The Research on Trajectory Planning of Agricultural Intelligent Robot Based on Quintic Polynomials

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Abstract. To ensure stable and continuous motion of agricultural intelligent robot and avoid operational jitter, this paper presents a quintic polynomial method to construct segmented motion trajectories for robot, which are divided into three stages: acceleration, uniform velocity and deceleration. The quintic polynomial can impose continuous constraints on displacement, velocity and acceleration. Through segmented trajectory connection design, sudden velocity changes and acceleration jumps during trajectory switching are effectively eliminated to ensure smooth transition of motion parameters in each stage. This trajectory planning method takes both motion continuity and operational stability into account, adapting to the start-stop and variable-speed motion requirements of agricultural intelligent robot. It avoids mechanical impact and vibration caused by discontinuous trajectories, improves the motion control accuracy and operational reliability of robot, and provides feasible ideas and technical references for similar flexible trajectory planning and precise control.

Keywords: trajectory planning, agricultural intelligent robot, quintic polynomials, MATLAB

1 Introduction

Currently, the commonly used robot trajectory planning methods include cubic polynomials and quintic polynomials. In the trajectory planning process, emphasis is placed on time optimality to improve work efficiency, while the problems of jumps and impacts existing in the operation trajectory are often ignored, which will reduce work quality and affect the performance and service life of the robot [1]. Industrial robots commonly adopt 3-5-3 piecewise polynomials for trajectory planning, but cubic polynomials have inherent defects at the start and end moments [2]. The 3-5-3 piecewise polynomial method uses cubic polynomials for acceleration and deceleration segments and a quintic polynomial for the middle constant velocity transition segment, ensuring continuity of position, velocity and acceleration at waypoints, as well as smooth jerk transition to suppress motion impact. For agricultural intelligent robot undertaking

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precise operations like crop picking and spraying, trajectory smoothness and stability are crucial for improving operation quality and reducing crop damage. But they only ensure the continuity of position and velocity at waypoints, not acceleration, leading to sudden acceleration changes of robot joints. This causes impact loads on the mechanical structure, reducing motion stability and smoothness, accelerating transmission component wear, shortening service life and affecting end effector positioning accuracy in high-precision scenarios. Therefore, this study proposes a 5-1-5 robot trajectory planning method. Centering on segmented interpolation and smooth connection, it breaks the single- interpolation mode of traditional polynomial trajectory planning and achieves high- precision control of robot motion trajectories by introducing fifth- order spline and polynomial interpolation. Through the segmented combination structure of "quintic polynomial-linear polynomial-quintic polynomial", it balances the trajectory smoothness and motion efficiency [3]. Among them, quintic polynomial interpolation is adopted for the starting and ending segments of the trajectory, which can realize four-order continuity of position, velocity, acceleration and jerk, fundamentally eliminating the problem of sudden acceleration changes of traditional cubic polynomial trajectories during the start-up and termination phases [4, 6].

This avoids unstable phenomena such as jumps and impacts during the robot's operation, effectively reduces the wear of mechanical structures, and extends the service life of agricultural intelligent robot. Linear polynomial interpolation is used for the middle segment, which can maximize the speed of the uniform motion phase on the basis of ensuring smooth trajectory connection, laying a foundation for the realization of the time-optimal goal.

2 Methodology

The displacement of agricultural intelligent robot in the general field can be represented by a cubic polynomial. Then, by getting the first and second derivatives of the cubic polynomial, the expressions for the velocity and acceleration of the agricultural intelligent robot can be obtained, which are shown in Equation (1):

$$\begin{cases} \theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 \\ \theta(t) = a_1 + 2a_2 t + 3a_3 t^2 \\ \theta(t) = 2a_2 + 6a_3 t \end{cases} \tag{1}$$

Similarly, we can get the displacement, velocity and acceleration expressions for quintic polynomial motion trajectories, which are shown in Equation (2):

$$\begin{cases} \theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5 \\ \theta(t) = a_1 + 2a_2 t + 3a_3 t^2 + 4a_4 t^3 + 5a_5 t^4 \\ \theta(t) = 2a_2 + 6a_3 t + 12a_4 t^2 + 20a_5 t^3 \end{cases} \tag{2}$$

Suppose that the values of the initial position and velocity are 10 (°) and 0 (°/s), respectively and the values of the final position and velocity are 5 (°) and 0 (°/s), respectively. At the same time, the values of positions and velocities during

interpolations t_1 and t_2 are 8 (°) and 6 (°), 3 (°/s) and 2 (°/s), respectively. The actual execution time is 3 seconds.

Substituting these values into the expressions of the coefficients of the system of equations (1) and (2), the motion trajectories shown in Figure 1:

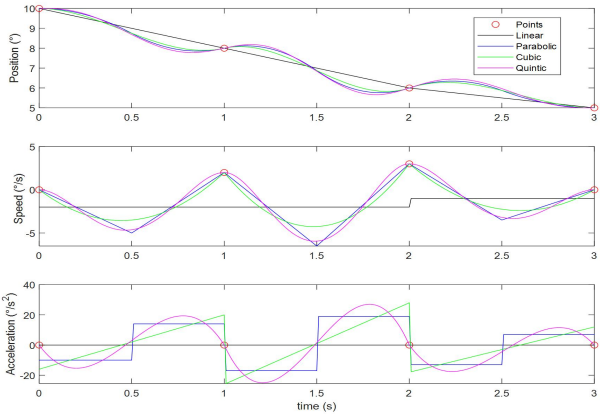


Fig. 1. Comparative diagram using linear, parabolic interpolation, cubik and quintic polynomials

Fig. 1 intuitively compares the motion trajactory state changes under four different interpolation methods, reflecting the differences in trajectory smoothness, continuity and stability among various methods. It can be seen from the figure that the trajectories obtained by linear interpolation and parabolic interpolation have obvious discontinuities, which may cause jumps and impacts during agricultural intelligent robot operation; the trajectory of cubic polynomial interpolation is relatively smooth but still has defects in acceleration continuity; the trajectory of quintic polynomial interpolation is continuously smooth without sudden changes, which can effectively ensure the stable operation of the agricultural intelligent robot and provide a basis for the rationality of the 5-1-5 trajectory planning method proposed in this study.

This study constructs a 5-1-5 segmented polynomial motion trajectory based on the quintic polynomial and its motion trajectory expression is shown in Equation (3):

$$\begin{cases} \theta_{i1}(t) = a_{i10} + a_{i11}(t-t_0) + a_{i12}(t-t_0)^2 + a_{i13}(t-t_0) \\ \quad + a_{i14}(t-t_0)t^4 + a_{i15}(t-t_0)^5 \qquad t \in [t_{i0}, t_{i1}] \\ \quad \theta_{i2}(t) = a_{i20} + a_{i21}(t-t_1) \qquad t \in [t_{i1}, t_{i2}] \\ \theta_{i3}(t) = a_{i30} + a_{i31}(t-t_2) + a_{i32}(t-t_2)^2 + a_{i33}(t-t_2) \\ \quad + a_{i34}(t-t_2)t^4 + a_{i35}(t-t_2)^5 \quad t \in [t_{i2}, t_{i3}] \end{cases} \tag{3}$$

where: $\theta_1(t)$, $\theta_2(t)$ and $\theta_3(t)$ denote the trajectory expressions for the acceleration segment, constant- velocity segment and deceleration segment, respectively; t_0, t_1 and t_2 represent the corresponding time instants of motion; t_1 and t_2 are the interpolation time points along the whole trajectory.

To get the interpolation of velocity, acceleration and jerk, the first-order, second-order and third-order derivatives of the trajectory expression can be calculated. Several constraints need to be introduced to achieve a continuous trajectory. These constraints require that the position, velocity and acceleration at the start and end of adjacent trajectory segments are equal, as given in Equations (4) and (5):

$$\theta_{1(t_1)} = \theta_{2(t_1)}, \theta_{1(t1)} = \theta_{2(t_1)}, \theta_{1(t_1)} = \theta_{2(t_1)} \tag{4}$$

$$\theta_{2(t_2)} = \theta_{3(t_2)}, \theta_{2(t2)} = \theta_{3(t_2)}, \theta_{2(t_2)} = \theta_{3(t_2)} \tag{5}$$

In addition to Equations (4) and (5), constraint conditions shown in Equations (6) - (8) should be defined to ensure a continuous motion trajectory.

$$\theta_{3(t_3)} = \theta_f, \theta_{3(t_3)} = 0, \theta_{3(t_3)} = 0 \tag{6}$$

$$\theta_{1(t_0)} = \theta_0, \theta_{1(t_0)} = 0, \theta_{1(t_0)} = 0 \tag{7}$$

$$\theta_{1(t_1)} = \theta_1, \theta_{2(t_2)} = \theta_2 \tag{8}$$

where: the determined position interpolation values are equal to θ_0, θ_1, θ_2 and θ_f, respectively, while the velocity and acceleration at the start and end are zero to ensure operational safety.

The agricultural intelligent robot is modeled based on the human upper limb arm and the robot model is established in MATLAB [5]. The specific parameters of agricultural intelligent robot are presented in Table 1.

Table 1. The parameters of agricultural intelligent robot

Number(*i*)	a_i(mm)	α_i(*rad*)	d_i(mm)
1	50	-pi/2	50
2	260	0	0
3	350	-pi/2	0
4	0	pi/2	0

Sample of a Table footnote. (*Table footnote*)

Where: the four-degree-of-freedom agricultural intelligent robot, designed according to the human upper limb, consists of three parts, namely the shoulder, elbow and wrist.

Suppose that forearm flexion training is required, with the flexion angle ranging from 0.017 rad to 0.139 rad. The entire training process lasts 3 seconds, where the acceleration segment, constant-velocity segment and deceleration segment each take 1 second.

3 Results and Analysis

We simulate in MATLAB and get trajectory curves according to the requirements for single joint trajectory planning and Equation (3). The displacement curve of the single joint agricultural intelligent robot is shown in Fig. 2:

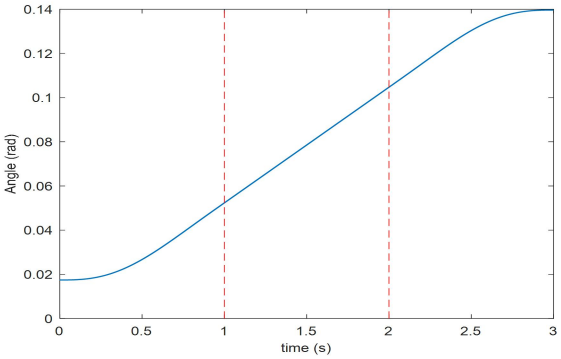


Fig. 2. The displacement curve of the single joint

The curve in Fig. 2 represents the angular response curve of the robot with time, which is smooth and continuous without abrupt changes or sharp peaks. Specifically, the curve varies gently from 0 to 1 second, corresponding to the start-up phase where the angular velocity rises slowly; the period from 1 to 2 seconds denotes the uniform motion phase with steadily increasing angular displacement; from 2 to 3 seconds, the slope of the curve gradually decreases and levels off at the end, enabling the robot to decelerate smoothly and approach the target position.

The speed curve of the single joint agricultural intelligent robot is shown in Fig. 3:

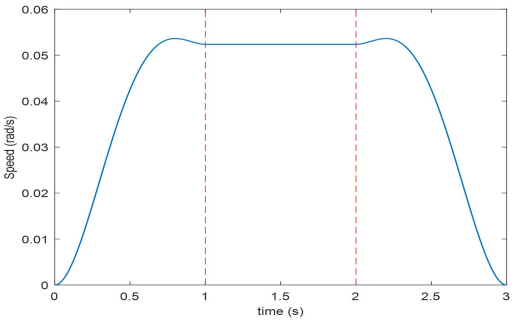


Fig. 3. The speed curve of the single joint

The curve plotted in Fig. 30 reacts the time-varying angular velocity response of the robot, exhibiting a typical trapezoidal velocity profile with smoothness and continuity throughout the whole motion cycle, where no abrupt velocity variations or mechanical shocks are observed. Specifically, the angular velocity increases steadily within the time interval of 0-1 seconds, corresponding to the uniformly accelerated startup phase of the robotic manipulator; a constant angular velocity is maintained from 1 to 2 seconds, enabling stable constant-velocity operation for field tasks; thereafter, the angular velocity declines gently during 2-3 seconds to accomplish uniformly decelerated braking.

The acceleration curve of the single joint for agricultural intelligent robot is shown in Fig. 4:

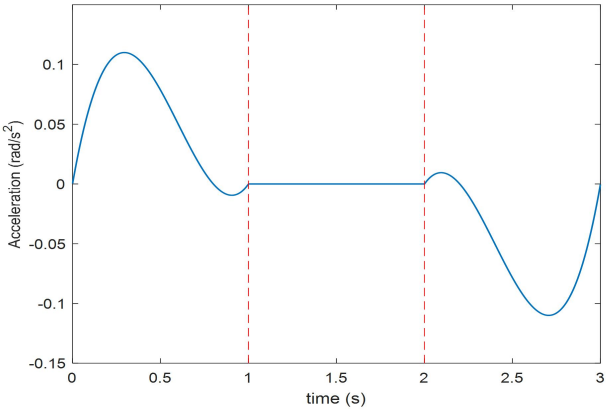


Fig. 4. The acceleration curve of the single joint

The curve in Fig. 4 reacts the time-varying angular acceleration response of the robot, featuring continuous variation throughout the motion cycle without abrupt shocks. During the time interval of 0-1 second the angular acceleration initially increases in the positive direction, subsequently decreases, which corresponds to the startup-acceleration phase and smooth velocity transition of the robot. During 1-2 seconds, the angular acceleration maintains a steady zero value, consistent with the constant-velocity motion segment free from acceleration-deceleration perturbations. In the 2-3 seconds phase, the angular acceleration rises negatively at first and then gradually converges to zero, corresponding to the deceleration-braking stage of the robotic system.

Suppose multi-joint simulation is to be implemented, with the whole motion process spanning 3 seconds, where the acceleration phase, constant-velocity phase and deceleration phase each last for 1 second. With the initial and terminal positions predefined, two interpolation nodes are determined by virtue of the MATLAB Robotics Toolbox, from which four motion waypoints are derived, as tabulated in Table 2.

Table 2. Robot Motion Path Points in Cartesian Space (cm)

Point	*X*	*Y*	*Z*
X0	66	0	5
X1	64.64	5.656	-5.888
X2	60.68	10.7	-16.3
X3	54.42	14.58	-25.77

Sample of a Table footnote. (Table footnote)

Where: *X0* and *X3* denote the start and end points of the agricultural intelligent robot path in Cartesian space, while *X1* and *X2* represent the interpolation nodes.

Corresponding to the agricultural intelligent robot path points in Cartesian space, the agricultural intelligent robot moves along the spatial joint points listed in Table 3.

Table 3. Robot Motion Path Points in Joint Space (Rad)

Joint (*i*)	X_0	X_1	X_2	X_3
1	0	0.0873	0.1745	0.2618
2	0	0.1047	0.2094	0.3142
3	0	0.1309	0.2618	0.3927
4	0	0.1571	0.3142	0.4712

Sample of a Table footnote. (*Table footnote*)

Where: X_0 and X_3 are the start and end points of the path in joint space, and X_1 and X_2 are the interpolation nodes.

So, the motion path is divided into three segments: the path segments from X_0 to X_1 and from X_2 to X_3 are defined by a quintic polynomial, where as the path segment from X_1 to X_2 is defined by a linear function. The durations of the acceleration and deceleration segments are separately set to 1.5 s and the constant velocity segment lasts for 2 s, forming a total motion time of 5 s. The multi joints displacement curves of the agricultural intelligent robot are shown in Fig. 5:

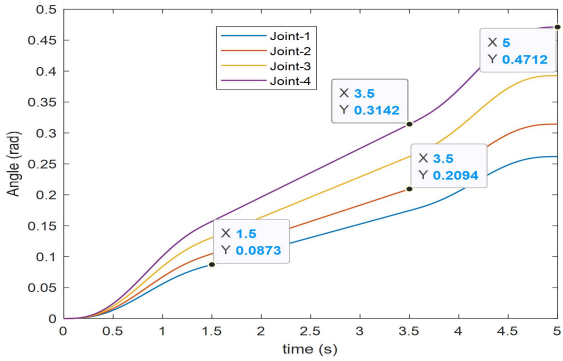


Fig. 5. The angular curve of the multi joints

The multi joints speed curves of agricultural intelligent robot are shown in Fig. 6:

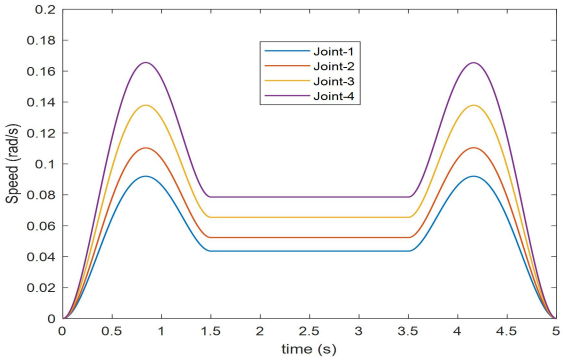


Fig. 6. The speed curve of the multi joints

The multi joints speed curves of agricultural intelligent robot are shown in Fig. 7:

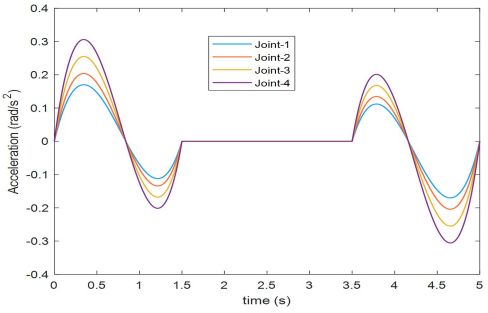


Fig. 7. The acceleration curve of the multi joints

Fig. 5 illustrates the displacement-time curves of each joint for a 4-joint intelligent agricultural robot. The horizontal axis represents time in seconds, while the vertical axis denotes joint displacement. The four curves correspond to Joint-1, Joint-2, Joint-3, and Joint-4 respectively. The total motion duration is 5 s, planned by a 5-1-5 segmented polynomial interpolation trajectory: the acceleration phase lasts from 0 to 1.5 s, the constant-velocity phase ranges from 1.5 to 3.5 s, and the deceleration phase covers 3.5 to 5 s. Time-displacement coordinates at key waypoints are marked. All joint displacement curves are continuous and smooth without abrupt changes, which meets the control requirements for stable intelligent agricultural robot motion.

The well-smoothed velocity transition demonstrates that the adopted trajectory planning strategy can effectively mitigate dynamic impacts on mechanical components and guarantee high-quality motion stability of the agricultural intelligent robot.

Fig. 6 shows the velocity-time curves of each joint of a four-joint intelligent agricultural robot, where the horizontal axis represents time and the vertical axis denotes joint motion velocity, with four curves corresponding to Joint-1 to Joint-4. Adopting the 5-1-5 segmented polynomial interpolation for trajectory planning, each

joint accelerates steadily to its peak velocity from 0 s to 1.5 s, maintains constant velocity during 1.5 s–3.5 s, and decelerates smoothly to zero from 3.5 s to 5 s.

Fig. 7 shows the acceleration-time curves of each joint of a four-joint agricultural intelligent robot, where the horizontal axis represents motion time and the vertical axis denotes joint acceleration, with four curves corresponding to Joint-1, Joint-2, Joint-3 and Joint-4 respectively. Based on the 5-1-5 segmented polynomial interpolation trajectory planning, the acceleration increases positively and then decreases negatively during the acceleration phase from 0 s to 1.5 s, maintains zero in the constant-velocity phase of 1.5 s–3.5 s, and presents the same variation trend of positive-first-then-negative growth in the deceleration phase of 3.5 s–5 s.

4 Discussion

The multi joints angle curves of agricultural intelligent robot are shown in Fig. 8:

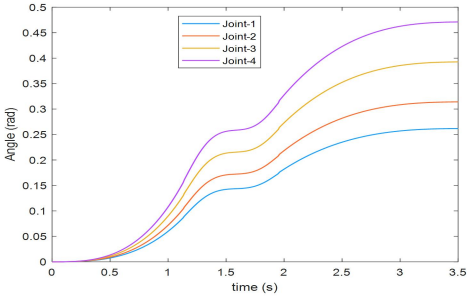


Fig. 8. The angle curve of the multi joints with 3-5-3

The multi joints speed curves of agricultural intelligent robot are shown in Fig. 9:

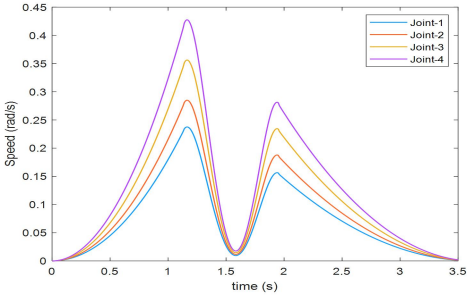


Fig. 9. The speed curve of the multi joints with 3-5-3

The multi joints acceleration curves of agricultural intelligent robot are shown in Fig. 10:

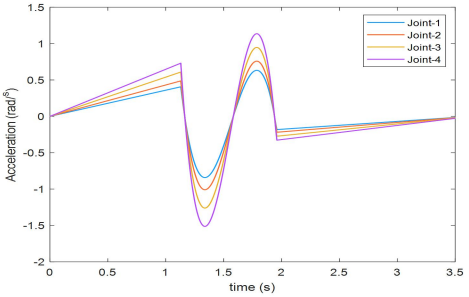


Fig. 10. The acceleration curve of the multi joints with 3-5-3

Compared with the traditional 3-5-3 piecewise polynomial, the 5-1-5 piecewise polynomial has obvious advantages. It adopts quintic polynomials for acceleration and deceleration segments, further improving the continuity of jerk and reducing motion impact, which is superior to the 3-5-3 method in motion smoothness. All joint acceleration curves are continuous and smooth without abrupt shocks, which indicates that the planning method can effectively suppress joint vibration and ensure the motion stability of the robot.

For agricultural intelligent robot, it can better adapt to complex field environments, reduce vibration during crop picking and spraying, avoid crop damage, and improve operation precision. Meanwhile, its simpler segment structure reduces computational complexity, shortens trajectory planning time, and enhances real-time performance, which is suitable for the dynamic and variable operation requirements of agricultural intelligent robot.

In the future, a genetic algorithm will be introduced to solve the time-optimal problem of the trajectory and optimize motion timing, so as to adapt to diversified and dynamic field working conditions of agricultural intelligent robot.

5 Conclusion

This study uses quintic polynomials for agricultural intelligent robot segmented trajectory planning and divides trajectory into acceleration, constant-velocity and deceleration segments. Continuous constraints are applied to displacement, velocity and acceleration to restrain motion trajectory jumps and removes robot jitter. This method ensures the stability and continuity of agricultural intelligent robotic motion during field work and improves environmental adaptability under complex farmland conditions.

Acknowledgments

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References

1. Wang W, He L, Jiang Q, et al. Path planning algorithm of a novel massage robot [C]. 2016 9th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI), Datong, China, 2016:1670-1674.
2. Wang H, Zhao Q, Li H, et al. Polynomial-based smooth trajectory planning for fruit-picking robot manipulator[J]. Inform. Process. Agr., 2022, 9(1):112-122.
3. Peng Y, Tang B, Huang D, et al. Manipulator trajectory planning based on clustering curve discretization and B-Spline [J]. Journal of Field Robotics, 2025, 42(5):1991-2004.
4. Zhongjie Y, Shenglong X, Yuntang L, et al. A structural design and workspace analysis of a lumbar massage robotic arm[J]. Recent Patents on Mechanical Engineering, 2025, 18:1-14.
5. Cai J, Deng J, Zhang W, et al. Modeling method of autonomous robot manipulator based on D-H algorithm[J]. Mobile Information Systems, 2021, 2021(1):4448648.
6. Xie Y, Yan Y H, SHI Z, et al. Adaptive optimal tracking control for multi-joint manipulator on space robot[J]. Optim. Contr. Appl. Met., 2020, 41(6):1995-2007.

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