, a, θ, d. The transformation matrix from the coordinate system i to the coordinate system i-1 is a function which is only related to the joint variable q_i, and the forward kinematics equation is constructed by the homogeneous transformation matrix M.

$$\mathrm{M}=A_i^{i-1}(q_i)=\begin{bmatrix} \cos\theta_i & -\sin\theta_i\cos\alpha_i & \sin\theta_i\sin\alpha_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i\cos\alpha_i & -\cos\theta_i\sin\alpha_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

For the NAO robot arm motion, the total homogeneous transformation matrix T:

$$T_n^0(q)=A_1^0(q_1)A_2^1(q_2)\cdots A_n^{n-1}(q_n) \quad (2)$$

Rotation of LelbowYaw and LWristYaw only affect the pose of end effector, and do not affect the position in three-dimensional space manipulator, so ignoring the two rotary joint, LShoulderRoll is not considered on the basis of this study. Then we can get the kinematic parameters of the NAO robot D-H left arm as shown in TABLE I,.

TABLE I. D-H KINEMATICS PARAMETERS

Joint name	α_i	α_i	θ_i	d_i
LShoulderPitch	-π/2	α_1	θ_1	0
LElbowRoll	0	α_2	θ_2	0

According to the parameters above D-H kinematics model for NAO robot arm kinematics, we obtain the relation between the position of NAO at the end of the arm and each joint angle in the joint space. Forward kinematics calculation equation via following formula

$$T_0^2=A_1^0A_2^1=\begin{bmatrix} \mathrm{c}(\theta_1+\theta_2) & 0 & \mathrm{s}(\theta_1+\theta_2) & a_2\,\mathrm{c}(\theta_1+\theta_2)+a_1c\theta_1 \\ \mathrm{s}(\theta_1+\theta_2) & 0 & \mathrm{c}(\theta_1+\theta_2) & a_2\mathrm{s}(\theta_1+\theta_2)+a_1\mathrm{s}\theta_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

Where c=cos, s=sin, the position of a end effector of the manipulator is shown as following:

$$\begin{cases} x=a_2\,\mathrm{c}(\theta_1+\theta_2)+a_1c\theta_1 \\ y=a_2\mathrm{s}(\theta_1+\theta_2)+a_1\mathrm{s}\theta_1 \end{cases} \quad (4)$$

C. Inverse Kinematics

Manipulator inverse kinematics is known at the end of manipulator posture, to calculate arm joint angle. In order to handle the processing of mechanical arm of the complex geometric parameters, a connecting rod coordinate system is fixed on each link of the manipulator at first, then the relationship between these coordinates are described. The inverse kinematics solutions are often with multiple solutions, or may not exist. The inverse kinematics solution of the complexity of structure and mechanical arm often have a great relationship. Manipulator inverse solution of kinematics generally attributed to the solution of nonlinear equations, which is directly related to the mechanical arm movement analysis, off-line programming, trajectory planning and real-time control work. Because the velocity and acceleration analysis should be carried out on the basis of the kinematic analysis, so the inverse kinematics problem is the basis of manipulator motion planning and trajectory planning, only through the inverse solution to convert the spatial position for joint variable kinematics, to achieve control of the end effectors.

The inverse solution method includes algebraic method, geometric method and so on. The problem is solved by geometric method in this paper. The position of the end effector is p (x, y), and referring to the range of the joint angle of the NAO robot, the simplified inverse kinematics equation:

$$\begin{cases} \theta_1 = \arctan\dfrac{y}{x} \pm \arccos\dfrac{x^2+y^2+a_1^2-a_2^2}{2a_1\sqrt{x^2+y^2}} \\ \theta_2 = \arccos\left(\dfrac{x^2+y^2-a_1^2-a_2^2}{2a_1a_2}\right) \end{cases} \quad (5)$$

Where θ2>0,

$$\theta_1 = \arctan\frac{y}{x} - \arccos\frac{x^2+y^2+a_1^2-a_2^2}{2a_1\sqrt{x^2+y^2}} \quad (6)$$

θ2<0,

$$\theta_1 = \arctan\frac{y}{x} + \arccos\frac{x^2+y^2+a_1^2-a_2^2}{2a_1\sqrt{x^2+y^2}} \quad (7)$$

III. TARGET RECOGNITION

NAO robots belong to robots that observe and act again, the robot must stop first when it obtain the target location of the image, the highest resolution of NAO robot camera is 1280 x 960, so it is very important to choose the appropriate size of Naomarks.

A. Naomarks

Naomarks consist of black circles with white triangle fans centered at the circle's center. The specific location of the different triangle fans is used to distinguish one Naomark from the others, as shown in Fig. 2. Aldebaran has realized the Naomarks identification and decoding algorithm, and can be used in NAOqi SDK, which belongs to the ALLandMarkDetection visual module.

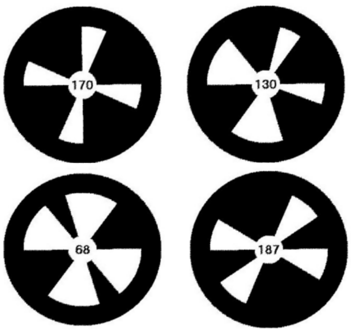

Fig. 2: Naomarks

The distance from the Naomarks to the camera is calculated according to the angular diameter of the measurement. Distance D (from camera to landmark) is shown as following:

$$D = \frac{d}{2\tan(\delta/2)} \quad (8)$$

Where *d* is the actual value of the angle diameter, and the δ is how large the angle is from the given angle of view, as shown in Fig. 3.

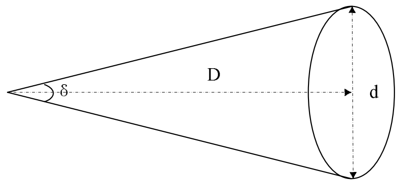

Fig. 3: Camera to Naomarks

B. NAO's Frames

When creating a command for a robot, much attention needs to be placed on the space used to define the command, as a mistake in space could lead to disastrous results. For NAO robots, there are three spaces, FRAME_TORSO, FRAME_ROBOT, FRAME_WORLD, as shown in Fig. 4.

- FRAME_TORSO: this is attached to the robot's torso reference, so moves with the robot as he walks and changes orientation as he leans. This space is useful when you have very local tasks, that make sense in the orientation of the torso frame.
- FRAME_ROBOT: this is average of the two feet positions projected around a vertical z axis. This space is useful, because the x axis is always forwards, so provides a natural ego-centric reference.
- FRAME_WORLD: this is a fixed origin that is never altered. It is left behind when the robot walks, and will be different in z rotation after the robot has turned. This space is useful for calculations which require an external, absolute frame of reference.

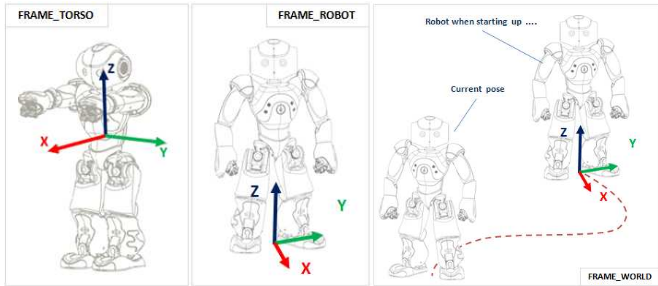

Fig. 4: NAO's frames

C. Detect Naomarks

Using Naomarks detection function, when we call ALLandMarkDetection in the software Choregraphe video box, we can see the Naomarks as shown in Fig. 5.

Fig. 5: Detection screen

We can get the coordinates of Naomarks in FRAME_ROBOT, in meters.

$$\begin{cases} x = 0.17 \\ y = 0.06 \\ z = 0.39 \end{cases}$$

IV. EXPERIMENTAL RESULTS

For the trajectory planning of NAO robot arm, we should take into account the extreme value of the joint trajectory must not exceed the physical and geometric limits of each joint variable, in addition, time should be taken into account. The initial and termination phases of the trajectory are determined by the speed of the hand approaching and leaving the support surface, also determined by the motor characteristics of the joint, the time of the middle or middle segment of the trajectory is determined by the maximum speed and acceleration of each joint.

In the path planning experiment, we take two points between the starting point and the end point, the time interval between adjacent points is 1s. starting point q_i=(0.05,0.1,0.23), middle point q_1=(0.066,0.105,0.236), q_2=(0.081,0.096,0.274), q_3=(0.104,0.086,0.291), q_4=(0.136,0.074,0.341), q_4=(0.158,0.066,0.366), end point q_e=(0.17,0.06,0.39). By using the above formula(5), the joint angles of four positions are obtained by inverse kinematics solution, as shown in TABLE II. The NAO robot arm movement capture picture as shown in Fig 6. Collect trajectory points during the motion as shown in Fig 7.

TABLE II. JOINT ANGLES OF LOCUS POINTS

Locus points	q_i	q_1	q_2	q_3	q_4	q_5	q_e
θ_1	1.47	1.41	1.44	1.32	1.11	0.86	0.6
θ_2	-0.41	-0.62	-1.02	-1.21	-1.24	-1.11	-1.1

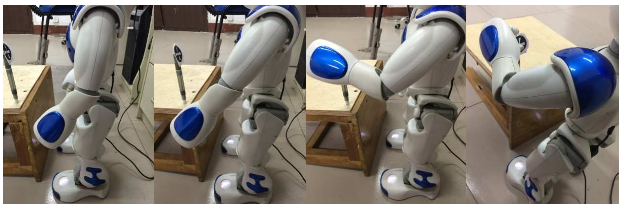

Fig. 6: Nao's Arm Movement Capture Picture

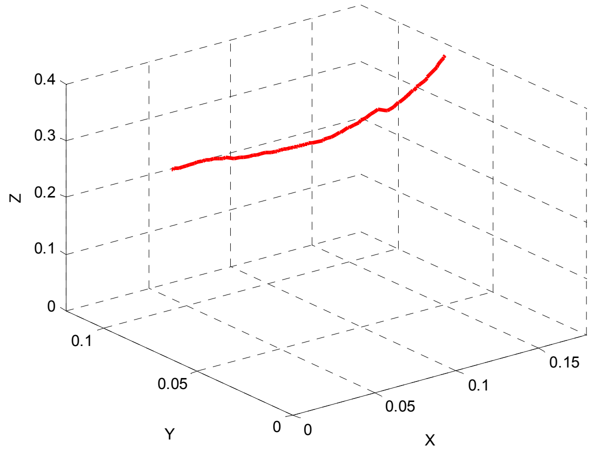

Fig. 7: Motion Trajectory

V. CONCLUSION

In this paper, the trajectory planning of NAO robot arm is researched, the kinematics model is established by considering the kinematics algorithm. NaoMarks is used to locate the target object and the joint angle of the pose is obtained by inverse kinematics solution, where the Cartesian space is combined with the joint space. Experimental results show that the robot arm can achieve the target position smoothly and quickly in the trajectory planning.

ACKNOWLEDGEMENTS

This work is supported by Key Program of Education Department Foundation of Henan Province in China (17A120015) and Science and Technology Innovation Group of Education Department of Henan Province in China (14IRTSTHN024).

REFERENCES

[1] Figat J, Kasprzak W, "NAO-mark vs QR-code Recognition by NAO Robot Vision," Progress in Automation, Robotics and Measuring Techniques, pp. 55-64, 2015.

[2] Tianzhu Lu, Li Luo, Kailiang Hu, "Research on Garbage Collection Process and Algorithm Based on Nao Robot, " Vol. 11, No. 11, pp.154-155, 2015.

[3] Wang Q, Fang M, Zhang H, "Grasp Track Planning with the NAO Robot Under Mixed Constraints of Multi-space," Journal of Changchun University of Science & Technology,2014

[4] Xiujuan Zheng, "Research on Motion Control and Trajectory Planning Algorithm For mobile Manipulator," Wuhan University of Science and Technology, 2012.

[5] Qian D H, Wen-Luo M A, Wang J W, et al., "Time optimal trajectory planning of robots under multi-constraints," Manufacturing Automation, 2011.

[6] Xiuping Sun, "Research on Trajectory Planning of Robot Manipulator," Journal of Inner Mongolia Normal University(Natural Science Edition), Vol. 38, No. 02, pp.174-177, 2009.

[7] Yong Guan, "Researeh And Smiulation For Industrial Robot Kinematies System Beasd On Matlab, " Hefei University of Technology, 2004.

[8] Wenjun Zhang, Wei Wang, “Time Optimal Trajectory Planning For Industrial Robots, ” South Agricultural Machinery, Vol. 47, No. 6, pp.80-80, 2016.

[9] Chao Li, Jixian Dong, “Analysis of Joint Space Trajectory Interpolation Method in Robot Trajectory Planning, ” Journal of Northwest University of Light Industry, No. 05, pp.42-44, 2002.

[10] Siciliano B, Sciavicco L, Villani L, et al., “Robotics: Modelling, Planning and Control, ” Springer Publishing Company, Incorporated, 2010.

[11] Zhiyuan Ma, “The Study on Robot Modeling and Control Based on Nao Robot, ” Yanshan University. 2015.

[12] Shuju Fan, “Kinematic Algorithm Design of Manipulator, ” Zhejiang University. 2008.

[13] Lu Shen, “Study on Trajectory Planning and Simulate of Robot with Six Degrees of Freedom, ” Dalian University of Technology. 2013.

[14] Qiang Ma, “Trajectory Planning of 6 DOF Manipulator, ” Harbin Engineering University. 2007.

[15] Chuan Zhao, Pengchao Zhang, Xiaolei Pan, et al., “The Robot Trajectory Interpolation Method of Research and Analysis, ” Manufacturing Technology & Machine Tool, No. 6, pp.65-69, 2016.