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Research on Kinematics Simulation of PUMA560 Robot

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Abstract

This paper is on the basis of the kinematics model and the structure parameters of PUMA560 industrial robot, under the environment of ADAMS, establishing the virtual physical model of PUMA560 industrial robot. And when the robot fixture has been attached a load which the quality is m, then moving from one point to another point, using interpolation method and linear motion of the fixture to simulate trajectory and position under the environment of ADAMS respectively.

Keywords*: PUMA560, ADAM, modeling, simulation*

1. Introduction

The robot is an important part of the industry, they can accurately perform a variety of tasks and operations, and they don't need the safety measures and comfortable working conditions when people working. For the development and design of the robot, engineering designers can build virtual prototype model on the PC, analyzing a variety of performances of virtual prototype model, improving the design continuously according to the requirement of the task, we use the virtual prototype model to test, instead of using the traditional physical prototype [1-2]. We could reduce the design process and the development process of mechanical products through the application of virtual prototype technology, reducing the product development time, reducing development costs, improving the quality of products greatly, to get the innovative and optimized product design[3-4].

In this paper, the application of ADAMS software is designed for virtual prototype of mechanical product development tools. ADAMS software provides a very large modeling and simulation environment for users, designers can make many kinds of mechanical system modeling simulation and analysis of the experiment, it is very powerful [5]. The main advantage of this software is that it can well reflect the characteristics of the actual physical model when using it to establish the virtual model, the simulation results are consistent with the results of actual physical model. Taking the PUMA560 robot as the research object in this paper, analyzing Kinematic of the mechanical system in ADAMS software to optimize the overall system [6-7].

2. Structure and Parameters of PUMA560 Robot

PUMA560 belongs to the rotary multi joint robot, its six connecting rods are composed of six rotating joints connected together, the first three joints determine the position of the reference point of wrist, the other three joints determine the orientation of the wrist, like most of the industrial robot, the other three joint axes intersect at one point. This point can be used as the reference point of the wrist, it can also be used as origin of connecting rod coordinate system {4}, {5} and {6}. The axis of joint 1 is vertical direction, the axis of joint 2 and 3 are horizontal direction, and they are parallel, the distance is a_2, the axis of joint 1 and 2 are

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vertical intersection, the axis of joint 3 and 4 are vertical staggered, the distance is a_3, the end actuator is fixed on the connecting rod 6, the foundation bed is fixed, each joint has a single degree of freedom, so PUMA560 is a robot with 6 degrees of freedom manipulator. It is shown in Figure 1.

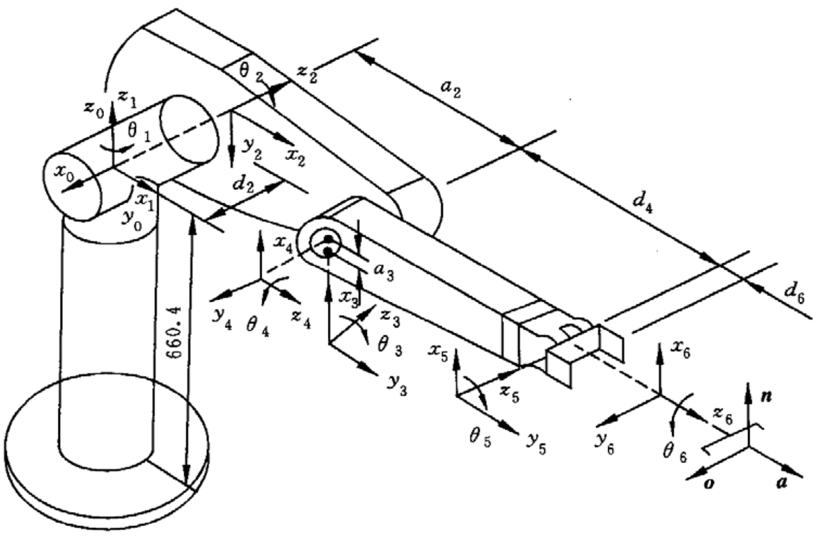


Figure 1. Curves of Sampling Current Changing

The foundation bed of the coordinate system is denoted as {0}, the connecting rod of I coordinate system is denoted as {i}. a_{i-1} is the distance between z_{i-1} and z_i along x_{i-1} axis, α_{i-1} is the angle moved from z_{i-1} to z_i along x_{i-1} axis, d_i is the distance between x_{i-1} and x_i along z_i axis, θ_i is the angle moved from x_{i-1} to x_i along z_i axis. We can obtain from the structure, the robot is connected by a base and each joint arm. Each joint installs drive motor, driving each bar of the robot to move according to the trajectory under the function of control system, to realize the functions of assembly and transport of the end operator.

Table 1. Connecting Rod Parameters Of PUMA560 Robot

Connecting rod 1	Variable θ_i	α_{i-1}	a_{i-1}	d_i	Variable range
1	$\theta_2(90°)$	0°	0	0	−160° ~ 160°
2	$\theta_2(0°)$	−90°	0	d_2	−225° ~ 45°
3	$\theta_3(-90°)$	0°	a_2	0	−45° ~ 225°
4	$\theta_4(0°)$	−90°	a_3	d_4	−110° ~ 170°
5	$\theta_5(0°)$	90°	0	0	−100° ~ 100°
6	$\theta_6(0°)$	−90°	0	0	−266° ~ 266°

Connecting rod parameters are shown in table 1, $a_2 = 431.8mm$, $a_3 = 20.32mm$, $d_2 = 149.09mm$, $d_4 = 433.07mm$. In all parameters, θ is variable, α , a , d are constant.

3. PUMA560 Robot Kinematics

In order to solve each joint angle, we need to introduce homogeneous transformation between adjacent coordinates. For the convenience of writing, ordering $S = \sin$, $C = \cos$, $T_i = {}^{i-1}T_i$. The homogeneous transformation between two adjacent coordinates is:

$$ {}^{i-1}T_i = \begin{bmatrix} C\theta_i & -C\alpha_i S\theta_i & S\alpha_i S\theta_i & \alpha_i C\theta_i \\ S\theta_i & C\alpha_i C\theta_i & -S\alpha_i C\theta_i & \alpha_i S\theta_i \\ 0 & S\alpha_i & C\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1} $$

Multiply each matrix, we can get the general transformation matrix is:

$$ {}^0T_6 = {}^0T_1(\theta_1)\,{}^1T_2(\theta_2)\,{}^2T_3(\theta_3)\,{}^3T_4(\theta_4)\,{}^4T_5(\theta_5)\,{}^5T_6(\theta_6) = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2} $$

The total transformation matrix is the function of each joint variable $\theta_1, \theta_2, \cdots, \theta_6$.

$$ n_x = c_1[c_{23}(c_4c_5c_6 - s_4s_6) - s_{23}s_5c_6] + s_1(s_4c_5c_6 + c_4s_6) \tag{3} $$

$$ n_y = s_1[c_{23}(c_4c_5c_6 - s_4s_6) - s_{23}s_5c_6] - c_1(s_4c_5c_6 + c_4s_6) \tag{4} $$

$$ n_z = -s_{23}(c_4c_5c_6 - s_4s_6) - c_{23}s_5c_6 \tag{5} $$

$$ o_x = c_1[c_{23}(-c_4c_5s_6 - s_4s_6) + s_{23}s_5s_6] + s_1(c_4c_6 - s_4c_5s_6) \tag{6} $$

$$ o_y = s_1[c_{23}(-c_4c_5s_6 - s_4s_6) + s_{23}s_5s_6] - c_1(c_4c_6 - s_4c_5s_6) \tag{7} $$

$$ o_z = -s_{23}(-c_4c_5c_6 - s_4c_6) + c_{23}s_5s_6 \tag{8} $$

$$ a_x = -c_1(c_{23}c_4s_5 + s_{23}c_5) - c_1s_4s_5 \tag{9} $$

$$ a_y = -s_1(c_{23}c_4s_5 + s_{23}c_5) + c_1s_4s_5 \tag{10} $$

$$ a_z = s_{23}c_4s_5 - c_{23}c_5 \tag{11} $$

$$ p_x = c_1[a_2c_2 + a_3c_{23} - d_4s_{23}] - d_2s_1 \tag{12} $$

$$ p_y = s_1[a_2c_2 + a_3c_{23} - d_4s_{23}] + d_2s_1 \tag{13} $$

$$ p_z = -a_3s_{23} - a_2s_2 - d_4c_{23} \tag{14} $$

In the above formulas, $s_i = \sin\theta_i$, $c_i = \cos\theta_i$.

$$c_{23} = \cos(\theta_1 + \theta_2) = c_2 c_3 - s_2 s_3 \quad (15)$$

$$s_{23} = \sin(\theta_2 + \theta_3) = c_2 s_3 + s_2 c_3 \quad (16)$$

To check the accuracy of the result ${}^0T_6$, calculating the value of ${}^0T_6$ when $\theta_1 = 90°$, $\theta_2 = 0°$, $\theta_3 = -90°$, $\theta_4 = \theta_5 = \theta_6 = 0°$, the calculation result is:

$${}^0T_6 = \begin{bmatrix} 0 & 1 & 0 & -d_2 \\ 0 & 0 & 1 & a_2 + d_4 \\ 1 & 0 & 0 & a_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (17)$$

It is consistent with the situation that shown in Figure 1.

4. Creating PUMA560 Robot Kinematics Model

Modeling includes building geometric model, adding constraint mechanism and establishing driving function, and so on. Using ADAMS to modeling, we need to analyze and simplify according to the actual model.

Using geometric modeling tool library to establishing the three-dimensional model of PUMA560 robot under ADAMS/View environment, taking foundation, joint 4, joint 6 to create cube, taking joint 1 and joint 5 to create cylinder, taking joint 2 and joint 3 as connecting rod, taking clutch to create sphere and named as Gruz. To import the corresponding dimension values and coordinate points to the created geometric model according to the PUMA560 robot appearance parameters. And last, generating PUMA560 robot model as shown in Figure 2. It can be seen that we could create more complex model through Boolean operation function of ADANS.

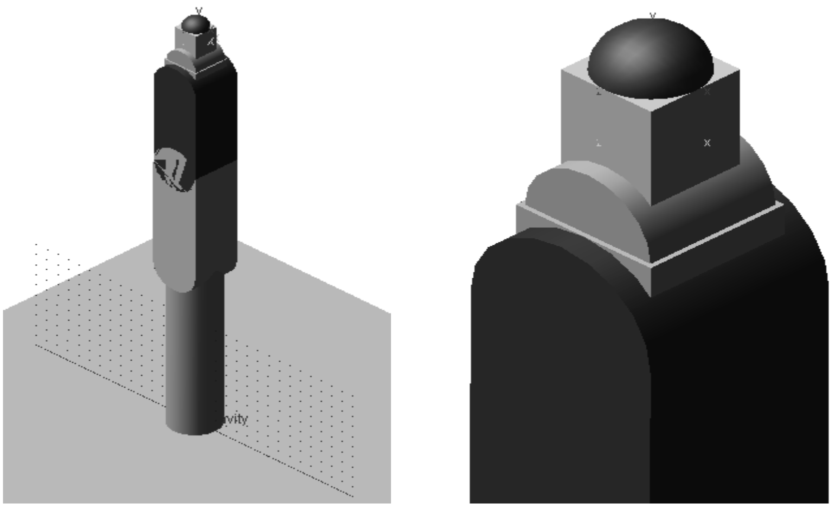


Figure 2. Final Generated PUMA560 Robot Model

Assuming that the actual movement of the robot is gradually and step by step in this paper, ADAMS provides a step driver function, the expression is: STEP (x, BeginAt, Initial Function Value, EndAt, Final Function Value). And in this expression, x is independent variable, the value of the variable is the initial value Initial Function Value when x is less-than Begin At; dependent variable value is termination value Initial Function Value when x is more than End At; dependent variable value is smooth over according to certain rules when z is between initial value and termination value.

According to the data of PUMA560, quoting formula:

$$STEP(time,0,0,1,\omega_H)*pi/180+STEP(time,1,0,3,\omega_H-\omega_K)*pi/180$$

Importing each joint driving function in "Function Builder" dialog box, each joint driving function form of robot are shown in Table 2.

Table 2. Each Joint Driving Function List

Joint name	Function
Joint 1	STEP(time , 0 , 0 , 1 , -15)*pi/180+STEP(time , 1 , 0, 3 , -95)*pi/180
Joint 2	STEP(time , 0 , 0 , 1 , 75)*pi/180+STEP(time , 1 , 0, 3 , 65)*pi/180
Joint 3	STEP(time , 0 , 0 , 1 , 30)*pi/180+STEP(time , 1 , 0, 3 ,-130)*pi/180
Joint 4	STEP(time , 0 , 0 , 1 , 25)*pi/180+STEP(time , 1 , 0, 3 , 115)*pi/180
Joint 5	STEP(time , 0 , 0 , 1 , -80)*pi/180+STEP(time , 1 , 0, 3 , -95)*pi/180
Joint 6	STEP(time , 0 , 0 , 1 , 15)*pi/180+STEP(time , 1 , 0, 3 , 75)*pi/180

Chronologically, taking the horizontal axis as the time axis to establish joint angle curve of joint 1 through Step function, the curve is shown in Figure 3.

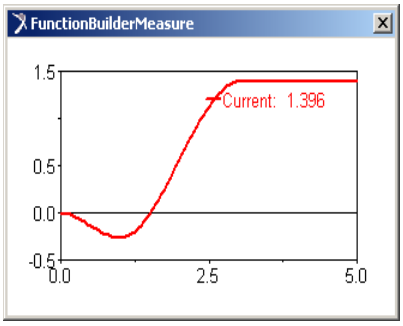
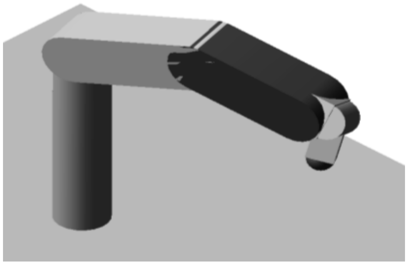


Figure 3. Changing Curve of Joint Angle

5. Kinematic Simulation of PUMA560 Robot

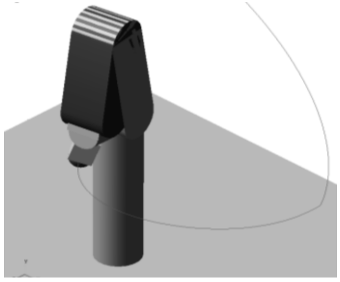
We adopt interactive simulation control according to the requirements of PUMA560 robot.

Clicking the simulation button in the main toolbar, pop-up interactive simulation control dialog: is run simulation calculation, is termination simulation calculation, is return to the starting position, is play a recent animation of simulation, is verification model. Selecting the required article Kinematic, selecting Steps, to set the number of simulation steps to 100, selecting Step Size, to set the simulation time to 3s, so the initial state of robot simulation is shown in Figure 4, termination state is shown in Figure 5.



Robot Simulation

Figure 4. The Initial State of PUMA56



Robot Simulation

Figure 5. The terminal state of PUMA560

5.1. Interpolation Trajectory

Using PostProcess module of ADAMS, we could draw curve as shown in Figure 6, setting up Gruz.

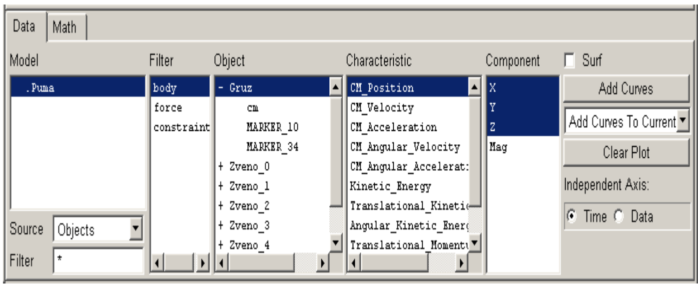


Figure 6. Curve Data Source Selection Region

At the post processing interface, selecting the Plotting item in the upper left corner of the processing type drop-down menu select box, it is the interface to process data curves.

Editing dialog box as shown in Figure 7.

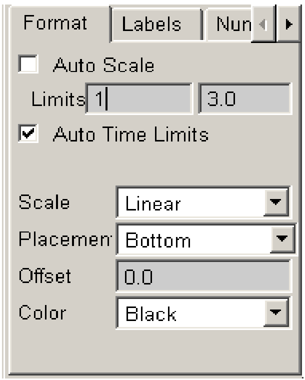


Figure 7. Curve Attribute Edit Area

We could obtain the diagram as shown in Figure 8.

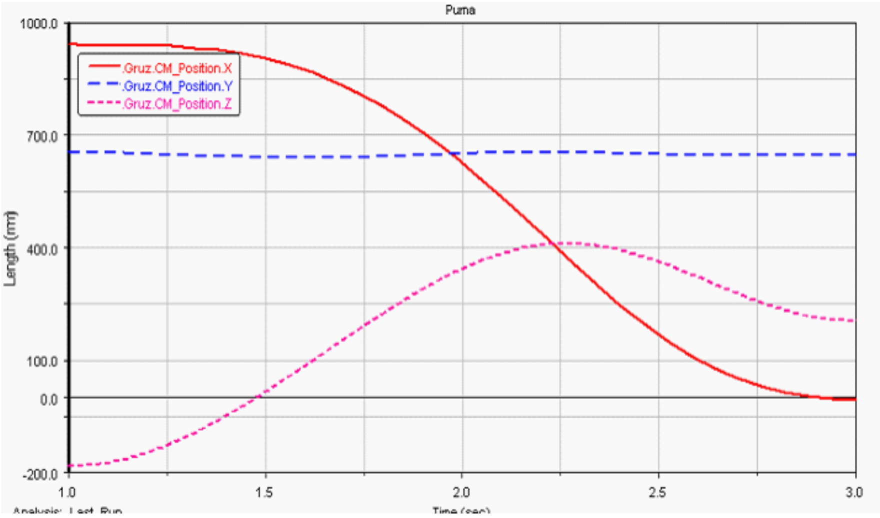


Figure 8. Gruz Diagram

We could get X axis direction diagram of other joints according to above steps. They are shown in Figure 9.

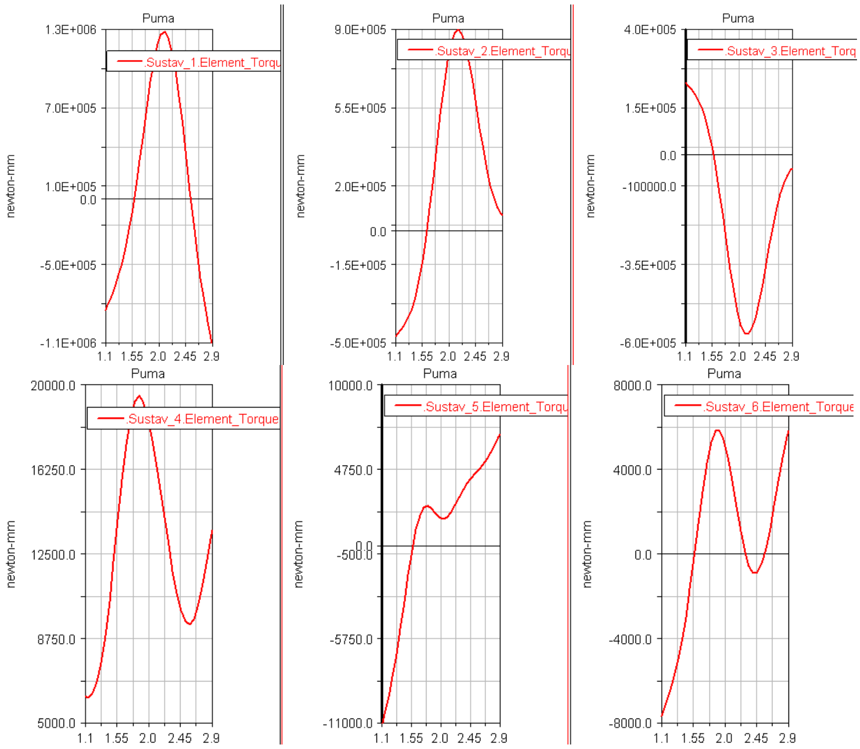
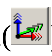


Figure 9. Other Joint Junction Curves

5.2. Straight-Line Trajectory

In order to get the track of the linear motion, firstly we set up all the joints that could be free to rotate, click the right mouse button, select Joint—Modify, open Modify joint, and select Impose motions in sub window, in Impose motions window, set up z axis as Free, other joints and so on.

Establishing the linear track of load, adopt General point motion(),connecting the load with the grand, click the left mouse button, create motion oscillator, and select

General motion—Modify in menu, we could obtain displacement and angular velocity diagrams of the load, it is shown in Figure 10.

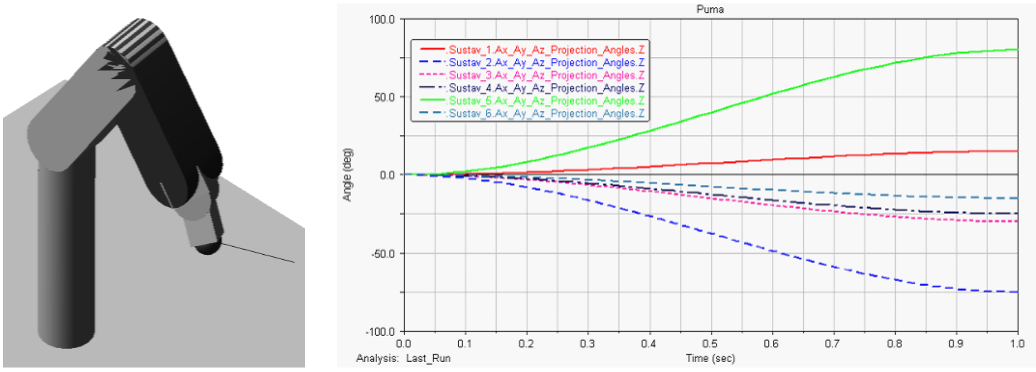


Figure 10. Displacement and Angular Velocity Diagrams of Each Component

From Figure 10, we know that there is no linear movement way from start to finish to robot load.

We could also establish angular velocity of linear motion trajectory through another method, assuming $R_y = 0$, we could obtain the diagram in X axis direction, it is shown in Figure 11.

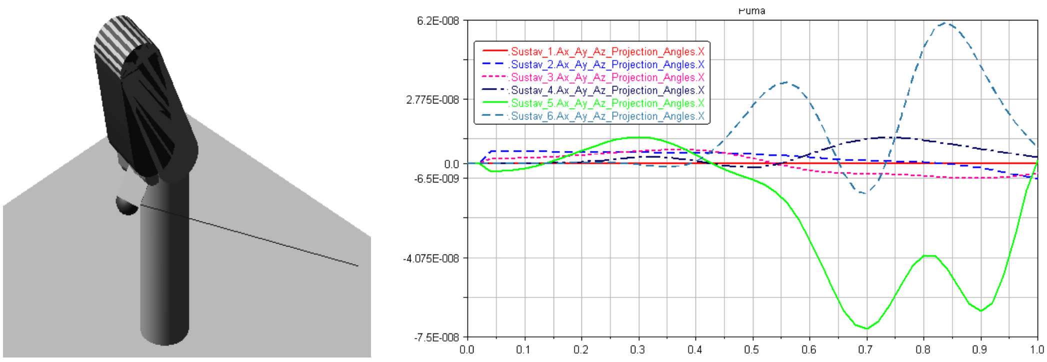


Figure 11. Angular Velocity Diagram in X Axis Direction of Each Component

6. Conclusion

We construct the model to PUMA560 robot in ADAMS according to the structure parameters of PUMA560 robot, such as length, quality and inertia mass of the hinged arm. Using ADAMS dynamic analysis software to simulate the moving condition of mechanical arm, and obtaining the torque curves of each joint in the process of the movement, and analyzing the simulation results. It can be seen that the robot modeling and simulation approach which combines with ADAMS technology has the characteristic of good real-time and good visibility, it applies to kinematic simulation analysis of complex mechanical systems, and it is contribute to the design of the system optimization.

Acknowledgment

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References

[1] L. Chen and Y. Zhang, "Mechanical system dynamics analysis and ADAMS application tutorial", Tsinghua University press, **(2005)**, pp. 12-467.
[2] Z. Li, "ADAMS Detailed Introduction and Examples", National Defense Industry Press, **(2007)**, pp. 32-543.
[3] T. Wang, "Simulation of the Motion Reliability of Tandem Robot Based on ADAMS", Northeastern University, **(2006)**, pp. 25-348.
[4] Z. Cai, "Robotics, Tsing hua University press", **(2000)**, pp. 12-257.
[5] Y. Zhou, "Motion simulation and control system simulation for the series six DOF robot", Qingdao University of Science and Technology, **(2014)**, pp. 20-35.
[6] C. Wang, " Research on Trajectory Planning of Tandem Robot Based on Energy Optimal Six Degree of Freedom", Changchun University of Technology, , **(2014)**, pp. 15-42.
[7] X. Zhang, "Research on the Design and Dual Control of PUMA560 Robot Control System", Harbin Institute of Technology, **(2010)**, pp. 5-27.