

# ***S-curve Velocity Planning For Both Single-Degree-of-Freedom (SDOF) and Five-Degree-of-Freedom (5-DOF) Robotic Arm Systems***

**Jiale Zeng**

*Department of Mechanical Engineering, Dalian University of Technology, Dalian, China  
1044060@mail.dlut.edu.cn*

**Abstract:** Robotics has become increasingly prevalent across diverse domains, offering enhanced efficiency and convenience through robotic technologies. Consequently, the investigation of motion planning and control strategies for robotic arms has emerged as a research focus in robotics. This paper presents a comprehensive study and implementation of motion control methodology based on S-curve velocity planning for both single-degree-of-freedom (SDOF) and five-degree-of-freedom (5-DOF) robotic arm systems. The S-curve velocity planning divides motion into three phases: acceleration, constant velocity and deceleration stages. This segmentation effectively minimizes acceleration mutation, thereby facilitating smooth transitional movements of robotic arm and significantly reducing damage to robotic arm due to system vibration and shock. For the SDOF system, this paper meticulously derives the mathematical framework of S-curve velocity planning, accompanied by analyses of velocity, acceleration and jerk curve. Simulation results validate the method's superior motion smoothness characteristics compared to conventional approaches. For the 5-DOF system, the study extends S-curve velocity planning by introducing a coordinated velocity planning algorithm for multi-degree-of-freedom systems. This algorithm not only individually optimizes each joint velocities but also accounts for inter-joint coupling effects. Through simulation experiments, this paper verifies the effectiveness and superiority of S-curve velocity planning in SDOF and 5-DOF robotic arm systems. The experimental results demonstrate significant improvements in motion smoothness, substantial reductions in system vibrations and shocks, while maintaining high precision in end-effector trajectory. This research contributes reliable solutions and practical insights for motion planning in both single and multi-degree-of-freedom robotic manipulators, offering substantial applicability in engineering implementations and industrial automation scenarios.

**Keywords:** velocity planning, SDOF, 5-DOF

## **1. Introduction**

Robotics has become integral to industries like manufacturing, healthcare, and services, with robotic arm motion planning emerging as a core research focus [1-2]. Despite advancements, challenges remain in balancing path accuracy, motion smoothness, and mechanical protection across varying

degrees of freedom (DOF). Optimizing motion planning algorithms is crucial for enhancing robotic arm performance.

Multi-DOF systems present greater complexity than single-DOF configurations, requiring joint coordination to ensure end-effector trajectory precision. These systems must account for kinematic and dynamic constraints, joint velocity/acceleration transitions, and mechanical stress from abrupt acceleration changes. Smooth, efficient motion planning for multi-DOF systems is thus a critical research direction [3].

S-curve velocity planning addresses these challenges by dividing motion into acceleration, constant velocity, and deceleration phases [4]. This method reduces acceleration discontinuities inherent in traditional trapezoidal planning, enhancing motion stability and accuracy. While S-curve planning is well-established for single-DOF point-to-point motion, its application to 5-DOF systems demands individual joint velocity planning and inter-joint coordination [5].

This paper investigates S-curve planning for both single-DOF and 5-DOF systems. For single-DOF, we derive the mathematical model and analyze velocity, acceleration, and jerk profiles, demonstrating motion smoothness advantages. For 5-DOF, we extend the approach with a coordinated joint velocity planning algorithm, validated through MATLAB simulations to ensure motion stability and end-effector accuracy. The study provides theoretical and practical insights for multi-DOF robotic arm motion planning [6].

## 2. Introduction to Related Theories

Motion planning of a robotic arm is based on kinematics, so before simulation and motion planning of a robotic arm, the kinematics of the robotic arm is modeled. In order to determine the relative relationship between the robotic arm system and the environment, it needs to be described using appropriate mathematical relationships. When studying the motion of a robotic arm, it is usually described using the matrix method [7]. This method allows complex kinematic equations to be expressed in a compact matrix form and can describe the robotic arm in a concise and intuitive form.

### 2.1. Modeling of DH Kinematics

Assuming that a robotic arm can be viewed as a series of linkage mechanisms connected by joints, each joint of the robotic arm can be used as the origin of a coordinate system. A joint and a connecting rod are treated as a linkage mechanism, and the coordinate system is fixed in each linkage mechanism, and the relative positions and directions of these coordinate systems can be described by chi-square transformations. Through the relative displacement, velocity and acceleration changes of each link mechanism, different postures can be realized in each link mechanism, and then its velocity, acceleration and other parameters can be adjusted so that the motion of each joint can be smoothly transitioned [8].

For the coordinate system  $\{A\}$ , the Z-axis is the axis of rotation or direction of motion along the joints, the X-axis is the common normal of two neighboring joints, and the Y-axis is determined by the right-hand rule. The positional relationship of the joints can be described by the position vectors of this coordinate system, and the orientation of the joints can be described by the deflection angle, pitch angle, and slew angle of their position vectors. Among them, the deflection angle is generated by rotating around the X-axis, the pitch angle is generated by rotating around the Y-axis, and the slew angle is generated by rotating around the Z-axis.

## 2.2. Transformation of the Connecting Rod Coordinate System

Table 1: DH Parameters.

| Symbols  | Definition                            | Units |
|----------|---------------------------------------|-------|
| d        | The deviation of the joint            | mm    |
| a        | The length of connecting rod          | mm    |
| $\alpha$ | The twist angle of the connecting rod | (°)   |
| $\theta$ | The angle of joint                    | (°)   |

Table 1 shows the four parameters of the robot arm. Among them, d is the distance between the origin of the current coordinate system and the Z-axis of the last coordinate system; a is the distance between the origin of the current coordinate system and the X-axis of the last coordinate system;  $\alpha$  is the rotation angle of the current coordinate system with respect to the X-axis of the last connecting rod coordinate system;  $\theta$  is the rotation angle of the current coordinate system with respect to the Z-axis of the last connecting rod coordinate system.

For two neighboring connecting rods i and i-1, these four parameters  $d_i$ ,  $a_i$ ,  $\alpha_i$ ,  $\theta_i$  determine the relative relationship between them. The transformation rule between the connecting rods follows four steps. Firstly, rotate  $\theta_{n+1}$  about  $Z_n$ -axis, let the robotic arm coordinate  $X_n$  parallel to  $X_{n+1}$ . Secondly, translate  $d_{n+1}$  along  $Z_n$ -axis, let the robotic arm coordinate  $X_n$  and  $X_{n+1}$  collinear. Then, translate  $a_{n+1}$  along the  $X_n$ -axis, let the current  $X_n$ -axis coincides with the origin of the next  $X_{n+1}$ -axis. Lastly, rotate the  $Z_n$ -axis in the current coordinate system by  $\alpha_{n+1}$  about the  $X_{n+1}$ -axis in the next coordinate system, let the  $Z_n$ -axis in the current coordinate system and the  $Z_{n+1}$ -axis in the next coordinate system collinear. The transformation from the link i-1 coordinate system to the link i coordinate system is:

$$T_i = R(z, \theta_i)T(0, 0, d_i)T(a_i, 0, 0)R(x, \alpha_i)$$

$$= \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{i-1} \\ \sin\theta_i\cos\alpha_{i-1} & \cos\theta_i\cos\alpha_{i-1} & -\sin\alpha_{i-1} & -d_i\sin\alpha_{i-1} \\ \sin\theta_i\sin\alpha_{i-1} & \cos\theta_i\sin\alpha_{i-1} & \cos\alpha_{i-1} & d_i\cos\alpha_{i-1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

For an n-degree-of-freedom robotic arm, the kinematic equations are:

$${}^0T_n = {}^0T_1(\theta_1){}_1T_2(\theta_2)\dots {}^{n-1}T_n(\theta_n) \quad (2)$$

## 3. Derivation of S-shaped Velocity Planning

S-shaped velocity planning is a velocity planning method for smooth motion control in which the acceleration is continuously varied by controlling the degree of jump. The complete S-shaped velocity planning is divided into seven stages, which is more complicated compared to the traditional trapezoidal velocity planning. To study the motion of a robotic arm system under S-shaped velocity planning, its kinematic equations must be determined first. Thus, they can be described mathematically and are derived below.

### 3.1. Stage1- Acceleration Stage

Let the time of the seven stages of motion of the robotic arm system be  $T_i$ ,  $i = 1, 2, \dots, 7$ . In the first phase, the system acceleration  $A > 0$ , jerk  $J > 0$  and constant, the time  $t \in [0, T_1]$ .

For robotic arm systems:

$$\text{Jerk: } J(t) = \frac{dA(t)}{dt} \quad (3)$$

$$\text{Acceleration: } A(t) = \int J(t)dt = Jt + A_0 \quad (4)$$

$$\text{Velocity: } v(t) = \int A(t)dt = \frac{1}{2}Jt^2 + A_0t + v_0 \quad (5)$$

$$\text{Displacement: } S(t) = \int v(t)dt = \frac{1}{6}Jt^3 + \frac{1}{2}A_0t^2 + v_0t + S_0 \quad (6)$$

Among this,  $A_0$  denotes the initial acceleration of the robotic arm system,  $v_0$  denotes the initial velocity, and  $S_0$  denotes the initial displacement. In the first stage, these three initial quantities are all 0, then its kinematic equation is:

$$A(t) = Jt \quad (7)$$

$$v(t) = \frac{1}{2}Jt^2 \quad (8)$$

$$S(t) = \frac{1}{6}Jt^3 \quad (9)$$

### 3.2. Stage2 - Uniform acceleration stage

In this phase, the system acceleration  $A > 0$  and is constant, the jerk  $J = 0$ , and the time  $t \in [T_1, T_2]$ . From the first stage, the velocity at the end of the first stage can be gotten, the equations of motion are:

$$v(t) = A_2(t - T_1) + v_1, v_1 = \frac{1}{2}JT_1^2 \quad (10)$$

$$\begin{aligned} S(t) &= \frac{1}{2}A_2(t - T_1)^2 + v_1(t - T_1) + \frac{1}{6}JT_1^3 \\ &= \frac{1}{2}A_2(t - T_1)^2 + \frac{1}{2}JT_1^2(t - T_1) + \frac{1}{6}JT_1^3 \end{aligned} \quad (11)$$

### 3.3. Stage3 - Reduction acceleration stage

In this phase, the system acceleration  $A > 0$ , the jerk  $J < 0$  and constant, and the time  $t \in [T_2, T_3]$ . From the first and second phases, the displacement  $S_1$  at the end of the first phase and the acceleration  $A_2$  at the end of the second phase can be gotten, the equations of kinematics are:

$$A(t) = -J(t - T_1 - T_2) + A_2, A_2 = JT_1 \quad (12)$$

$$\begin{aligned} v(t) &= v_1 + A_2(t - T_1) - \frac{1}{2}J(t - T_1 - T_2)^2 \\ &= \frac{1}{2}JT_1^2 + A_2(t - T_1) - \frac{1}{2}J(t - T_1 - T_2)^2 \end{aligned} \quad (13)$$

$$\begin{aligned} S(t) &= S_1 + v_1(t - T_1) + \frac{1}{2}A_2(t - T_1)^2 - \frac{1}{6}J(t - T_1 - T_2)^3 \\ &= \frac{1}{6}JT_1^3 + \frac{1}{2}JT_1^2(t - T_1) + \frac{1}{2}A_2(t - T_1)^2 - \frac{1}{6}J(t - T_1 - T_3)^3, S_1 = \frac{1}{6}JT_1^3 \end{aligned} \quad (14)$$

### 3.4. Stage4 - Uniform motion stage

In this phase, the system acceleration  $A = 0$ , the jerk  $J = 0$ , and the motion time  $t \in [T_3, T_4]$ . The velocity reaches a maximum value  $v_{max}$  when  $t = T_1 + T_2 + T_3$ . From the third stage, the displacement at the end of the third stage  $S_3$  can be gotten, the equations of kinematics are:

$$v(t) = v_{max} = v_1 + A_2(T_2 + T_3) - \frac{1}{2}JT_3^2$$

$$= \frac{1}{2}JT_1^2 + A_2(T_2 + T_3) - \frac{1}{2}JT_3^2 \quad (15)$$

$$\begin{aligned} S(t) &= S_3 + v_{max}(t - T_1 - T_2 - T_3) \\ &= \frac{1}{6}JT_1^3 + \frac{1}{2}JT_1^2(T_2 + T_3) + \frac{1}{2}A_2(T_2 + T_3)^2 - \frac{1}{6}JT_3^2 + \frac{1}{2}JT_1^2(t - T_1 - T_2 - T_3) \\ &\quad + A_2(T_2 + T_3)(t - T_1 - T_2 - T_3) - \frac{1}{2}JT_3^2(t - T_1 - T_2 - T_3) \end{aligned} \quad (16)$$

### 3.5. Stage5 - Acceleration reduction stage

In this phase, the system acceleration  $A < 0$ , the jerk  $J < 0$  and constant, at time  $t \in [T4, T5]$ . Its kinematic equations are:

$$A(t) = -J(t - T_1 - T_2 - T_3 - T_4) \quad (17)$$

$$\begin{aligned} v(t) &= v_{max} - \frac{1}{2}J(t - T_1 - T_2 - T_3 - T_4)^2 \\ &= \frac{1}{2}JT_1^2 + A_2(T_2 + T_3) - \frac{1}{2}JT_3^2 - \frac{1}{2}J(t - T_1 - T_2 - T_3 - T_4)^2 \end{aligned} \quad (18)$$

$$\begin{aligned} S(t) &= S_3 + v_{max}T_4 - \frac{1}{6}J(t - T_1 - T_2 - T_3 - T_4)^3 \\ &= \frac{1}{6}JT_1^3 + \frac{1}{2}JT_1^2(T_2 + T_3) + \frac{1}{2}A_2(T_2 + T_3)^2 - \frac{1}{6}JT_3^3 \\ &\quad + \frac{1}{2}JT_1^2T_4 + A_2(T_2 + T_3)T_4 - \frac{1}{2}JT_3^2T_4 - \frac{1}{6}J(t - T_1 - T_2 - T_3 - T_4)^3 \end{aligned} \quad (19)$$

### 3.6. Stage6 - Uniform deceleration stage

In this phase, the system acceleration  $A < 0$  and is constant, the jerk  $J = 0$ , and the time  $t \in [T5, T6]$ . Its kinematic equations are:

$$\begin{aligned} v(t) &= v_{max} - \frac{1}{2}J(t - T_1 - T_2 - T_3 - T_4)^2 - A_6(t - T_1 - T_2 - T_3 - T_4 - T_5) \\ &= \frac{1}{2}JT_1^2 + A_2(T_2 + T_3) - \frac{1}{2}JT_3^2 - \frac{1}{2}J(t - T_1 - T_2 - T_3 - T_4)^2 - A_6(t - T_1 - T_2 - T_3 - T_4 - T_5) \quad (20) \\ S(t) &= S_3 + v_{max}T_4 - \frac{1}{6}J(t - T_1 - T_2 - T_3 - T_4)^3 - \frac{1}{2}A_6(t - T_1 - T_2 - T_3 - T_4 - T_5)^2 \\ &= \frac{1}{6}JT_1^3 + \frac{1}{2}JT_1^2(T_2 + T_3) + \frac{1}{2}A_2(T_2 + T_3)^2 - \frac{1}{6}JT_3^3 + \frac{1}{2}JT_1^2T_4 + A_2(T_2 + T_3)T_4 - \frac{1}{2}JT_3^2T_4 \\ &\quad - \frac{1}{6}J(t - T_1 - T_2 - T_3 - T_4)^3 - \frac{1}{2}A_6(t - T_1 - T_2 - T_3 - T_4 - T_5)^2 \end{aligned} \quad (21)$$

### 3.7. Stage7 - Deceleration stage

In this phase, the system acceleration  $A < 0$ , the jump  $J > 0$  and constant, and the time  $t \in [T6, T7]$ . From the sixth stage, the acceleration at the end of the sixth stage is  $A_6$ , and its kinematic equations are:

$$\begin{aligned} A(t) &= -A_6 + J(t - T_1 - T_2 - T_3 - T_4 - T_5 - T_6), A_6 = -JT_5 \quad (22) \\ v(t) &= v_{max} - \frac{1}{2}J(t - T_1 - T_2 - T_3 - T_4)^2 \\ &\quad - A_6(t - T_1 - T_2 - T_3 - T_4 - T_5) + \frac{1}{2}J(t - T_1 - T_2 - T_3 - T_4 - T_5 - T_6)^2 \\ &= \frac{1}{2}JT_1^2 + A_2(T_2 + T_3) - \frac{1}{2}JT_3^2 - \frac{1}{2}J(t - T_1 - T_2 - T_3 - T_4)^2 \end{aligned}$$

$$\begin{aligned}
 & -A_6(t - T_1 - T_2 - T_3 - T_4 - T_5) + \frac{1}{2}J(t - T_1 - T_2 - T_3 - T_4 - T_5 - T_6)^2 \\
 & S(t) = S_3 + v_{max}T_4 - \frac{1}{6}J(t - T_1 - T_2 - T_3 - T_4)^3 \\
 & -\frac{1}{2}A_6(t - T_1 - T_2 - T_3 - T_4 - T_5)^2 + \frac{1}{6}J(t - T_1 - T_2 - T_3 - T_4 - T_5 - T_6)^3 \\
 & = \frac{1}{6}JT_1^3 + \frac{1}{2}JT_1^2(T_2 + T_3) + \frac{1}{2}A_2(T_2 + T_3)^2 - \frac{1}{6}JT_3^3 + \frac{1}{2}JT_1^2T_4 + A_2(T_2 + T_3)T_4 \\
 & -\frac{1}{2}JT_3^2T_4 - \frac{1}{6}J(t - T_1 - T_2 - T_3 - T_4)^3 - \frac{1}{2}A_6(t - T_1 - T_2 - T_3 - T_4 - T_5)^2 \\
 & + \frac{1}{6}J(t - T_1 - T_2 - T_3 - T_4 - T_5 - T_6)^3
 \end{aligned} \tag{24}$$

#### 4. Single Degree of Freedom Simulation

The main objective of this simulation experiment is to verify the effectiveness of S-shaped velocity planning. The velocity, angle, acceleration and jump curves of the single-degree-of-freedom robotic arm are investigated and the acceleration is observed for any sudden change in the acceleration.

In the case of the initial angle of  $0^\circ$ , the angle of the final position of the robotic arm is  $150^\circ$ , the speed is 80 mm/s, the acceleration is  $80 \text{ mm/s}^2$ , and the total movement time is 4s; in the case of the initial angle of  $20^\circ$ , the angle of the final position is  $180^\circ$ , and other conditions remain unchanged.

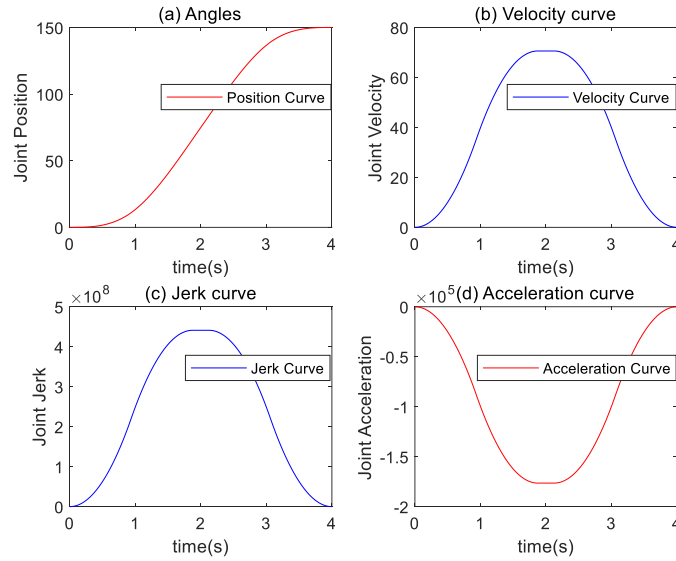


Figure 1: Simulation results of single degree of freedom robotic arm with an initial angle of  $0^\circ$ : (a) Angles; (b) Velocity curve; (c) Jerk curve; (d) Acceleration curve.

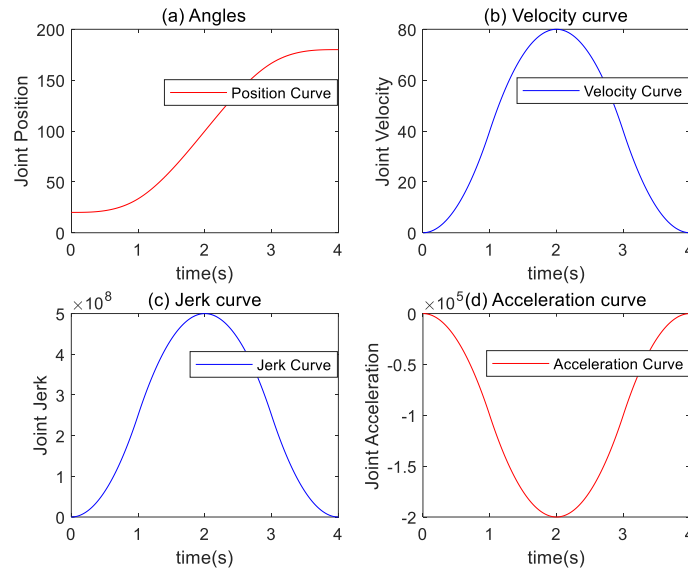


Figure 2: Simulation results of single degree of freedom robotic arm with an initial angle of 20°: (a) Angles; (b) Velocity curve; (c) Jerk curve; (d) Acceleration curve.

The parameter profiles of the single-degree-of-freedom robotic arm with zero and non-zero initial angles are shown in Figures 1 and 2. During the motion process, the arm is able to smoothly transition through the different motion phases without sudden changes in acceleration.

In the motion control of a single-degree-of-freedom manipulator, research based on S-type velocity planning demonstrates that this method offers significant advantages in enhancing motion smoothness, minimizing mechanical vibration, and optimizing motion time. Through both experimental and theoretical analysis, the following conclusions can be drawn: S-type velocity planning significantly improves the motion smoothness of the robotic arm by introducing continuous changes in acceleration and jerk. Compared to traditional trapezoidal velocity planning, the S-type approach avoids abrupt acceleration changes, thereby reducing the impact on the robotic arm during start, stop, and directional changes. This results in reduced mechanical vibration and wear. The parameters of S-type velocity planning, including maximum speed, maximum acceleration, and maximum jerk, can be flexibly adjusted to meet specific task requirements, making it adaptable to diverse motion scenarios. For instance, in high-speed motion scenarios, increasing the maximum acceleration can improve motion efficiency, while in high-precision scenarios, reducing the maximum acceleration can further suppress vibration. Overall, S-type velocity planning provides a robust and versatile solution for optimizing the performance of robotic manipulators across a wide range of applications.

## 5. Five Degree of Freedom Simulation

The main objective of this simulation experiment is to generalize the single-degree-of-freedom based S-shaped velocity planning. The velocity, angle, acceleration and jump curves of the five-degree-of-freedom robotic arm and the trajectory of the robotic arm motion are investigated to observe whether there is any abrupt change in acceleration and the accuracy of the trajectory.

The initial angles of the robotic arm are  $(\theta_1 \theta_2 \theta_3 \theta_4 \theta_5) = (0^\circ 0^\circ 0^\circ 0^\circ 0^\circ)$ , the angles of the final position are  $(\theta_1 \theta_2 \theta_3 \theta_4 \theta_5) = (100^\circ 800^\circ 120^\circ 85^\circ 80^\circ)$ , the velocity are  $(v_1 v_2 v_3 v_4 v_5) = (80\text{mm/s } 80\text{mm/s } 80\text{mm/s } 80\text{mm/s } 80\text{mm/s})$ , the acceleration are  $(a_1 a_2 a_3 a_4 a_5) = (80\text{mm/s}^2 \ 80\text{mm/s}^2 \ 80\text{mm/s}^2 \ 80\text{mm/s}^2 \ 80\text{mm/s}^2)$ , and the motion time is  $(t_1 t_2 t_3 t_4 t_5) = (4\text{s } 4\text{s } 4\text{s } 4\text{s } 4\text{s})$ ; When the initial angles are

not zero, the angles are  $(\theta_1 \ \theta_2 \ \theta_3 \ \theta_4 \ \theta_5) = (20^\circ \ 20^\circ \ 20^\circ \ 20^\circ \ 20^\circ)$ , and other conditions remain unchanged.

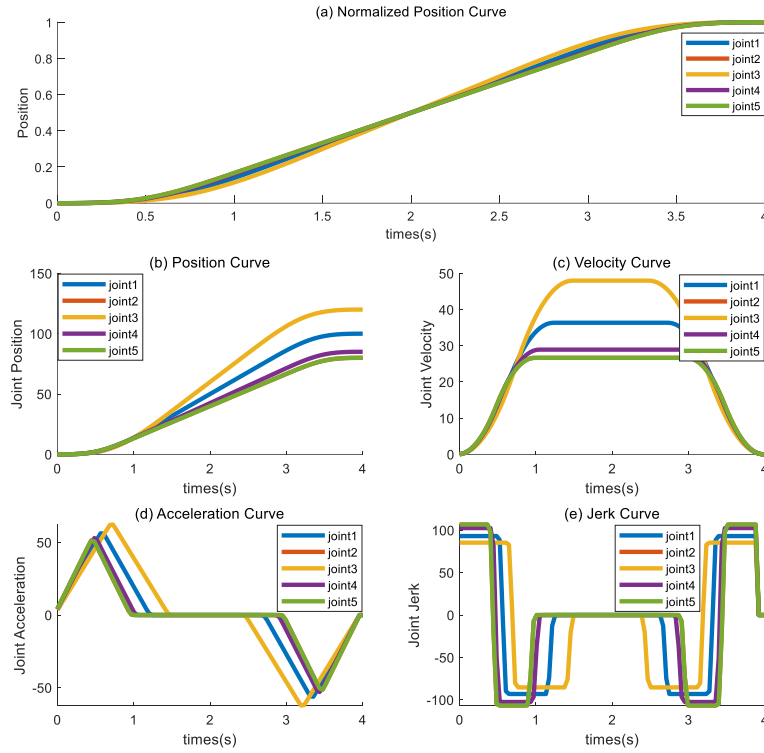


Figure 3: Simulation results of five degree of freedom robotic arm with an initial angle of  $0^\circ$ : (a) Normalized position curve; (b) Position curve; (c) Velocity curve; (d) Acceleration curve; (e) Jerk curve.

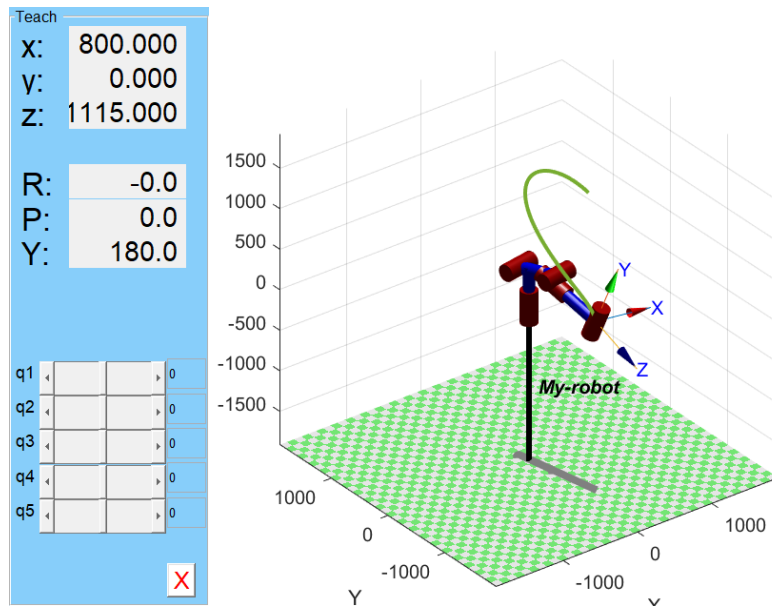


Figure 4: Trajectory of the end-effector of the robotic arm with the initial angle is  $0^\circ$ .

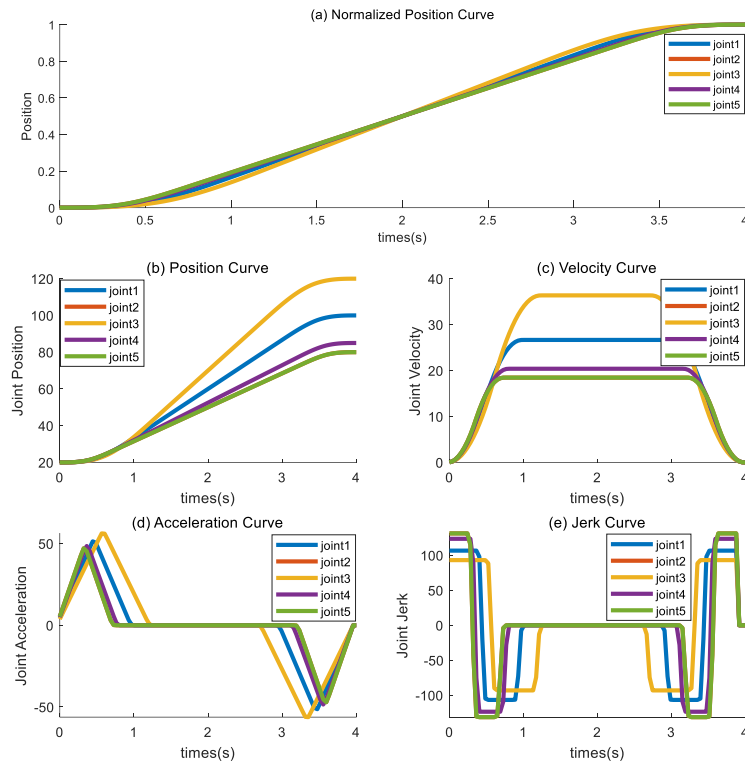


Figure 5: Simulation results of five degree of freedom robotic arm with an initial angle of  $20^\circ$ : (a) Normalized position curve; (b) Position curve; (c) Velocity curve; (d) Acceleration curve; (e) Jerk curve.

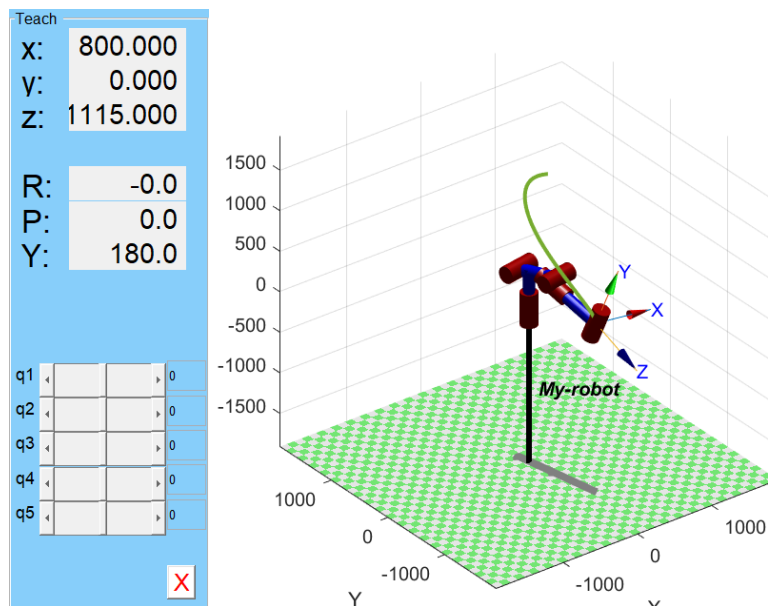


Figure 6: Trajectory of the end-effector of the robotic arm with the initial angle is  $20^\circ$ .

The figure3 to figure6 show the parameter profiles of a five degree of freedom robotic arm with zero and non-zero initial angles. During the motion, the robotic arm is able to smoothly transition to

different stages of motion without sudden changes in acceleration. Also, the trajectory accuracy of the end-effector of the robotic arm is shown. The selected simulation parameters are shown in Table 2.

Table 2: The connecting rod parameters of a five-degree-of-freedom robotic arm.

| Rod<br>i | $a_i$ /<br>mm | $\alpha_i$ /<br>(°) | $d_i$ /<br>mm | $\theta_i$ /<br>(°) | Angles of rotation range/(°) |
|----------|---------------|---------------------|---------------|---------------------|------------------------------|
| 1        | 150           | 90                  | 430           | $\theta_1$          | -170~170                     |
| 2        | 560           | 0                   | 0             | $\theta_2$          | -170~170                     |
| 3        | 125           | 90                  | 0             | $\theta_3$          | -170~170                     |
| 4        | 0             | -90                 | 650           | $\theta_4$          | -170~170                     |
| 5        | 0             | 90                  | 0             | $\theta_5$          | -170~170                     |

In the motion control of a 6-DOF manipulator, the research based on S-type velocity planning shows that this method has significant advantages in improving motion smoothness, optimizing motion time and reducing mechanical vibration. Through theoretical analysis and experimental verification, the following conclusions can be drawn: By introducing continuous changes of acceleration and Jerk, S-type velocity planning effectively avoids the problem of sudden acceleration in traditional trapezoidal velocity planning. The vibration of the 6-DOF manipulator can be effectively suppressed because the acceleration is limited by S-type velocity planning. This is particularly important for high-precision operations (such as precision assembly, welding or engraving), which can significantly improve the positioning accuracy and operational stability of the robot arm and reduce errors due to vibration. In a 6-DOF manipulator, S-type velocity planning can coordinate the motion of each joint to avoid the discontinuity of the whole motion caused by a single joint motion mutation. Through global optimization, S-type velocity planning achieves smooth transition of multi-joint motion and improves the overall motion performance of the manipulator. Flexible and adaptable parameter adjustment: S-shaped speed planning parameters (such as maximum speed, maximum acceleration, and maximum acceleration) can be flexibly adjusted according to specific task requirements to adapt to different motion scenarios and load conditions.

## 6. Conclusion

This paper investigates and implements S-curve velocity planning for both single degree of freedom (SDOF) and five degree of freedom (5-DOF) robotic arm systems. Through theoretical analysis and simulation experiments, we demonstrate the superiority of the proposed method in enhancing motion smoothness, ensuring trajectory accuracy, and mitigating system shock.

For the SDOF system, S-curve velocity planning effectively minimizes abrupt acceleration changes during motion initiation and termination, significantly reducing system vibrations and shocks. Mathematical modeling and simulation results confirm its advantage over traditional trapezoidal planning in achieving smoother motion transitions, offering improved solutions for diverse practical applications.

For the 5-DOF system, we propose a coordinated joint velocity planning algorithm that extends the SDOF approach. This algorithm not only optimizes individual joint velocities but also accounts for inter-joint coupling effects. Simulation results validate its ability to maintain end-effector

trajectory precision while enabling smooth joint transitions, reducing system vibrations and shocks across motion phases, and enhancing the robotic arm's operational lifespan.

The study establishes S-curve velocity planning as a robust solution for both SDOF and 5-DOF systems, significantly improving dynamic performance while ensuring motion smoothness and trajectory accuracy. However, for higher-DOF systems and complex physical environments, additional constraints and models must be considered to optimize planning effectiveness, as a universal solution remains impractical.

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