Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 32 (2019) 960–968

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

The 12th International Conference Interdisciplinarity in Engineering

Optimal Trajectory Planning for Spherical Robot Using Evolutionary Algorithms

Dikra El Haiek[a,]*, Badreddine Aboulissane[a], Larbi El Bakkali[a], Jalal El Bahaoui[a]

[a]Team Modeling and Simulation of Mechanical Systems, Abdelmalek Essaadi University, Faculty of Sciences, Tetouan, Morocco

Abstract

The trajectory planning problem of robot is addressed in this paper, which is consist of finding an optimal trajectory for a given path from an initial and final positions in the operating space. We aim to determine the optimal trajectory for three degrees of freedom spherical wrist with concurrent axis by using genetic algorithm. The optimized trajectory must have a minimum trajectory time and minimum joint traveling distance with free path collision in the workspace. In order to move from the initial point to the final point, we propose the use of polynomial interpolation, the optimization technique allow to determine the coefficients of the optimal trajectory. The simulation results for a three degrees of freedom robots are presented and discussed.

Keywords: Genetic Algorithm; 3 DOF serial robot; Trajectory planning.

1. Introduction

Motion planning for robot is one of the principal areas for robotic application. It focuses on automatic computation of collision-free paths for a robotic system operating in a crowded areas. The solution of this problem, called trajectory, is presented as a continuous sequence of geometric situations successively occupied by the robot during its displacement, which allow a robot to go from an initial state to a desired final state by satisfying certain criterion such as obstacle avoidance, minimum space, minimum jerk, minimum execution time, and minimum kinetic energy consumed by robot [1].

* Corresponding author. Tel.:+212-676-031-413.
E-mail address: dikra.elhaiek@gmail.com

10.1016/j.promfg.2019.02.309

In order to find an optimal trajectory with respect to some constraints, an optimization approach can be used. Which aim to find a set of values of the parameters to be optimized in order to maximize or minimize objective function. One of the famous method of optimization is evolutionary algorithms, essentially the genetic algorithm. These algorithms are stochastic optimization techniques inspired by Darwin's theorem of evolution, whose goal is to obtain an approximate solution, in a correct time. Genetic Algorithms use techniques derived from genetics and natural evolution: crosses, mutations, selections, etc [2]-[3]-[4].

Much research in robotics has addressed this purpose. A. Gasparett and al. [5] presented the trajectory planning problem and different approach proposed to generate collision free paths, such as the potential field method and the probabilistic roadmap planners. Also, they discussed the main optimality criteria for trajectory planning problem which are: minimum execution time, minimum energy and minimum jerk. In [6] a new method for optimal trajectory planning is proposed, execution time and the integral of the squared jerk along the whole trajectory are considered in the objective function. [7] Described a novel continuous genetic algorithm for Collision-Free Cartesian Path Planning for two robotic structures; two degree of freedom planar manipulator and the PUMA 560 robot, this technique consists of minimizing the deviation between the generated and the desired Cartesian path, and maximizing the minimum distance between the manipulator links and the obstacles.

In addition, a genetic algorithm optimization is applied for 2 DOF planar space robots in order to determine a global minimum-jerk trajectory of a space robotic in joint space [8]. Another work [9] presented an optimal trajectory planning of three degrees of freedom spatial robot based on minimizing energy consumed by actuators by using genetic algorithm.

This paper is organized as follows, in section 2; we firstly present the robot manipulation under study and its geometrical description. Section 3, shows a trajectory planning strategy based on interpolation polynomial. Section 4, is an overview of genetic algorithm and it implementation to solve the optimal trajectory planning problem. The simulation study and result are illustrated in section 5.

Nomenclature

GA	genetic algorithm
DOF	degree of freedom
q_i	Joint variable
t_i	Execution time required to through from one position to another
l_i	length of link i
n	number of intermediate point between the initial and the final positions
T	total time required to through from the initial position to a final position
l	number of joint positions from the initial to final position
k	number of robot links
x	position coordinates of the end effector along x axis
y	position coordinates of the end effector along y axis

2. Robot manipulators

Fig. 1. shows the structure of robotic manipulator considered in the present work, is one of the most known spherical robots. It is a serial robot with three degree of freedom in which the three joint axes intersect in a single point.

This type of structure is widely used in the industrial field, as for example the Stanford manipulator robot. It is designed at Stanford University by Victor Scheinman [10]. Another example is the PUMA robot, an industrial robot consisting of an open-chain mechanism used in various applications such as welding and surgery 11].

Our aim is to study this structure whose purpose is to use it in the medical field to achieve a spherical displacement, such as of the medical application of tele-echography[12]

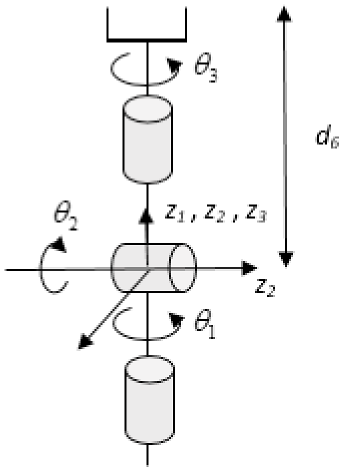

Fig. 1. Kinematic structure of a spherical wrist

θ_1 , θ_2 and θ_3 are revolute joints of the first, second and third link respectively.

In this work, we focus to study this robot in (x,y) plan, the Cartesian position of end effector can be expressed as follows:

$$x = d_3 \cos(\theta_1) \sin(\theta_2) \tag{1}$$

$$y = d_3 \sin(\theta_1) \sin(\theta_2) \tag{2}$$

$$z = d_3 \cos(\theta_2) \tag{3}$$

With d_3 is the distance between x_2 and x_3 along z_2

3. Trajectory generation

A trajectory of robot can be represented by a sequence of trajectories defined between a whole of intermediate points. In our case we propose one intermediate point between the initial and the final positions.

In general, several functions make it possible to define a trajectory as a function of time between an initial position and a final position. The use of polynomial calculus is a very practical tool for calculating motion. The most frequently encountered polynomial interpolation methods are interpolation with polynomials of degree three, four and five. The choice of a five-order polynomial ensures the continuity of motion in position, velocity and acceleration, verifying in addition the boundary conditions [13].

In our case, we used a quadrinomial polynomial to generate the segments trajectories between the initial point and intermediate point. The articular movement is described as:

$$q_{i,i+1}(t) = a_{i0} + a_{i1}t_i + a_{i2}t_i^2 + a_{i3}t_i^3 + a_{i4}t_i^4 \tag{4}$$

With $i = 0, \ldots, n-1$

There are five constants to be determined: a_{i0}, a_{i1}, a_{i2}, a_{i3}, a_{i4}

$$a_{i0} = q_i \tag{5}$$

$$a_{i1} = \dot{q}_i \tag{6}$$

$$a_{i2} = \ddot{q}_i / 2 \tag{7}$$

$$a_{i3} = (4q_{i+1} - \dot{q}_{i+1}T_i - 4q_i - 3\ddot{q}_i T_i^2) / T_i^3 \tag{8}$$

$$a_{i4} = (\dot{q}_{i+1}T_i - 3q_{i+1} + 3q_i + 2\dot{q}_i T_i + \ddot{q}_i T_i^2 / 2) / T_i^4 \tag{9}$$

$$\ddot{q}_{i+1} = 2a_{i2} + 6a_{i3}T_i + 12a_{i4}T_i^2$$

The trajectory between the n intermediate point and final position can be described by a five order polynomial as follows:

$$q_{i,i+1}(t) = b_{i0} + b_{i1}t_i + b_{i2}t_i^2 + b_{i3}t_i^3 + b_{i4}t_i^4 + b_{i5}t_i^5 \tag{10}$$

With $i = 0, \ldots, n$
$b_{i0}, b_{i1}, b_{i2}, b_{i3}, b_{i4}, b_{i5}$ are constants to be determined

$$b_{i0} = q_i \tag{11}$$

$$b_{i1} = \dot{q}_i \tag{12}$$

$$b_{i2} = \ddot{q}_i / 2 \tag{13}$$

$$b_{i3} = (20q_{i+1} - 20q_i - (8\dot{q}_{i+1} + 12\dot{q}_i)T_i - (3\ddot{q}_i - \ddot{q}_{i+1})T_i^2) / 2T_i^3 \tag{14}$$

$$b_{i5} = (12q_{i+1} - 12q_i - (6\dot{q}_{i+1} + 6\dot{q}_i)T_i - (\ddot{q}_i - \ddot{q}_{i+1})T_i^2) / 2T_i^5 \tag{15}$$

From the fourth-order interpolation we have been able to determine the expression of acceleration, so it is not necessary to use the five-order polynomial interpolation, since this requires the determination of eight variables, which takes time to calculate at each intermediate point

4. Evolutionary algorithms

These algorithms are stochastic optimization techniques inspired by Darwin's theorem of evolution, whose goal is to obtain an approximate solution, in a correct time. Generally the process of GA starts by generating an initial population of chromosomes, usually defined in a random way. Each chromosome of the population will then be evaluated on the basis of an objective function. The next step is about basic operators which are selection, crossover, and mutation.

- Selection: a 5-tournament is used because this method is the one with which we obtain the most satisfactory results

- Crossover: It can be noted that the number of crossing points as well as the probability of crossing make it possible to introduce more or less diversity. In our work we apply a cross at a single point.
- Mutation: The mutation operator therefore modifies the characteristics of a solution in a completely random manner, which makes it possible to introduce and maintain diversity within our population of solutions. This operator plays the role of a "disruptive element "; it introduces "noise" within the population. It is simply the inversion of a bit being in a very specific locus and also it is randomly determined.

These operators allow creating a new population that will be used for the next generation [2]-[3].

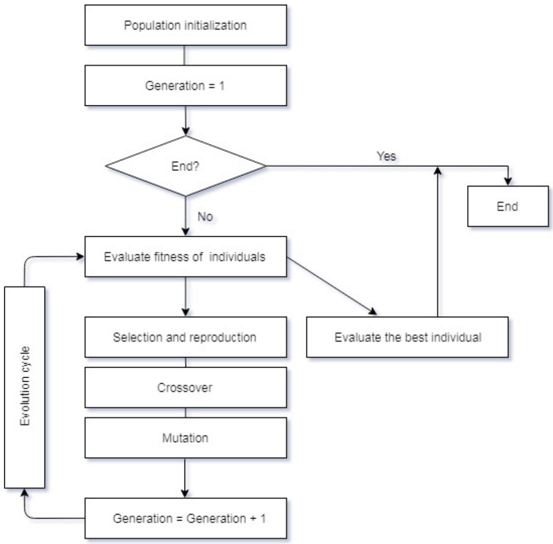

Fig 2. Flowchart of genetic algorithm

The optimization consists of two objectives:

- Minimum time trajectory: This criterion plays an important role in many applications, like in industrial domain where the robots will have to travel a given trajectory in a minimum of time in order to reduce the production time.
- Joint traveling distance: It consist of find a shorter possible trajectory.

For our robot the chromosomes are encoded using real codification which are: The intermediate joint angles θ_i ($i = 1, 2, 3$), the intermediate joint velocity $\dot{\theta}_i$, the global angle of the final point of the end-effectors θ_g and the execution time form initial to intermediate point, and from intermediate to target point, t_1, t_2 respectively.

The fitness function of this problem can be expressed in Equation (16).We transformed this constraint problem into unconstraint problem by using a penalization function:

$$F_f = \beta_1 T + \beta_2 F_q \tag{16}$$

With

$$T = t_1 + t_2 \tag{17}$$

$$F_q = \sum_{i=1}^{k} \sum_{j=2}^{l} \left| q_{ij} - q_{ij-1} \right| \tag{18}$$

β_1 and β_2 are the weighting factors.
The ith joint variable for a robot intermediate jth position is q_{ij}
In the case of obstacle existence, the objective function can be expressed as:

$$F = (\beta_1 T + \beta_2 F_q) / F_o \tag{19}$$

With:

$$F_o = \begin{cases} 1 & \sum_{j=1}^{l} \sum_{i=1}^{k} \left(link_{ij} \cap obstacle \right) = 0 \\ 0 & Otherwise \end{cases} \tag{20}$$

5. Results:

The parameters for the proposed GA are as follows:

Table 1. Values of Genetic Algorithm's parameters.

Parameter	Value
Size of population	200
Crossover prabability	0.8
Probability for of mutation	0.05
Number of generations	80

The range of the three joints is restricted to -180 < q_i < 180 with i=1, 2, 3

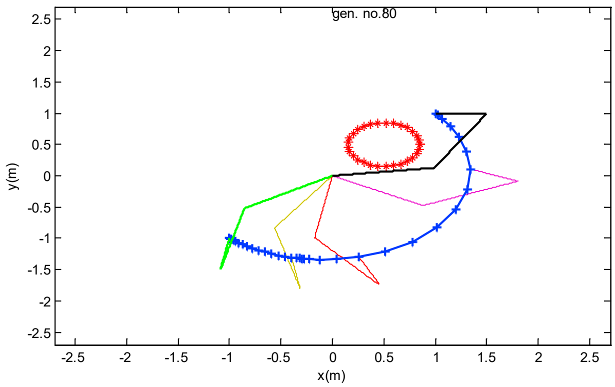

Fig 3. Trajectory planning with an obstacle

The Fig. 3. Shows the path trajectory with obstacle existence in the work environment, which is located at (0.5, 0.5) from an initial point with coordinates (-1,1) and final point located at (1,1).

From the Fig. 3. We can see that the deviation of the first rotation angle is low compared to the second and the third rotation angle.

From Fig. 4. the algorithm reach a near optimal solution with a fitness value of 8.1, this is achieved after about 46 generations.

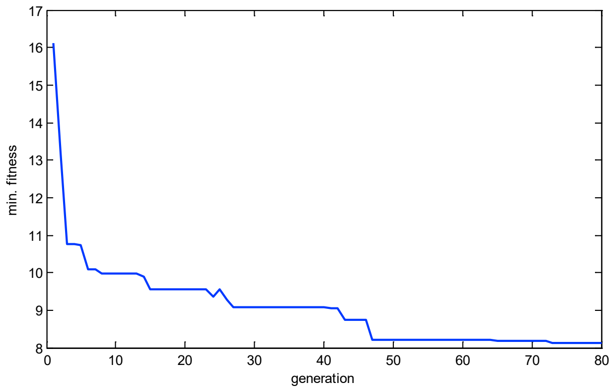

Fig. 4. Best - Fitness individual for the robot

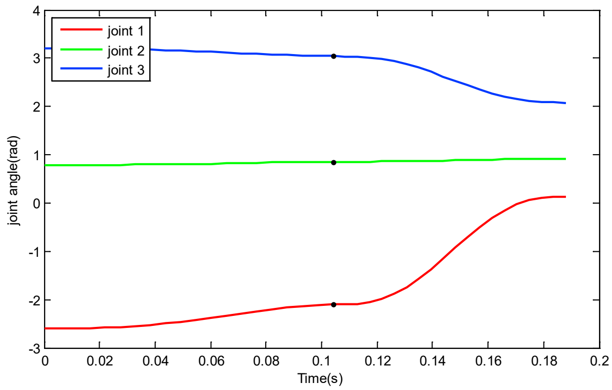

Fig. 5. Joint position trajectory

The variation of each joint angle during the motion are shown in Fig 5. According to the simulation, it is clearly seen that the robot has changed the path at about 0.1 s. The second joint angle has a low change, so it remains almost constant. The first joint angle decrease slowly until approximately in the middle of the motion trajectory, where it start to decrease rapidly. Contrary to the second joint angle, whose begin to increase until the end of motion.

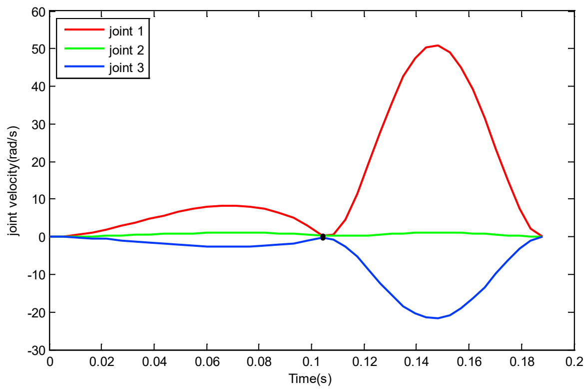

Fig. 6. Joint angular velocity trajectory

The joint angular velocity trajectory of each joints are shown in Fig. 6. In the beginning of the trajectory, the variation of joint angular velocity is relatively small. When the joint angular velocity trajectory comes in the middle, it know a big change, where the first joint reached a high velocity, the second joint keep relatively the same velocity shape and the third joint had a falling tendency.

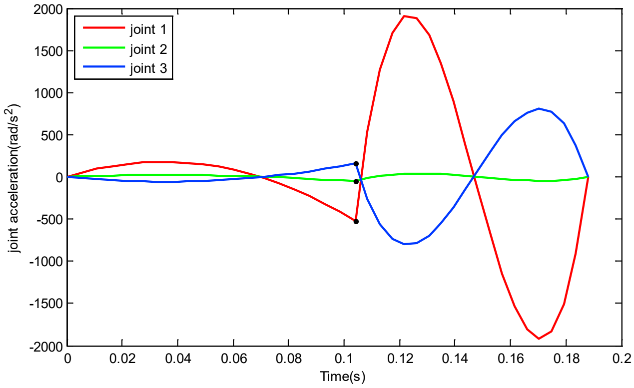

Fig 7. Joint angular acceleration trajectory

In regards to Joint angular acceleration trajectory illustrated in Fig. 7. It is observed that also the change is at the level of the second part of motion trajectory. In which the first joint reached a high acceleration and low acceleration in the third parts. Also, the second joint acceleration does not change during the trajectory.

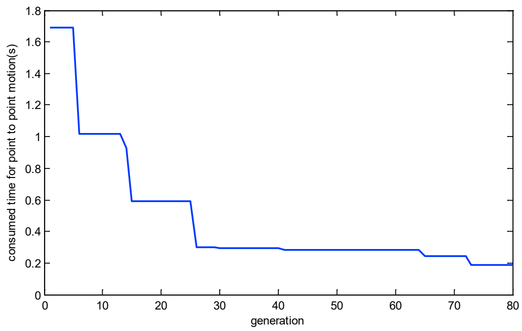

Fig 8. Consumed time of motion

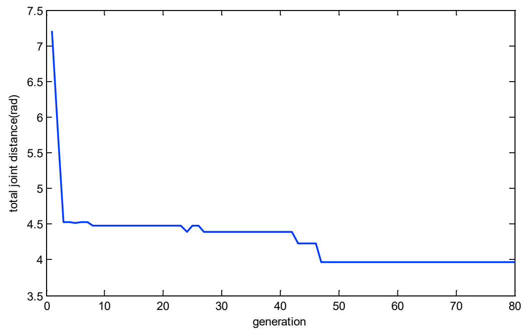

Fig 9. Total joint distance

The Fig. 8. Shows the consumed time during the motion. The optimal time obtained is about 0.2 s, the optimal solution. And The Fig. 9. Illustrate the total joint distance of the end effector during the algorithm process.

6. Conclusion:

A multi-objective genetic algorithm has been used for trajectory planning problem for a three degree-of-freedom robot. Which consist of minimizing the time trajectory of manipulator to move from an initial position to a final position and the Cartesian trajectory length, while also considering the obstacle existence in the work environments.

For the trajectory strategy, the polynomial interpolation have been used which satisfy the boundary conditions

Based on the obtained results, the robot could successfully find an optimal trajectory without collision while minimizing the time and the length trajectory. Genetic algorithms have proved to be an efficient tool.
It is expected to generate next work on moving different shape of obstacles in three dimensions.

References:

[1] J. E. Bobrow, Optimal robot plant planning using the minimum-time criterion. IEEE Journal on Robotics and Automation, 4(4)(1988), 443-450.
[2] W. Parvez, S. Dhar, Path planning optimization using genetic algorithm. International Journal of Computational Engineering Research, 3(4)((2013), 23-28.
[3] L. Tian, C. Collins, An effective robot trajectory planning method using a genetic algorithm. Mechatronics, 14(5)(2004), 455-470.
[4] M. P. Vicmudo, E. P. Dadios, R. R. P. Vicerra, Path planning of underwater swarm robots using genetic algorithm. In Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM), 2014 International Conference on IEEE, (2014) 1-5.
[5] A. Gasparetto, P. Boscariol, A. Lanzutti, R. Vidoni, Trajectory planning in robotics. Mathematics in Computer Science, 6(3) (2012) 269-279.
[6] A. Gasparetto, V. Zanotto, A new method for smooth trajectory planning of robot manipulators. Mechanism and machine theory, 42(4) (2007), 455-471.
[7] Z. E. S. Abo-Hammour, O. M. Alsmadi, S. I. Bataineh, M. A. Al-Omari, N. Affach, Continuous genetic algorithms for collision-free cartesian path planning of robot manipulators. International Journal of Advanced Robotic Systems, 8(6) (2011), 74.
[8] P. Huang, Y. Xu, B. Liang, Global minimum-jerk trajectory planning of space manipulator. International Journal of Control, Automation, and Systems, 4(4) (2006), 405-413.
[9] A. Biswas, B. L. Deekshatulu, S. S. Roy, Energy optimal trajectory planning of a robotic manipulator using genetic algorithm. In AIP Conference Proceedings, 1298(1) (2010) 492-497.
[10] Xi. Han, Optimization on Trajectory of Stanford Manipulator based on Genetic Algorithm. MATEC Web of Conferences, 128 (2017).
[11] Y. I. Al Mashhadany, H. MIEEE, ANFIS-inverse-controlled PUMA 560 workspace robot with spherical wrist. Procedia Engineering, 41(2012), 700-709.
[12] D. El Haiek, B. Aboulissane, J. El Bahaoui, L. El Bakkali, Kinematic and Manipulability Analysis of Hybrid Robot Used in Tele-echography Application", International Review of Mechanical Engineering, 11(8) (2017).
[13] Z. Tang, C. Zhou, Z. Sun, Trajectory Planning For Smooth Transition Of A Biped Robot, IEEE International Conference on Robotic & Automation, 2(2003), 2455-2460.