Optimization of Energy in Robotic arm using Genetic Algorithm

[1]Gouri Shankar Sharma, [2]Amanpreet kaur
[1]Deptt of Electronics and Communication, ITM Bhilwara, Rajasthan, India
[2]Deptt of Electronics and communication, BBSBEC, FGS, Punjab, India

Abstract
This paper proposes Genetic algorithm (GA) to optimize the point-to-point trajectory planning for a 3-link robotic arm. The objective function for the proposed GA is to minimize energy consumed by the actuators in Robotic arm and traveling time, while not exceeding a maximum pre-defined torque, without collision with any obstacle in the robot workspace. Fourth and fifth order polynomials are used to describe the segments that connect initial, intermediate, and final point at joint-space. Direct kinematics has been used for avoiding the singular configurations of the robot arm. The algorithm finds the shortest path for the end-effectors with minimum joint movements. The GA is applied for all the intermediate points between the initial and final point, and thus the accuracy is increased in terms of achieving final point. Results of GA approach are then compared with Geometrical approach.

Keyword
Inverse kinematics, Genetic algorithm (GA), Robotic arm.

I. Introduction

Industrial robots are quite prevalent in high volume manufacturing processes. In many field applications where technical support is required, man handling is either dangerous or is not possible. In such situations, three or more arm manipulators are commonly used. They are in great demand to speed up the automation processes [1, 2]. Three-link robotic arm should be able to locate any location, which is the required movement in real world situations. These are used in micro to macro scale applications viz. chip fabrications to huge mechanical actuators used in chemical processes [3]. In these cases, the motion profile of the robot rarely changes throughout the whole operation. Therefore, searching an optimal robot arm movement is a favorable solution to those problems [4, 5]. Literature survey reveals that there is need to optimize the movement for energy consumption and various other mechanical and control related Attributes like friction, settling time etc., which will improve the performance [6, 7, 8]. The GA can be used to search the parameters of the polynomial to minimize the energy consumption. Intelligent methods like fuzzy logic, neural network, genetic algorithm etc. are widely used in different areas, especially in advanced computing, control and optimization problems. Even when prior complete knowledge about a system is not available, these intelligent methods can be conveniently used to control or optimize a complicated engineering system. Intelligent methods can also be used in optimization of movement and trajectory planning of manipulators [9, 10]. These methods can be used for solving redundancy resolution problems. Genetic algorithms are viewed as function optimizers. The range of problems to which genetic algorithms can be applied is quite broad. Implementation of genetic algorithms begins with a population of random chromosomes. A fitness function evaluates and allocates reproductive opportunities in such a manner that only the chromosomes representing a better solution to the target problem are given chance to reproduce than those chromosomes which are poorer solutions [11].

II. Material and Methodology

A 3-link robotic arm having three degree of freedom is used to evaluate the approach. The simple mechanism line diagram of the system used is shown in Fig.1. Each link can independently rotate in the arm. This can be modeled similar to a robot, where each link's movement is measured relative to a current frame attached to previous link. For point _a' to _b', a set of equations that describe the position of point C in X – Y plane, is as follows [12,14].

$$x_C = l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2) + l_3\cos(\theta_1+\theta_2+\theta_3) \quad (1)$$
$$y_C = l_1\sin\theta 1 + l_2\sin(\theta_1+\theta_2) + l_3\sin(\theta_1+\theta_2+\theta_3) \quad (2)$$

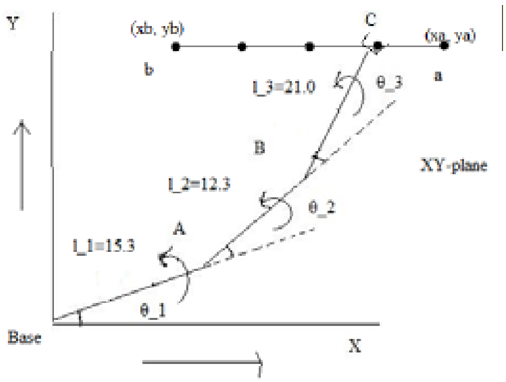

Fig. 1: Line diagram of 3- link robotic

The Jacobian matrix for a planar robot with two degrees-of-freedom is

$$J(\theta_1+\theta_2+\theta_3) = \begin{matrix} l_1\sin\theta 1 + l_2\sin(\theta 1+\theta 2) + l_3\sin(\theta_1+\theta_2+\theta_3) \\ l_1\cos\theta 1 + l_2\cos(\theta 1+\theta_2) + l_3\cos(\theta_1+\theta_2+\theta_3) \end{matrix} \quad (3)$$

Initial to final point trajectory is divided in ten equal parts to find out the suitable angle using inverse kinematic. The GA is applied for all the intermediate points between the initial and final point. Since the GA is used for all the ten points hence the accuracy is increased. Now, this problem is formulated by the equal distance travel by the robot hand with reference to previous position. The objective function is to minimize the energy consumed by each motor using GA. It is found that the first angle moved is very small than the second & the second angle moved is less than the third one. The reason for this is that for the first motor the power requirement is greatest, lesser for the second motor and least for the third motor, because the load associated with these motors is decreasing respectively.

III. Genetic Algorithm Implementation

Conventional methods of optimization require an accurate mathematical model. In a two-degrees- freedom planar robot any mathematical modeling.

Inaccuracy will hamper the mathematical optimization process. Also, as the configuration is changed, the optimization needs to be redefine.Genetic Algorithms is an intelligent optimization method [3, 11, 12, 13]. Here in this work, genetic algorithm is proposed

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to search the optimal angular displacement of robotic arms. The stepwise approach for GA is as follows:
1. Initialize. (time t=0)
2. Form the initial population consisting of n chromosomes P0 = $\{C_1, C_2, \ldots, C_n\}$
3. Obtain fitness of each chromosomes FC_i = fit (C_i), i=1…n.
4. Obtain fitness of the whole population F_t = fit (P_t).
5. Select the best chromosome C_i from the population P_t
6. Select the second best chromosome from the population. A_{c1} = Get (B_t) A_c = Crossing (A_c , A_{c1}).
7. Get crossover probability and apply the crossover operator on the two chromosomes as obtained in steps 5 and 6, above.
8. Get mutation probability and apply the mutation operator.
9. Find a suitable inversion probability and apply the inversion operator.
10. Place this chromosome in the new population.
11. Repeat steps 5 to 10 —n|| times.
12. Increment the current epoch number t=t+1.
13. Check the stop condition, if met, terminate the loop, and else go to step 3.

A. Fitness

In this case, the inverse of fitness function considered is given as

$$F(s) = \sqrt{(xi- xf)2 + (yi- yf) 2} \quad (4)$$

Fitness faction =1/1+F(s) (5)

Depending upon the value of fitness function a chromosome survives to the next generation.

B. Genetic Reproduction

Parents with better fitness will have a better chance of selection. For this purpose, the rank selection method is used. In this evolutionary process, parents combine to generate each new generation. Care has to be taken in not letting the parent chromosomes search falling into local optima. Elitism feature used in the proposed genetic algorithms will retain few good chromosomes in every next generation. A suitable value of elitist rate is chosen. Parent chromosomes to be crossed over are randomly chosen by keeping a suitable crossover rate with the crossover position selected randomly. Genetic Mutation is performed on bit-by-bit basis by keeping a suitable mutation rate.

C. Simulations

In the simulations, the population is P = 120, the bit string size=16, the elitist rate = 0.01, the crossover rate = 0.9 and the mutation rate = 0.01. After 5 generations the fitness functions assumes a plateau profile with fitness measures around 2.75. The undulations in the evolutionary process converge greatly for the optimal angular displacement of robotic arms after 500 generations. Next, a higher elitist rate will further converge the optimal angular displacement for still lesser number of generations.

IV. Results and Discussion

Optimization of energy is done for the servo motors used in the arm. Calculation is done by the following formula

V = 0.08*N & Energy E=VI cosθ

Where 0.08 is voltage consumed per degree movement of end-effectors.
N= 3*(θ1) +2*(θ2) + 1*(θ3) is total _weighted angle 'movement.
Thus E = 0.08*N*I (For power factor =1.)
Calculation of the Distance is on X-Y plane only using

$$\text{Distance} = \sqrt{X_1 - X_2^{\,2} + Y_1 - Y_2^{\,2}}$$

for this robotic arm GA is designed to achieve the best trajectory for the given Initial and final points such that, the energy consumed should be minimum and distance travelled for this energy should be least. In response to this objective function, GA calculates joint angles for all ten intermediate points and then the least distance possible. For different points in X-Y plane, joint angles and error is calculated for that trajectory. Angles and Error values for some of the points are plotted against number of steps in that trajectory are shown below.

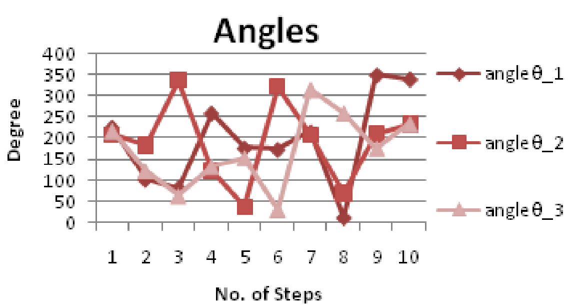

Fig. 2: Angle of joints for {(19, 25) to (11, 6)}.

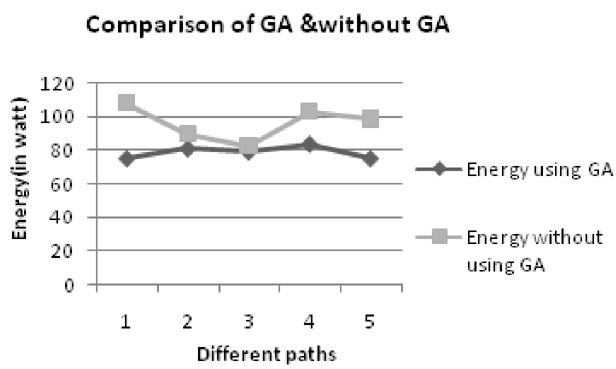

Fig. 3: Energy comparison using GA & without GA.

From the Fig. 2, it is clear that using GA approach energy consumed for the given initial and final points the movement of joint angle in ten equal parts . Fig. 3 shows that the distance travelled in five trajectories is lesser by using GA than by geometrical approach. Ten equal intermediate points were selected from initial to final points, and GA is implemented at each point for better accuracy.

IV. Conclusion

Two points are defined in X-Y plane and point to point trajectory of 3 links robotic Arm is modeled in terms of joint angles, Energy and Distance travelled. Result of various point to point trajectories show that optimization of part to part path is possible using GA. Optimization is done by minimizing Energy consumed to move robotic arm, Distance travelled form one point to another and error in final location of end -effectors, using 4th order polynomial. The optimized result is compared with manual movement of possible paths and the result by GA method is better than without GA.

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AMANPREET KAUR received her Bachelor's of engineering degree in Electronics and Instrumentation from Thapar University, Patiala, India, in 2007, the Master's of engineering degree in EIC from Thapar University, Patiala, India, in 2009. Presently, she is working as an Assistant Professor, with Electronics & Communication Department at BBSBEC, Fatehghar sahib, Punjab, India. Her research interests include Matlab, Virtual Instrumentation and Embedded Systems.