2016 International Conference on Intelligent Manufacturing and Materials (ICIMM 2016)
ISBN: 978-1-60595-363-2

Research on Robot Trajectory Planning Based on Interpolation with Cosine Function Transition in Joint Space

Suoxian Yuan, Ruifeng Huang, Fuming Yu and Hehua Niu

ABSTRACT

In order to improve industrial robotic smooth and steady property, reduce vibration and impact and avoid fluctuation in motion, a new method for the robot trajectory planning based on interpolation with cosine function transition in joint space was proposed. The three common trajectory planning methods in the joint space, including interpolation using cubic polynomial, interpolation using quintic polynomial and interpolation with parabola transition, and the method based on interpolation with cosine function transition were compared and analyzed in terms of joint positions, joint velocity and joint acceleration. There are many characteristics of the method based on interpolation with cosine function transition through the comparison and analysis. The characteristics include smooth position curve of joint, no fluctuation the lower joint maximum velocity and implement easily, good motion performance and no acceleration in some motion process and then the wear of robot joint parts can be reduced. The conclusion was obtained that the new method has a good comprehensive function finally.

INTRODUCTION

With the development of industry, the demands for robotic steady and smooth and accuracy in motion are improved increasingly. In order to enhance robot's

---

Suoxian Yuan, Ruifeng Huang, Fuming Yu, Hehua Niu, Mechanical Engineering and Automation of Northeastern University, Liaoning, China, 110819

characteristic mentioned above, the study on robot trajectory planning should be done deeply. Trajectory planning of robot consists of trajectory planning in Cartesian space and joint space[2]. The research on robot trajectory planning in joint space was done in this paper. Recently, there are many kinds of robot trajectory planning including interpolation using cubic polynomial, interpolation using high order transition, interpolation with parabola transition and so on[1,4-7]. However, the methods for trajectory planning mentioned above have drawbacks. For example, the maximum velocity of interpolation using cubic polynomial and high order polynomial is even bigger than others and the acceleration curve of interpolation with parabola transition is discontinuous. The shortcomings are not good for robot in motion. A novel method for the robot trajectory planning based on interpolation with cosine function transition in joint space was proposed.

CREATEINTERPOLATIONWITHCOSINEFUNCTION TRANSITION

A good trajectory planning can make robot steady and smooth in motion. According to the paper[3], the interpolation with parabola transition is the most popular trajectory planning.

The function of interpolation with parabola transition is shown as equation (1).

$$\theta(t)=\begin{cases} \frac{1}{2}\ddot{\theta}t^2+\theta_0, & 0\le t<t_b \\ \ddot{\theta}t_b(t-t_b)+\theta_b, & t_b\le t\le t_f-t_b \\ \theta_f-\frac{1}{2}\ddot{\theta}(t_f-t)^2, & t_f-t_b<t\le t_f \end{cases} \quad (1)$$

The initial conditions are given as follows:

$$t_0=0,\theta_0=0,t_f=1\text{s},\theta_f=\pi/4,\dot{\theta}_0=\dot{\theta}_f=0,t_b=\pi/20.$$

The values of unknowns in equation (1) are shown as follows:

$$\theta_b=0.073,\ddot{\theta}=5.934.$$

Therefore, the function express of equation(1) can be obtained and joint position curve, joint velocity curve and joint acceleration curve based on interpolation with parabola transition as shown in Figure 1 and Figure 2 respectively.

Figure 1 shows that joint position curve is smooth and trapezoid velocity curve consists of three linear sections including acceleration, uniform speed and slowdown.

Figure 2 shows that joint acceleration curve consists of three linear sections and each section is constant. Therefore, the interpolation with parabola transition has a good performance and implement easily in motion.

The interpolation with parabola transition has a good performance in motion, but it has a fatal weakness that the acceleration curve is discontinuous. The situation that acceleration curve is discontinuous will make robot vibrate and impact in motion. In order to overcome the shortcoming, a novel method for the robot trajectory planning based on interpolation with cosine function transition in joint space was proposed.

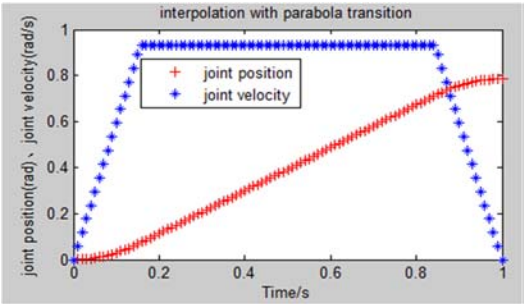


Figure 1. Joint position and joint velocity curve based on interpolation with parabola transition.

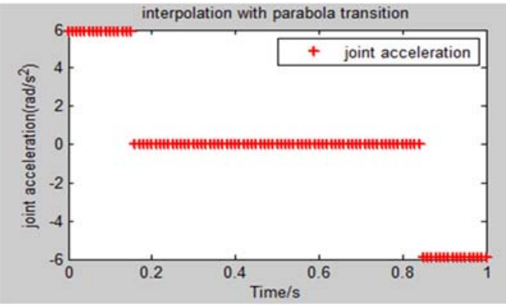


Figure 2. Joint acceleration curve based on interpolation with parabola transition.

The interpolation with cosine function transition is shown as equation (2).

$$\theta(t)=\begin{cases} a[1-\cos(wt)]+\theta_0, & 0\le t<t_b \\ wa\sin(wt_b)(t-t_b)+\theta_b, & t_b\le t\le t_f-t_b \\ a[\cos(wt-wt_f)-1]+\theta_f, & t_f-t_b<t\le t_f \end{cases} \quad (2)$$

Where a is amplitude; w is angular frequency; θ_0 is initial angular position; θ_b is transition angular position; θ_f is target angular position.

The initial conditions of interpolation with cosine function transition and interpolation with parabola transition are same. In addition, another initial condition of interpolation with cosine function transition is $wt_b=\pi/2$. The extra condition can make the acceleration curve continuous.

The values of unknowns in equation (2) are shown as follows:

$$a=0.0887\,,w=10\,,\theta_b=0.0887\,.$$

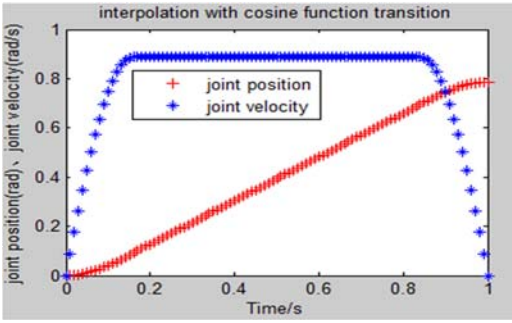


Figure 3. Joint position and joint velocity curve based on interpolation with cosine function transition.

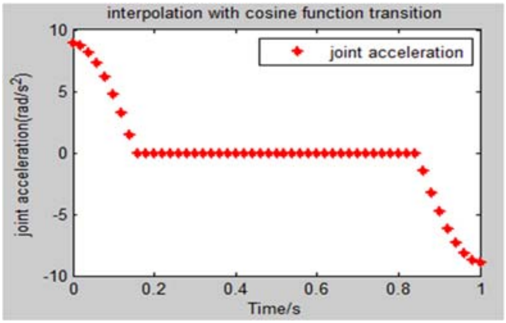


Figure 4. Joint acceleration curve based on interpolation with cosine function transition.

Therefore, the function express of equation(2) can be obtained and joint position curve, joint velocity curve and joint acceleration curve based on interpolation with cosine function transition as shown in Figure 3 and Figure 4 respectively.

Figure 3 shows that joint position curve is smooth and velocity curve being similar to trapezoid consists of three sections including acceleration, uniform speed and slowdown. The joint velocity is easy to implement.

Figure 4 shows the most significant difference between interpolation with cosine transition and interpolation with parabola transition is that the acceleration curve of latter is continuous.

COMPARE AND ANALYZE INTERPOLATION WITH COSINE FUNCTION TRANSITION WITH THREE COMMON TRAJECTORY PLANNING METHODS

In order to identify that interpolation with cosine function transition has a superior property in motion, joint position curve, joint velocity curve and joint acceleration curve of four methods mentioned above were compared and analyzed respectively under the same initial conditions.

The cubic polynomial function is shown as equation (3).

$$\theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3, \quad 0 \le t \le t_f \tag{3}$$

The quintic polynomial function is shown as equation (4).

$$\theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5, \quad 0 \le t \le t_f \tag{4}$$

The interpolation with parabola transition and interpolation with cosine function transition as shown in equation (1) and equation (2) respectively.

The mutual initial conditions of four trajectory planning methods are shown as follows:

$$t_0 = 0, \theta_0 = 0, t_f = 1\text{s}, \theta_f = \pi/4, \dot{\theta}_0 = \dot{\theta}_f = 0, t_b = \pi/20.$$

The values of unknowns in equation (3) are shown as follows:

$$a_0 = a_1 = 0, a_2 = 2.356, a_3 = -1.571.$$

The other three trajectory planning methods except for interpolation using cubic polynomial need some additional initial conditions.

The additional initial conditions of the interpolation with cosine function

transition and interpolation with parabola transition are given above and the values of unknowns in equation (1) and equation (2) are shown above.

The additional initial conditions of interpolation with quintic polynomial are shown as follows:

$$\ddot{\theta}_0 = \ddot{\theta}_f = 0.$$

The values of unknowns in equation (4) are shown as follows:

$$a_0 = a_1 = 0, a_2 = 0.1, a_3 = 7.654, a_4 = -11.681, a_5 = 4.712.$$

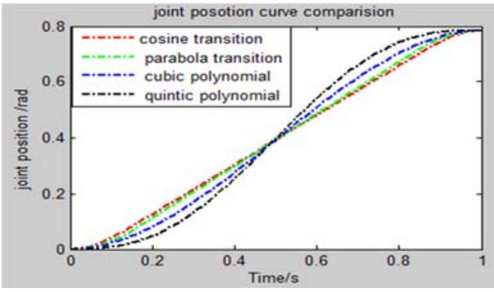
The joint position function express of four trajectory planning methods can be obtained through calculations and then the joint velocity express and joint acceleration express can be obtained. The joint position curve, joint velocity curve and joint acceleration curve as shown in Figure 5, Figure 6 and Figure 7 respectively.

Figure 5 shows that the joint position curve of each trajectory planning method is steady and smooth and robot has no vibration and fluctuation in motion.

Some information can be obtained from Figure 6.

(1)The velocity curve of interpolation with parabola transition and interpolation with cosine function transition consists three sections including acceleration, uniform speed and slowdown and easier to implement than others.

(2) The maximum velocity of interpolation with cosine function transition is the minimum in four trajectory planning methods. The maximum velocity is significant for robot. The bigger the maximum velocity, the greater the momentum when robot has a constant mass. Big velocity means an accident when robot stops urgently. In order to reduce the momentum, the trajectory planning method with the smaller maximum velocity will be selected[6].



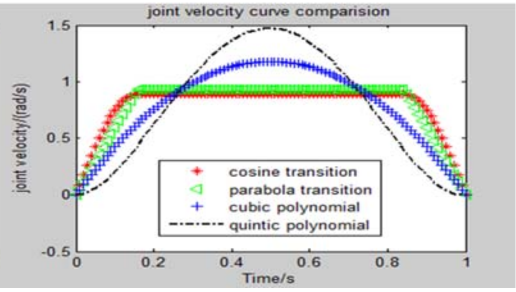


Figure 5. Four trajectory planning methods' comparison of joint position curve.

Figure 6. Four trajectory planning methods' comparison of joint velocity curve.

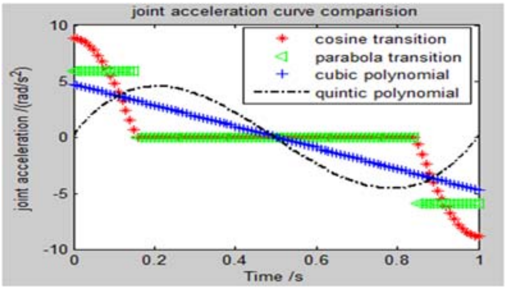


Figure 7. Four trajectory planning methods' comparison of joint acceleration curve

Some information can be obtained from Figure 7.

(1) The value of the joint acceleration is zero in a period of time with methods of interpolation with cosine function transition and interpolation with parabola transition. The wear of robotic joint parts can be reduced in this situation.

(2) The acceleration curves of other three trajectory planning methods are continuous except for interpolation with parabola transition. The continuous acceleration can avoid impact in motion for robot.

CONCLUTIONS

Some conclusions can be obtained through comparison and analyzation of interpolation with cosine function transition and three common trajectory planning methods as follows:

(1) Joint position curve of interpolation with cosine function transition is steady and smooth. There is no fluctuation in motion.

(2) Joint velocity curve of interpolation with cosine function transition consists of three sections including acceleration, uniform speed and slowdown. The joint velocity is easy to implement.

(3) The maximum velocity of interpolation with cosine function transition is the minimum than other three trajectory planning methods. There is a good performance in motion.

(4) The joint acceleration curve of interpolation with cosine function transition is continuous. There is no vibration and impact in motion.

Therefore, interpolation with cosine function transition is a novel trajectory planning method in joint space for robot.

REFERENCES

1. Cesare R., Sergio S. 2013. " Robot Trajectory Planning by Assigning Positions and Tangential Velocity," *J. Robotics and Computer-integrated Manufacturing*, 29: 139-156.
2. Liu J.F. 2012.*Fundamentals of Robot Techniques*. Higher Education Press, pp.123-140. "In Chinese"
3. Tan M. and Xu D. 2007. *Advanced Robot Control*. Higher Education Press, pp. 92-95. "In China"
4. Cai Z.X. 2000. *Robotics*. Tsinghua University Press, pp. 269-272. "In Chinese"
5. Zhu H.Y. 2012. "Research of 7DOF Humanoid Manipulators' Trajectory Planning and Control," Zhejiang University of Technology. "In Chinese"
6. Tian X.Y. 2008. "The research of robotic trajectory planning," Beijing University of Posts and Telecommunications. "In Chinese"
7. Peter A.M., Ryad B. and Steven L. 2012. "Smooth and Time-optimal Trajectory Planning for Robot Manipulators," The 2012 American Control Conference, June 27-29, 2012.