

Trajectory Planning of Ammunition Loading Robot Based on Cubic-B Spline

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Abstract. To solve the problem of continuous and steady work and obstacles avoidance of ammunition loading robot, the trajectory plan method of ammunition loading robot based on cubic-B spline has been put forward. The paper analyzed the solution of cubic-B spline, finishing the obstacle avoiding trajectory plan of ammunition loading robot with key control points in joint space based on cubic-B spline, and the ammunition loading robot joints' angular displacement, angular velocity and angular acceleration is simulated by dynamic simulation software, the results showing that the method can quickly generate obstacle avoidance trajectory and dynamic characteristics of the trajectory is fine, guaranteeing the ammunition loading robot work smoothly with no impact and avoid obstacles effectively.

Introduction

With the increasing caliber of gun, ammunition weight reached the limits of artificial loading and active service autoloader exists problems such as low efficiency and poor reliability, the ammunition loading robot has become a domestic and international hot topic of automatic loading technology research[1][2]. Ammunition loading robot is PRR-3R type six degrees of freedom robot in which working space there are obstacles breechblock, seat ring and so on. In order to avoid these obstacles in the working process, the end effector need pass precisely all the key obstacle avoiding points smoothly with no impact[3][4], using the traditional polynomial interpolation method can't guarantee good characteristics of trajectory when it passing the key obstacle avoiding points[5][6]. The paper fulfil the obstacle trajectory plan of ammunition loading robot based on cubic-B spline, simulating the joints' dynamics by simulation software, verifying it is practical to proceed trajectory plan of ammunition loading robot with multiple obstacle avoidance points based on cubic-B spline.

Cubic-B Spline

The i th segment of cubic-B spline curve of ammunition loading robot trajectory is

$$\theta_i(t) = X_0(t)P_{i-1} + X_1(t)P_i + X_2(t)P_{i+1} + X_3(t)P_{i+2} \quad (1)$$

In type (1), t is time, $X_i(t)$ is the basic function of cubic-B spline, P_i is the control point of the cubic-B spline curve.

Since the whole trajectory is continuous, the values of adjacent cubic-B spline curves are equal at the connecting point:

$$\theta_i(1) = \theta_{i+1}(0) \quad (2)$$

In addition, at the connection of two adjacent cubic-B spline curve, the derivatives and the second derivatives is equal, that means the velocity and acceleration of end effector is continuous, so we can get:

$$\theta'_i(1) = \theta'_{i+1}(0), \quad \theta''_i(1) = \theta''_{i+1}(0) \quad (3)$$

Taking the derivative of type (2) combined with type (3), we can get:

$$\begin{aligned} X'_0(1) &= X'_3(0), \quad X'_0(0) = X'_1(1), \quad X'_2(1) = X'_1(0), \quad X'_3(1) = X'_2(0) \\ X''_0(1) &= X''_3(0)=0, \quad X''_0(0) = X''_1(1), \quad X''_2(1) = X''_1(0)=0, \quad X''_3(1) = X''_2(0) \end{aligned} \quad (4)$$

By the Cauchy standard of cubic-B spline basic function, we can get:

$$X_0(t) + X_1(t) + X_2(t) + X_3(t) = 1 \quad (5)$$

Combined type (2) to type (5), the basic functions of the cubic-B spline curves are obtained:

$$\begin{aligned} X_0(t) &= 1/6(-t^3 + 3t^2 - 3t + 1) \\ X_1(t) &= 1/6(3t^3 - 6t^2 + 4) \\ X_2(t) &= 1/6(-3t^3 + 3t^2 + 3t + 1) \end{aligned} \quad (6)$$

In trajectory planning, the control points of the cubic-B spline curves are needed, and the key obstacle avoiding points of the joint space trajectory of ammunition loading robot must be given before solving the control point, that is, the key obstacle avoiding points of M_i . From type (6) we can get:

$$\theta_{i-1}(1) = \theta_i(0) = 1/6 P_{i-1} + 2/3 P_i + 1/6 P_{i+1} \quad (7)$$

Further,

$$\begin{aligned} \theta'_i(0) &= -1/2 P_0 + 1/2 P_2 = 0 \\ \theta'_{i-1}(0) &= -1/2 P_{i-2} + 1/2 P_i = 0 \end{aligned} \quad (8)$$

Combined type (7) with type (8), we can get:

$$\begin{bmatrix} -3 & 0 & 3 & 0 & L & 0 & 0 & 0 \\ 1 & 4 & 1 & 0 & 0 & L & 0 & 0 \\ 0 & 1 & 4 & 1 & 0 & 0 & L & 0 \\ M & M & M & M & M & M & M & M \\ 0 & 0 & L & 0 & 1 & 4 & 1 & 0 \\ 0 & 0 & 0 & L & 0 & 1 & 4 & 1 \\ 0 & 0 & 0 & L & 0 & -3 & 0 & 3 \end{bmatrix} \begin{bmatrix} P_0 \\ P_1 \\ P_2 \\ M \\ P_{i-1} \\ P_i \\ P_{i+1} \end{bmatrix} = \begin{bmatrix} 0 \\ M_1 \\ M_2 \\ M \\ M_{i-1} \\ M_i \\ 0 \end{bmatrix} \quad (9)$$

In type (9), M_1, M_2, \dots, M_i is known quantity, so the only solution is the control points of the cubic-B spline trajectory.

Put control points into type (9) combined with the basic function we can get cubic-B spline curve:

$$\theta_i(t) = 1/6 \begin{bmatrix} t^3 & t^2 & t & 1 \end{bmatrix} \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 0 & 3 & 0 \\ 1 & 4 & 1 & 0 \end{bmatrix} \begin{bmatrix} P_{i-1} \\ P_i \\ P_{i+1} \\ P_{i+2} \end{bmatrix} \quad (10)$$

Trajectory Plan

One loading process of ammunition loading robot of a workflow can be separated into four parts: fetching, supplying, pulling and reset, of which the supplying stage need to pass the obstacle avoidance region. As shown in Figure 1, the end effector of ammunition loading robot starting point from P_1 crossing obstacle avoidance area, finally reaching the P_2 , and then finish the loading action, in order to avoid the breechblock and seat ring, the end effector must pass four key obstacle avoiding points M_1 - M_4 .

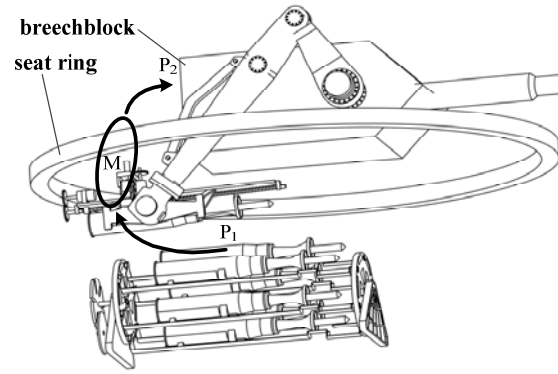


Fig.1. The supplying stage of ammunition loading robot

The joint variables corresponding to the starting point P_1 , the point P_2 and the key obstacle avoidance point $M_1 \sim M_4$ are solved by using the inverse kinematics of ammunition loading robot. See Table 1.

Table 1 The joint variables corresponding to the starting point P_1 , the point P_2 and the key obstacle avoidance point $M_1 \sim M_4$

kepoints	T(s)	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6
P_2	0	50	55.8	-70.6	20	0	0
M_1	0.5	50	43.4	-49.6	15	20	10
M_2	1	50	58.2	-37.8	34.3	30	10
M_3	1.5	50	48.3	-27.2	42.9	30	10
M_4	2	50	32.8	-18.5	15.4	20	0
P_3	2.5	50	52.4	-20.5	29.6	0	0

Solving the control points of the cubic-B spline trajectory:

$$\begin{cases} P_1 = [31.4287 & 67.9856 & 31.4287 & 66.6995 & 50.9732 & 19.2077 & 68.9962 & 19.2077] \\ P_2 = [-96.7498 & -140.7751 & -96.7498 & -111.2258 & -76.9469 & -51.9866 & -74.5067 & -51.9866] \\ P_3 = [37.6000 & 86.2000 & 37.6000 & 74.8000 & 90.4000 & 34.6000 & 10.6000 & 34.6000] \end{cases}$$

Trajectory planning is completed in joint space of ammunition loading robot based on cubic-B spline, and 2th, 3th and 4th joint trajectories are expressed as piecewise polynomial form:

$$\theta_2(t) = \begin{cases} 193.2552t^3 - 146.2284t^2 + 55.8 & (0 \leq t \leq 0.5) \\ -163.7664(t-0.5)^3 + 143.6556(t-0.5)^2 - 1.287(t-0.5) + 43.4 & (0.5 \leq t \leq 1) \\ 46.6104(t-1)^3 - 101.9944(t-1)^2 + 19.5444(t-1) + 58.2 & (1 \leq t \leq 1.5) \\ 130.1240(t-1.5)^3 - 32.0784(t-1.5)^2 - 47.4918(t-1.5) + 48.3 & (1.5 \leq t \leq 2) \\ -241.5080(t-2)^3 + 163.1080(t-2)^2 + 18.0230(t-2) + 32.8 & (2 \leq t \leq 2.5) \end{cases} \quad (11)$$

$$\theta_3(t) = \begin{cases} -195.4024t^3 + 176.1012t^2 - 126.1 & (0 \leq t \leq 0.5) \\ 143.008(t-0.5)^3 - 117.0028(t-0.5)^2 + 29.5494(t-0.5) - 106.5 & (0.5 \leq t \leq 1) \\ -77.4312(t-1)^3 + 97.51(t-1)^2 + 19.8028(t-1) - 103.1 & (1 \leq t \leq 1.5) \\ -50.8824(t-1.5)^3 - 18.6372(t-1.5)^2 + 59.2392(t-1.5) - 78.5 & (1.5 \leq t \leq 2) \\ 123.3608(t-2)^3 - 94.9608(t-2)^2 + 2.4402(t-2) - 59.9; & (2 \leq t \leq 2.5) \end{cases} \quad (12)$$

$$\theta_4(t) = \begin{cases} 244t^3 - 194.4t^2 + 70 & (0 \leq t \leq 0.5) \\ -143.2(t-0.5)^3 + 171.6(t-0.5)^2 - 11.4(t-0.5) + 51.9 & (0.5 \leq t \leq 1) \\ -66.4(t-1)^3 - 43.2(t-1)^2 + 52.8(t-1) + 71.2 & (1 \leq t \leq 1.5) \\ 137.6(t-1.5)^3 - 142.8(t-1.5)^2 - 40.2(t-1.5) + 78.5 & (1.5 \leq t \leq 2) \\ 21.6(t-2)^3 + 63.6(t-2)^2 - 79.8(t-2) + 39.9 & (2 \leq t \leq 2.5) \end{cases} \quad (13)$$

Simulations and Verification

Based on the trajectories, the angle, angular velocity and angular acceleration of the 2th, 3th and 4th joints of the ammunition loading robot are simulated, and the results are shown in Figure 2 to Figure 4.

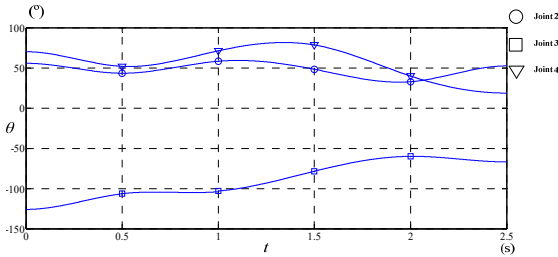


Fig.2. Joint angle-time relationship of trajectory

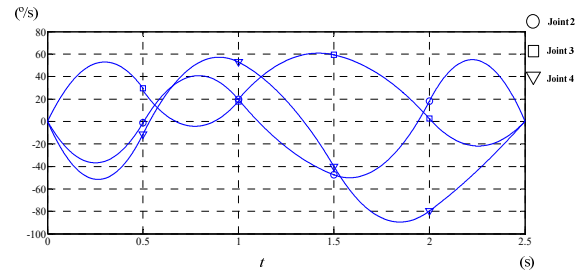


Fig.3. Joint angle velocity-time relationship of trajectory

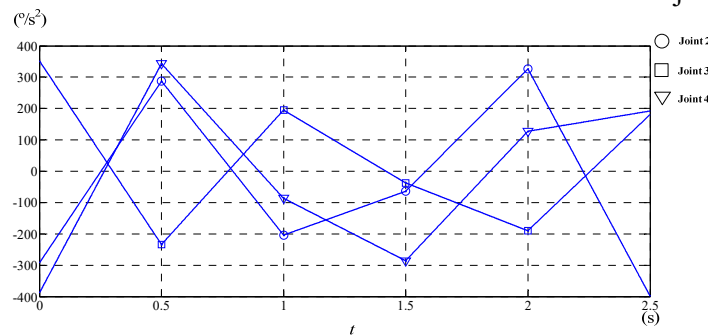


Fig.4. Joint angle acceleration-time relationship of trajectory

Figure 2 shows that the trajectories of ammunition loading robot in joint space using cubic-B spline are continuous, smooth, and pass all obstacle avoiding key points with no position mutation; Figure 3 shows that joint velocity curves are smooth, continuous, with no sudden change; Figure 4 shows that ammunition loading robot joint acceleration curve is continuous, with no sudden change. In summary, the joint space trajectory planning of ammunition loading robot based on the cubic-B spline is not only satisfy the kinematic requirements of ammunition loading robot, but also guarantee its good dynamic characteristics.

Conclusions

The paper put forward the obstacle avoidance trajectory planning method based on cubic-B, by which the trajectories planning in joint space of ammunition loading robot are finished. Simulate the 2th, 3th, 4th joints dynamics characters of ammunition loading robot by using dynamic simulation software, and the joint trajectory curves are continuous and smooth, angular velocity and angular acceleration curves are continuous with no sudden change, verifying that trajectories generating by cubic-B spline have good dynamic characteristic, making the ammunition loading robot in the working process no impacts, and guaranteeing ammunition loading robot complete loading task, also can prolong the service life of ammunition loading robot.

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