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A DETAILED REVIEW ON PICK AND PLACE ROBOT

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Abstract: In this study, the trajectory planning of robotic arm having six-degree-of-freedom (DOF) in real time with motion in a constraint path is presented. A 6-DOF robotic arm with a base and six links is developed in SOLIDWORKS modelling software and used in MATLAB/Simulink environments. The joint motion limit is provided to support the motion at each joint, and the direction of motion is identified by providing the sine function. Both forward as well as inverse kinematics of the robotic arm have been performed. Two different trajectories in polynomial trajectory planning, such as cubic and quintic polynomials with the same waypoint, have been employed. It is observed that the quintic polynomial trajectory is more effective than the cubic polynomial. It provides a smoother result with minimum jerk and also minimises power consumption. The robotic arm with a quintic polynomial trajectory is a better option for trajectory planning for a smoother trajectory.

Keywords: Manipulator, Trajectory planning, Robotic arm, Polynomial trajectory

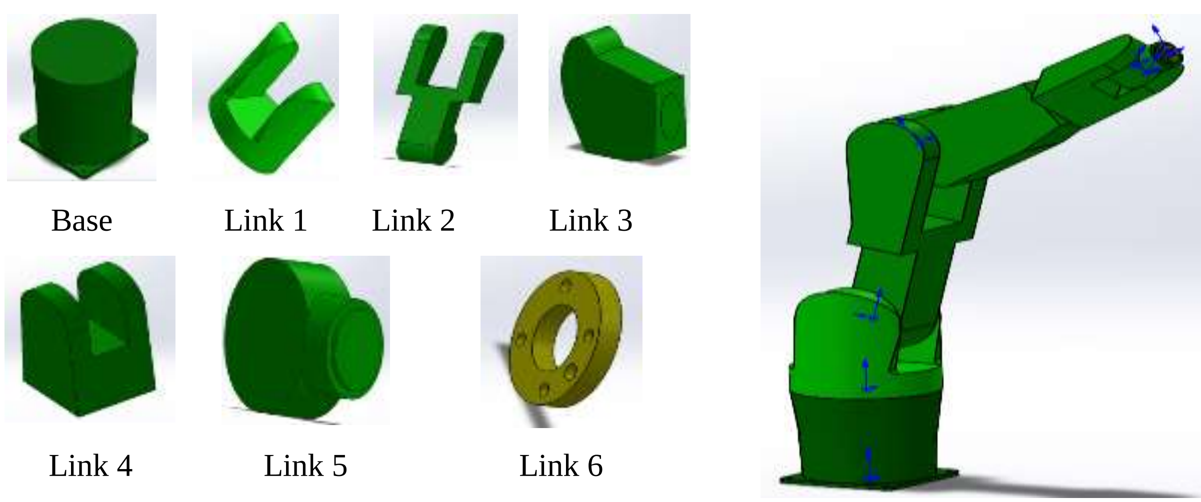
1. Introduction

A particular kind of robot arm known as a robotic manipulator may be used for a variety of activities in both industrial and non-industrial environments and includes a number of tasks such as handling materials, robotic surgery, painting, welding, assembly, automobiles, electronics, aerospace, healthcare, and others. The working of a robotic manipulator is like an arm mechanism that comprises a sequence of segments that are typically sliding or jointed and referred to as cross-slides. A robotic manipulator's workspace is the three-dimensional area where the robot arm can move around and carry out tasks. The capabilities of a robotic manipulator are greatly influenced by its workspace. The process of generating a sequence of joint angles that a manipulator should follow in order to change from its initial location to a desired final location while adhering to constraints such as maximum velocity, maximum acceleration, and the avoidance of obstacles in its path is known as "trajectory planning." The use of interpolation algorithms to construct a smooth trajectory between the starting point and the destination position is a frequent approach that can be taken.The different research works related to trajectory planning for robotic applications are reviewed. Some important works are briefly illustrated here. Faroni et al. [1] investigated robot velocity, acceleration, and torque limits, modifying the velocity profile on the basis of approximated look-ahead criteria. Bulut et al. [2] addressed path planning for hyper-redundant manipulators in cluttered, confined spaces, employing procedures such as finding tangent points and locating path points closest to the end point of the link. Conkue et al. [3] defined kinematic redundancy when the joint space dimension exceeds the end-effector space, providing enhanced manipulator mobility. Hirose et al. [4] demonstrated how kinematic redundancy affords manipulators greater mobility within their working space. Wen et al. [5] emphasized the need to locate collision-free routes for manipulators to navigate through their workspace without obstruction. Khatib et al. [6] categorized motion planning into low-level and high-level planning, focusing on collision avoidance and efficient collision-free planning, respectively. Chirikjian et al. [7] proposed maintaining a constant-length backbone curve for obstacle avoidance. Graham et al. [8] applied an algorithm to generate virtual torque at manipulator joints, bypassing complex inverse kinematics and operating in real-time. Konno et al. [9] utilized curvilinear theory to set the posture of hyper-redundant manipulators, employing the serpenoid curve method. Liang et al. [10] discussed the use of objective-switching functions for navigating obstacles within the workspace. Burhannuddin et al. [11] introduced collision avoidance path-planning techniques executed in Euclidean space. Concur et al. [12] suggested discretized paths as a solution to restrictions imposed by B-spline curves' analytical equations. Gammell et al. [13] computed collision-free routes between initial and end configurations as part of the planning process. Xidias et al. [14] proposed trajectory planning of manipulators in hyper-redundant using a time-optimal multi-population evolutionary algorithm and super-concave convex surfaces. Wei et al. [15] presented a time-optimal trajectory planning technique using two-population heredity and chaotic local search. Huashan et al. [16] emphasized considering manipulator's intrinsic kinematic restrictions when planning trajectories. In the present work, two different polynomials for trajectory planning of a serial redundant robotic arm in the constrained environment is investigated. The constraints on the trajectory, velocity, and acceleration of arm are considered. The relative trajectory performance of considered polynomials are evaluated.

The paper is arranged in the following orders: the design and modelling of a 6-DOF robotic arm are presented in Section 2. Section 3 contains the trajectory planning section, in which mathematical models of the considered trajectory polynomial functions are explained. The results are analyzed and compared in Section 4. The paper is concluded in Section 5.

2. Design and modeling of 6-DOF robotic arm

A robotic arm is said to have six DOF if it has been given the designation of having six DOF, i.e., the arm may move in a total of six different directions (axes of motion). The robotic arm consists of different components, as shown in Figure 1(a).



(a) Different components of robotic arm (b) 6-DOF Robotic Arm Assembly

Figure: 1 Different component and their assembly of a 6-DOF robotic arm.

A robotic arm's base is a part that attaches its body to the platform or structure on which it is mounted. Depending on how the robotic arm will be used, the base's design may be changed to accommodate different uses. The term "link" refers to a stiff component of a robot arm that links

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two neighbouring joints. Each link in a chain normally has a specific length and can rotate along one or more axes, providing one or more DOF for the chain as a whole. The number of joints and DOF required to carry out the desired duties can determine how many links are included in a robotic arm. A robotic arm's kinematic chain, which explains the relationship between the position and orientation of each link and joint in the arm, is largely comprised of the arm's links.A crucial task that demands precise attention to detail and precise measurement is the assembly of links in a robotic arm. The assembly of the links is one of the key steps in the construction of a robotic arm. If this step is done improperly, the arm's performance might decline, and it could even become totally inflexible. A robotic arm assembly with 6-DOF is shown in Figure 1(b).

3. Trajectory planning

Robot motion planning and control both require careful consideration of a robot's trajectory. In addition to creating a smooth and feasible trajectory, the design of a trajectory for a manipulator necessitates making sure that the trajectory does not violate any of the restrictions set on the manipulator's movements. The maximum speed, the maximum acceleration, and the joint limitations are some of these restrictions. Different polynomial functions as trajectory generators are used. In this study, two different polynomial functions, namely cubic and quintic polynomials, are selected for investigation.

3.1 Cubic Polynomial: The cubic polynomial is polynomial of degree three, which can be written as:

$$q(t) = a_0 + a_1(t) + a_2(t^2) + a_3(t^3) \tag{1}$$

$$\dot{q}(t) = a_1 + 2a_2(t) + 3a_3(t^2) \tag{2}$$

$$\ddot{q}(t) = 2a_2 + 6a_3(t) \tag{3}$$

where $q(t)$= Trajectory displacement function in t, $\dot{q}(t)$ = Trajectory velocity function in t, $\ddot{q}(t) =$ Trajectory acceleration function in t, t = time value, and a_0, a_1, a_2, a_3 = coefficient of polynomial. The initial and final trajectory and trajectory velocity are known and described as: $q(t_0)$ = initial trajectory point, $q(t_f)$= final trajectory point, $\dot{q}(t_0)$ = velocity at initial point, and $\dot{q}(t_f)$= velocity at final point. The above equations (1)-(3)can be given in the matrix form as

$[A][X]=[B]$. The coefficients of cubic polynomial are obtained by solving the equation as $[X]=[A]^{-1}[B]$.

$$[A]=\begin{pmatrix} 1 & (t_0) & (t_0)^2 & (t_0)^3 \\ 0 & 1 & 2(t_0) & 3(t_0)^2 \\ 1 & (t_f) & (t_f)^2 & (t_f)^3 \\ 0 & 1 & 2(t_f) & 3(t_f)^2 \end{pmatrix}, [B]=\begin{pmatrix} q(t_0) \\ \dot{q}(t_0) \\ q(t_f) \\ \dot{q}(t_f) \end{pmatrix}, \text{and } [X]=\begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \end{pmatrix}.$$

3.2 Quintic polynomial: The Quintic polynomial is polynomial of degree five, which can be written as:

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

$$\dot{q}(t)=a_1+2a_2(t)+3a_3(t^2)+4a_4(a^3)+5a_5(t^4) \quad (5)$$

$$\ddot{q}(t)=2a_2+6a_3(t)+12a_4(t^2)+20a_5(t^3) \quad (6)$$

where $a_0, a_1, a_2, a_3, a_4,$ anda_5 are coefficients of polynomial and other terms are same in meaning as explained in previous polynomial.The coefficients of quintic polynomial are obtained by solving the equation as $[X]=[A]^{-1}[B]$.

$$[A]=\begin{pmatrix} 1 & (t_0) & (t_0)^2 & (t_0)^3 & (t_0)^4 & (t_0)^5 \\ 0 & 1 & 2(t_0) & 3(t_0)^2 & 4(t_0)^3 & 5(t_0)^4 \\ 0 & 0 & 2 & 6(t_0) & 12(t_0)^2 & 20(t_0)^3 \\ 1 & (t_f) & (t_f)^2 & (t_f)^3 & (t_f)^4 & (t_f)^5 \\ 0 & 1 & 2(t_f) & 3(t_f)^2 & 4(t_f)^3 & 5(t_f)^4 \\ 0 & 0 & 2 & 6(t_f) & 12(t_f)^2 & 20(t_f)^3 \end{pmatrix}, [B]=\begin{pmatrix} q(t_0) \\ \dot{q}(t_0) \\ \ddot{q}(t_0) \\ q(t_f) \\ \dot{q}(t_f) \\ \ddot{q}(t_f) \end{pmatrix}, \text{and } [X]=\begin{pmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{pmatrix}.$$

3.3 Analysis methodology: A 6-DOF robotic arm was constructed in SolidWorks modeling software with a base and six links. Each component was modeled separately and assembled in SolidWorks assembly, resulting in a robotic arm with six revolute joints. Subsequently, the model was exported to MATLAB/Simulink, where a Simulink file for the robotic arm was obtained upon extraction. Joint motion limits were then provided to facilitate motion at each joint. A sine function was applied to verify that the input and output corresponded accordingly for each joint. Both forward and inverse kinematics analyses of the robotic arm were performed. A signal was generated in the signal builder and fed into the inverse kinematic block to convert position into angles, which served as inputs to the robotic arm's joints, enabling the robot to follow the trajectory. The output of the robot, in terms of angles, was then converted back into positions using forward kinematics. The trajectory input in the builder, velocity, and output trajectory at the forward kinematics block were observed in the scope graph. Furthermore, various trajectories were provided in the polynomial trajectory planning block, such as cubic polynomial and quintic polynomialwith the same waypoints.

4. Results and discussion

In this study, the trajectory planning on the 6-DOF serial redundant manipulator arm is performed. For this, cubic and quintic polynomials as a trajectory are provided. In the polynomial trajectory block, we have selected three nodes in MATLAB/Simulink, one for position, another for velocity, and the rest for acceleration. The position input is converted into an angle by inverse kinematics. It is used by robot joints as an input to perform their operations and provide output. This angle output is passed through forward kinematics and provides output in the form of position. Utilizing cubic and quintic polynomials to plan the trajectory of a robotic arm's movements can help optimize the torque delivered by the arm. To achieve a motion that is both smooth and effective, it is necessary to calculate the appropriate torque that should be applied at each point along the path of the arm. We have also presented angular velocity and angular acceleration curves for cubic and quintic polynomials and analyzed the variation of end effector motion.

$$T = I_{eq} \times \ddot{q} \tag{7}$$

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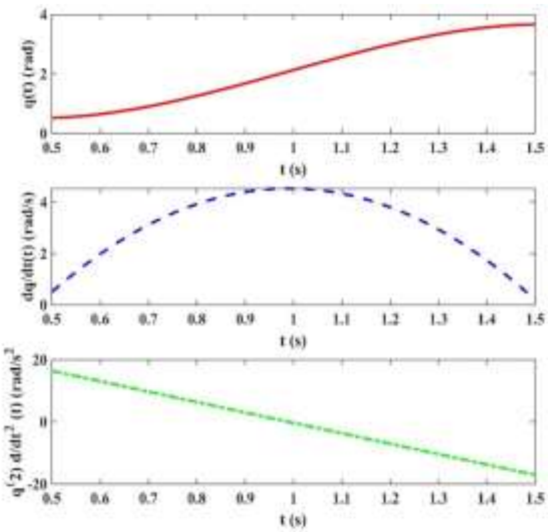
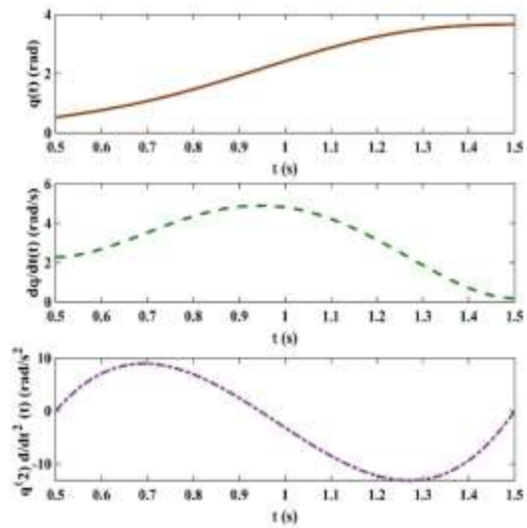


(a) Cubic polynomial curves



(b) Quintic polynomial curve

Figure: 2 Comparison of trajectory, velocity and acceleration for cubic and quintic polynomial curves.

Figure 2 represents the trajectory curve along with the velocity and acceleration curves for cubic and quintic polynomials. The variation of trajectory is presented in the time interval of 0.5 ~1.5 sec. The initial and final positions are selected and uniformly distributed into 100 divisions. With the help of the coefficient matrix, the angular velocity and angular acceleration are obtained at every instant of time. The torque at each instant is obtained, and the maximum torque is noted amongst all. From the results, it is observed that the torque required for the quintic polynomial is the minimum for the same inertia. So, it can be said that the consumption of power is lower for quintic polynomials. In order to get the velocity and acceleration profiles, the polynomial equations need to be differentiated in order to compute the torque profile. These are further used to optimize the torque. The movement of the robotic arm can be controlled to be smooth and efficient if the ideal torque required at each location is determined. This prevents the robotic arm from demanding excessive torque, which could either cause damage to the arm or waste energy.

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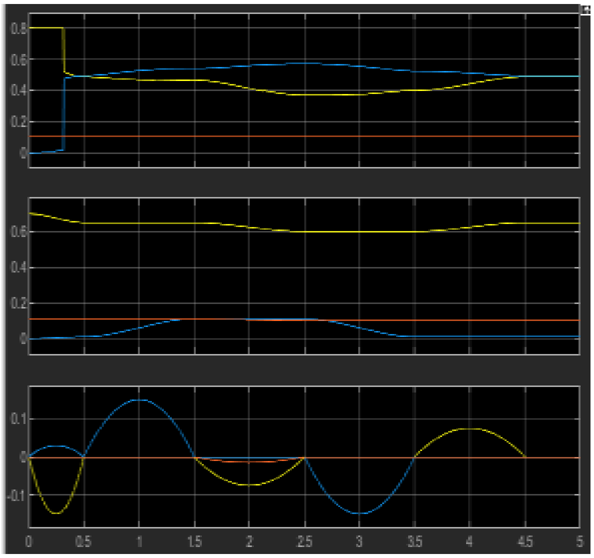
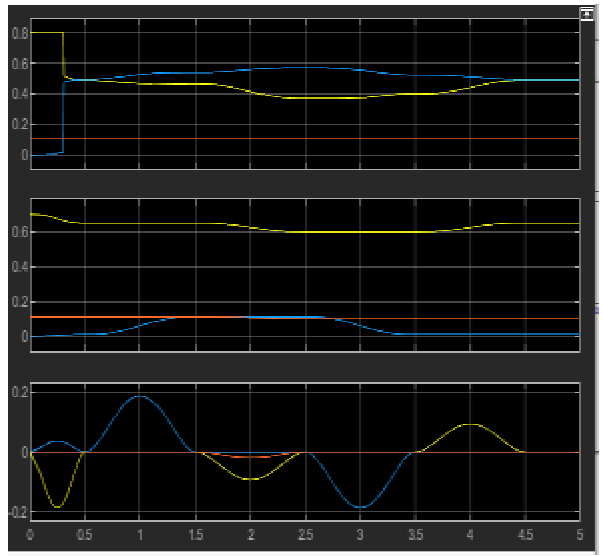


(a) Scope curve for cubic Polynomial



(b) Scope curve for quintic polynomial

Figure: 3 Comparison of responses obtained from the cubic and quintic polynomials.

Figure 3 represents the comparison of responses for cubic and quintic polynomials. In this figure, three different responses, such as the output of inverse kinematics as well as forward kinematics, input position trajectory, and input velocity, are illustrated. It is observed that quintic polynomials are better than cubic polynomials due to their lower jerk and smoother curves. In addition to this, the velocity profile of a quintic polynomial is smoother than that of a cubic polynomial. So, it can be said that a quintic polynomial trajectory is more preferable than another polynomial trajectory considered here. It also has a minimum power consumption. Moreover, constraints are considered, particularly regarding acceleration constraints; the quintic polynomial trajectory performs better than the cubic polynomial trajectory.

5. Conclusions

In this work, the trajectory planning of a 6-DOF robotic redundant serial manipulator with motion in a constraint path is presented. The model of a robotic manipulator is developed in SolidWorks, and trajectory-motion analysis is performed in MATLAB/Simulink. Two different polynomials for trajectory planning, namely cubic and quintic polynomials, are selected for the study, and their relative performance is compared. From the analysis, it is observed that the torque required is minimum for quintic polynomials and provides a smoother trajectory with minimum jerk. Moreover, constraints are considered, particularly regarding acceleration constraints; the quintic polynomial trajectory performs better than the cubic polynomial trajectory. Hence, it is concluded that a robotic arm with a quintic polynomial is a better choice for trajectory planning to obtain a smoother trajectory. In the future, the present work will be extended by considering the base movement of robots.

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Declarations

Conflict of Interests: The authors declare that there is no known conflict of interest.
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