

Kinematic analysis and simulation for a kind of Planar Articulated robot based on ADAMS

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Abstract: According to the structure and motion characteristics of Planar Articulated robot to simply the model. On the basis of the robot kinematics analysis, use D-H matrix for modeling, mathematical model of the pose is obtained. Based on the dynamic simulation software ADAMS to establish the Virtual prototype of Planar Articulated robot. Then the hand-end displacement, velocity and acceleration curves are obtained. Analyze the simulation results to verify the feasibility of the structural design, and provide a basis for optimum design.

1 Foreword

Planar Articulated robot is a kind of industrial robots. It has been widely used not only due to small and drive principle is simple, but also in-plane motion with greater flexibility. It is the most typical mechanical and electrical integration of digital devices^[1]. Robot Kinematics describe the relationships between the joint and the pose of the robotic arm^[2]. The pose is the most important guarantee which can determine the robot work in accordance with the requirements precisely. Using three-dimensional software to build the model of the robot, then import it to the simulation software to create a virtual prototype model for the simulation analysis, simultaneously compare with the kinematic equations to verify the reliability of the design. It is very necessary and important carry out the dynamic and analysis before the manufacturing of the prototype.

ADAMS is quite powerful in the kinematics and dynamics simulation analysis. but the capability of modeling is relatively weak, unable to complete modeling the complex part.^[3] Firstly, modeling in Solidworks and simplify it, then export Parasolid format of the model, build a virtual prototype model.

2 mechanical arm Simulation modeling

Using Solidworks to build the three-dimensional model of the robot's arm, as shown in Figure 1, The structure of robot can be divided into base, waist, shoulders, arm, forearm, wrist and so on. Rotary joints are called waist joint, shoulder joint, elbow joint and wrist joint. All joint are driven by servo motor, while using harmonic reducer to decelerate.

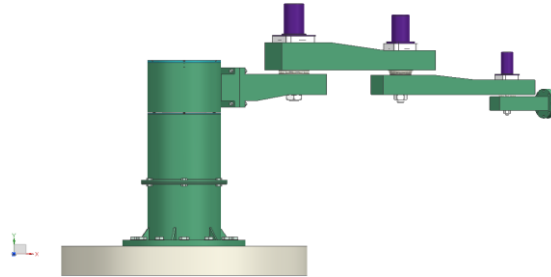


Figure 1 three-dimensional model of the plane articulated robot

Import the three-dimensional model which was simplified into ADAMS, and create a virtual prototype model, as shown in Figure 2.

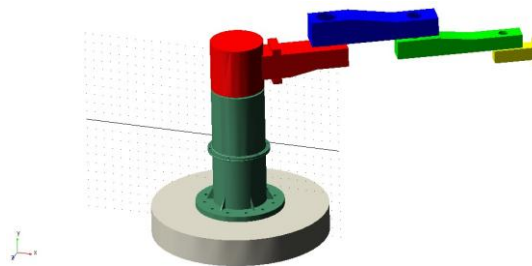


Figure 2 simulation model of Planar Articulated robot

Then use Boolean operators to merge some of the components inside, in order to add constraints and driving easier during the simulation, they were imported to the front part and solid rename. Add rotation constraints to each rotary joint and add a fixed constraint between the base and the ground, then add drivers to each rotary joint, and finally applied load to carry out the simulation and analysis.

3 The kinematic analysis of arm

The Kinematics of arm is to study the relationship between the joint angle and the end pose. The structure of Robot can be simplified into a number of connecting rod with four parameters that length, twist angle, distance and angle between two links, Figure 3 is the coordinate system of the planar articulated robot's connecting rods, Table 1 shows the parameter list of the connecting rods.

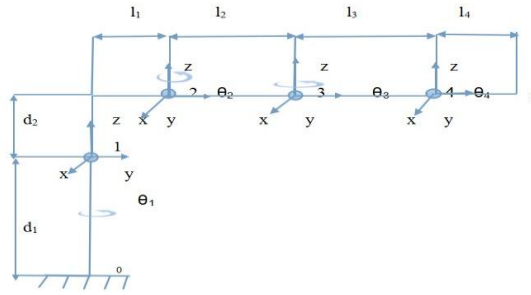


Figure 3 link coordinate system

Table 1 link parameter table

Link number	Connecting rod twist angle α_{n-1}	Link length a_{n-1}	Connecting rod distance d_n	Joint angle θ
1	0	l_1	d_2	θ_1
2	0	l_2	0	θ_2
3	0	l_3	0	θ_3
4	0	l_4	0	θ_4

$l_1=300\text{mm}$, $l_2=500\text{mm}$, $l_3=500$, $l_4=200\text{mm}$, $d_1=738\text{mm}$, $d_2=232\text{mm}$ 。

Homogeneous transformation matrix formula:

$${}^{n-1}T_n = \begin{bmatrix} C\theta_n & -S\theta_n & 0 & a_{n-1} \\ C\alpha_{n-1}S\theta_n & C\alpha_{n-1}C\theta_n & -S\alpha_{n-1} & -S\alpha_{n-1}d_n \\ S\alpha_{n-1}S\theta_n & S\alpha_{n-1}C\theta_n & C\alpha_{n-1} & C\alpha_{n-1}d_n \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Coordinate system 1 is the matrix of the relative basic point coordinate system.

$${}^sT_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad A_1 = \begin{bmatrix} C_1 & -S_1 & 0 & 0 \\ S_1 & C_1 & 0 & l_1 \\ 0 & 0 & 1 & d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad A_2 = \begin{bmatrix} C_2 & -S_2 & 0 & 0 \\ S_2 & C_2 & 0 & l_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_3 = \begin{bmatrix} C_3 & -S_3 & 0 & 0 \\ S_3 & C_3 & 0 & l_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad A_4 = \begin{bmatrix} C_4 & -S_4 & 0 & 0 \\ -S_4 & C_4 & 0 & l_4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$C_n = \cos \theta_n, S_n = \sin \theta_n$$

It is possible to get the pose function,

$${}^0T_4 = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$n_x = C_1 C_2 C_3 C_4 - C_1 C_2 S_3 S_4 - C_1 S_2 S_3 C_4 - C_1 S_2 C_3 S_4 - S_1 S_2 C_3 C_4 + S_1 S_2 S_3 S_4 - S_1 C_2 S_3 C_4 - S_1 C_2 C_3 S_4$$

$$n_y = S_1 C_2 C_3 C_4 - S_1 C_2 S_3 S_4 - S_1 S_2 S_3 C_4 - S_1 S_2 C_3 S_4 + C_1 S_2 C_3 C_4 - C_1 S_2 S_3 S_4 + C_1 C_2 S_3 C_4 + C_1 C_2 C_3 S_4$$

$$n_z = 0$$

$$o_x = -C_1 C_2 C_3 S_4 - C_1 C_2 S_3 C_4 + C_1 S_2 S_3 S_4 - C_1 S_2 C_3 C_4 + S_1 S_2 C_3 S_4 + S_1 S_2 S_3 C_4 + S_1 C_2 S_3 S_4 - S_1 C_2 C_3 C_4$$

$$o_y = -S_1 C_2 C_3 S_4 - S_1 C_2 S_3 C_4 + S_1 S_2 S_3 S_4 - S_1 S_2 C_3 C_4 - C_1 S_2 C_3 S_4 - C_1 S_2 S_3 C_4 - C_1 C_2 S_3 S_4 + C_1 C_2 C_3 C_4$$

$$o_z = 0$$

$$a_x = 0$$

$$a_y = 0$$

$$a_z = 1$$

$$p_x = -C_1 C_2 S_3 l_4 - C_1 S_2 C_3 l_4 - C_1 S_2 l_3 + S_1 S_2 S_3 l_4 - S_1 C_2 C_3 l_4 - S_1 C_2 l_3 - S_1 l_2$$

$$p_y = -S_1 C_2 S_3 l_4 - S_1 S_2 C_3 l_4 - C_1 S_2 l_3 - C_1 S_2 S_3 l_4 + C_1 C_2 C_3 l_4 + C_1 C_2 l_3 + C_1 l_2 + l_1$$

$$p_z = d_1 + d_2$$

Arm transformation matrix 0T_4 describes the relative position and orientation of the end of the arm base coordinate system, in order to verify the correctness of the transformation matrix, can be verified zero, that is, when $\theta_1 = \theta_2 = \theta_3 = \theta_4 = 0$, $\cos \theta_n = 1$, $\sin \theta_n = 0$,

$${}^0T_4 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & l_1 + l_2 + l_3 + l_4 \\ 0 & 0 & 1 & d_1 + d_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

the figure is consistent with the case, indicating the motion equations describing the pose correctly.

4 The simulation of robot's arm

Modeling ,simulation and analysis can be carried out by ADAMS,which is with the function of strong dynamics and kinematics analysis. There are a lot of modules in ADAMS software ,usually mechanical system only need the basic module :view and post processor to complete^[4].

The main steps were simulated robot arm

(1)The parasolid file which was exported from the simplified three-dimensional model is imported into ADAMS software, then Boolean operation and naming for the relevant member are carried out in order to make it easier to add constrain and drive.

(2)Setting Up the working Environment. The direction of gravity is -y , and the units of it is MKS.

(3)Add properties to material.Select the steel as the Material, and then add the centroid position according to the input when the three-dimensional software which calculated intact structure and quality of the various components to the ADAMS.

(4) Add constraints for each part. First, add a fixed base and earth Fixed Joint, in the joints, shoulder, elbow and wrist add to Revolute Joint. In order to facilitate the simulation will be actuator with the wrist in one, the center of the actuator MARKER point conduct Measure output measurement points^[5].

(5) Add Drive. Add a drive (motion) in the Revolute Joint position.

(6) Simulation, setting time 6s, 1000 steps, measure the end of the center MARKER displacement, velocity and acceleration curve in X, Y, Z direction, shown in chart 4.

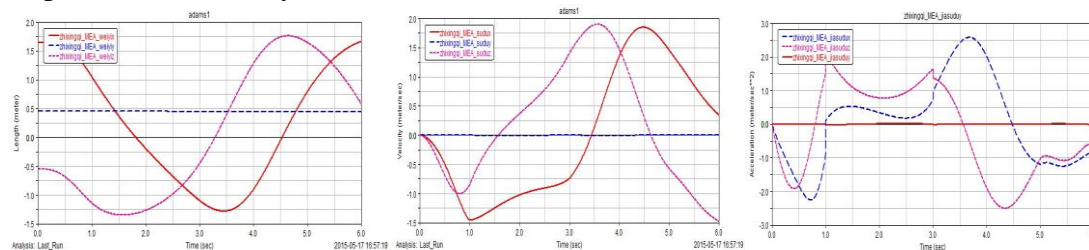


Figure 4 The end of the X, Y, Z direction displacement, speed, acceleration simulation curve

5 Analysis of simulation results

(1) From the above analysis of three figures can be seen in the Y-axis direction of displacement, velocity and acceleration are close to zero, exactly corresponding to the relative movement does not occur with the Y direction, there will be slight deviation, but are within the range of accuracy, to meet the design requirements.

(2) Simulation analysis showed that from the end of displacement, maximum displacement in X direction is 1.68m, Z direction of 1.72m, and the distance to the waist in the design end of the 1.727m, illustrate the ultimate displacement less than the maximum working space to meet the working conditions.

(3) Analysis known from displacement and acceleration simulation graph, the curves gently without the mutation, indicating that the plane of the articulated robot at work all smooth articulation, no rigid impact, can guarantee the quality of the work completed.

6 Conclusion

In this paper, establishment of a plane articulated robot kinematics equations is based on the D-H matrix method, obtained at the end of a mechanical arm pose function and verify its correctness with zero validation. Kinematic analysis is the basis of the robot trajectory planning and optimization design, using simulation software ADAMS to conduct kinematics simulation analysis, intuitive understand the movement, of the basis for future real-time control, laying the foundation for subsequent optimization.

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