Grenze International Journal of Engineering and Technology, Special Issue

A Multi Performance Characteristics Optimization of Robotic Arm Trajectory using Machine learning Technique

Arunadevi M[1] and C P S Prakash[2]
[1]Dayananda Sagar College of Engineering /Mechanical, Bangalore, India
Email: arunadevi.dsce@gmail.com
[2]Dayananda Sagar College of Engineering /Mechanical, Bangalore, India
Email: drcpsprakash@gmail.com

***Abstract*—This paper presents trajectory planning algorithm for a 3 Degrees-of-Freedom (3-DOF) articulated robot that is intended to serve assembly/pick and place operation under fixed obstacle with minimum time and minimum jerk. However the time and jerk value depends on the position of the intermediate point(s) and the orientation of the end effector. Intermediate points are determined based on the fixed obstacle. Cubic B-spline interpolation is used to generate smooth path. Minimax (Minimize the maximum jerk value) method is used to minimize the jerk value. This paper proposes a Genetic algorithm (GA) based heuristic to determine the position and orientation of the end effector which generates the trajectory with minimum time and minimum jerk value.**

***Index Terms*— Optimization, Robot Manipulator, Genetic Algorithm and Trajectory planning.**

I. INTRODUCTION

Robot manipulators are powerful tools in today's manufacturing industry, and their performance can be enhanced through well-developed trajectory planning. One of the major problem faced by trajectory planning of robot manipulator is, nonlinearity of robot manipulator variables which leads to high jerk values. These high jerk values wear out the robot structure and heavily excite its resonance frequencies and also damage the robot actuators by vibrations. To overcome the above issue, the trajectory is developed with minimum jerk value. But minimizing the jerk value leads to increase in execution time. So the objective of this work is to develop an algorithm for smooth trajectory with minimum jerk and minimum execution time.

Two approaches for minimizing the jerk value are described in the literature, Minimax approach (Minimizing the maximum jerk value) described in [1,3].and the time integral of jerk value described in [1,4].Smooth trajectory has been generated using Trigonometric spline interpolation[2],cubic spline interpolation[3] and Fifth order B-spline interpolation.

Optimization of jerk and time has been solved using techniques like Sequential Quadratic Programming [4] and Genetic Algorithm [6].

Some of the research work for minimizing jerk has been carried out without constraints [1,3]. Simon and Isik

Grenze ID: 01.GIJET.4.3.32

[2] have considered constraints with predefined execution time. Gasparetto.A and Zanotto.V [4] have considered kinematic constrains without predefining the execution time, higher order B-Splines were used to generate smooth path which leads to computational difficulty. Some have used simple curves to overcome the above difficulty, but they lack in accuracy of computation.
This work tends to accommodate the kinematic constraints and execution time function in the model. Cubic B-splines have been used for generating the smooth trajectory.

II .PROBLEM DESCRIPTION

A. Robot Configuration

This work considers a 3-DOF planar robot of articulated arm configuration, which consists of three rotary joints which is shown in figure.1.

B. Working Environment

The robot is intended to serve pick and place operation. It is a planar robot which moves in a plane, it has 3 individual movements in their 3 joints like mini drafter. An obstacle which lies between the initial point and target point restricts the free movement of end effector. The end effector moves from initial point to target point via four intermediate control points, which would avoid hitting the obstacle.

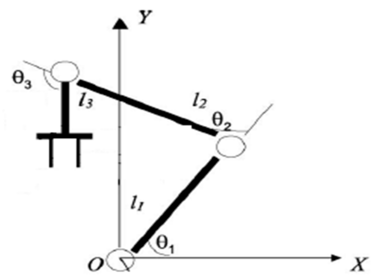

Figure:1 3-DOF planar robot

C. Assumptions

1. Continuous velocity, acceleration & Discontinuou jerk.
2. Dynamic constraints are not considered.
3. Predefined obstacle.

D. Objective

To develop an algorithm for smooth trajectory with minimum jerk and minimum execution time for a articulated robot for performing pick & place operations.

E. Problem Statement

Given the position of the end effector at initial and final position, the problem is to determine the intermediate control points that make a trajectory with minimum jerk and minimum execution time.

III. METHODOLOGY

The problem is based on the minimization of an objective function that takes into the account both an execution time and jerk along the whole trajectory. The objective function adopted in proposed technique is given by sum of two terms having opposite effect. First term is proportional to the maximum jerk value and second term is proportional to the execution time.

Objective function

Minimize {Jerk + Execution Time}

Subject to

Kinematic constraints

Reducing the first term of objective function will leads to smoother trajectories. Reducing the second term of objective function will lead to a smoother trajectory featuring large values of kinematic quantities (velocity, acceleration, jerk) .The trade off between these two tendencies can be performed by suitably adjusting the weight of the two terms of the objective function. A larger weight of the jerk term will lead to smoother but slower trajectories. A larger weight of time term will lead to faster but less smooth trajectories. Both the objectives are conflicting in nature.

A. Mathematical Formulation

$$Min\left\{W_J \max\Big|_{i=1}^{2} \Big|_{k=0}^{12} J_i(k) + W_T \sum_{L=1}^{12} \max\Big|_{i=1}^{2} \left[\frac{p_i(l) - P_i(l-1)}{v_i}\right]\right\}$$

Sub to,

$V_i \leq V_{imax}$, $A_i \leq A_{imax}$, $J_i \leq J_{imax.}$

Weighting Objectives is one of the most usual (and simple) substitute models for multi objective optimization problems. It permits a preference formulation that is independent from the individual minimum for positive weights. Therefore smooth trajectory planning can be achieved by giving more weightage to the jerk minimization.

B. Algorithm

Step 1: Input values:
Number of joints i = 3 (varies from 1 to 3)
Number of control points (n+1) =6 (varies from 0 to 5)
Initial point IP (x_0, y_0)
Final point FP (x_5, y_5)
Link lengths L_i
Angular Velocity of joints Vc
Square shape Obstacle in the centre of initial and final point.
Step 2: Control points definition:

Control points are fixed based on the obstacle which is shown in figure 2.In this obstacle is shown by yellow color. The Length from the centre of IP and FP to the top corner of the obstacle which will give the radius for inner circle is measured. Using this radius one semicircle has been drawn from the centre. Then second semicircle has been drawn by giving offset to the radius. This outer semicircle is divided in to (n) 5 parts by the lines. The cutting point of outer circle and straight lines will give the control points from the trajectory which will avoid the obstacles. Control points are

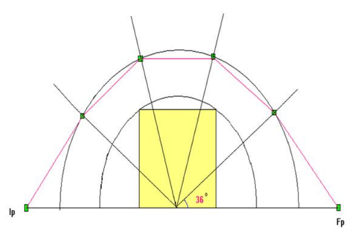

Figure:2 Control Point Definition

Orientation angle Ψ are fixed based on joint angles and length of the joints, can be generated using Genetic Algorithm based Heuristic
Step 3:Control points in joint space is determined using Inverse kinematic equations .

$$\Psi = (\theta_1 + \theta_1 + \theta_1)$$

$$\theta_{1j} = \tan^{-1}(y_j / x_j) \pm \cos^{-1}\left[\frac{x_j^{\,2} + y_j^{\,2} + L_1^2 - L_2^2}{2L_1\sqrt{x_j^{\,2} + y_j^{\,2}}}\right]$$

$$\theta_{2j} = \cos^{-1}\left[\frac{x_j^{\,2} + y_j^{\,2} - L_1^2 - L_2^2}{2L_1L_2}\right]$$

$$\theta_{3j} = \Psi - (\theta_{1j} + \theta_{2j})$$

Step 4: Control points defined in join space is given as as a input and the path is obtained using cubic B – spline polynomials. From the path the position, velocity, acceleration and jerk values are obtained by varying the parameter u from 0 to 3.

u = (k/4).

u values can be obtained by varying the k value from 0 to 12.

If (0≤u≤1)

Angular Displacement Equation

$$P_i(k) = \theta_{i0}(1-u)^3 + \frac{\theta_{i1}\left(7u^3 - 18u^2 + 12u\right)}{4} + \frac{\theta_{i2}\left(-11u^3 + 18u^2\right)}{12} + \frac{\theta_{i3}(u^3)}{6}$$

Angular Velocity Equation

$$V_i(k) = \theta_{i0}(-3(1-u)^2 + \frac{\theta_{i1}\left(21u^2 - 36u + 12\right)}{4} + \frac{\theta_{i2}\left(-33u^2 + 36u\right)}{12} + \frac{\theta_{i3}(u^2)}{2}$$

Acceleration Equation

$$A_i(k) = \theta_{i0}\,6(1-u) + \frac{\theta_{i1}(42u - 36)}{4} + \frac{\theta_{i2}(-66u + 36)}{12} + \theta_{i3}u$$

Jerk Equation

$$J_i(k) = \theta_{i0}(-6) + \theta_{i1}(10.5) + \theta_{i2}(-5.5) + \theta_{i3}(1)$$

If (1≤u≤2)

Angular Displacement Equation

$$P_i(k) = \frac{\theta_{i1}(2-u)^3}{4} + \frac{\theta_{i2}\left(7u^3 - 18u^2 + 5u - 18\right)}{12} + \frac{\theta_{i3}\left(-7u^3 + 27u^2 - 27u + 9\right)}{12} + \frac{\theta_{i4}(u-1)^3}{4}$$

Angular Velocity Equation

$$V_i(k) = \frac{-\theta_{i1}(3(2-u)^2}{4} + \frac{\theta_{i2}\left(21u^2 - 36u + 5\right)}{12} + \frac{\theta_{i3}\left(-21u^2 + 54u - 27\right)}{12} - \frac{\theta_{i4}(3(u-1)^2)}{4}$$

Acceleration Equation

$$A_i(k) = \frac{\theta_{i1}(6(2-u))}{4} + \frac{\theta_{i2}(42u - 36)}{12} + \frac{\theta_{i3}(-42u + 54)}{12} + \frac{\theta_{i4}(6(u-1))}{4}$$

Jerk Equation

$$J_i(k) = \theta_{i1}(-1.5) + \theta_{i2}(3.5) + \theta_{i3}(-3.5) + \theta_{i4}(1.5)$$

If (2≤u≤3)

Angular Displacement Equation

$$P_i(k) = \frac{\theta_{i2}(3-u)^3}{6} + \frac{\theta_{i3}\left(11u^3 - 81u^2 + 189u - 135\right)}{12} + \frac{\theta_{i4}\left(-7u^3 + 45u^2 - 93u + 63\right)}{4} + \theta_{i5}(u-2)^3$$

Angular Velocity Equation

$$V_i(k) = \frac{-\theta_{i2}(3-u)^2}{2} + \frac{\theta_{i3}\left(33u^2 - 162u + 189\right)}{12} + \frac{\theta_{i4}\left(-21u^2 + 90u - 93\right)}{4} - \theta_{i5}(3(u-2)^2)$$

Acceleration Equation

$$A_i(k) = \theta_{i2}(3-u) + \frac{\theta_{i3}(66u - 162)}{12} + \frac{\theta_{i4}(-42u + 90)}{4} + \theta_{i5}(6(u-2))$$

Jerk Equation

$$J_i(k) = \theta_{i2}(-1) + \theta_{i3}(5.5) + \theta_{i4}(-10.5) + \theta_{i5}(6)$$

Step 5: Calculation of Total execution time (T) using the formula.

$$T = \sum_{l=0}^{11} T(l) \qquad \text{Where, } T(l) = \Big|_{L=0}^{11} \max\{ \mathop{T_i}_{i=1}^{2}(l)\}$$

$$\text{Where, } T_i(l) = \Big|_{i=1}^{2} \Big|_{L=0}^{11} \{(p_i(l) - P_i(l-1))/v_i\}$$

Step 6: Maximum jerk value is obtained using

$$\text{Maximum Jerk value} = \max \left| \sum_{i=1}^{2} \right| \sum_{k=0}^{12} J_i(k)$$

Step 7: Find the objective function by giving the weightage to the jerk and time vale.

$$Min\left\{ W_J \max \left| \sum_{i=1}^{2} \right| \sum_{k=0}^{12} J_i(k) + W_T \sum_{L=1}^{12} \max \left| \sum_{i=1}^{2} \left[\frac{p_i(l) - P_i(l-1)}{v_i} \right] \right\}$$

Step 8: Go to step2 to change the orientation angle.

Step 9: Repeat steps 3-8 till termination criterion is satisfied. The minimum f(x) value in each iteration is stored and best among the bests stored as optimal one.

C. Numerical Example

A 3-DOF planar robot manipulator is shown in figure.1.The link length of this mechanism is represented by $l_1 = l_2 = 0.4$, and $l_3 = 0.2$, respectively. The end effector is supposed to move along a trajectory from IP (-0.4, 0.2) to FP (0.4, 0.2) which has to avoid 0.1m square shape obstacle in the centre of the IP and FP.

Control points defined:

$(x_1, y_1) = (-0.24, 0.38)$, $(x_2, y_2) = (-0.1, 0.49)$, $(x_3, y_3) = (0.1, 0.49)$, $(x_4, y_4) = (0.24, 0.38)$

Orientation angle of end effector is generated using genetic algorithm.

The numerical example is solved through above methodology without constraints. The output is shown in table I.

TABLE I: OUTPUT OF GA

Genr	Orientation angle Ψ(deg)	Time(s)	Jerk(rad/s^3)	F(x)
1	104.7	11.07	16.39	14.8
2	163.3	14.52	16.54	15.9
3	97.3	13.60	17.70	16.4
4	192.6	11.16	16.48	14.8
5	112	14.36	6.49	8.86
6	**200**	**14.35**	**6.49**	**8.85**
7	156	13.47	18.12	8.9

IV. CONCLUSION

An algorithm to perform the optimal trajectory planning of robot manipulators with minimum jerk and execution time, without colliding against the fixed obstacle, is developed. Smooth trajectory is achieved using Cubic B-Spline interpolation. In the future an algorithm will be developed, considering dynamic constraints and would be applied in PUMA560 for industrial applications.

REFERENCE

[1] Kyriakopoulos.K.J,. Saridis G.N,(1988) "Minimum jerk path generation", in Proceedings of the 1988 IEEE International Conference on Robotics and Automation, Philadelphia, pp. 364–369.

[2] Simon.D, Isik.C, (1993) "A trigonometric trajectory generator for robotic arms", *International Journal of Control* 57(3) 505–517.

[3] Piazzi.A, Visioli .A,(1997),"An interval algorithm for minimum-jerk trajectory planning of robot manipulators", in: *Proceedings of the 36th Conference on Decision and Control, San Diego, California, December* 1997, pp. 1924–1927.

[4] Gasparetto.A ,Zanotto.V,(2007) "A New Method of Smooth Trajectory Planning of Robot Manipulators", *Mechanism and Machine Theory* 42 (2007) 455-471.

[5] Saravanan.R,Ramabalan.S, Balamurugan.C, (2007) "Evolutionary collision-free optimal trajectory planning for intelligent robots"*Int J Adv Manufacture Technology*, 8 Jan 2007.

[6] Jawahar.N,SaravanaPerumaal.S,SivakamasundariR,(2005)"A Genetic Algorithm Based Heuristic for Minimum Move Time in 4-Dof Articulated Robot"in *ISME International Conference on Mechanical Engineering in Knowledge Age.Dec2005.*

[7] Piazzi.A, Visioli.A,(2000) "Global minimum-jerk trajectory planning of robot *manipulators", IEEE Transactions on Industrial Electronics 47,(1), (2000) 140–149*

[8] Yang Liu, Zongwa Xie, Yikun Gu and Chunguang Far(2017), "Trajectory planning of robot manipulators based on unit quaternion", *IEEE International conference on Advanced Intelligent Machatronics, July 2017.*

TABLE II. NOMENCLATURE

Symbol	Meaning	Unit
i	Number of joints.	-
j	Number of control points.	-
k	Number of points in the path.	-
l	Number of intervals in the path.	-
u	Parameter	-
L_i	Link length	m
θ_{ij}	joint angle at i^{th} joint when the end effector at the j^{th} control point	deg
$P_i(k)$	Position values of joint i when the end effector at the k^{th} point	deg
$V_i(k)$	Velocity value of joint i when the end effector at the k^{th} point.	deg/s
$A_i(k)$	Acceleration value of joint i when the end effector at the k^{th} point.	deg/s^2
$J_i(k)$	Jerk value of joint i when the end effector at the k^{th} point.	deg/s^3
$T_i(l)$	Time taken to cross l^{th} interval	sec
V_{imax}	Maximum velocity at i^{th} joint	deg/s
A_{imax}	Maximum Acceleration at i^{th} joint	deg/s^2
J_{imax}	Maximum Jerk at i^{th} joint	deg/s^3
W_J	Weight assigned to Jerk.	-
W_T	Weight assigned to execution time	-