Please refer to: Ghafil H. N., Jármai K.: Trajectory planning of a robot arm using flower pollination algorithm, 3rd International Conference on Engineering Sciences and Technologies: ESAT2018, Tatranske Matliare, September 12-14, Slovakia, Proceedings on CD: 023-Ghafil,Jarmai.pdf 4 p. Eds. Peter PLATKO; Mohamad AL ALI; Štefan KUŠNÍR, ISBN:978-80-553-2982-6

Trajectory planning of a robot arm using flower pollination algorithm

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ABSTRACT: Trajectory planning is a crucial step for the dynamic analysis of a robotic arm since the dynamic forces and torques depend on the amount of the acceleration of the moving links. In this paper flower pollination algorithm FPA was used to optimize 3 point cubic spline curve and these three points shall be the via points for the trajectory planning. The same algorithm (FPA) also has used to map all points from the Cartesian space to the joint space where the trajectory planning occurs. 9th order polynomial equation presented to express the trajectory equation of the angular position, velocity and acceleration.

1 INTRODUCTION

Knowing the dynamic equations of the robot arm is very necessary for the mechanical design of the arm. Some the forming parameters in these equations are the angular position, velocity and acceleration of the actuators. Using the Euler-Lagrange equations, one can estimate the stress-strain distribution along the robot physical links. This is necessary for the fatigue design of the arm or estimate the failure limits. Employing the Euler-Lagrange equations, it could be easy to do vibration analysis, which is very important in position tracking and control.
In this work, trajectory planning was done using flower pollination algorithm FPA (Yang 2012) and (Alyasseri et al 2018) to calculate angular velocity and acceleration trajectories needed for dynamical analysis for each robot configuration . FPA is used for global optimization by a wide range of researchers in different topics. The flower pollination algorithm was used for the path planning process to calculate optimum positions of the intermediate points which will be used in the trajectory planning process. The same algorithm is used to optimize the position of the robot tip, for the inverse kinematic which is necessary to transfer all points; start, end and intermediate points of the Cartesian space to joint space where the trajectory occurs (Spong et al 2006). Two links planar robot manipulator RR have used as an example during this work because of its simple kinematics, which is shown in Figure 1 with its Denavit-Hartenberg parameters which are illustrated in Table 1. Each link has assumed to be 750 mm length also $q_1$and q_2 are the rotational angles of the link 1 and link 2 respectively, with z-axis in the direction of the reader.

2 VIA POINTS OPTIMIZATION

It is assumed there are obstacles in the configuration space of the robot that constrained the motion of the robot arm while moving from start to goal point. Figure 2 illustrates the path which is planned in the constrained environment, where this path has been planned, using three points cubic spline curve to smooth the corners. These three points as mentioned above will be later the via points for the trajectory planning. Flower pollination algorithm is used for the optimization process by handling iterative three points which are responsible for forming the cubic spline curve . FPA main parameters are explained in Table 2 while workspace parameters which are handled to the algorithm are; minimum x-value =0, minimum y-value =0, maximum x-value = 1620, maximum y-value = 1630 with four circular obstacles shown in Figure 2. The cubic spline curve, which is governed by the three points consists of 100 sub-points and start with (1470,33) and end with (174,1350) and the fitness function is taken to be the total distances between each of these points.

$$fitness = \sum \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2} + penalty \quad (1)$$

where i = *1,2,…99* and penalty taken to be 1000 whenever the curve touch an obstacle

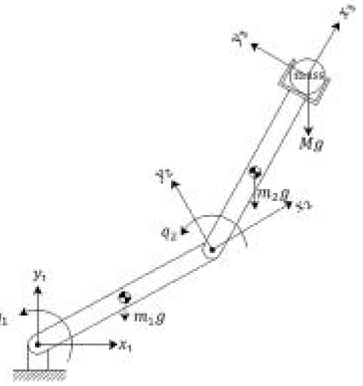


Figure 1. Two links planar robot manipulator

Table 1. DH parameters for the robot

Link	a_i mm	α_i	d_i mm	q_i
1	750	0	0	q_1
2	750	0	0	q_2

Table 2 Flower pollination parameters

Parameter	amount
Population size	25
probability switch	0.5
No. of iterations	2000
No. of variables	3

Each variable that should be optimized is a structure of 2 points represent x- and y-axis. It is clear from Figure 2 that the flower pollination algorithm gives good results on path planning, but it usually falls into local minima and sticks there during many trails. Figure 3 shows the cost reduction of the fitness function during iterations. The solution is stable around 1000 iterations. The three circles on the path in Figure 2 represent the final positions of the governing points of the curve (via points).

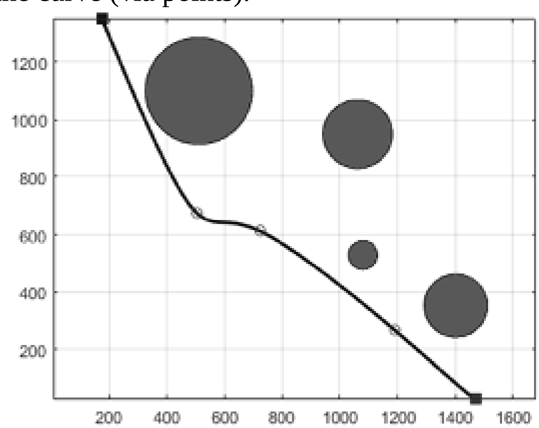


Figure 2. Via points on the path

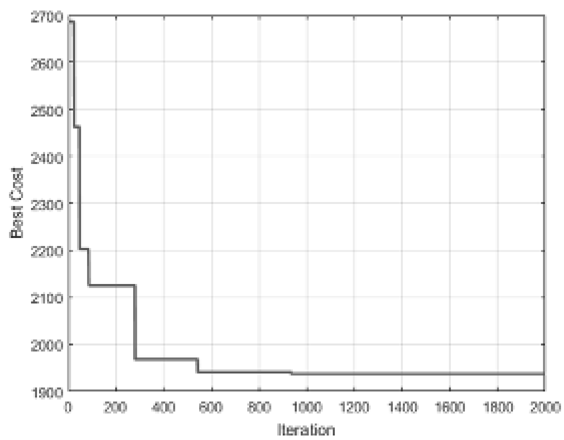


Figure 3. Best cost during the optimization process

3 MAPPING TO THE JOINT SPACE

It is necessary to map all points in the working space; start, goal and via points to the joint space by using inverse Kinematics for the sake of the trajectory planning. FPA also has used to optimize the forward kinematic equations (Ghafil 2015) of the two link planar robot with same parameters mentioned in Table 2. The fitness function of the inverse problem is the distance between the base and the end-effector frame of the robot (E Gilbert 1985)

4 POLYNOMIAL TRAJECTORIES

In this paper a polynomial equation of 9th order has been used to plane trajectory between start and goal points during three via points. The equation takes the following form:

$q(t) = a_1 + a_2 t + a_3 t^2 + a_4 t^3 + a_5 t^4 + a_6 t^6 + a_7 t^7 + a_8 t^8 + a_9 t^9$ ………(2)

Where t; is the time variable and a_1 ….a_9 are constants

This equation can be solved by using the following boundary conditions which they represent the inverse form of the Cartesian points shown in Table 3 while Figure 4 represent the corresponding pose for each point:

For joint variable 1:

$q(0) = 12.7$, $\dot{q}(0) = 0$, $\ddot{q}(0) = 0$, $q(1) = 107.5$, $\dot{q}(1) = 0$, $\ddot{q}(1) = 0$, $q(0.25) = 48.2$, $q(0.5) = 91.2$, $q(0.75) = 109$

For joint variable 2:

$q(0) = 22.82$, $\dot{q}(0) = 0$, $\ddot{q}(0) = 0$, $q(1) = -49.7$, $\dot{q}(1) = 0$, $\ddot{q}(1) = 0$, $q(0.25) = -71.1$, $q(0.5) = -101.7$, $q(0.75) = -111.7$

Solving this problem in MATLAB is a common work, and the result is:

$q_1(t) = 12.7 + 8383.4t^3 - 41147t^4 + 88190t^6 - 98866t^7 + 56593t^8 - 13058t^9$ …..(3)

$q_2(t) = 22.82 - 33651t^3 + 2.0385 * 10^5 t^4 - 5.1 * 10^5 t^6 + 6.41 * 10^5 t^7 - 4 * 10^5 t^8 + 98851t^9$ …..(4)

Deriving equations (3) and (4) lead to velocity and acceleration profile for each joint

Table 3. Start and goal and via points in Cartesian and joint space

Point	x-axis mm	y-axis mm	Corresponding joint angles degree	
			q_1	q_2
1	1191	266.9	48.2	-71.1
2	721.4	612.6	91.2	-101.7
3	504.5	674.1	109	-111.7
Start point	1470	33	12.7	22.82
Goal point	174	1350	107.5	-49.7

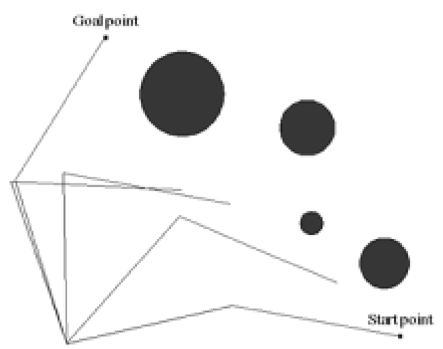
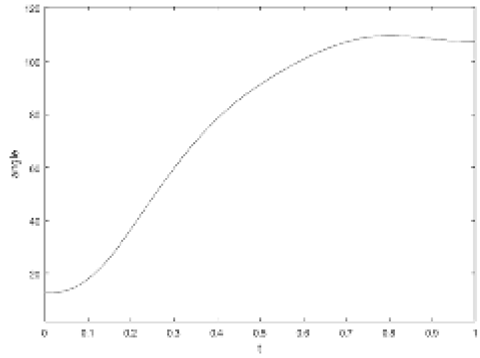
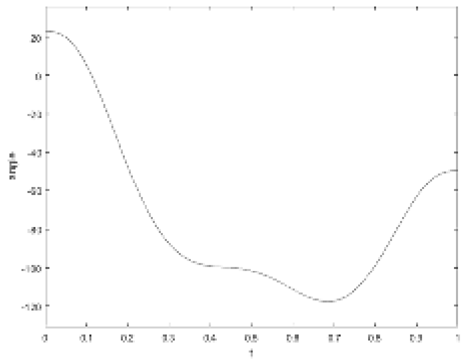


Figure .4 Inverse kinematic for each point

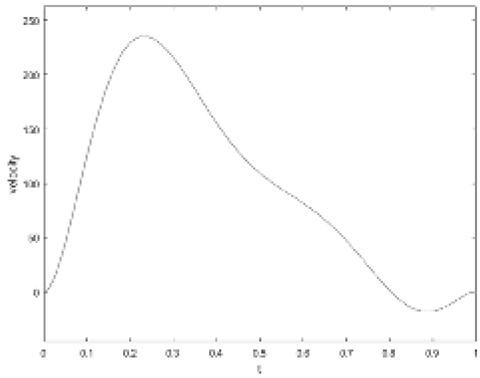
Figure 5 and 6 illustrate the angular position, velocity and acceleration for the two links during simulation time [0,1] seconds. It's clear from Figures 5.c and 6.c that the acceleration planned using the 9th order polynomial equation is a continuous function and that is desired to reduce vibrations during run time.



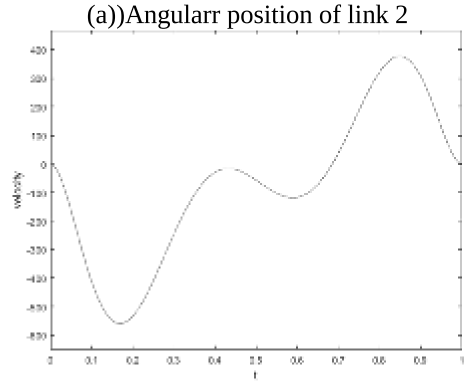
(a)Angularr position of link 1



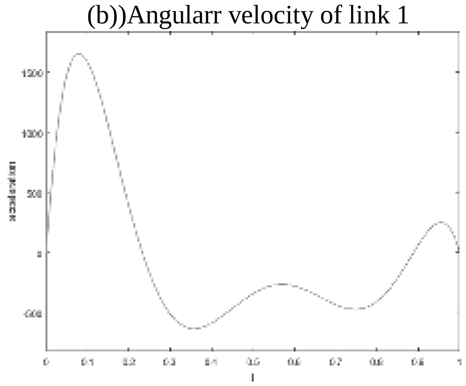
(a))Angularr position of link 2



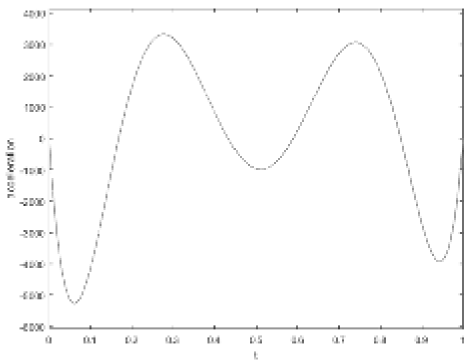
(b))Angularr velocity of link 1



(b))Angularr velocity of link 2



(c))Angularr acceleration of link 1



(c)Angularr acceleration of link 2

Fig.5 Joint 1 trajectories

Fig.6. Joint 2 trajectories

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