Fuzzy-Genetic Optimal Control for Four Degree of Freedom Robotic Arm Movement

V. K. Banga, R. Kumar and Y. Singh

Abstract—In this paper, we present optimal control for movement and trajectory planning for four degrees-of-freedom robot using Fuzzy Logic (FL) and Genetic Algorithms (GAs). We have evaluated using Fuzzy Logic (FL) and Genetic Algorithms (GAs) for four degree-of-freedom (4 DOF) robotics arm, Uncertainties like; Movement, Friction and Settling Time in robotic arm movement have been compensated using Fuzzy logic and Genetic Algorithms. The development of a fuzzy genetic optimization algorithm is presented and discussed. The result are compared only GA and Fuzzy GA. This paper describes genetic algorithms, which is designed to optimize robot movement and trajectory. Though the model represents is a general model for redundant structures and could represent any n-link structures. The result is a complete trajectory planning with Fuzzy logic and Genetic algorithms demonstrating the flexibility of this technique of artificial intelligence.

Keywords—Inverse kinematics, Genetic algorithms (GAs), Fuzzy logic (FL), Trajectory planning.

I. INTRODUCTION

AUTONOMOUS navigating robots have become increasingly important. Motion planning is one of the important tasks in intelligent control of an autonomous mobile Robot. Optimal movement is critical for efficient autonomous mobile robot. Many proposed approaches either used fuzzy logic or genetic algorithms [6,8,12,13]. Path conditions can be modeled using fuzzy linguistic variables so as to allow for imprecision and uncertainties of path data. Many new A basic and general framework for Robot control has been developed [4]. The obstacles have always been a source of malfunctioning of the Robot and Robotic arm. Various efforts have been made to develop efficient arm movement trajectories for eluding obstacles. Probability goes along with the real time process and their control for better performance. Olson C.F. et al. [3] have developed model and techniques for probabilistic self localization for mobile Robot. Davendra P.

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Garg et. al.[5] successfully implemented torque minimization for path optimization of multiple manipulators.

Fuzzy logic system is introduced to approximate the unknown robotic dynamics by using adaptive algorithm. Edward T. Lee [1] has implemented fuzzy logic to robot navigation. H. F. Ho et al. [11] have developed a stable adaptive fuzzy-based tracking control for robot systems with parameter uncertainties and external disturbance.

Genetic algorithms are often viewed as function optimizers, although the range of problems to which genetic algorithms have been applied is quite broad. A Genetic algorithm based path-planning software for mobile robot systems focusing on energy consumption. This algorithm is executed within two different phases of the optimization process [2, 7]. In the execution phase of the GA itself, the results of the preparation phase are used to find optimum paths. Industrial robots should perform complex tasks in the minimum possible cycle time in order to obtain high productivity. The problem of determining the optimum route of a manipulator's end effector using genetic algorithms have successfully implemented by Zacharia P. Th. et. al. [10].

Galantucci L. M. et al. [9] implemented the hybrid fuzzy logic-genetic algorithms (FL-GA) methodology to plan the automatic assembly and disassembly sequence of products.

The hybridization model consists of the fuzzy controller for the parameters of single link manipulator [14] and also for simultaneous localization and mapping of mobile robots[15].

In this paper, genetic optimization is employed to find optimum joint angles for four degree-of–freedom robotic systems. The cost function in genetic algorithm as implemented in this case is augmented by three attributes viz. joint movement, fiction and least settling time. At any time the values of these three attributes is found with the help of fuzzy logic. In a given case of cost function the weitages for these three attributes are determined through fuzzy reasoning. Fuzzy logic models have been developed for the above said three attributes as its input and the weitages as required for these three attributes in the cost function as three outputs.

II. ROBOTIC SYSTEMS

Robotic systems are characterized by their degree-of freedom (DOF). A very simple robotic system may have two degree-of-freedom, whereas a complex a robotic system have more degree-of-freedom. Robotic arm movement is effected by joint movement, friction and settling time.

The robotic arm movement depends upon the angular movement of the joint. Joint movement determines the power required. The joint movement must be adjusted to stay within the power available on the robotic system to be used.

Friction must also be considered in relation to robotic arm movement. The actual angular arm movement is defined as theoretical angular movement, which is provided by the controller minus the movement lost due to friction.

Settling time is the most important factor in the case of any real time system. It refers to the transient response, which contains dam pings (vibrations) for a given change in the input (step function). High-speed robots must have least settling time thus exhibiting minimum physical vibrations in the movement of robotic arm.

III. MATHEMATICAL MODEL OF FOUR DEGREE-OF-FREEDOM (4 DOF) ROBOTIC SYSTEM

In Four degree of freedom of the robotic arm the inverse kinematics equations are as below with figure 1 as four degree-of-manipulator.

$$x = \cos \theta (L \cos \phi + L_4 \cos \psi) \qquad (1)$$

$$y = \sin \theta (L \cos \phi + L_4 \cos \psi) \qquad (2)$$

$$z = L_1 + L \sin \phi + L_4 \sin \psi \qquad (3)$$
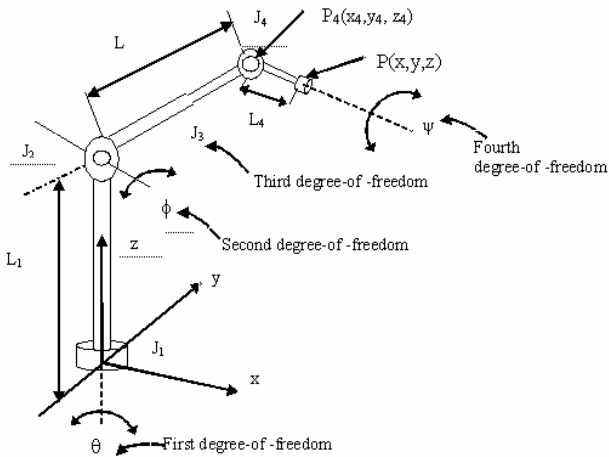
where ψ: Pitch angle

Fig. 1. Four degree-of –freedom manipulator

Let the position of fourth joint "P_4" be (x_4, y_4, z_4). Also

$$x_4 = x - \cos \theta (L_4 \cos \psi) \qquad (4)$$

$$y_4 = y - \sin \theta (L_4 \cos \psi) \qquad (5)$$

$$z_4 = z - L_4 \sin \psi \qquad (6)$$

The manipulator has four degree-of -freedom: joint 1 (J_1) allows rotation about the z-axis; joint 2 (J_2) allows rotation about an axis that is perpendicular to the z-axis; joint 3 (J_3) is a linear joint which is capable of sliding over a certain angle; and joint 4 (J_4) which allows rotation about an axis that is parallel to the joint 2 (J_2) axis. Rotation along joint 1 (J_1) to the base rotation θ; the angle of rotation of joint 2 (J_2), elevation angle ϕ; the length of linear joint 3 (J_3), extension L (L represents a combination of link 2 and 3); and the angle that joint 4 (J_4) makes with x-y plane, pitch angle ψ. Knowing the arm link lengths L_1, L and L_4 for position (x, y, z) we had calculated the values of joint angles θ, ϕ and ψ

IV. PROBLEM FORMULATION

In robot manipulator any mathematical modeling inaccuracy will hamper the mathematical optimization process. Also, as the configuration is changed, the optimization needs to be redefined. Here in this work, genetic algorithms are proposed to search the optimal angular displacement of robot arms as shown in flowchart figure 2.

The Genetic Algorithm for generating the population of chromosomes having optimized values.

[Start] Generate random population of *n* chromosomes (suitable solutions for the problem).

[Fitness] Evaluate the fitness *f(x)* of each chromosome *x* in the population.

[New population] Create a new population by repeating following steps until the new population is complete.

a. Selection. Select two parent chromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected).

b. Crossover. With a crossover probability, cross over the parents to form new offspring (children). If no crossover was performed, offspring is the exact copy of parents.

c. Mutation. With a mutation probability, mutate new offspring at each locus (position in chromosome).

d. Accepting. Place new offspringin the new population.

[Replace] Use new generated population for a further run of the algorithm.

[Test] If the end condition is satisfied, stop, and return the best solution in current population.

[Loop] Go to [Fitness].

Solutions obtained from inverse kinematics are fed to the Genetic Algorithm for generating the population of chromosomes to be optimized.

In our case Fitness of each chromosome depends upon many factors. We will consider three mains factors on which the fitness function will be calculated by applying fuzzy Logic. These three main factors are:

- Joint Movement (A1)
- Friction (A2)
- Least Settling Time (Min. Vibration) (A3)

First we will decide the importance and value of these three attributes for the each angle separately.

The corresponding cost function (*f*c) is given below by equation (7).

$$fc = A1 \times \lambda1 + A2 \times \lambda2 + A3 \times \lambda3 \qquad (7)$$

Attributes joint movement (A1), friction (A2) and settling time (A3) are inputs and weights $\lambda1$, $\lambda2$ and $\lambda3$ are outputs of fuzzy models. Table 1 and 2 show the inputs fuzzy

expressions and output fuzzy expressions, respectively. The ranges of fuzzy input membership functions and output membership functions are from 0 to 1 (per unit basis).
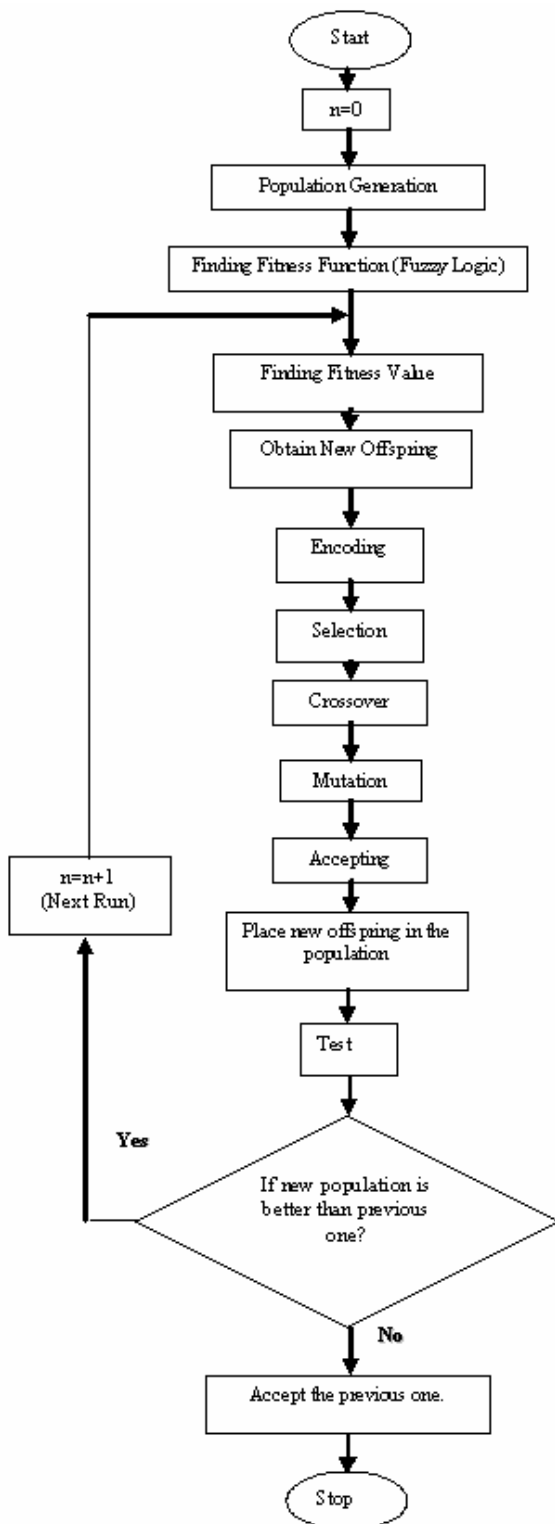

Fig. 2. Flowchart Using Genetic Algorithm

TABLE I INPUT FUZZY EXPRESSIONS

1st input (joint movement)		2nd input (friction)		3rd input (settling time)		Index representation for all three inputs
S	Small	S	Small	S	Small	0.3
M	Medium	M	Medium	M	Medium	0.7
L	Large	L	Large	L	Large	1.0

TABLE II OUTPUT FUZZY EXPRESSIONS

1st Output ($\lambda 1$)		2nd Output ($\lambda 2$)		3rd Output ($\lambda 3$)		Index representation
VS	Very small	VS	Very small	VS	Very small	0.20
S	Small	S	Small	S	Small	0.40
M	Medium	M	Medium	M	Medium	0.60
L	Large	L	Large	L	Large	0.80
VL	Very large	VL	Very large	VL	Very large	1.00

V. SIMULATION AND TESTING

Four degree-of-freedom (4 DOF)

Maximum reach of the robot arm : 915 mm
Length of first link (l1) : 305 mm
Length of second link (L) : 434 mm
Length of third link (l4) : 51 mm
Origin or reference
 Point (O) coordinates : (0, 0, 0)
Destination Point (P) coordinates : (x, y, z)
 x: 406 mm
 y: 127 mm
 z: 533 mm

The system has been considered for developing the software code using GA (whose flowchart is shown in fig 4),. Solving these equations we get the following values for the angles of the links:

$\theta = 17.37°$
$\phi = 30.09°, 26.26°$
$\psi = 84.69°, 5.26°$

By applying the inverse kinematics initially and then from successive runs performed during the design and development for the optimization

From the above simulation, we obtained optimized result for various joints:
$\theta = 17.36°$
$\phi = 20.06°, 36.29°$
$\psi = 84.69°, 5.26°$

VI. RESULTS AND DISCUSSIONS

An optimization method based on the genetic algorithms and fuzzy logic is proposed. In the developed genetic algorithms, in order to obtain the optimal angular displacements for the robotic arms in the whole workspace, elitism has been retained from the previous generation to the next. Figure. 3 illustrates percentage fitness versus generation graph for 4 DOF systems.

Figure 4 shows the convergence of best of each generation for robotic system. It can be seen that there is rapid convergence within 20 generations to an almost perfect solutions. Where as in the case of only GA there is rapid convergence within 40 generations. The performance is

optimal is over all possible input values as the evolution function exhaustively test the possible input spaces.

It is concluded that GA and FL is practical and effective method for achieving optimization of robotic arm angular displacements.
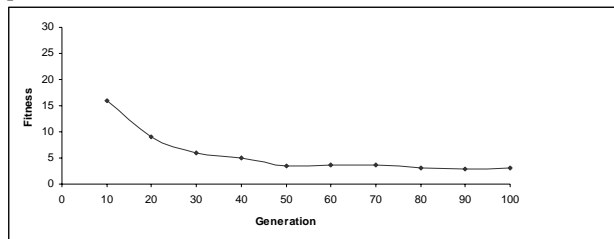

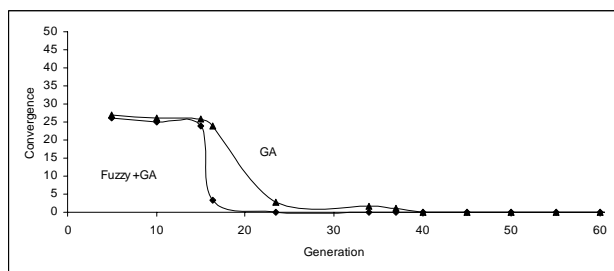Fig. 3. Fitness versus generations graph

Fig. 4. Convergence versus generation graph

The method proposed in this paper is robust, optimal for robotic arm movement and adaptation to be dynamic conditions in the environment.

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