Review Paper on Trajectory Planning

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Abstract

The main objective of this paper is to determine joint motor selection & trajectory planning of 6 DOF robotic arm. The kinematic equations of motion are derived using Denavit-Hartemberg representation. The Workspace of the robot is investigated based on the kinematic equations as well as the physical limit of each joint. The dynamic equations of motion are derived using a Lagrangian-Euler technique. The required torque to move each joint based on prescribed trajectories are calculated for proper selection of the motor torques. The trajectories for the joint variables are generated in fifth-order spline form using general constrained nonlinear optimization, taking into consideration the joint position, velocity, acceleration, jerk and overall current consumption constraints during the movement.

Keywords: *kinematics, dynamics, trajectory planning*

INTRODUCTION

The study proposed a strategy smooth trajectory planning to follow the path constrained with time optimal trajectories for the manipulator. The problem in trajectory planning was to find a smooth trajectory function and optimal joint optimization processes. Such trajectories were obtained by considering the kinematics properties for velocities, accelerations and jerks profiles in joint coordinates for the end-effectors to move the path constraints. The method was based on the position profile composed of three polynomial segments such as 4-3-4, 3-5-3 and 3-cubic trajectory and five polynomial segments for 5-cubic trajectory. These polynomial segments combination allowed the analytical solution to the minimum time trajectory problem under consideration of ve locity, acceleration and jerk. For comparison on varying time ratio 4-3-4 gave a reasonably smooth for normal trajectory condition and a ramp at middle segment to generate a minimum free-space time compared to 3-5-3 and cubic trajectories. For PPO and CP, 4-3-4 trajectory generated a lower value for accelerations and jerks compared to 3-5-3 and cubic trajectories. This showed the 4-3-4 trajectory was the best type of joint interpolated trajectory planning for any path planning operations. The stages of robot trajectory design are carried out as follow:

1) Selection of mechanical design of links and joint: To design a robot which has to follow the pick & place activities, the robot has 6 rotary joint J1, J2, J3, J4, J5, J6 viz. base joint, shoulder, elbow, wrist 1,pitch & wrist 2 and 6 links.
2) Calculation of joint torque at each joint: To calculate the joint torque at each joint we have to form jacobian matrix at each joint by using the equation of arm dynamics and also we have to form force matrix which include the mass of each link, using these two matrix we calculate joint torque

3) Selection of 4-3-4 trajectory segment: It means we divide the trajectory in three segments, first segment is denoted by fourth order polynomial equation, second segment is denoted by third order polynomial equation & last segment is denoted by fourth order polynomial equation.
4) Calculation of velocity and acceleration at each joint: By considering joint space trajectory planning by knowing the joint angle and time required to reach this position at each joint we calculate the velocity & acceleration at each joint with the equation of 4-3-4 trajectory.
5) Development of program on c++: By using the equation of velocity, acceleration & torque we developed a program to calculate it. In this program the input is joint angle and the output is velocity, acceleration & torque.

Literature Review

[1] Lianfang Tian, Curtis Collins

In this paper the main task of path planning for robot manipulators is to find an optimal collision-free trajectory from an initial to a final configuration. The task is defined as a combination of two displacements. The first one brings the robot closer to the goal configuration, and the second one enables the robot to avoid the local minimum. we consider a robot with two joints and two links. The goal is to search a sequence of desired points which make up a detailed smooth path, such that the end-effectors of the robot moves from the given start point to the target while avoiding obstacles. As a result, the proposed GA method is an effective optimization method for the trajectory planning of robot manipulators. It works well under different conditions and environments. The Hermite cubic interpolation method applied in this paper for the trajectory planner is straightforward and practical. By using this method, the trajectory always satisfies the boundary conditions. The proposed method can be easily extended to an n-DOF robot in a three dimensional space.

[2] Yi Yue, Feng Gao, Xianchao Zhao, Q. Jeffrey Ge

In this paper *a 6*-DOF perpendicular parallel micromanipulator *(PPMM)* is proposed and its prototype is developed. The actuated flexure pairs of micromanipulators are affected not only by actuators but also by elastic reaction forces and torques exerted on them so the study on the relationship of IPSD (input-force, payload, stiffness & displacement) is a basic issue to understand how micromanipulators work. Therefore, this paper focuses on the relationship among IPSD of the 6-DOF PPMM. To verify the IPSD model of the 6-DOF PPMM proposed in this paper, simulations by FEM software are performed. When given payload and the output displacement of end-effector, the input-force vector can be calculated. Then the drive force vector is applied to a virtual model in the FEM environment. By comparing the output displacement vector between the FEM model and the initial displacement given in the analytic model the right and efficiency of the IPSD model can be verified.

[3] Bahaa Ibraheem Kazem , Ali Ibrahim Mahdi, Ali Talib Oudah

In this paper, The authors use polynomial of 4th degree in time for trajectory representation to joint space variables. The supposed point-to-point trajectory is connected by several segments with continuous acceleration at the intermediate via point. It should be point out that joint angular acceleration at each intermediate point could be obtained. It is observed that the joint torque of the robot did not exceed its maximum pre-defined torque in both free and obstacle existence workspace case. Since GA uses the direct kinematics, the singularities do not constitute a problem. GA showed that it is able to achieve multi objective optimization efficiently. Finally, kinematics redundancy can be solved within GA according to the specified objective functions.

[4] Khaled Tawfik, Atef A. Ata, Wael A. Al-Tabey

This paper aims at investigating the kinematics and dynamics of six DOF micro-robot intended for surgery applications. The object of this paper is to present a full analysis of 6 DOF micro-robot for surgical applications. It is divided into three parts (kinematics analysis, trajectory planning and dynamic analysis). The 6 DOF manipulator kinematic parameters are derived using Denavit Hartemberg formulation. The workspace of the surgical manipulator can be representing by solving the kinematic equations and taking into consideration all the physical limits of the joints. Manipulator dynamics is concerned with the equations of motion, the way in which the manipulator moves in response to torques applied by the actuators, or external forces. The original torque history has many fluctuations. It is clear that the highest hub torque is for joint 1 while actuator torque of joint 6 is the lowest. It should be also noted that changing the final time for the joint trajectory changes the torque history considerably.

[5] Jan Mattmüller ,Damian Gisler

This paper presents a near time-optimal and jerk-constrained trajectory planner. The goal of this work was to develop and implement an algorithm that is able to compute a near time optimal trajectory for an almost arbitrary smooth path. Depending on the path and the constraints, this method will lead to one of three possible situations 1) Meet point 2)Split point3) Forbidden point. It is observed that to calculate near time-optimal jerk-constrained trajectories along three times differentiable paths in a nonperturbative way It could be shown that the jerks on the system can be substantially reduced while almost maintaining the total move time. This allows us to considerably reduce the vibration in the overall system with a minimal speed penalty. As the trajectories also become more complex, it will become important to optimize the algorithm even further.

[6] Haihua MU, Yunfei ZHOU, Sijie YAN, Aiguo HAN

In this paper a third-order trajectory planning method for point-to-point motion. Point-to-point motion requires high positioning accuracy without concerning the process. Consider the trajectory with zero-constraints, that is, zero velocity, acceleration and jerk. Various trajectory shapes will be determined according to different given constraints. For third-order trajectory, there exist six different possible trajectory shapes. The determination of specific trajectory instance relies on two issues. One is that acceleration trajectory shape is alternatively triangular or trapezoidal. The other is that the positive and negative shapes in the acceleration trajectory are continuous. Based on these, the equations of the trajectory planning can be derived directly.

Conclusion

In the trajectory planning, the most important thing is the smoothness of the path, because, if the path of the robot makes robot tilt or crash, or if the robot makes dangerous movements, there is no meaning to make trajectory planning or path generation. In the method used, the smoothness is the key point. The optimization is not considered in the trajectory planning. In fact, some optimization criteria may be considered, such as, minimum time or minimum energy. Besides starting and ending points, via points are determined and the robot has to be passed from these points. This criterion avoids us to apply minimum energy optimization. In this trajectory planning method, time must be given as the input to optimize it, the iterative method must be used. Time optimization in this method is also very lengthy subject for this trajectory planning method and it can be the future work. If there are two points, above formulation does not work. Because, in this case, 5th order polynomial must be fitted. Because there are 6 variables (position velocity & acceleration of both points) to be fitted. The stability of the polynomial decreases when the value of degree of the polynomial increases.

Future work

For 6 DOF robotic arm the kinematic equations of motion are to be derived using Denavit-Hartemberg representation. The trajectories for the joint variables are generated in Fifth-order spline form using general constrained nonlinear optimization, taking into consideration the joint position, velocity, acceleration, jerk and overall current consumption constraints during the movement. For the simulation work MATLAB software is used.

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