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Stamping Manipulator Trajectory Planning Based On Virtual Prototype Technology Research

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Abstract

In view of the problem that the joint type multiple DOF Manipulator is easy to collide with the surrounding equipment and jitter caused by the joint movement, this paper based on the stamping manipulator of five DOF cylindrical coordinate type, planned a straight path through actual stamping process in Cartesian space and quadratic programmed by using a bounded deviation theory. Then, this paper respectively used cubic polynomial, five polynomial and B-spline interpolation on interpolation points in joint space, and analyzed the displacement, velocity and acceleration of the end reference point. Finally, model in virtual prototype and real experiments were verified to ensure the safety and precision of the path. The results meet the requirements of the stamping process, succeeded in raising the stamping accuracy, and ensured the quality of stamping, and can arrange the entire auto production line equipment. So, it has important theoretical and practical significance to improve the stamping process.

***Keywords**: manipulation, virtual prototype, trajectory planning, interpolation operation*

1. Introduction

As one of the important developing direction of modern manufacturing technology, the stamping process has been paid much attention. With the development of modern technology, automated production line has become a hot issue in the research. And as an important part of the automated production line, the extent of the stamping manipulator's research and development directly determines the level of development of the entire stamping automated production lines.

In view of the phenomenon that some stamping manipulator due to its own large size or smaller working space, it is easy to collide with surrounding equipment and its own machine in work process. So this paper combined with the specific requirements of the stamping process and planed for the punching path in the Cartesian space. In this paper, the theory of bounded deviation is used for two times, and the interpolation points are applied to three times, five polynomial and B spline function interpolation. It majored to establish the modal of stamping manipulator in the virtual prototype, and the actual experimental verification is the second. By analyzing the displacement, velocity and acceleration of the reference point of the end point, the B spline function interpolation can make the punching machine run smoothly, without impact phenomenon, meet the requirements of the stamping process, and improve the accuracy of stamping.

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2. Research on the Linear Trajectory Planning of Stamping Manipulator

2.1. Cartesian Space Trajectory Planning

Stamping manipulator a major role in the production line is up and down the material, and its three-dimensional structure diagram is shown in Figure 2.1. To make stamping robots can safely run from the starting point to the end, we need to plan a route in advance to avoid colliding with the surrounding environment and its own machine. The safest path was straight segment, because it can effectively avoid obstacles. According to the requirements of stamping work and working space, we draw the size of the device outside the path, as in Cartesian space planning. The end of the stamping manipulator is the end picking-up device, whose midpoint was taken as a reference point. The expected trajectory is shown in Figure2.2:

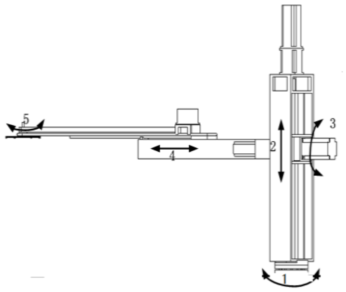


Figure 2.1.The Diagram of Stamping Robot Three-Dimensional Structural

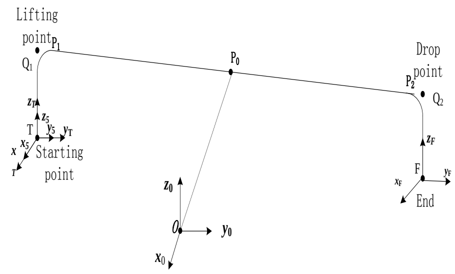


Figure 2.2.The Anticipated Trajectories of Reference Point

As shown in Figure 2.2, {0} is the base coordinate system,{5} is a terminal coordinate system,{T} is a starting coordinates, {F} is the end point of the coordinate system, P_0 is the origin point of the end actuator. First, passing point P_2 arrive lifting position, lifting points is reduced to the right angle turning point of the path falling to the starting point, which requires lifting point at zero speed, resulting in acceleration is not continuous, so here uses a circular arc transition. Then, falling to the starting point T, after the end actuator pickup crawl work piece, lifting point Q_1 , after a transition arc arrival point P_2 along a straight line running for some time, after falling to a transition arc at the end of F, the end actuator pickup down the work piece, the original road return after the completion of this process, and thus the completion of a cycle.

2.2. The Secondary Linear Trajectory Planning of Bounded Deviation Method

Taylor proposed a spatial motion algorithm based on joint variables, called the bounded deviation of the joint path method. The basic idea is to get enough of the intermediate point in the preform planning trajectory to ensure that the reference point of the manipulator's end actuator deviates from the ideal trajectory in each section of motion and the error range is within the range of sanity. The first need is to determine the position of the first two points P_0 and P_1 in the right angle space, and then through inverse kinematics to obtain the corresponding joint vector q_0 and q_1 in the joint space. Finally, the interpolation points are obtained in the joint space.

For slow convergence and other shortcomings, which will be improved on the basis BDJP algorithm, this paper proposed a new algorithm, which has uniform convergence and convergence speed and other characteristics. In the process of stamping movement, the attitude is in less demanding, just the end of the process at the end of the movement can be able to meet the requirements of attitude. The algorithm is as follows:

(1)Calculate the joint variables Solutions

(2) Calculate the midpoint of the joint variables

(3) Calculate the maximum space of the Cartesian coordinate system

(4) Find out the deviation errors

(5)If the margin of error checking, $\delta_p \le \delta_p^{\max}$ and $\delta_R \le \delta_R^{\max}$,the condition is satisfied, stop the operation, otherwise the Cartesian coordinates corresponding to the midpoint of the P_c joint vector, in P_c replace P_1, then the two sub-end to perform recursive step (2) - (5).

2.3. Trajectory Planning in Joint Space

Since the stamping process needs to consider issues such as obstacle avoidance, path planning is generally straight. A straight path through the secondary plan, setting the maximum deviation, plan out the interpolation points, and then you can replace the Cartesian space trajectory planning in joint space. Now, this paper respectively used cubic polynomial, five polynomial and B-spline interpolation on trajectory planning in joint space.

Cubic polynomials satisfy four constraints required, *i.e.*

$$\begin{cases} \theta(0) = \theta_0 \\ \theta(f) = \theta_f \end{cases} \qquad \begin{cases} \dot{\theta}(0) = 0 \\ \dot{\theta}(f) = 0 \end{cases}$$

The four constraints can be determined only one cubic polynomial:

$$\theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3$$

For the higher required motion trajectory, such as the displacement, velocity and acceleration of the starting point and the end point of the certain track are specified requirement, that is, the constraint conditions are increased. The three time polynomial can not meet the requirements. The measure is often used to use the high degree polynomials, which is the most commonly used five Polynomials:

$$\theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5$$

Where the polynomial coefficients are required to satisfy the constraints:

$$\begin{cases} \theta_0 = a_0 \\ \theta_f = a_0 + a_1 t_f + a_2 t_f^2 + a_3 t_f^3 + a_4 t_f^4 + a_5 t_f^5 \\ \dot{\theta}_0 = a_1 \\ \ddot{\theta}_0 = 2a_2 \\ \dddot{\theta}_f = 2a_2 + 6a_3 t_f + 12 a_4 t_f^2 + 20 a_5 t_f^3 \end{cases}$$

For the joint position-the time series $\{p_i, t_i\}$, joint control points p_i can be used as the control point of B spline curve to obtain B-spline curve fitting. B spline curve equation is:

$$p(u) = \sum_{i=0}^{n} d_i N_{i,k}(u)$$

3. Simulation of Virtual Prototype Model

3.1. Cartesian Space Trajectory Simulation

In this paper, a simulation model of the Adams is established, and the manipulator has 5 degrees of freedom, which need to be added with 5 constraints, including 3 rotating pairs and 2 mobile assistant. For the trajectory planning of the end actuator, defined a general point motion in the end actuator, adding constraints as well as the point moving position shown in Figure 3.1. The reference point of the end of the manipulator is used as the reference point drive parameters, the choice of CUSPL as a function of the each joint driving function. set the parameters: End time = 10.0, Steps = 200, generated trajectory, as shown in Figure 3.2.

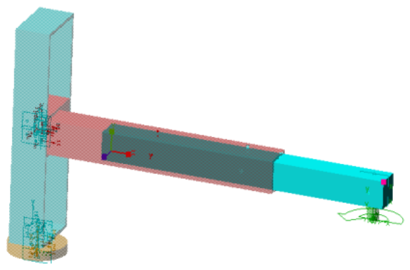


Figure 3.1. The Position Schematic Diagram of Constraint and Point Moon

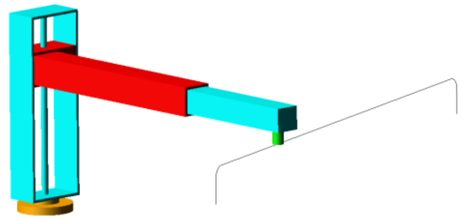


Figure 3.2. The Diagram of Reference Point Trajectory

3.2. Difference Calculation Trajectory Simulation

In order to verify the correctness of the algorithm, a straight line is planned in the model, as shown in Figure3.3. Take interpolation points in accordance with the above algorithm. In order to facilitate a comparison, the layout of a straight line along a predetermined right angle coordinate. Play the displacement of the trajectory in Cartesian space.

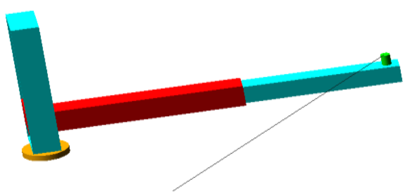


Figure 3.3. The Diagram of Virtual Prototype Straight Trajectory

(1) A difference

Take the P_0 point P_1 and the point P_i of the straight line and obtain the parameters q_0 and q_1 of each joint by using the inverse kinematics. The results are shown in Table 1:

Table 1. The Nodal Points of All Joints on One Interpolation

Joint / interpolation point	1	2	3	4	5
1	-0.591	-150	0	-275.661	-0.6435
2	0.652	50	-3.1416	-275.661	0.6435

(2) Quadratic interpolation

Take intermediate point coordinates of a straight line in Cartesian space, use inverse kinematics to calculate value of the joint space, as shown in Table 2.

Table 2. Nodal Points of All Joints on Two Interpolation

Joint / interpolation point	1	2	3	4	5
1	-0.591	10	0	-275.661	-0.6435
2	0	-90	-1.571	-0.844	0
3	0.652	-190	-3.1416	-275.661	0.6435

(3) Cubic interpolation

As the middle point of the whole line in Cartesian coordinate system, P_c divided the whole line into two line segments, respectively, so as the end point of the front line segment and the beginning point of the latter line segment and respectively find an intermediate point of two straight line segments. Interpolation points as shown in Table 3.

Table 3. The Nodal Points of All Joints on Three Interpolation

Joint / interpolation point	1	2	3	4	5
1	-0.591	10	0	-275.661	-0.6435
2	-0.344	-40	-0.7854	-73.2	-0.3218
3	0	-90	-1.571	-0.844	0
4	0.344	-140	-2.3562	-73.2	0.3218
5	0.652	-190	-3.1416	-275.661	0.6435

In the virtual prototype, each of these joint interpolation point are interpolated, actual motion trajectory is obtained by taking the end reference point, and we draw the difference between the deviation of the ideal trajectory.

3.3. Joint Space Trajectory Simulation

According to the expected trajectory planning, this paper used new algorithms bounded deviation obtaining interpolation point in a straight line, then used cubic polynomials respectively, five polynomial and B-spline solving, various joint displacement graphs plotted in Matlab, according to various joint displacement curve, the respective joint acquisition interpolation points, save as txt. Format and imported into the simulation Adams and draw the end of each axis reference point displacement, velocity and acceleration curve.

4. Stamping Manipulator Experimental Platform

Robotics is the use of PC-Based control system architecture which can be simply expressed as the following shown in Figure 4.1:

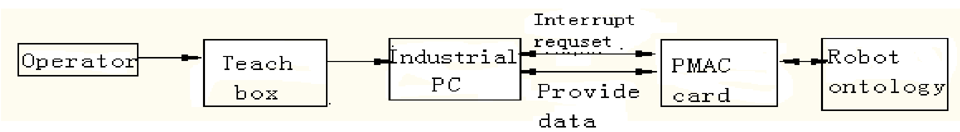


Figure 4.1. The Motion Control System of Robot

IPC is responsible for human-computer interaction systems, system scheduling and coordination, Forward and Inverse Kinematics and trajectory planning and so on. In servo motion control system, PMAC card is in the main sports program execution, execution of the PLC program, servo adjustment ring-host communication and so on. PMAC card on test platform does not have a planning algorithm for the trajectory of six degrees of freedom vertical articulated robot model, so we use the following strategies to achieve motion control programming: IPC complete trajectory planning Forward and Inverse Kinematics etc based on user settings PMAC card according to the motion status of the actuator sends an interrupt request to the IPC to provide sports related data.

Figure 4.2 is a laboratory robot motion control platform which consists of three parts: display, control cabinet (control equipment) and robot body and peripheral equipment. We can input data via the display changes during exercise and observe the joint variables; control cabinet mainly include IPC and PMAC card and other control equipment and related cables; the robot body are mainly executed tasks.

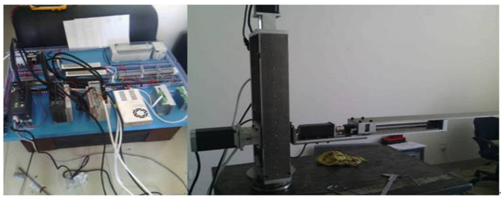


Figure 4.2. The Motion Control Platform of Robot

5. Results and Analysis

5.1. Cartesian Spatial Displacement Simulation

Figure 5.1 below is displacement map of the end of the reference point on each reference axis, and compared with the path planning in advance, as shown in Figure 5.2.

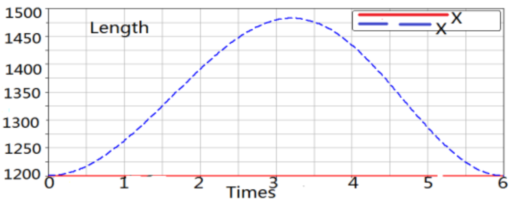


Figure 5.1.The Simulation Diagram of Prototype Model

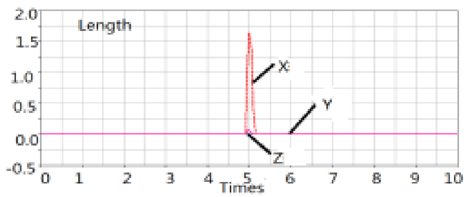


Figure 5.2. Simulation Error Diagram of Prototype Model

From the displacement map can be drawn that after the simulation, the track of the end reference point is in no difference with the pre-planned trajectory, so it can complete punching positioning requirements. While in the process of running, in addition to the deviations at the midpoint of the ideal trajectory, but within the allowable range, so the simulated track in Cartesian space meet the process requirements.

5.2. End Displacement Simulation after the Difference

After once, twice, three times difference, the trajectory displacement and deviation of the end reference point were respectively shown in Figure 5.3, 5.4, 5.5:

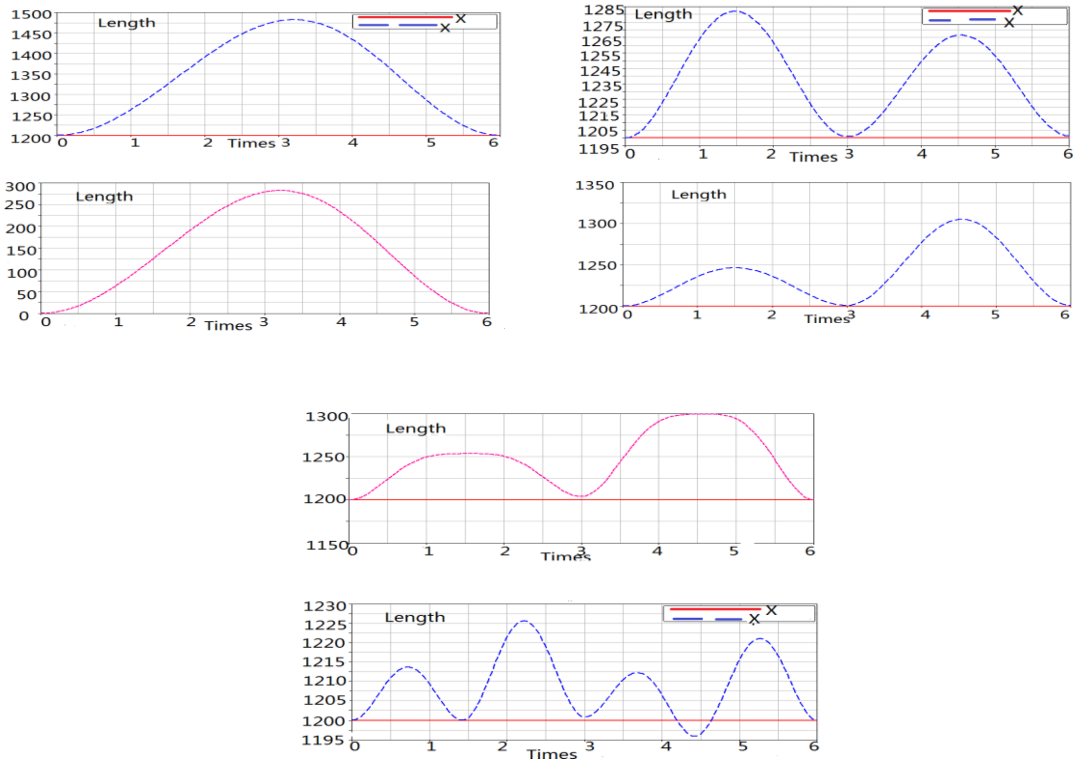
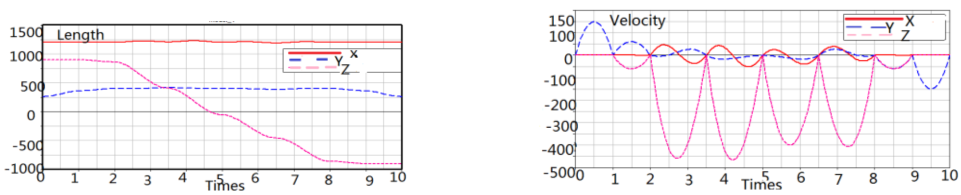


Figure 5.5. The End Effector Trajectory Diagram on Two-Interpolation

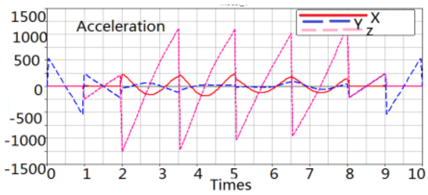
From the chart we can see that through an interpolation, its trajectory is a circular arc. By analyzing the trajectory figure of the end of the reference $\Delta\delta_p = 280\text{mm}$ point shows that the maximum deviation between the actual trajectory and the ideal trajectory is, after the maximum deviation of the second difference is 84mm, and after three difference between the maximum deviation is 26mm. Comparative results that through interpolation, position deviation decline much. The deviation results of the second interpolation once a decline of 70.3 percent than the first, and third interpolation ratio reached 68.7% decline than the second, which proved the effective of the difference algorithm.

5.3. Physical Simulation of the Joint Spatial Reference Points

According to the joint displacement curves of three polynomial, five polynomial and B spline function, the collected joint interpolation points are saved as the format of txt. Then, introduced these points to simulate in Adams, and we can get the curves of the displacement, velocity and acceleration, as shown in Figure 5.6, 5.7 and 5.8:

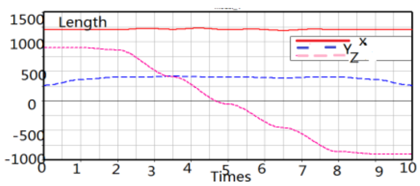


(a) (b)

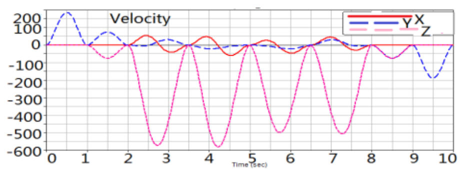


(c)

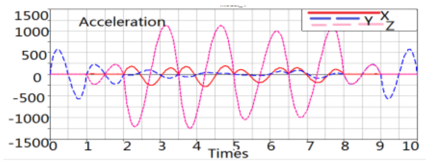
Figure 5.6. The Displacement, Velocity and Acceleration Curve Diagram of End Effector Reference Point of Three Polynomial



(a)

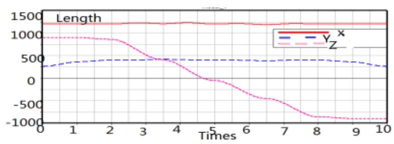


(b)

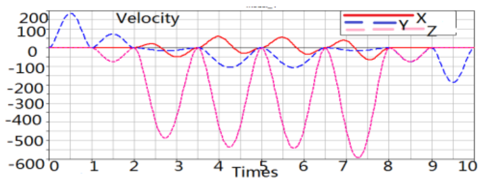


(c)

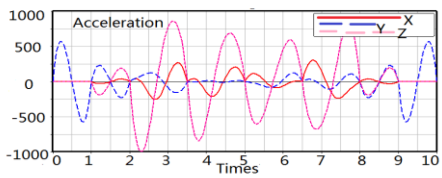
Figure 5.7. The Displacement, Velocity and Acceleration Curve Diagram of End Effector Reference Point of Five Polynomial



(a)



(b)



(c)

Figure 5.8. The Displacement, Velocity and Acceleration Curve Diagram of End Effector Reference Point of B-Spline Interpolation

Cubic polynomial interpolation analysis from Figure 5.6 shows that although the displacement and velocity of joint variables is ensured a smooth transition, its acceleration can not meet the requirements for a smooth transition. So it can result in shocking; from Figure 5.7 and Figure 5.8 analysis shows that the use of five polynomial interpolation and five B-spline joint variable difference can ensure a smooth transition of displacement and velocity, acceleration in its smooth transition to meet the requirements, so that the end is in motion the process to run smoothly, without impact of the phenomenon. Figure 5.9 is for the acceleration figure of the five polynomial interpolation and five B-spline interpolation in the Z-axis.

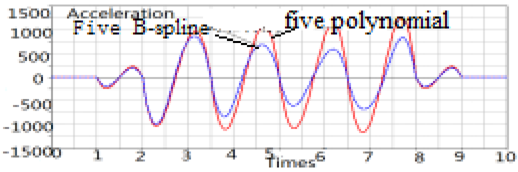


Figure 5.9. The Acceleration Correlation Diagram of Two Interpolation Algorithm

From the above analysis, the acceleration of the two algorithms is continuous, but the acceleration of the end point of the B spline interpolation function is smaller than that of the five polynomials.

6. Conclusions

In this paper, the stamping manipulator in automatic stamping production line is used for the study, and the trajectory is once and quadratic programmed in Cartesian space and joint space and simulated in a virtual prototype. So we can find that: (1) in Cartesian space, the track of the end reference point is in no difference with the pre-planned trajectory, so it can complete punching positioning requirements; (2) through interpolation, the reference point position deviation decline much, and the more the interpolated number, the greater the deviation decline, thus proving the difference between the effectiveness of the algorithm; (3) B-spline interpolation function enables smooth running, has no impact of the phenomenon, and meet the requirements of the stamping process. After more research and discussion on the stamping manipulator trajectory planning, the results are that the tamping manipulator can improve the precision stamping machinery hand and ensure the quality of stamping.

Acknowledgements

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References

[1] M. Xuechuan, "stamping equipment loading robot research and development", [D]. Guangzhou: South China University of Technology, **(2012).**

[2] C. Weihua, "Research on the space trajectory planning of industrial robot Descartes", [D]. Guangzhou: South China University of Technology, **(2010).**

[3] Q. Yuntao, "Independent design and development of stamping manipulator and robot design",[D]. in Qinhuangdao: Yanshan University, **(2012)**.

[4] Youlun. "Robot technology based", [M]. Wuhan: Huazhong University of science and Technology Press, **(1992)**, pp. 94.

[5] L. Xiaoxia and W. Mulan, "combination machine tool and automatic processing technology", [J]. **(2012)**, pp. 8.

[6] M. H. Ghasemi, N Kashiri and M Dardel, "Time-optimal trajectory planning of robot manipulators in point-to-point motion using an indirect method", [J].Journal of Mechanical Engineering Science, no. 226, **(2012)**, pp. 473-484.

[7] Z. Shujie, "Simulation of welding robot based on Virtual Prototyping Technology", [D]. Nanchang: Nanchang University, **(2013)**.
[8] A. Gasparetto and Paolo Boscariol, "Trajectory Planning in Robotics", [J]. Mathematics in Computer Science, no. 6, **(2012)**, pp. 269-279.
[9] K.G Shin and N.D McKay, "A Dynamic programming approach to trajectory planning of robotic manipulators",[J]. IEEE Transactions on Automatic Control, vol. 31, no. 6, **(1986)**, pp. 491-500.
[10] R. Taylor, "Planning and Execution of Straight Line Manipulation Trajectories in Robot Motion", Massachusetts [J]. The MIT Press,**(1983)**.

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